LEAF LITTER PRODUCTION AND SOIL FERTILITY IMPROVEMENT IN A HOMEGARDEN IN THE AKUAPEM DISTRICT OF GHANA

A THESIS SUBMITTED BY

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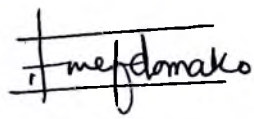
Declaration

I hereby certify that this thesis is my own original work; all assistance and references to relevant literature have been duly acknowledged.

This thesis has not been submitted, either in whole or in part, for a degree or other qualification in any other university.



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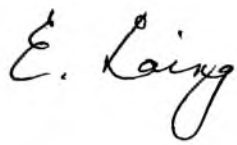

Emeritus Professor E. Laing

Principal Supervisor

Dedication

To Maame Yaa Agyepoma, a very special daughter

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List of Abbreviations and Symbols

ANOVA	Analysis of variance
CEC	Cation exchange capacity
Cmol/kg	Concentration in moles per kilogram of soil
e.g.	for example
et al.	et alii (and others)
FAO	Food and Agriculture Organisation of the United Nations
Fig. (Figs.)	Figure(s)
ICRAF	International Council for Research in Agroforestry
i.e.	that is
IITA	International Institute of Tropical Agriculture
ILCA	International Livestock Centre for Africa
IUCN	International Union for Conservation of Nature and Natural Resources, also known as World Conservation Union
k	decomposition rate constant
LSD	Least significant difference
NPK	A synthetic fertiliser containing nitrogen, phosphorus and potassium
OC	Organic carbon
OM	Organic matter
TSBF	Tropical Soil Biology and Fertility
t_{50}	The time required for 50 % loss in an initial mass of litter
UN	United Nations
UNEP	United Nations Environment Programme
WAP	Weeks after planting
WWF	World Wide Fund for Nature
>	greater than
<	less than
#	number

Quotation

The Eleventh Commandment

Thou shalt inherit the Holy Earth as a Faithful Steward
Conserving its resources and productivity from generation to generation

Thou shalt safe-guard
Thy fields from soil erosion;
Thy living waters from drying up!
Thy forests from desolation, and
Protect the hills from over-grazing
by the herds,
That thy descendants may have
abundance forever.
If any shall fail in this good stewardship of the land,
Thy fruitful fields shall become
sterile, stony ground and wasting gullies
And thy descendants shall decrease and
live in poverty or
Perish from off the face of the earth.

(Lowdermilk, 1966)

Abstract

Ceiba pentandra, *Cola gigantea*, *Lannea welwitschii*, *Milicia excelsa* (all non-leguminous) and *Milletia zechiana* (leguminous) are among the various tree species retained on cropping fields in the Akuapem District of Ghana, but little is known of the actual contribution of these species to soil fertility improvement.

Leaf litter samples from the above-mentioned non-leguminous species were analysed to determine their nutrient content. Leaf litter production was also quantified monthly over a four-month period and hence the potential contribution of the different types of leaf litter to the soil nutrient pool was calculated.

Results from pot experiments, in which maize (*Zea mays*) was used as a test crop indicated that when the leaf litter produced by the four non-leguminous species are used as mulch, the nutrients contained in them are not readily available for plant growth. Nonetheless, studies of soil chemical properties beneath tree canopy, at canopy edge and outside tree canopy suggest that long term accumulation of leaf litter from *C. pentandra* and *L. welwitschii* results in higher availability of nitrogen and phosphorus.

Millettia zechiana, on the other hand, was found to have nodulation ability and hence is potentially capable of contributing to soil enrichment through biological nitrogen fixation.

CHAPTER 1 - INTRODUCTION

With the increasing growth of the world's population especially in developing countries, more and more virgin lands are being opened to agriculture. This is because the increasing food needs of growing populations leave no alternative as long as productivity per unit area remains constant (German Bundestag, 1990). As a result of the imbalance between the rates of population growth and food production, various literature are now replete with citations of alarming rates of widespread soil erosion and land degradation (e.g. FAO, 1983; IUCN/UNEP/WWF, 1991; UN, 1992; Reij et al., 1996).

In Sub-Saharan Africa, for example, although total food production has increased, the rate of increase has not been fast enough to keep pace with the high population growth rate (Harrison, 1987). In many instances, the increase in food production has been as a result of cultivating new lands using traditional technologies (Guthrie, 1986). This has resulted in widespread land degradation in areas of high population densities and agricultural expansion into marginal and sloping lands. A case in point is the spread of cultivation up the mountain slopes in the Machakos and Aberdare districts of Kenya (Wolman and Fournier, 1987; Cooper et al., 1996).

One traditional land-use technology that has been widely implicated in the loss of productive lands is the bush fallow system. Commonly referred to as shifting cultivation, the bush fallow system - which has been practised on such a wide range of soils amid so many types of vegetation - involves the clearing of land for a short period of cropping, followed by a relatively long period of fallow. It has been practised by peoples of such diverse origin and culture that it shows great variations, not

only in the types of crops grown, but also in the methods of cultivation and the length of the cropping and fallow periods (Nye and Greenland, 1960). Generally, however, shifting cultivation is an ecologically sustainable, low input farming system that can continue indefinitely on the infertile, highly leached soils characteristic of the tropics and sub-tropics, provided the following conditions are met:

- Low population density,
- Long fallow,
- Relatively short cropping period.

Unfortunately, the increasing pressure on land due to the increasing food needs of the world's ever-growing population, has resulted in a new mode of shifting cultivation that is totally destructive. It is characterised by long cropping periods and relatively short fallows. In the mountain areas of Xishuangbanna in South West China, for instance, the increase in local population has resulted in a shortening of the fallow period from 8–10 to 3-5 years (Cao and Zhang, 1996). Owusu (1990) has also reported a shortening of the fallow period by farmers in the Mampong Valley of Ghana. The result of short fallows is a loss of the coppicing potential as well as a depletion of the soil seed bank and/or soil nutrients of the over-cropped piece of land. Invasion of weeds and pests is also enhanced, resulting in a decrease in crop productivity (Nye and Greenland, 1960; Kang et al., 1990).

'Agroforestry' is often cited as a solution to the problem of loss of productive lands and an answer to food shortages. It is a collective name for sustainable land management systems that involve the deliberate association of trees and other woody perennials with crops, animals and or pasture on the same piece of land either sequentially or simultaneously. There are usually both ecological and

economic interactions between the trees and other components of the system (Nair, 1984; Rocheleau et al., 1988; Prinsley, 1990; Swaminathan, 1992; Young, 1989 and 1997).

Agroforestry has been practised in various forms around the world, and the bush fallow system is in fact a notable example of the sequential association of the various components of agroforestry on the same piece of land. Other old agroforestry practices include the homegarden system, in which simultaneous association occurs between forest trees, crops and livestock. Another is the taungya, in which food crops are cultivated in association with forestry species during the early stages of plantation establishment. Cropping ceases when the canopies of the forestry species begin to close (Nair, 1993).

Although agroforestry has been practised for centuries, it was not until 1977 that it became institutionalised through the establishment of the International Council for Research in Agroforestry (ICRAF). The task of ICRAF was to support, plan and co-ordinate agroforestry research on a worldwide basis. This was in response to a growing awareness of the need for a more scientific approach to research into agroforestry systems, and a challenge to develop more efficient and ecologically sustainable alternatives to land –extensive traditional technologies (Nair, 1984; Wilson and Lal, 1986; King, 1989; Nair, 1993).

Over the past two decades, much research has been carried out into a wide range of agroforestry systems for the maintenance of soil fertility and the prevention of soil erosion losses as well as the consequent expansion into marginal and/or ecologically fragile lands (e.g. coastal wetlands). In the early 1980s, the International Institute of Tropical Agriculture (IITA) developed the alley cropping system. The latter is a land-intensive agroforestry technique that entails the planting of

multipurpose trees and shrubs in rows and growing food crops in the intervening lanes or alleys (Whitmore, 1990; Cook and Grut, 1989; Kang et al., 1984). Since its development, various woody perennials (both leguminous and non-leguminous) have been tested in the alley cropping system. The leguminous species include *Leucaena leucocephala*, *Gliricidia sepium*, *Cajanus cajan*, *Sesbania rostrata* and *Flemingia congesta*. In spite of their inability to fix nitrogen, non-leguminous species such as *Acioa barterii*, *Alchornea cordifolia* and *Gmelina arborea* have also been tested because of their efficiency in nutrient cycling and litter accumulation throughout the year (Kang et al., 1984; Okigbo, 1989).

The term 'alley cropping' was replaced by 'alley farming' when the International Livestock Centre for Africa (ILCA) extended the alley cropping concept to include livestock by using some or all the tree/shrub prunings as livestock fodder, instead of mulch. In certain cases, the livestock are allowed to graze the hedges directly resulting in the term 'alley grazing' (Reynolds and Atta-Krah, 1989; Carter, 1996). In this thesis, alley farming will be used as an all-embracing term for the various alley systems. Synonymous terms for alley farming include *hedgerow intercropping*, *avenue cropping*, and *contour hedgerow farming* where the hedgerows are planted along contours on sloping land to control erosion (Nair, 1993; Bayliss-Smith, 1994).

Generally, encouraging results have been obtained during the past two decades of agroforestry research, both in technical performance and farmer enthusiasm. Nonetheless, it is now widely recognised that agroforestry solutions to land degradation are always likely to be location-specific in their relevance, performance and farmer acceptability (Rocheleau et al., 1988; Kerkhof, 1990; Cooper et al., 1996). Alley farming, for example, has been found to have far less potential than was initially anticipated. Although the total global expenditure on alley farming research, development and

promotion runs into tens of millions of US dollars, major limitations have emerged in both its socioeconomic and technical characteristics. These limitations include land and tree tenure systems, rainfall patterns, the type of annual crop and the type of alley species (Taylor, 1987; Cook and Grut, 1989; Francis, 1989; Mungai et al., 1990; Bruce, 1993; Swinkles, 1994; Carter, 1996).

It is now abundantly clear that the local people in any area possess valuable knowledge about what trees and shrubs are appropriate for their peculiar ecological and socioeconomic conditions. It has been reported that the Tonga people of the Zambezi River and farmers at Mtwapa (Kenya) retain *Acacia albida* in cropping fields and cultivate under their canopies (Campbell et al., 1991; Jama and Getahun, 1991). Fenglin and Lijuan (1994) and Blomley (1994) respectively have reported the great agroforestry potential of *Lespedeza bicolor* and *Melia volkensii*. *Lespedeza bicolor* is a leguminous shrub that is widely cultivated by farmers in China for fuelwood and fodder. *Melia volkensii*, on the other hand, is a timber species planted on crop fields by farmers in most parts of Kenya.

Evidently, the scientific community has a lot to learn from the people whom they intend to assist. Thus, instead of regarding them as 'backward' people for whom development must be planned and implemented, researchers must be willing to learn from local people and, where necessary, improve upon their indigenous knowledge and practices (Rocheleau et al., 1988; Barrow, 1991). There is also the need to increase research emphasis on the domestication of high value indigenous trees, and their integration into more sustainable, diverse and intensive land-use systems (Wood and Burley, 1991; Cooper et al., 1996).

In Ghana, farmers in the Akuapem district of the Eastern Region practise an indigenous agroforestry system (similar to homegarden agroforestry) that lends stability to the traditional

farm environment. They retain a variety of forest species on their farms because of their peculiar socio-economic values as sources of human food, animal feed or fodder, traditional medicine, fuelwood, building materials, etc.

A list of some of the species used by farmers in Gyamfiase and Adenya (two nearby villages in the district) is given in Appendix 1. Apart from the socioeconomic values of the various species, interviews with a few farmers revealed that they are retained on cropping fields for the following additional reasons:

(1) They do not have perceivable adverse effects on annual crops.

(2) They are not too shady and their leaves decompose quickly.

(3) They contribute to soil conservation via the mulching effect of their litter.

Although *Cola gigantea* (Family Sterculiaceae) was a common feature on most farms, some farmers indicated their dislike for it because in their view its leaves are hard and decompose slowly. According to these farmers, the leaf litter from *C. gigantea* usually forms an impervious mat under the tree, which intercepts rainfall and thus influences the moisture content of the soil below the tree canopy. In one farm, it was observed that cassava plants growing directly under a *C. gigantea* tree were much shorter than those growing farther away, although they were all planted at the same time.

Ceiba pentandra, on the other hand, is widely acclaimed by the farmers in the two villages as having a very positive influence on its immediate soil environment, which is manifested in the luxuriant growth of crops planted under this species.

This research study aimed at finding scientific explanations to the farmers' claims. It was envisaged that it would not only add to the current knowledge on agroforestry systems, but also would provide a better understanding of this indigenous practice. This is essential for the effective management of the system to ensure the sustained production and income of the traditional, low-resource farmer.

Five of the indigenous woody species: *Ceiba pentandra*, *Cola gigantea*, *Lannea welwitschii*, *Milicia excelsa* (all non-leguminous) and *Millettia zechiana* (leguminous) were chosen for this study. The objectives of the study were to find answers to the following:

1. How much nutrients are the non-leguminous species potentially capable of contributing to the soil nutrient pool through litterfall?
2. Are there significant differences in the rates of decomposition of litter produced by *C. pentandra*, *C. gigantea* and *L. welwitschii*?
3. To what extent does the presence of the non-leguminous species influence the availability of moisture and nutrients in their immediate soil environment?
4. Is *Cola gigantea* really a problem tree as asserted by some farmers?
5. Does *Millettia zechiana* have the ability to nodulate, and if so does it exhibit nodulation promiscuity?

From the answers obtained , inferences were drawn regarding the roles of the various species in soil fertility improvement in the homegarden agroforestry system in question.

CHAPTER 2 - LITERATURE REVIEW

2.1. Tree Influence on Soils

According to Young (1989), underlying all consideration of the role of agroforestry in soil amelioration is the fundamental proposition that trees improve soils. Evidence for the effects of trees on soils comes from studies that compare soil properties under individual tree canopies with those outside the canopies.

In one such study, Jaiyeoba (1996) - who studied the effect of *Acacia albida*, *Eucalyptus camaldulensis* and *Parkia biglobosa* on soil properties beneath the tree canopy, at the canopy edge and outside the canopy - observed that organic matter, nitrogen (N) and cation exchange capacity (CEC) decreased with increasing distance from the tree species.

Aggarwal (1980) has reported higher soil organic matter and N content under tree canopies of *Prosopsis cineraria* and *Prosopsis juliflora* than in adjacent open land. Although Aggarwal's findings have been corroborated by work done by Radwanski and Wickens (1981), these authors also found that soil phosphorus (P) content in a fallow under *Azadirachta indica* was much lower than that in an adjacent bare fallow farmland.

Various authors (e.g. Nair, 1984; Young, 1989, Whitmore, 1990) have reviewed the role of trees in soil productivity and conservation and hence have concluded that trees improve soils by:

(1) improving soil physical properties such as water-holding capacity,

(2) increasing nutrient additions to the soil through build-up of organic matter, nitrogen fixation and deep nutrient uptake, and

(3) reducing losses in soil organic matter and nutrient content by checking erosion and enhancing recycling.

Having reviewed the literature on the potential role of trees in nutrient cycling, Buresh (1995) asserts that the ability of agroforestry systems to enhance nutrient supply and availability, with the exception of N, depends on the existing reserves of nutrients in the soil.

Shepherd et al. (1996), on the other hand, have reported that agroforestry systems do not significantly reduce N deficits except when a high proportion of the total biomass was returned to the soil, rather than removed from it. Using a static model of N and P flows for a standard farm system representative of typical subsistence farms in humid parts of the East African Highlands, they found that agroforestry increased N input through biological N fixation and deep N uptake. This input was, however, offset by a larger nutrient loss from the farm in harvested products. Evidently, the importance of the application of mulch materials to soil fertility maintenance in agroforestry systems cannot be over-emphasised.

In indigenous agroforestry systems, where food crops are cultivated under the canopies of already established trees (sometimes many meters tall), the periodicity of the major phenophases of the trees becomes very important in the provision of litter for mulching purposes. Chandrashekara (1996) has studied characters such as crown architecture, leaf phenology and branching pattern in 9 forest trees growing in homegardens in Kerala (India) with a view to assessing their suitability as components in homegarden agroforestry systems. His study

indicated inter alia that foliage phenology is important in determining the appropriate crop mixture in homegardens. For instance, there is scope for cultivating light-demanding, short-duration crops under species such as *Tectona grandis*, *Macaranga peltata*, *Grewia tiliifolia*, *Xylia xylocarpa* and *Terminalia paniculata*, which are deciduous in nature and leafless for three to four months. The short-duration crops can also take advantage of the nutrients released by the decomposing leaves shed by the deciduous forest species.

Negi (1995) has also carried out a study to determine the suitability for agroforestry of commonly occurring multipurpose trees found in the central Himalayan region. Here, the focus was on leaf and twig growth patterns, phenology, and leaf nitrogen dynamics of 5 species which were growing around crop fields and have been utilized by the local people for centuries. This author found that the phenology of the species (*Bauhinia variegata*, *Ficus palmata*, *Pyrus pashia*, *Prunus cerasoides* and *Grewia optiva*) was such that competition with agricultural crops for soil, water, nutrients and sunlight was minimal. Besides, the species exhibited high foliage biomass production and the capacity to add large amounts of N to the soil through litterfall.

2.2 Litter Production and Decomposition

In any vegetational ecosystem, the rate of litter accumulation is the result of the interaction between litter production and the rate of litter disappearance.

Litter production can be defined as the weight of dead material (of both plant and animal origin) that reaches a unit area of soil surface within a standard period of time (Chapman, 1976). It is usually estimated directly by means of litter traps, and different types of litter traps have been

described in the literature (Newbould, 1967; Chapman et al., 1975). Veneklaas (1991) used litter traps made of plastic gauze bags (1mm mesh, 0.5 x 0.5 m), suspended from galvanised wire frames and placed at a height of about 1 m while Songwe et al. (1997) used plastic sheets that were spread on raised pegs. Whatever the design, Chapman (1976) argues that a litter trap must fulfil a number of basic requirements:

1. It must intercept litter fall before it reaches the ground with as little aerodynamic disturbance as possible.
2. It must retain trapped litter.
3. It must be designed or placed such that litter already on the soil surface cannot enter it.
4. It must allow drainage of water without loss of litter, particularly fine litter.
5. The size and number of litter traps used in any study must provide an estimate of the required degree of accuracy.

Brady (1990) has outlined the three general processes that occur when organic material (in the form of litter) is added to the soil. Firstly, there is the decomposition process in which the bulk of the material undergoes enzymatic oxidation resulting in the production of CO_2, water and heat energy. This process is a complex one and is regulated by the interactions between decomposing organisms, physical environmental factors (particularly temperature and moisture) and litter quality (normally defined by the concentrations of lignin, nitrogen and condensed and soluble polyphenols in the litter). While climate is the dominant regulating factor in areas subjected to unfavourable weather conditions, litter quality remains the most important regulator of litter decomposition under favourable conditions (Swift et al., 1979; Couteaux et al., 1995; Reddy, 1995).

Secondly, there is the mineralisation process in which essential elements such as nitrogen, phosphorus and sulphur are released and/or immobilised by a series of specific reactions relatively unique for each element. Hence, the mineralisation pattern of litter is usually determined by analysing the nutrient content of decomposing litter at regular intervals during the decomposition process, and different researchers focus on different nutrient elements depending on the purpose of the study.

The third process that occurs when litter is added to the soil is the formation of soil humus. During this process, compounds very resistant to microbial action are formed either through modification of compounds in the original litter or by microbial synthesis; these resistant compounds collectively constitute soil humus.

Decomposition and mineralisation are, therefore, the main biochemical processes responsible for litter disappearance, although external losses due to leaching, animal consumption, wind transport and in some cases harvest by man can result in significant amounts of litter disappearance (Chapman, 1976).

Litter decomposition is often studied by the litter bag method, in which known weights of litter are confined in nylon mesh bags and either placed on the soil surface - as was done by John (1973) - or buried in the soil. The confinement of litter in a mesh bag makes it possible to recover the residual experimental material and defines the conditions under which the decomposing organisms operate. The presence of the mesh, the compaction of the litter in the mesh bag and the burial of the litter in the soil can create microclimates that are different from conditions in unconfined litter. In spite of this limitation, the litter bag method remains one of

the most convenient methods for comparative measurements of decomposition between sites and treatments (Chapman, 1976; Anderson and Ingram, 1993). Often when this method is applied, the rate of litter disappearance is assumed to be equal to the rate of decomposition.

The minimum requirement for litter decomposition rates in Tropical Soil Biology and Fertility (TSBF) studies is the time (t_{50}) taken for 50 % disappearance or loss of the initial mass of litter. Nonetheless, most studies in the literature report only the decomposition rate constant "k" from the negative exponential function

$W_t = W_o e^{-kt}$ ..... (1) where

W_o is the initial mass of litter, and

W_t is the amount of litter remaining at time "t"

Dividing both sides of equation (1) by W_o, I get

$W_t / W_o = e^{-kt}$ ..... (2)

Equation (2) is more conveniently expressed as the regression function

$\text{Log}_e W_t - \text{Log}_e W_o = -kt$, or

$\text{Log}_e W_t = -kt + \text{Log}_e W_o$, which is of the form $y = mx + c$ (the equation of a straight line).

Thus when $\log_e W_t$ is plotted vs. time (days) a straight line with a negative gradient which, in fact, is the decomposition rate constant (k) is obtained. Values of k are conventionally expressed as positive values and values of t_{50} are estimated from the reciprocal of k/day. To obtain k/year, values of k/day are multiplied by 365. The use of the exponential function is based on the assumption that decomposition rates are constant over time (Chapman, 1976; Anderson and Ingram, 1993). In many situations, however, this is not the case and Chapman (1976) has reviewed some objections to this simple model.

2.3 Mineralisation Patterns and Soil Amelioration

From existing literature, it appears that the rates of decomposition and mineralisation of any form of plant litter are important in determining the ultimate contribution of that litter to soil fertility improvement (Muoghalu et al., 1994; Songwe et al., 1995; Cadisch and Giller, 1997). Consequently, knowledge of the rates of decomposition and nutrient release of mulch materials is vital to their effective application in agroforestry systems (Schroth et al., 1992). Unfortunately, there is paucity of such data, which explains the current increase in research emphasis on leaf litter accumulation and rates of nutrient release as well as on soil and leaf nutrient dynamics.

Most of the studies in the literature mention N and P as the main nutrients analysed to determine mineralisation patterns, although the CN ratio and micronutrients such as Fe, Cu, Zn and Mn have also been analysed (Muoghalu et al., 1994; Songwe et al., 1995; Saravanan et al., 1995).

In their study on litter decomposition and organic element dynamics in a secondary rainforest in Nigeria, Muoghalu et al. (1994) found that the concentrations of Fe, Cu, Mn and Zn increased with decomposition whereas concentrations of N and P decreased first before increasing with decomposition.

In contrast, Songwe et al. (1995) reported initial increases in N and P concentrations when they carried out a similar study in a tropical rainforest in Cameroon. In their case, N was later released while P continued to increase reaching 2 – 3 times the initial concentration. These authors estimated the decomposition constants (per year) of litter from *Celtis zenkeri*, *Cola lepidota*, *Ceiba pentandra* and *Desbordesia glaucescens* to be 4.18, 2.18, 2.16 and 1.60

respectively.

Saravanan et al. (1995) conducted an incubation study with leaf litter from plantations of Eucalyptus, Acacia (both evergreen), apple (deciduous) and pine (coniferous) to investigate mineralisation patterns using the CN ratio. They found that due to their resistant nature, pine needles mineralised very slowly as compared to the other leaf litters under the prevailing climatic conditions although all the four types of litter eventually released N. These researchers quantified leaf litter accumulation monthly and hence calculated nutrient addition to the different plantations. They concluded that accumulation of leaf litter and eventual mineralisation results in soil fertility improvement.

Apparently, the mineralisation patterns described above were based on analysis of the chemical properties of litter at various stages of incubation. Although useful inferences can be made from such studies on the potential of some forestry species to improve soil fertility, they are still inadequate in providing the necessary knowledge for the efficient application of litter in agroforestry systems. This is because in all the studies described, the effect of litter quality on crop productivity was not tested and hence there is no information on the nutrient use efficiency of the various types of litter studied.

2.4 Nodulation and Biological Nitrogen Fixation

Nodulation and biological nitrogen fixation of leguminous tree and shrub species is another aspect of agroforestry, which has received considerable attention (Mulongoy et al., 1992).

Biological nitrogen fixation is the reduction of atmospheric dinitrogen (N_2) to a biologically useful, combined form of N–ammonia. Four groups of nitrogen fixing species have been identified in the literature (Ahn, 1970; Giller and Wilson, 1991; Elkan, 1992; Killham, 1994). These are:

(1) The symbiotic bacteria, collectively referred to as rhizobia, which usually exist in symbiotic associations with members of the legume family (Leguminosae). Some rhizobial strains are sometimes found in the soil as free-living bacteria and these are termed 'indigenous' strains. There are three separate rhizobial genera, namely *Rhizobium*, *Bradyrhizobium* and *Azorhizobium*.

(2) The cyanobacteria or blue-green algae, which exist both as free-living species and in associations with a variety of plants, most notably the aquatic fern *Azolla*.

(3) The actinomycetous *Frankia* species, which form symbiotic associations with flowering plants from a number of different families. The fast-growing tree genus *Casuarina* is a typical example.

(4)The free-living nitrogen fixers (aerobic and anaerobic bacteria) found in the soil and which fix atmospheric dinitrogen when other forms of N are unavailable. This group includes genera such as *Azotobacter*, *Beijerinckia* and *Azospirillum*, all of which are aerobic. The anaerobic nitrogen fixers belong to the genus *Clostridium*.

Of the four groups of nitrogen fixing species described above, the rhizobia are the predominant group shown to make a real contribution to tropical agroforestry systems. Not all genera within the

Leguminosae, however, have the ability to form rhizobial symbioses. The majority of leguminous species used for agroforestry are nodulated members of the two sub-families Papilionioideae and Mimosoideae, although a few members of the sub-family Caesalpinioidae (many of which do not nodulate) have also been used experimentally. These include the non-nodulating species belonging to what was formerly the genus *Cassia*[1].

The most important general principle of the symbiotic association between rhizobial strains and legume host plants is that it depends on the mutual acceptability of the host plant and the particular strain of the microbe. While some host plants have only one suitable or 'compatible' rhizobial strain with which they can form a symbiosis, others have several. Similarly, some rhizobial strains have only one suitable host legume plant, although many *Rhizobium* and *Bradyrhizobium* strains are so promiscuous that their hosts may include legume plants from different sub-families. Thus, if a suitable strain is not present in the soil, or not brought in artificially by inoculation, no nodulation takes place in a legume plant, which might otherwise nodulate and fix nitrogen.

It has been shown in molecular biological experiments that the initial interaction between legume host plants and their compatible rhizobia consists of activation of the *nod* (nodulation) genes of the rhizobia by certain molecules in secretions from the plant root (Peters et al., 1986; Redmond et al., 1986; Kosslak et al. 1987). Work done by Spaink et al. (1987) indicate that this chemical signalling is by no means completely specific since exudates from incompatible legume species can often activate the *nod* genes of a given *Rhizobium* strain to some degree. In some cases, even extracts from

[1] Taxonomic revision of this genus has led to the recognition of three separate genera namely *Cassia*, *Senna* and *Chamaecrista* - the latter contains only nodulating species (Giller and Wilson, 1991).

non-leguminous species (e.g. wheat seedlings) have been shown to induce nodulation (Le Strange et al., 1990).

The root exudates from legumes often contain tryptophan which the rhizobia convert to indole acetic acid (Cobley and Steele, 1976; Lynch and Wood, 1988). The presence of this auxin causes changes in the growth patterns of the root hairs resulting in many deformations including the characteristic 'shepherd's crooks'. Usually, disruption of the plant cell wall occurs at the centre of the crook, thus enabling the rhizobia to enter the cells of the root cortex through the root hair, although entry through an epidermal cell wall is also possible. Once the rhizobia gain entry, an infection thread is formed by the wall of the host cell. This branches and ramifies across one-third to one-half of the root cortex and encloses the rhizobia, which together with the root cortical cells divide rapidly for about 2 - 3 weeks after which they lose their motility and stop dividing. It is about this time that the rhizobia begin to fix atmospheric nitrogen, using carbohydrates from the host legume as their source of energy.

Sometimes, hypertrophies that could be mistaken for nodules by the inexperienced eye occur on roots, but there are straightforward methods of distinguishing these from true root nodules. According to Cobley and Steele (1976), all functioning nodules contain the red pigment leghaemoglobin. Thus one means of identifying true root nodules is to cut them up to see whether the pink colouration will appear.

Factors such as extreme temperatures, drought, soil acidity and nutrient deficiencies strongly influence the ability of nitrogen fixers to induce nodulation and actually fix nitrogen in the field.

Nutrient deficiencies cause reductions in the numbers and size of nodules formed and in the amount of nitrogen fixed (Cobley and Steele, 1976; Lynch and Wood, 1988; Giller and Wilson, 1991).

Arguably, knowledge of nodulation ability is of significant importance in the selection of leguminous tree and shrub species for agroforestry purposes, especially since one cannot assume that a plant would nodulate and fix nitrogen just because it is a legume. In spite of the recent work by various researchers (e.g. Sanginga et al., 1990; Njiti and Galiana, 1996; Kadiata et al., 1996) there remains a large number of leguminous species, particularly in the tropics, whose nodulation ability is yet to be confirmed. *Millettia zechiana* is one such species and this explains its inclusion in my study.

CHAPTER 3 - MATERIALS AND METHODS

3.1 Study Site/ Tree Selection and Mapping

A 95.8 m x 86.0 m farming plot at Adenya, on which various woody perennials have been retained, was chosen as the study site (Plate 1). The woody species found on the study site have been marked with asterisks in Appendix 1. The food crops which had been planted on the study site were plantain (*Musa* sp.), cocoyam (*Xanthosoma sagittifolium*) and cassava (*Manihot esculenta*), but plantain was the dominant crop (Plate 2). A few trees of oil palm (*Elaeis guineensis*) and cocoa (*Theobroma cacao*) were also found.

A total of seven (7) non-leguminous trees were selected for the study. These comprised: two (2) trees of *Ceiba pentandra*, two (2) *Cola gigantea* trees, two (2) trees of *Lannea welwitschii* and one (1) *Milicia excelsa* tree. Although *M. excelsa* had no replicate, it was included in the study because it was deemed important to assess the suitability of this established timber species to agroforestry systems. The tree selection was carefully done to ensure limited interaction between the crowns of the different tree species.

The southern and western boundaries of the study site were assumed to be the x and y axes and the relative positions of the selected trees on the study site were then recorded as x-y co-ordinates along these axes. For each of the selected trees the following measurements were also taken by means of a field measuring tape: height, crown width and girth at breast height or just above the buttress.

Plate 1: Parts of the study site showing the presence of woody perennials. Note the radially symmetric branching of *Ceiba pentandra* (left) and the straight bole of *Milicia excelsa* just behind the palm frond (right).

Plate 2: Sections of the study site showing lush growth of cocoyam, plantain and cassava. Note the dominance of plantain (top) and the presence of a cocoa tree behind Mr. Kofi Kwapong (owner of the farm).

3.2 Microclimatic and Phenological Studies

The air temperature, soil temperature, relative humidity and light intensity at the study site were recorded on November 11, 1998 from 11.00 a.m. to 4.00 p.m. at 30-minute intervals. With assistance from colleagues from the Department of Botany, each microclimatic parameter was measured simultaneously at four separate locations on the study site and their respective means calculated. Soil thermometers (inserted in the soil to a depth of 10 cm) were used to measure soil temperature whereas ordinary mercury thermometers (hung on twigs, about 1.5 m above the ground) were used to measure air temperature. Light meters and sling psychrometers were used to measure light intensity and relative humidity respectively. The soil thermometers, mercury thermometers and light meters were set up one hour before initial readings were taken. It was ensured that the wick of the sling psychrometer was wet throughout the period within which measurements were taken.

The phenology of each tree was recorded during field visits. The presence or absence of the major phenophases (i.e. leaf flushes, leaf fall, flowering and fruiting) was indicated by the plus (+) or minus (-) sign respectively. A pair of binoculars was used for observation since all the tree canopies were many meters above the ground. The following precautions were taken while using the binoculars:

(1) Avoidance of looking directly at the sun in order not to damage the eyes.

(2) Adjustment of the diopter to ensure clear vision.

(3) Adjustment of the angle between the eyepieces to provide the best and most comfortable view.

3.3 Determination of Tree Influence on Soil Properties

To determine the influence of each selected tree on its immediate soil environment, sampling was done at three locations away from the trunk of each tree, viz:

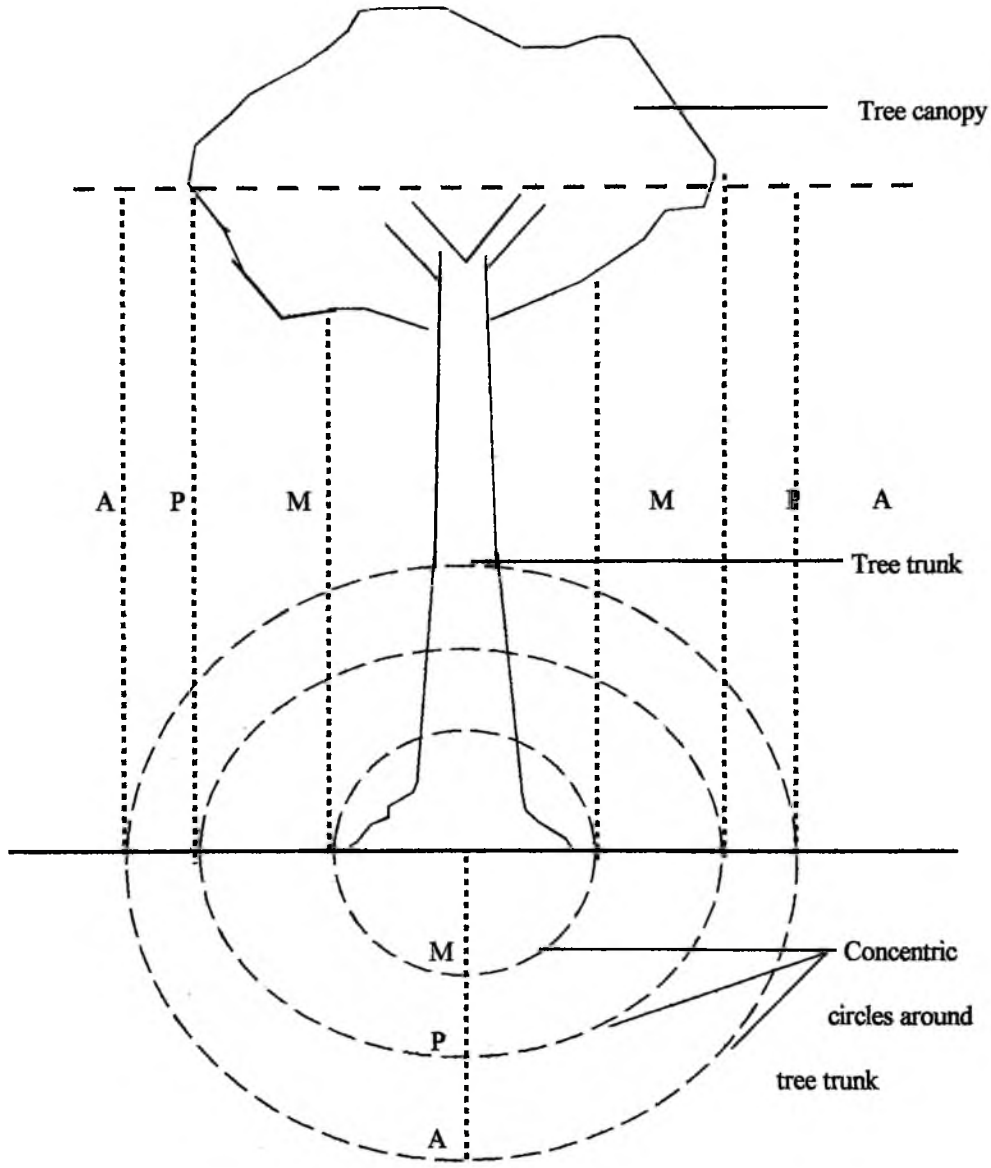
1. midway between the trunk of each tree and the periphery of the tree canopy (M),
2. at the periphery of each tree canopy (P), and
3. 2 m away from the periphery of each tree canopy (A).

Thus as one moved from M through P to A, one actually moved further away from the trunk of each tree species. Three concentric circles were marked around each tree, their radii representing the distance from the trunks of the trees to the three locations M, P and A. Three microsites were then chosen on the circumference of each circle from where soil samples were collected for analysis (Fig. 1). At each microsite, an auger was used to dig three pits to a depth of 15 cm. The soil collected from each set of three pits was bulked to give a fair representation of the soil conditions at each microsite.

3.4 Soil Analyses

The soil samples were analysed in the Ecological Laboratory (and sometimes in the Soil Science Laboratory) both located at the University of Ghana, Legon. The following soil chemical properties were analysed: total N, available N (NO_3^-N and NH_4^+N), available P, exchangeable cations (Na^+, K^+, Ca^{2+}, Mg^{2+}), exchangeable Fe, organic matter content, CN ratio, cation exchange capacity (CEC) and pH (in both water and calcium chloride solution). Soil physical properties namely particle size, texture and soil moisture content were also analysed.

Fig. 1 A schematic representation of soil sampling microsites around a tree species



Note: M: midway between the trunk of the tree and the periphery of its canopy; P: at the periphery of the tree canopy; and A: 2 m away from the periphery of the tree canopy.

To determine soil moisture content, about 5 g of each soil sample was placed in a moisture can of known weight (W_1) and the weight of can plus sample (W_2) was recorded. The samples were then oven-dried at 105 °C for 48 hours to a constant weight, cooled for 30 minutes in a desiccator and re-weighed (W_3). The percentage moisture content of each soil sample was then calculated as follows:

Weight of oven-dry soil $= (W_3 - W_1)$ g and Weight of moisture $= (W_2 - W_3)$ g

Hence, % Moisture (by weight) $= (W_2 - W_3) / (W_3 - W_1) \times 100$

Soil pH in both water and $CaCl_2$ was determined by means of a glass electrode pH meter (Peech, 1965) while the Bouyoucos hydrometer method was used for particle size analysis (Bouyoucos, 1962). After obtaining the results of the particle size analysis, the USDA guide for soil textural classification – reprinted in Olaitan and Lombin (1984) - was used to determine soil texture.

The percentage organic carbon content of the soil was determined by means of the Walkley-Black method. The organic matter content was subsequently calculated as follows: organic matter (%) = organic carbon (%) x 1.724. The use of the Van Bemmelen factor of 1.724 is based on the assumption that organic matter contains 58% carbon (Walkley and Black, 1934, Allison, 1965).

The total nitrogen content of the soil samples was determined by the Kjeldahl method while the inorganic forms of nitrogen (NO_3^-N and NH_4^+N) were determined by the Magnesium Oxide – Devarda Alloy method (Bremner, 1960; 1965). Cation exchange capacity, exchangeable cations and exchangeable Fe were all analysed by the method of ammonium saturation (Chapman, 1965a; 1965b) while available P was determined by the routine chemical extraction procedure. Bray solution (a mixture of ammonium fluoride and hydrochloric acid in the ratio 0.03 M : 0.025 M) was used as the extractant (Tan, 1996).

3.5 Litter Production Studies

Four 0.5 m x 0.5 m litter traps, made from wood and mosquito netting, were set under each tree canopy to collect falling litter. The litter traps were placed on wooden pegs about 1 m off the ground to prevent destruction by termites and to ensure interception of litter fall before it reaches the ground (Plate 3). Trapped litter was collected at monthly intervals. The litter collected from the traps under each tree was oven-dried and sorted into leaves, twigs, buds, flowers, fruits, animal litter and unidentified debris. The leaves were further sorted into leaves of *Ceiba*, *Cola*, *Lannea*, *Milicia* and 'Other' leaves. The various components of the litter were then weighed.

3.6 Litter Decomposition Studies

About 1 kg of the leaf litter produced by all the selected trees (except *Milicia*) was obtained from the accumulated litter on the soil surface and was oven-dried. From each dry litter sample, known weights of litter were taken and placed in twelve (12) litter bags made from nylon nets with a mesh size of less than 2 mm. The litter bags, each of which had a code number, were partly buried at random on the research site to ensure easy retrieval at a later date (Plate 4).

To ensure that the burial of litter bags was completely randomised, the study site was divided equally into 36 subplots and these were numbered from 1 - 36. The subplot numbers were written on pieces of paper and placed in a bag. They were then drawn from the bag, one at a time, and assigned to a litter bag which was also picked at random. After this had been done, the set of subplot numbers for each type of leaf litter were placed in separate bags. Three subplot numbers were drawn at a time from each bag to determine the order of retrieval of the litter bags from the study site. The results of these exercises are presented in Appendix 2.

Plate 3: Litter traps suspended on 1 m long wooden pegs. Note the trapped leaves and twigs (top).

Plate 4: Partly buried nylon mesh bags containing leaf litter.

Three bags from each set of twelve were retrieved every month (Plate 5). The retrieved litter bags were thoroughly, but carefully, washed with a lot of water to remove all the soil particles. They were then air-dried, transferred into large brown envelopes and oven-dried to a constant weight at 80 ^{0}C for 24 hours. Their weights were then recorded. Note was also taken of soil organisms that entered the litter bags.

In this study, the disappearance of litter was equated to decomposition although litter disappearance from the ecosystem is, in fact, a result of combined losses due to decomposition, mineralisation, leaching, animal consumption, wind transport and sometimes even harvest by man (Chapman, 1976).

3.7 Litter Quality Studies

Considerable amounts of the leaf litter produced by all the selected tree species were obtained from the accumulated litter on the soil surface, oven-dried and pulverised.

The pulverised litter samples were analysed for the following mineral nutrients: N, P, K, Ca, Mg, Fe, Mn, Cu and Zn. Since the primary aim of this part of the study was to determine the availability of nutrients released from the leaf litter for plant growth, it was important to have a test crop that had relatively high nutrient requirements. Maize was therefore chosen as the test crop because according to Purseglove (1972), it is a fast-growing crop, which germinates within a few (3 - 5) days after planting and requires a plentiful supply of water and nutrients. Besides, it is the most commonly cultivated cereal in the study area.

The maize was planted in pots of same dimensions, filled with 3 kg of soil to which the different litter samples were added. There were four replicates per litter sample, each of which was watered with

the same volume of water every day. For control, there were four pots of soil to which nothing was added and four other pots of soil containing ureate of potash (an inorganic fertiliser containing 25% N, 15% P and 5% K). The rate of fertiliser used was 80 kg N/ha.

Calculations were done to ensure that each litter sample added to the soil contained the same amount of N as that contained in the inorganic fertiliser. The calculations were as shown below.

1 ha of topsoil (0 – 15 cm) ≡ 2.23×10^6 kg of soil

Hence, 80 kg N/ha ≡ 80×10^3 g /2.23×10^6 kg soil = 0.036 g N/kg soil

Thus for 3 kg of soil, 3 x 0.036 g N = 0.108 g N (per pot) was needed

Since the organic fertiliser contains 25% N, it implies that 25 g of N is contained in 100 g of the fertiliser.

Therefore, 0.108 g N is contained in 0.108/25 x 100 g of fertiliser = 0.432 g

From the litter analysis, the total N content of leaf litter from *Ceiba*, *Cola*, *Lannea* and *Milicia* was found to be 1.57%, 1.19%, 1.47% and 1.02% respectively.

In other words, 1.57 g of N is contained in 100 g of *Ceiba* leaf litter.

Hence, 0.108 g N is contained in 0.108/1.57 x 100 = 6.88 g

Similarly, 0.108 g N is contained in 9.08 g of *Cola* leaf litter, 7.35 g of *Lannea* leaf litter and 10.59 g of *Milicia* leaf litter.

Three seeds of maize were planted in each pot, but these were thinned to two plants after germination (Plate 6). The number of leaves and plant height were recorded every two weeks.

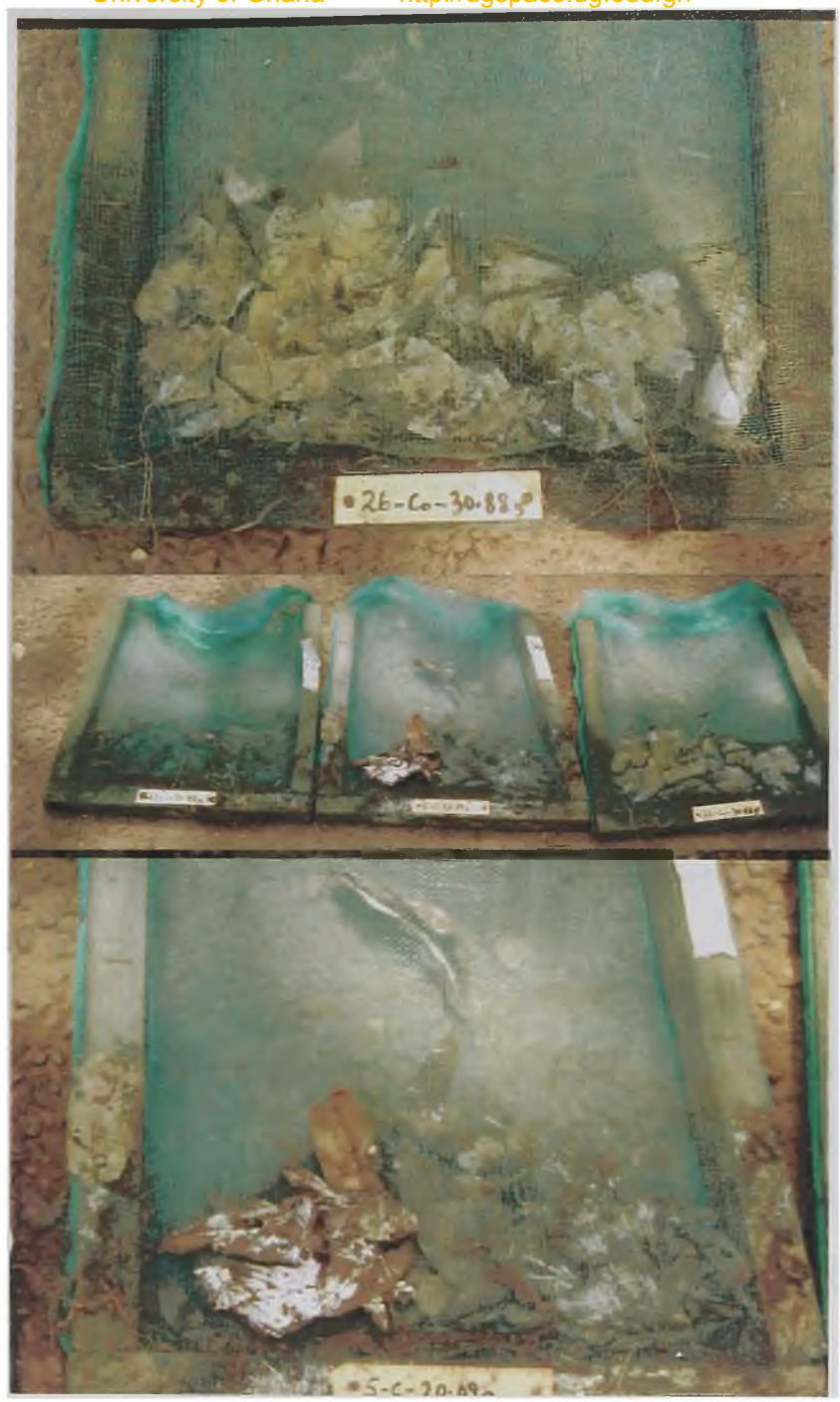


Plate 5: Litter bags retrieved after 10 weeks of decomposition. Note the growth of fungi (identified as *Sclerotium rolfsii* by Prof. G. T. Odamtten, Botany Dept., Legon) on the decomposing litter.

After four weeks of planting, two out of each set of four replicates per treatment were harvested. The shoots were cut just above the soil surface and weighed. The soil was then carefully washed away from the roots with water and these were also weighed. The roots and shoots were then placed separately in appropriately-labelled brown envelopes, oven-dried at 80 ^{0}C for 72 hours, allowed to cool and re-weighed. The remaining plants were harvested and treated in the same way two weeks later. The oven-dried plant parts were later pulverised and analysed for N, P, K, Ca and Mg.

3.8 Nodulation Studies of *Millettia zechiana*

Millettia zechiana is a shrub or small tree that grows up to 30 ft (9 m) high. It has pinnate leaves and reddish purple flowers. It flowers from June to August and sometimes from October to December, and fruits from January to February. Irvine (1961) described the shape of its pods as oblanceolate (Plate 7).

Viable seeds of *M. zechiana* were obtained from trees retained on a citrus farm located at Aburi. These were planted in 3 different soil types, viz: soil taken from under the canopy of the *M. zechiana* tree from which the seeds were obtained, soil taken from the study site, and soil taken from a farm at the Legon Botanical Gardens. Each soil type was analysed to determine its N, P and K content. There were five pots per soil type, each filled with 3 kg of soil.

Plate 6: Maize seedlings growing in soil to which different types of leaf litter have been added.

Plate 7: *Millettia zechiana* growing along the Aburi Hills road.

Two seeds were planted in each pot and these were watered daily with the same amount of water. Beginning from the fourth week, the plant height was recorded every two weeks till the eighth week. After 8 weeks of planting, three replicates per soil type were chosen for further growth measurements. The measurements taken were as follows: number of well-formed compound leaves, maximum number of leaflets per leaf, length/width of biggest leaflet, shoot dry weight, root dry weight, nodule numbers and nodule dry weight. The shoots were also analysed to determine the total amounts of N, P and K accumulated over the period.

3.9 Data Analysis

The analysis of variance (ANOVA) and the LSD (least significance difference) statistics were used to test the significance of most of the results obtained in this study. The LSD values, which were computed simultaneously with the variance ratio (F), were used to identify which means were significantly different from each other, only when F was found to be significant. This discrimination was made because according to Snedecor and Cochran (1967) when many differences are tested, some that appear significant are almost certain to be found even when the F-test is not significant and this may lead to error in interpretation. A 5 % significance level was chosen for all the ANOVA tests.

CHAPTER 4 - RESULTS

4.1 Tree Mapping/ Growth Parameters

The relative positions of the selected trees, which were measured as described in section 3.1, were plotted as a scatter chart to give a bird's eye view of the selected trees on the study site (Fig. 2a). The tree growth parameters (height, girth and crown width) were plotted as a bubble chart (Fig. 2b).

A bubble chart presents sets of three values like a scatter chart with the third value displayed as the size of the bubble marker. Thus the values shown against the bubble markers in Fig. 2b indicate the crown width of the selected trees and the widest bubble represents the tree with the widest crown. Fig. 2b shows that all the selected trees were more than 10 m high. The *Ceiba* trees were the tallest and had the widest trunks and crowns.

4.2 Climate of Study Area/ Microclimate of the Study Site

Fig. 3a shows the climate of the study area as recorded at the closest meteorological station (Koforidua). Monthly rainfall, temperature and relative humidity data for 1997 and 1998 were obtained from the Meteorological Services in Accra.

The climatic diagram indicates that the study area experiences two rainy seasons: a major season, which lasts from April to June and a minor season which spans the months of September and October. The periods between March and July and between August and November are relatively humid, whereas the periods between July and August and between December and February are

relatively dry. Mean monthly rainfall is highest in June and least in December, but March and August are respectively the hottest and coldest months of the year.

Fig. 3b indicates that generally relative humidity of the study area is high (~95 %) in the morning but drops appreciably by late afternoon. Fig. 4a, however, shows that on a daily basis, relative humidity is inversely proportional to air temperature and thus relative humidity values for late afternoon could be higher than those for the morning should there be an appreciable drop in temperature for any reason (e.g. the formation of rain clouds).

Microclimatic data obtained at the study site on November 11 (1998), indicate that in spite of fluctuations in light intensity, soil temperature was relatively constant throughout the day (Fig. 4b). Nonetheless, the highest soil temperature (31 °C) was first recorded at mid-day when the maximum light intensity (672 lux) was also recorded. The sharp decreases and increases in light intensity were probably due to the formation and dispersion of clouds.

Fig. 2a Relative positions of selected trees on the study site

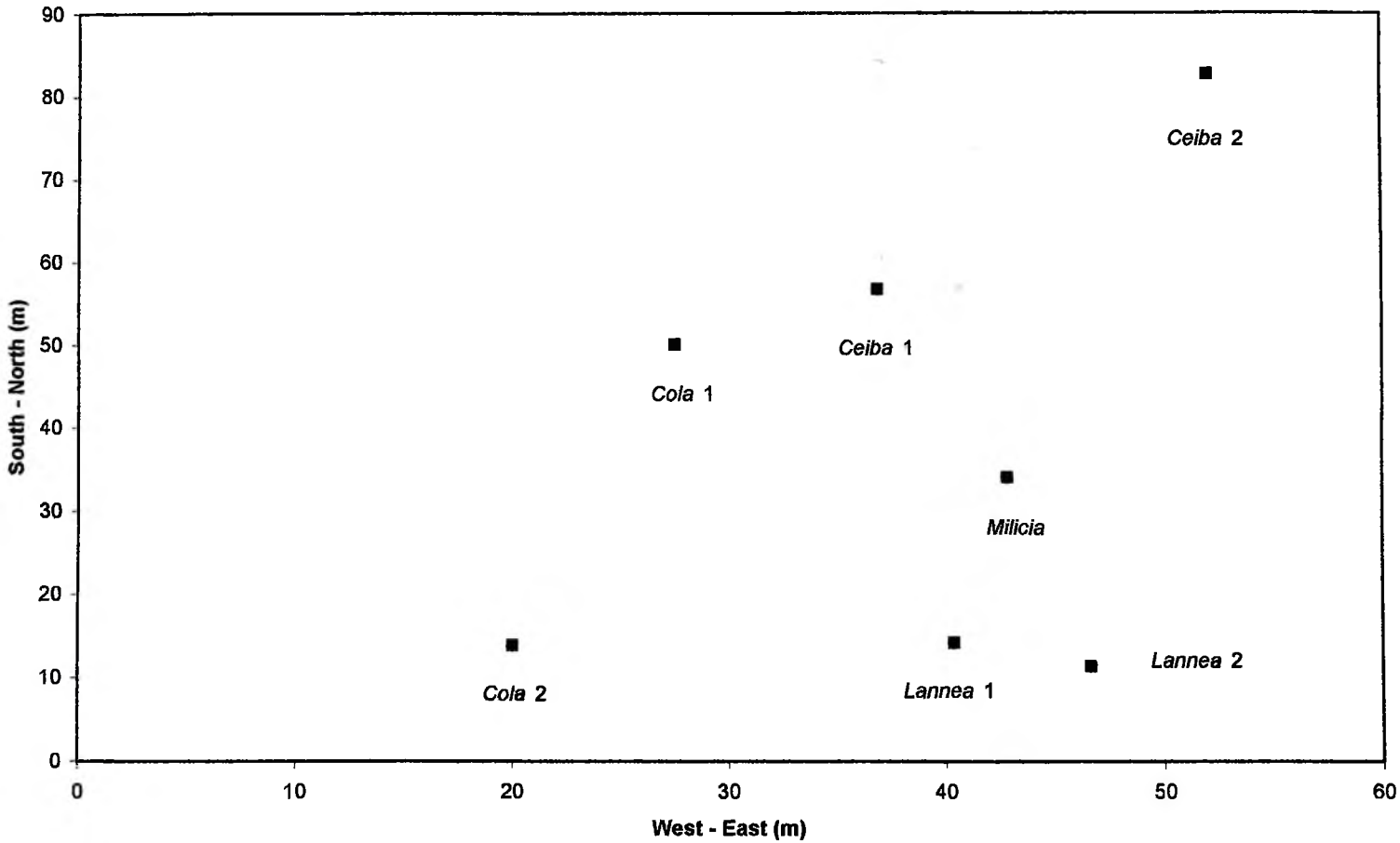


Fig. 2b Height, girth and crown width of selected tree species
(The figures represent the crown width in metres)

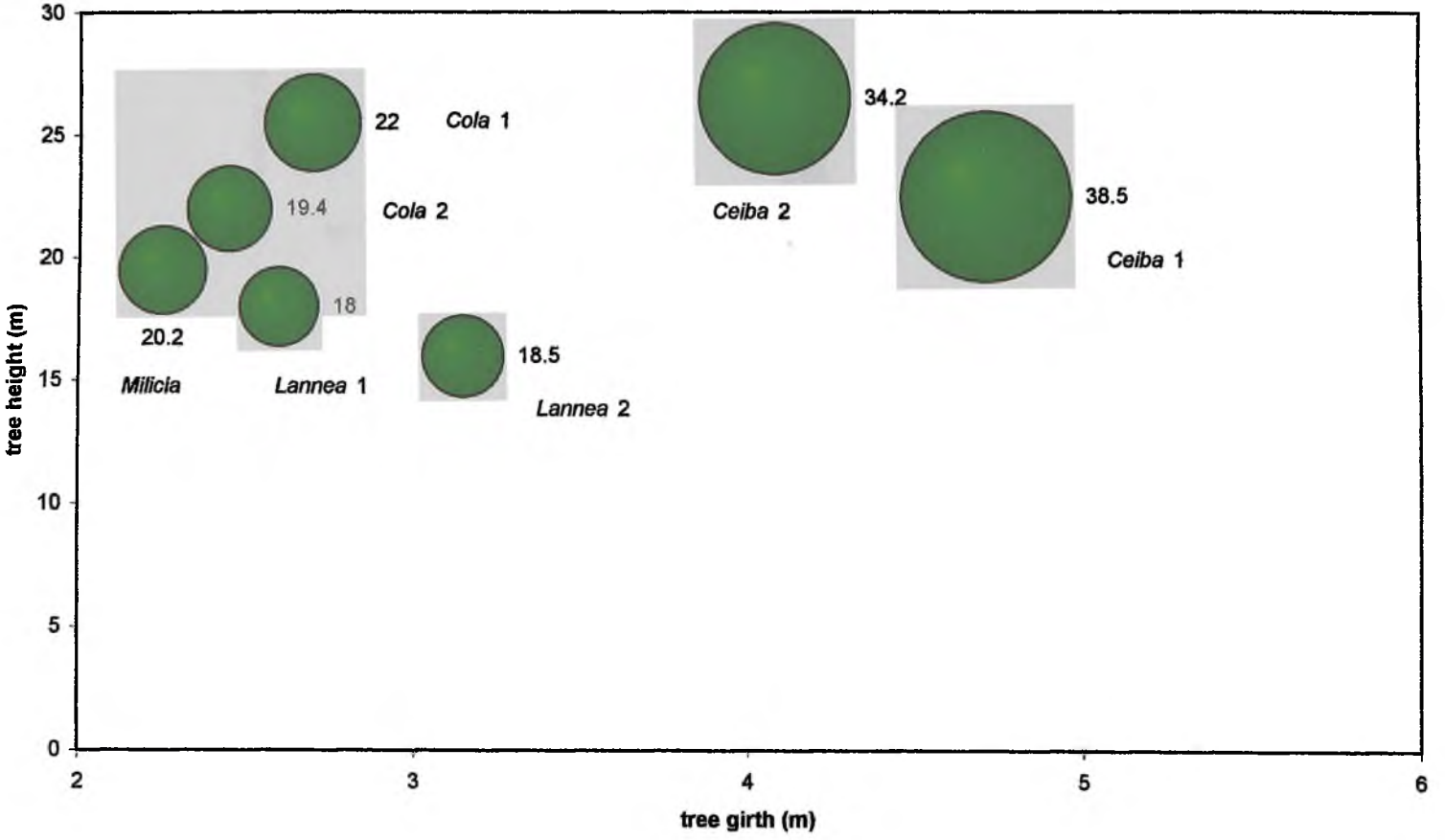
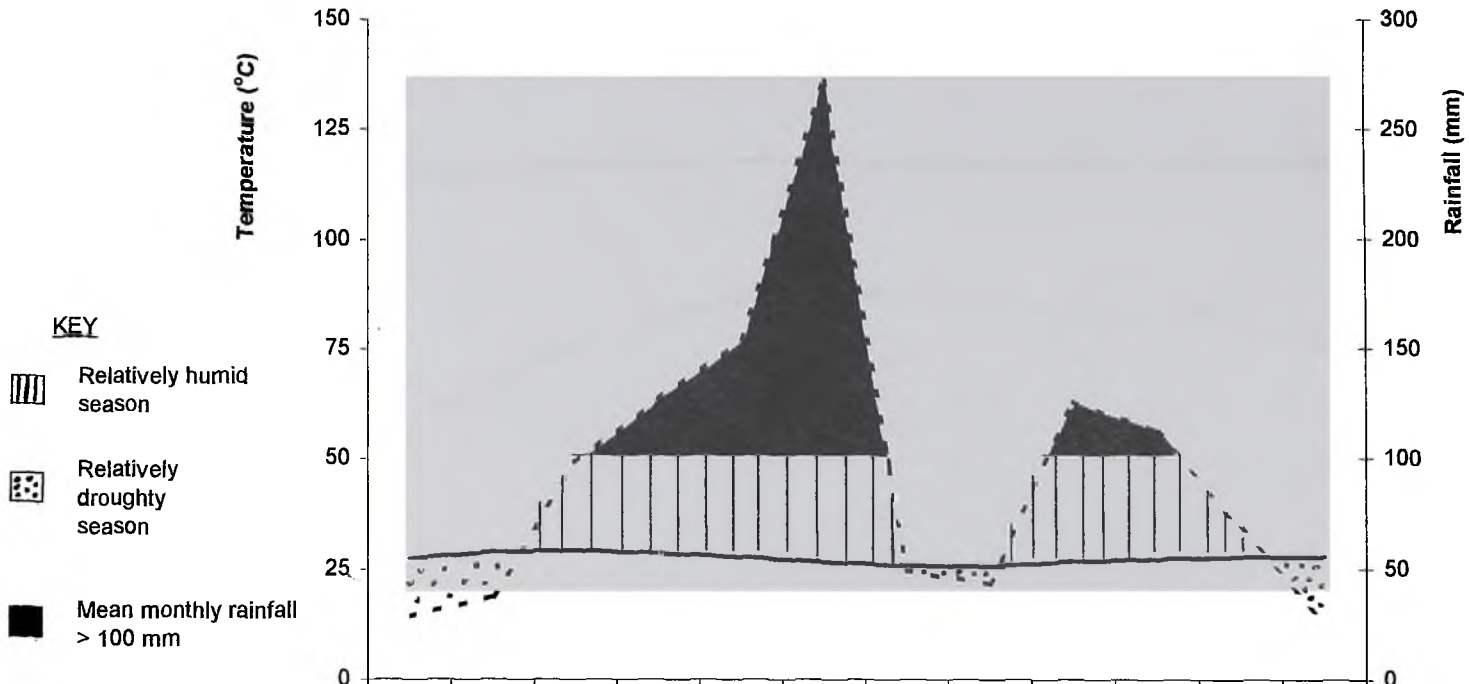


Fig. 3a Climatic diagram for Koforidua
(Data obtained from Meteorological Services, Accra)

27.6 1144.7

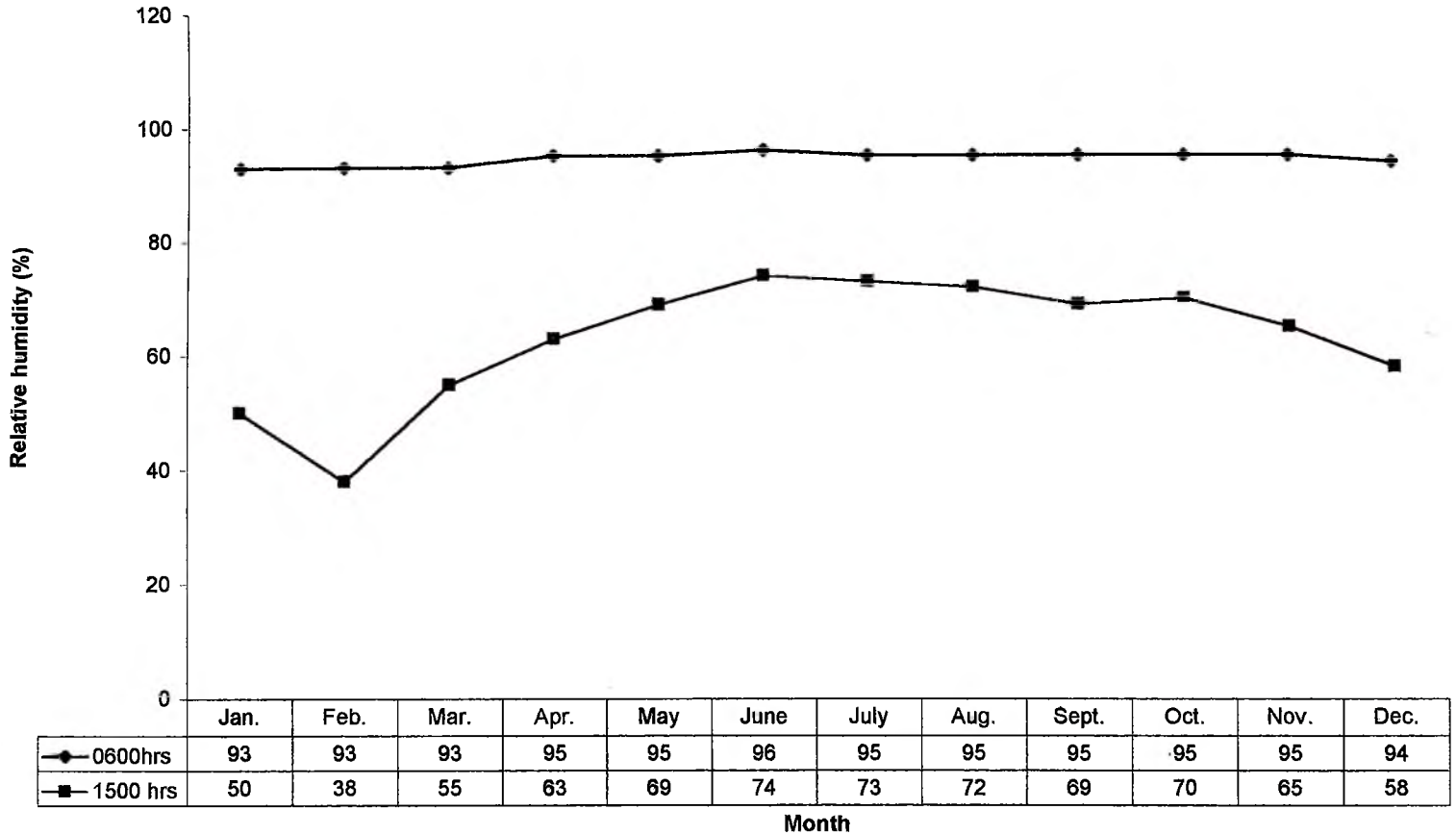
Koforidua
2, 2



	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean monthly temperature	27.5	29	29.3	28.7	27.8	26.8	25.9	25.7	26.9	27.4	27.8	27.8
Mean monthly Rainfall	28.6	37.7	98.6	127	154.3	272.2	49.6	43.6	125.85	112.5	68.4	26.5

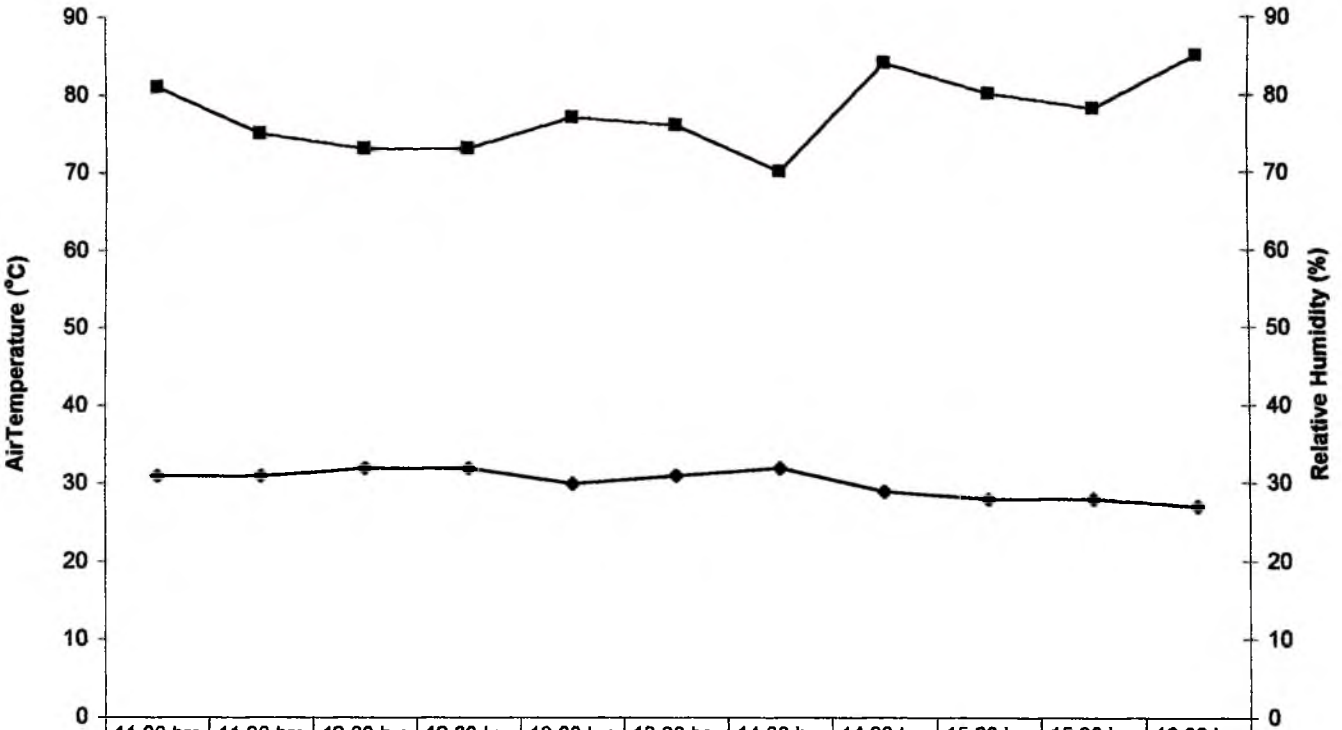
Month

Fig. 3b Mean monthly relative humidity for Koforidua (Data from Meteorological Services, Accra)



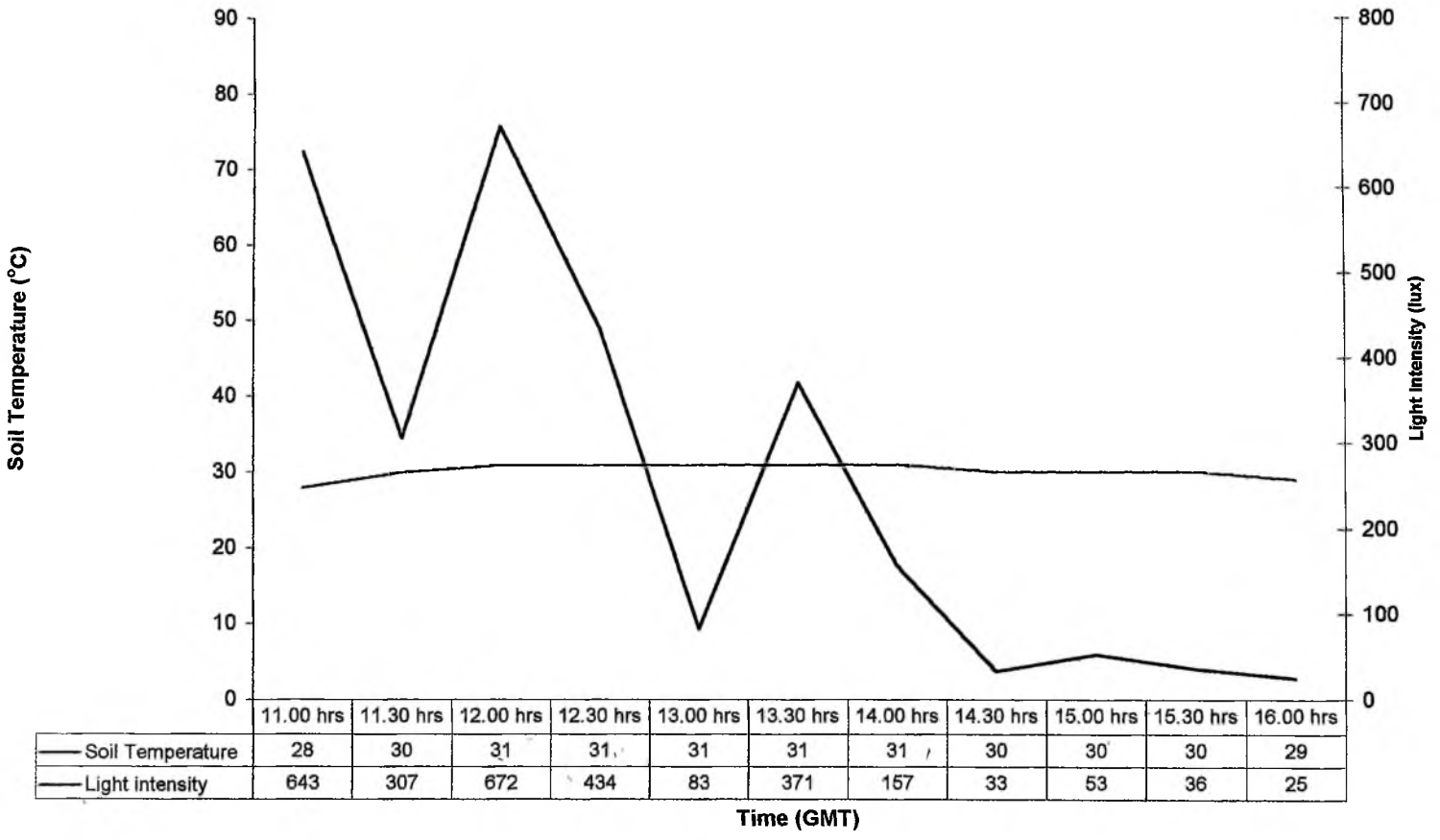
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0600hrs	93	93	93	95	95	96	95	95	95	95	95	94
1500 hrs	50	38	55	63	69	74	73	72	69	70	65	58

Fig. 4a Microclimatic measurements recorded at study site on November 11, 1998



	11.00 hrs	11.30 hrs	12.00 hrs	12.30 hrs	13.00 hrs	13.30 hrs	14.00 hrs	14.30 hrs	15.00 hrs	15.30 hrs	16.00 hrs
Air Temperature	31	31	32	32	30	31	32	29	28	28	27
Relative Humidity	81	75	73	73	77	76	70	84	80	78	85

Fig. 4b Other microclimatic measurements recorded at study site on November 11, 1998



	11.00 hrs	11.30 hrs	12.00 hrs	12.30 hrs	13.00 hrs	13.30 hrs	14.00 hrs	14.30 hrs	15.00 hrs	15.30 hrs	16.00 hrs
Soil Temperature	28	30	31	31	31	31	31	30	30	30	29
Light intensity	643	307	672	434	83	371	157	33	53	36	25

Time (GMT)

4.3 Phenology

Tables 1a and 1b provide a summary of the phenology of *Ceiba*, *Cola*, *Lannea* and *Milicia* as observed from September 1998 to April 1999.

While *Cola* shed some of its leaves throughout the study period, the leaves of *Ceiba* were shed between September and November. *Lannea* shed its leaves from November to December (Plate 8, left) while those of *Milicia* were shed from December to January.

Cola flowered from September - November, produced new leaves in December, February and March, and fruited from December - February. While leaf flushes of *Ceiba* were observed in December, those of *Milicia* were observed in February and March. Both species, however, did not flower or produce fruits during the study period. *Lannea*, on the other hand, flushed new leaves from December to March (Plate 8, right) and flowered from December to January but it also did not produce any fruits during the period of the study.

4.4 Litter Production

Between October 1998 - January 1999, leaves and twigs respectively constituted the largest and second largest components of litter collected from the litter traps placed under all the four tree species. Over the period of litter collection, leaves contributed 79 % whereas twigs contributed 15 % of the total litter collected from the study site (Table 2). Flowers, fruits, animal litter and unidentified debris, on the other hand, contributed relatively low amounts of the litter collected under all the tree species (Figs. 5 - 8).

Plate 8: *Lannea welwitschii* (with forked stem) exhibiting leaf fall in November (left) and leaf flushes in January (right). The new leaves which are actually bronze in colour appear as yellow patches in this picture.

Table 1a: Phenology of four tree species from September - December 1998

TREE SPECIES	PHENOPHASE	MONTH			
		September	October	November	December
Ceiba pentandra	leaf flushes	-	-		+
	leaf fall	+	+	+	-
	flowering		-	-	
	fruiting	-	-	-	-
	comments	Yellowing leaves	Yellow leaves	Complete leaf fall	Re-growth of leaves on all branches
Cola gigantea	leaf flushes	+	+	-	-
	leaf fall	+	+	+	+
	flowering	+	+		
	fruiting	-	-	-	+
	comments	Flowers are small and pink in colour	Limited leaf fall/flowering	Limited leaf fall/flowering	Low fruit density
Lannea welwitschii	leaf flushes	-	-	-	+
	leaf fall	-	-	+	+
	flowering	-	-	-	+
	fruiting		-	-	
	comments	A few yellowing leaves	A few yellowing leaves	More yellowing leaves	Leaf flushes are bronze in colour
Milicia excelsa	leaf flushes	-	-	-	-
	leaf fall	-	-	-	+
	flowering	-	-	-	-
	fruiting	-	-	-	-
	comments	Fairly green leaves	Fairly green leaves	A few yellowing leaves	More yellowing leaves; very limited leaf fall

Table 1b: Phenology of four tree species from January - April 1999

TREE SPECIES	PHENOPHASE	MONTH			
		January	February	March	April
Ceiba pentandra	leaf flushes	-	-	-	-
	leaf fall	-	-	-	-
	flowering	-	-	-	-
	fruiting	-	-	-	-
	comments	Leaves are green	Mature leaves	Nil	Nil
Cola gigantea	leaf flushes	-	+	+	
	leaf fall	+	-	-	-
	flowering	-			-
	fruiting		+		-
	comments	Some yellowing leaves	A few yellowing leaves	Leaf flushes are few	A few yellowing leaves
Lannea welwitschii	leaf flushes	+	+	+	
	leaf fall		-	-	
	flowering	+	-		-
	fruiting	-	-	-	
	comments	Abundant flowering	Complete flower fall	Re-growth of leaves on all branches	Nil
Milicia excelsa	leaf flushes	-	+	+	
	leaf fall	+	-	-	-
	flowering	-	-	-	-
	fruiting		-	-	-
	comments	Complete leaf fall	Re-growth of leaves on some branches	Re-growth of leaves on all branches	Nil

Table 2: Total litter collected between October 1998 - January 1999

Tree species under which litter traps were located	Weights (g) of the different components of litter collected from traps and their percentage contribution to the total litter collected						
	Leaves	Twigs	Flowers	Fruits	Animal litter	Unidentified debris	Total Litter
Ceiba	273.41	104.63	0.23	0.14	4.14	19.97	402.52
Cola	350.37	21.85	15.86	1.23	0.02	20.58	409.91
Lannea	319.51	99.52	23.71	0	0.18	8.73	451.65
Milicia	358.15	17.59	3.39	0	0.2	10.63	389.96
Total	1301.44	243.59	43.19	1.37	4.54	59.91	1654.04
% contribution	79	15	2	0	0	4	100

Fig. 5 Weights of different components of litter collected from litter traps under *Ceiba pentandra* (October, 1998 - January, 1999)

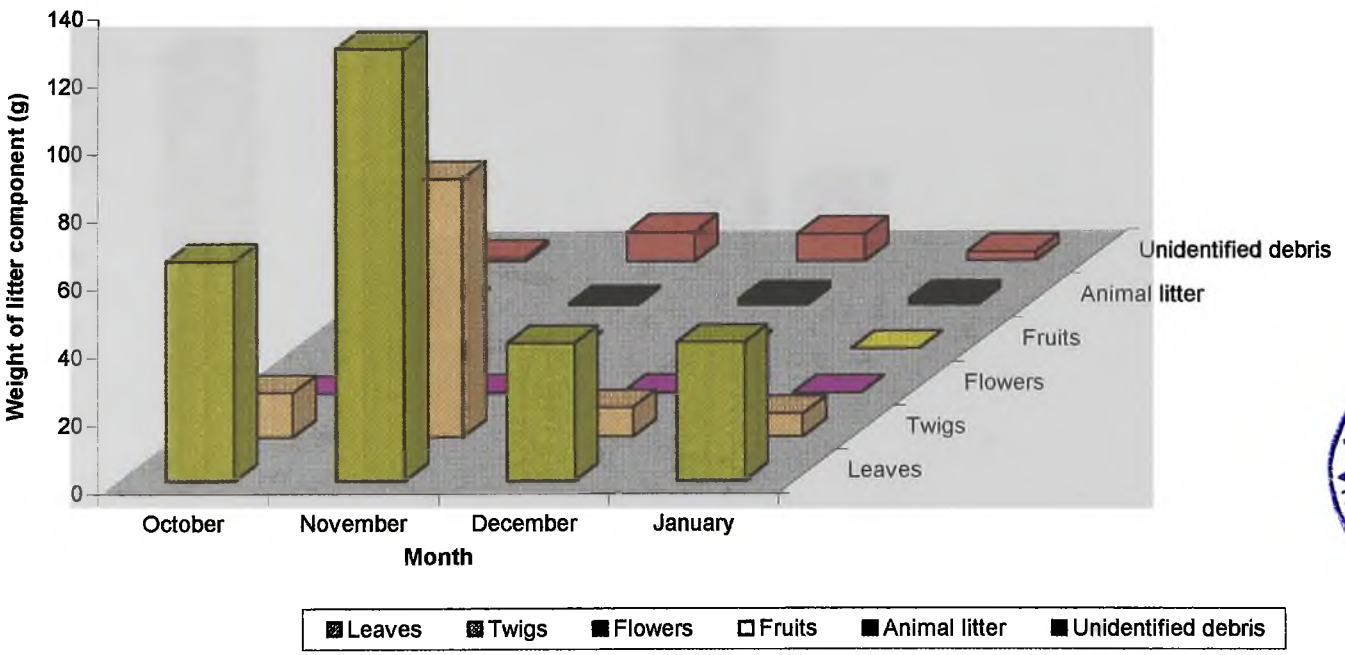


Fig. 6 Weights of different components of litter collected from litter traps under *Cola gigantea* (October, 1998 - January, 1999)

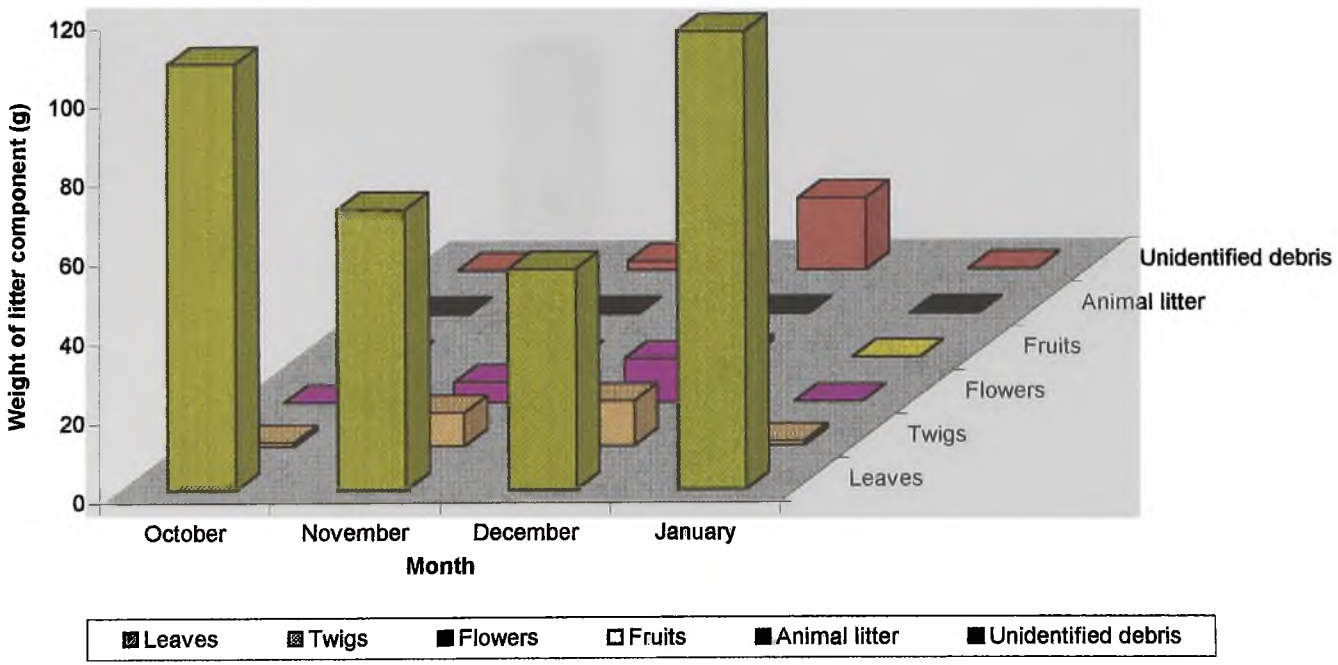


Fig. 7 Weights of different components of litter collected from litter traps under *Lannea welwitschii* (October, 1998 - January, 1999)

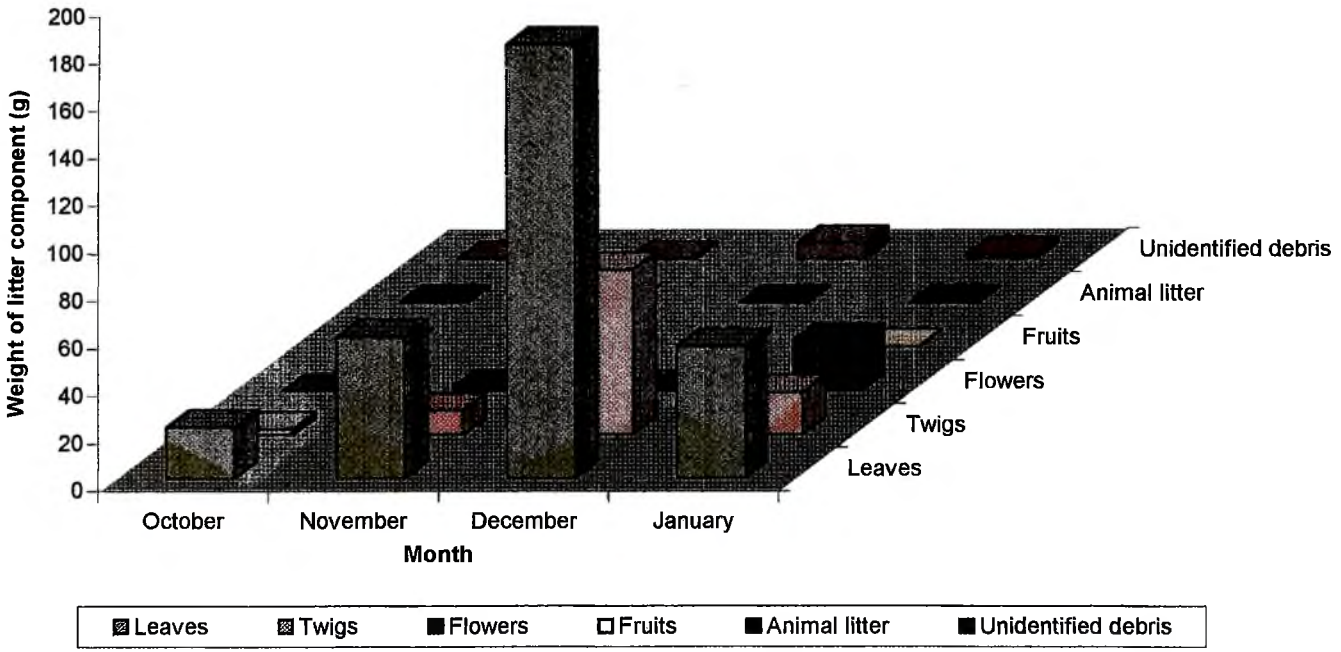
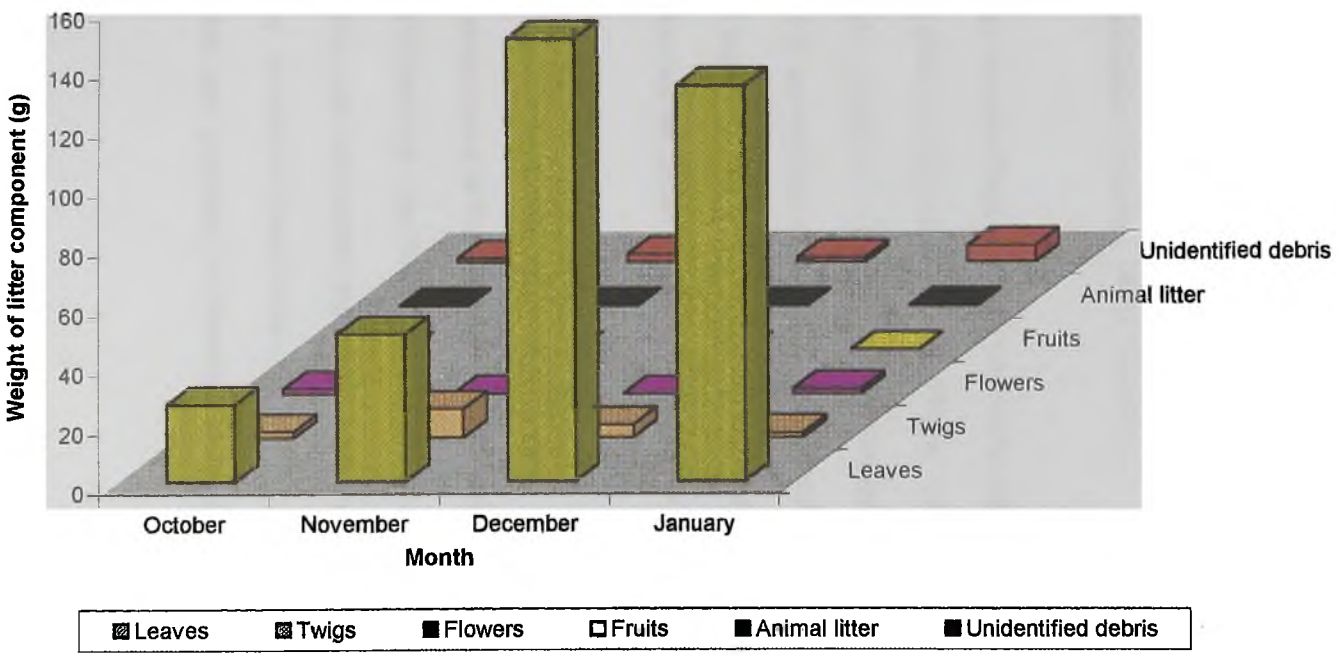


Fig. 8 Weights of different components of litter collected from litter traps under *Milicia excelsa* (October, 1998 - January, 1999)



A peak period of twig fall was observed in the dry season. Under *Ceiba* and *Milicia,* the highest amounts of twigs were trapped in November, while under *Cola* and *Lannea* the highest amounts were trapped in December (Fig. 9). Twig production was much higher under *Ceiba* and *Lannea* than under *Cola* and *Milicia*. In the case of *Lannea*, the production of twigs was apparently enhanced by the activity of insects, which were found debarking a branch of this tree species (Plate 9). With the help of the Chief Technician of the Zoology Department (University of Ghana, Legon), the insects were identified as *Mylabris trefasciata* (order: Coleoptera; family: Meloidae).

Although the leaves of one tree species were often found in the litter traps placed under another tree species due to wind-throw, Fig. 10 indicates that the highest amounts of *Ceiba, Cola, Lannea* and *Milicia* leaves were collected from the traps placed under their respective tree species. Thus, the highest amount of *Ceiba* leaves (158.43 g) was trapped under *Ceiba* while the highest amount of *Cola* leaves (268.34 g) was trapped under *Cola.* Similarly, the highest amount of *Lannea* leaves (186.56 g) was trapped under *Lannea* and the highest amount of *Milicia* leaves (91.09 g) was collected from traps under *Milicia.*

Table 3 shows that over the four-month period of litter production studies, *Cola* produced the highest mean weight (179.37 g) of leaf litter per tree, followed by *Lannea* (133.74 g), *Ceiba* (122.67 g) and *Milicia* (97.16 g) in that order. *Cola* (which is evergreen) had two peaks of leaf litter production in October and January. In contrast, *Ceiba, Lannea* and *Milicia* (all of which are deciduous) had single peaks of leaf litter production in November, December and January respectively (Fig. 11).

Fig. 9 Monthly twig production under four tree species (October, 1998 - January, 1999)

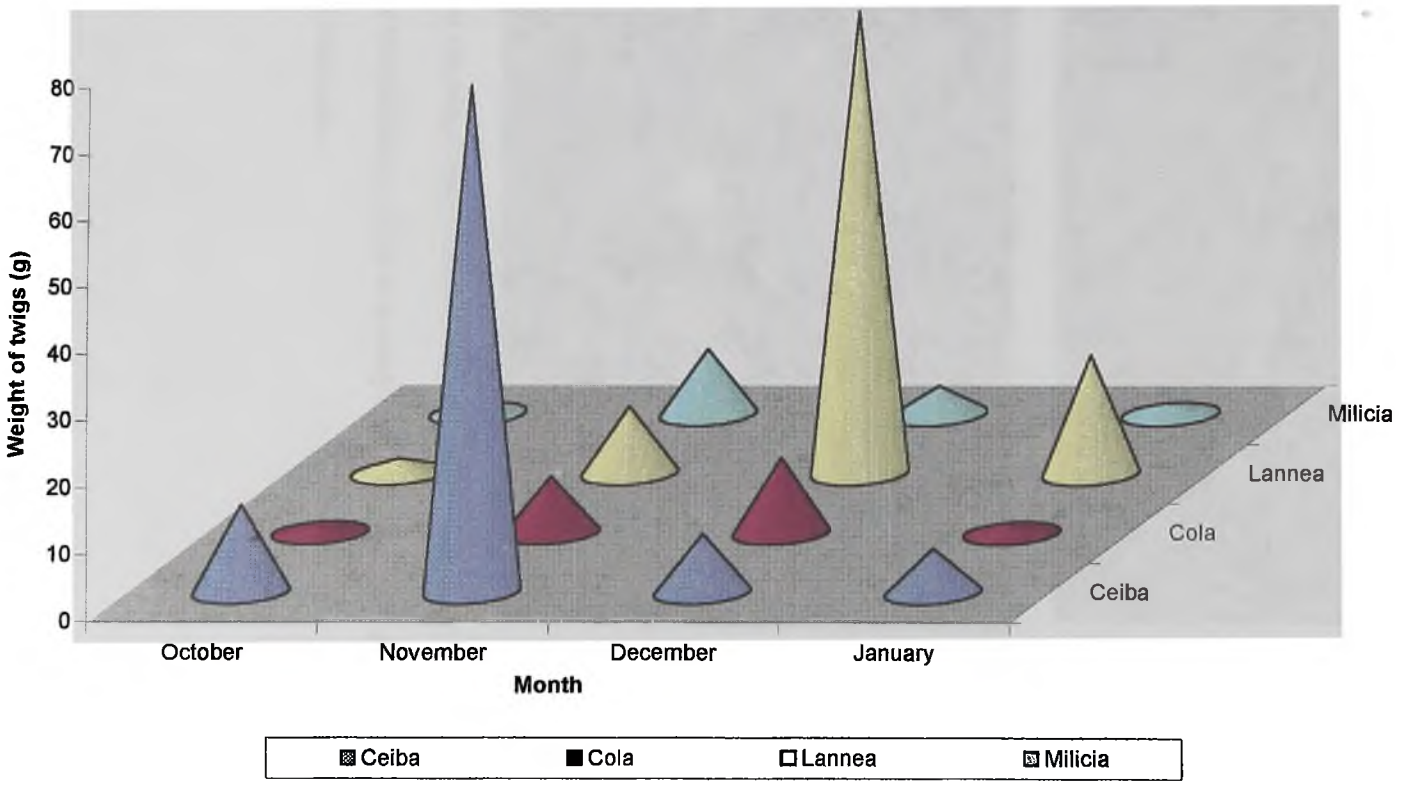


Plate 9: *Mylabris trefasciata* attacking a twig of *Lannea welwitschii* (top). Note the nifty debarking of the twig (bottom) by these beautiful insects, which have a body length of ~ 3 cm. Their antennae are about 0.5 times longer than their bodies.

Fig. 10 Weights of different types of leaves collected from litter traps under four tree species (October, 1998 - January, 1999)

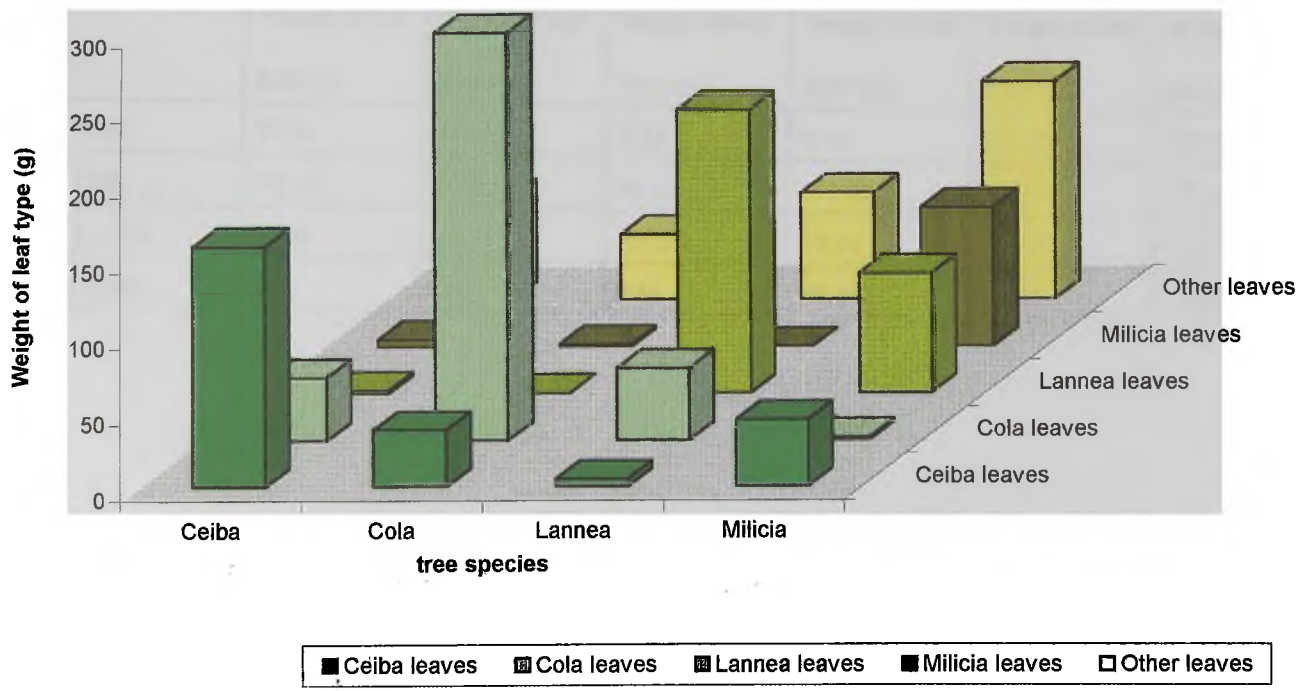
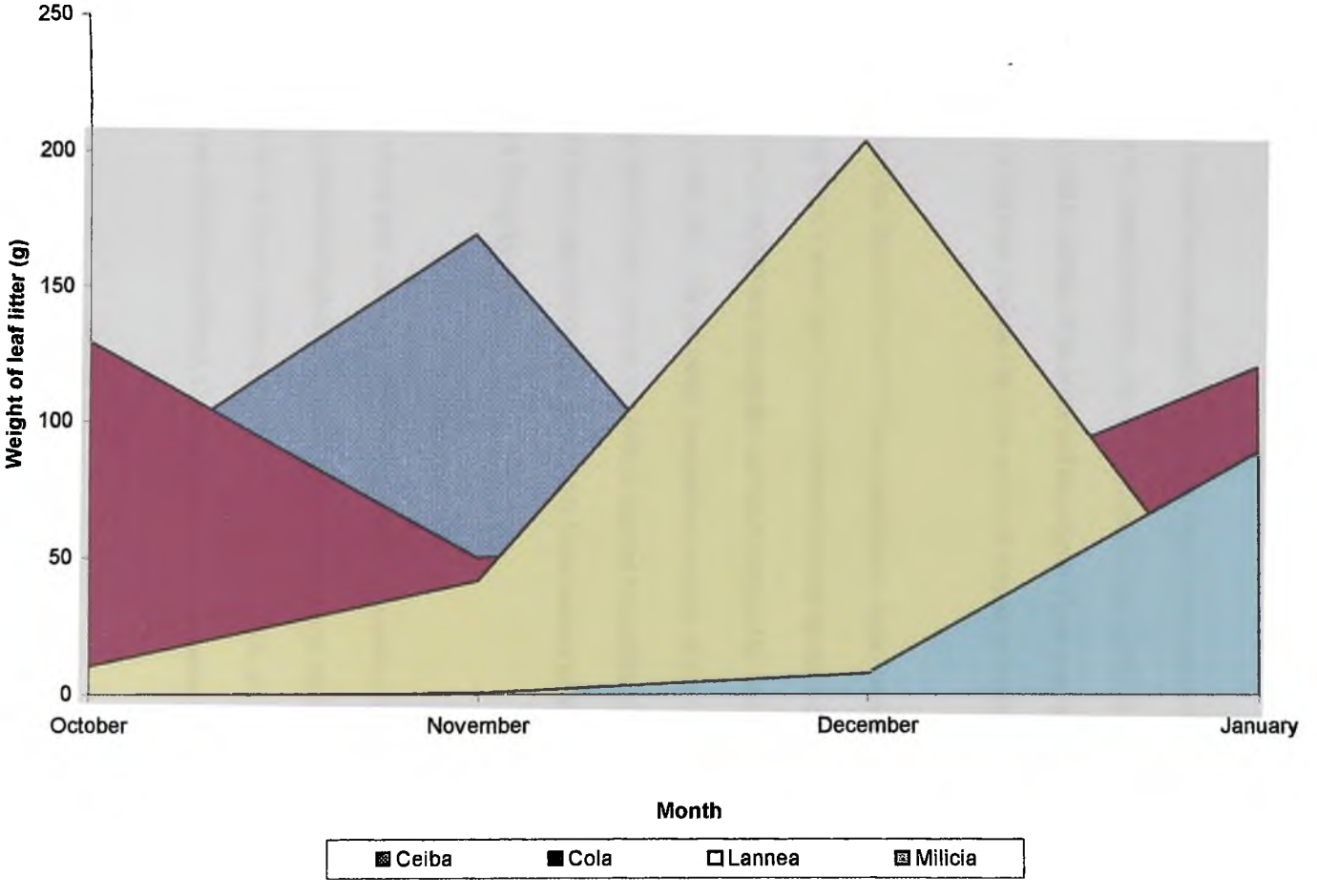


Table 3: Total leaf litter production by different tree species from Oct. 1998 - Jan. 1999

Tree species	October 14 Weight of leaf litter (g)	November 11 Weight of leaf litter (g)	December 9 Weight of leaf litter (g)	January 13 Weight of leaf litter (g)	Total Weight of leaf litter (g)	Mean weight of leaf litter per tree (g)
Ceiba	74.51	168.17	2.22	0.43	245.33	122.67
Cola	129.44	50.02	60.23	119.05	358.74	179.37
Lannea	10.49	41.73	201.82	13.43	267.47	133.74
Milicia	0	0.8	7.88	88.48	97.16	97.16

Fig. 11 Monthly Leaf litter production by four tree species (October, 1998 - January, 1999)



4.5 Nutrient Content of Leaf Litter produced by *Ceiba*, *Cola*, *Lannea* and *Milicia*

Apart from Zn which varied insignificantly, all the nutrient elements that were analysed varied significantly between tree species (see Appendix 3 for analysis of variance (ANOVA) tables for the various nutrient elements).

The amount of N in *Ceiba* leaf litter was significantly higher than the amounts of N in *Cola* and *Milicia*, but comparable to that in *Lannea* leaf litter. The latter contained the highest amount of P which was considerably higher than the P content of the other leaf litter types. There was, however, no difference between the P content of leaf litter produced by *Cola* and the P content of *Milicia* leaf litter (Table 4).

The K content of *Lannea* leaf litter (6.67×10^{-3} %) was significantly higher than in the other leaf litter types, although leaf litter from *Ceiba* and *Cola* contained the same amount of K (4×10^{-3} %). The highest amount of Ca (10.27 mg/kg) was recorded in leaf litter produced by *Milicia* but, as in the case of K, leaf litter from *Ceiba* and *Cola* contained comparable amounts of Ca (7.21 and 7.31 mg/kg respectively). Leaf litter from *Ceiba*, *Lannea* and *Milicia* showed no significant variation in their Mg content, but all three leaf litter types contained an appreciably lower amount of Mg than leaf litter from *Cola*, which contained 8.74 mg/kg of Mg.

Each of the four types of leaf litter contained significantly different amounts of Fe and Mn (Table 4). While *Ceiba* leaf litter contained the highest amount of Fe (0.863 mg/kg) and was followed by the others in the order *Ceiba* > *Cola* > *Milicia* > *Lannea*, the highest amount of Mn (0.161 mg/kg) was recorded in *Cola* leaf litter and was followed by *Milicia*, *Ceiba* and *Lannea*, in that order.

Table 4: Nutrient content of leaf litter from different tree species

Tree species	Nutrient element										
	C (%)	N (%)	P (%)	K (%)	Ca (mg/kg)	Mg (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	C/N (mg/kg)
Ceiba	45.47	1.57	0.123	4.00×10^{-3}	7.21	3.40	0.863	0.097	0.080	0.122	29.07
Cola	41.77	1.19	0.107	4.00×10^{-3}	7.31	8.74	0.673	0.095	0.161	0.121	35.07
Lannea	44.45	1.47	0.310	6.67×10^{-3}	4.48	3.00	0.404	0.048	0.059	0.117	30.20
Milicia	38.54	1.02	0.107	3.00×10^{-3}	10.27	3.15	0.544	0.038	0.117	0.126	37.80
LSD		0.112	0.013	5.00×10^{-4}	0.675	0.528	0.0746	0.0172	0.0129		

4.6 Potential Contribution of Different Types of Leaf Litter to Soil Nutrient Pool

The potential contribution of the four tree species to soil nutrient availability through leaf litterfall was determined by multiplying the mean weight of leaf litter produced per tree species by the nutrient content of leaf litter produced by each species. For example, Table 3 shows that *Ceiba* produced a mean weight of 122.67 g of leaf litter per tree and Table 4 indicates that 100 g of this leaf litter contained 1.57 g of N. Thus one *Ceiba* tree could contribute at least 1.93 g of N to the soil through leaf litterfall (Table 5) assuming total decomposition of all the litter produced.

Table 5 shows that although *Cola* leaf litter does not contain the highest amounts of C, N, Ca, Fe, Cu and Zn, it has the potential of contributing the highest amounts of these nutrients to the soil because of its high leaf litter producing ability. Since *Cola* leaf litter already contains high amounts of Mg and Mn, it has even greater potential of contributing to the availability of these nutrient elements to the soil.

Lannea, on the other hand, exhibited the potential to return the highest amounts of P and K to the soil nutrient pool, in consonance with the fact that its litter contained the highest amounts of these two nutrient elements. *Ceiba*, which had a significantly higher amount of N (1.57 %) in its leaf litter than *Cola* (1.19 %) showed less potential of contributing to the availability of N in the soil. Similarly, *Milicia* showed less potential than *Cola* with regard to the contribution of Ca to the soil nutrient pool, although the leaf litter produced by *Milicia* contained a significantly higher amount of Ca.

Table 5: Potential contribution of leaf litter from different tree species to soil nutrient pool

Tree species	Nutrient element									
	C (g)	N (g)	P (mg)	K (mg)	Ca (µg)	Mg (µg)	Fe (µg)	Cu (µg)	Mn (µg)	Zn (µg)
Ceiba	55.78	1.93	150.88	4.91	884.45	417.08	105.86	11.9	9.81	14.97
Cola	74.92	2.13	191.93	7.17	1311.19	1567.69	120.72	17.04	28.88	21.70
Lannea	59.45	1.97	414.59	9.36	599.15	401.22	54.03	6.42	7.89	15.65
Milicia	37.45	0.99	103.96	2.91	997.83	306.05	52.86	3.69	11.37	12.24

Table 6: Decomposition of leaf litter produced by different tree species

Tree species	Initial weight of leaf litter (g)	Weight remaining after 6 weeks (g)	Weight remaining after 10 weeks (g)	Weight remaining after 14 weeks (g)	Weight remaining after 18weeks (g)
Ceiba	30.00	25.21	23.10	21.32	16.66
Cola	30.00	24.75	22.65	20.37	18.74
Lannea	30.00	22.04	21.40	17.23	12.64
LSD	-	1.098	-	-	4.028

4.7 Decomposition of Leaf Litter

Table 6 shows the weights of the different types of leaf litter remaining after 6, 10, 14 and 18 weeks of incubation. There were no significant differences in the weights of *Ceiba* and *Cola* leaf litter remaining regardless of the period of incubation. The weights of *Lannea* leaf litter remaining after 6 and 18 weeks of incubation were, however, significantly lower than those of the other two species (see Appendix 4 for ANOVA tables). A plot of percent litter remaining against time showed that *Ceiba* and *Cola* have comparable rates of decomposition which are significantly lower than that of *Lannea* (Fig. 12).

Assuming a steady rate of decomposition over time, the decomposition rate constants (k) for leaf litter produced by *Ceiba*, *Cola* and *Lannea* were found from the linear trendlines in Fig. 12 to be 0.029/week (0.0041/day), 0.0272/ week (0.0039/ day) and 0.0434/ week (0.0062/ day) respectively. Hence the time (t_{50}) required for 50 % disappearance or loss of the initial mass of leaf litter were calculated from the reciprocal of k as follows:

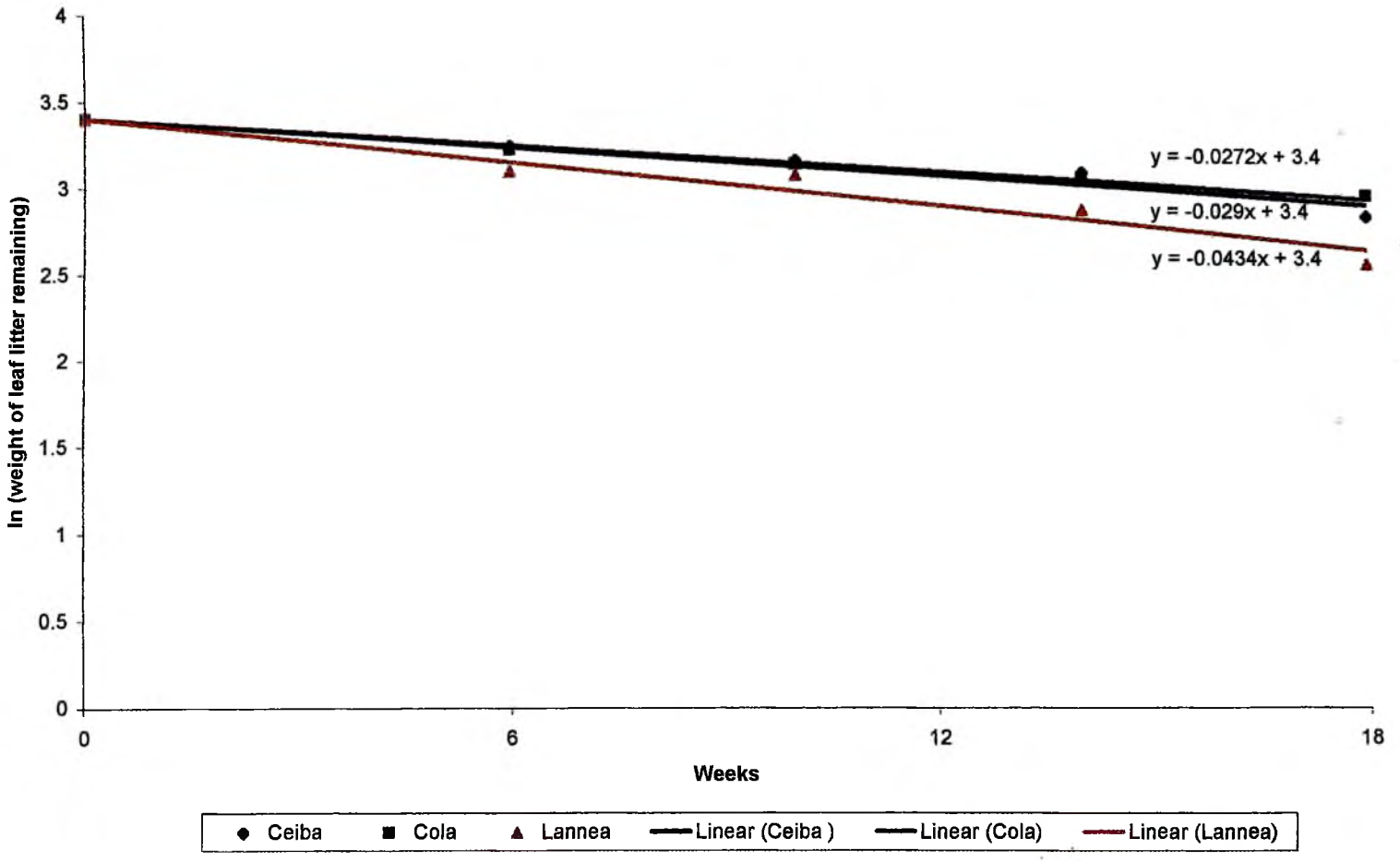
t_{50} for *Ceiba* = 1/ k for *Ceiba* = 1/ 0.0041 day $^{-1}$ = 244 days,

t_{50} for Cola = 1/ k for *Cola* = 1/ 0.0039 day $^{-1}$ = 256 days, and

t_{50} for *Lannea* = 1/ k for *Lannea* = 1/ 0.0062 day $^{-1}$ = 161 days.

Thus under steady state conditions, *Lannea* leaf litter will take a considerably shorter time to decompose than will *Ceiba* or *Cola* leaf litter.

Fig. 12 Decomposition of buried leaf litter produced by different tree species



4.8 Tree Influence on Soil Properties

It must be noted that whereas all the results obtained for the influence of *Ceiba*, *Cola* and *Lannea* on soil properties were based on soil sampling around two trees per species, those for *Milicia* were based on sampling around only one tree. Thus for each of the soil parameters presented in this section, the values for *Milicia* were not included in the calculation of the mean value at each location or the LSD values for 'Tree', 'Location' and 'Tree x Location' quoted in the various tables. All statistical analyses of results obtained for *Milicia* were carried out separately.

Tables 7, 8, 9, 10 and 11 show the CN ratio, total N, OC, OM and Na content of soil at various locations away from the trunks of the four tree species. The ANOVA tables in Appendix 5.1 indicate that these soil parameters did not vary significantly between tree species and locations. Thus, the "location effects" and trends that seem real in Tables 7 - 10 are not statistically significant.

The ANOVA tables in Appendix 5.2 show that both K and Mg content of the soil varied significantly between locations. Although the concentrations of these cations in the 'midway' and 'periphery' locations was not significantly different, they decreased significantly as one moved away from the crowns of *Ceiba*, *Cola* and *Lannea* (Tables 12 and 13). The trend of change in Mg content of the soil with increasing distance away from *Milicia* tallied with that exhibited by the other tree species. For *Ceiba*, *Cola* and *Lannea*, Mg content of the soil also varied significantly between tree species with the highest mean value (2.99 Cmol/kg soil) being recorded under *Lannea*.

The Ca and moisture content of the soil, pH (in both calcium chloride and water) as well as CEC varied significantly between tree species. For each of these parameters, the highest mean value was recorded under *Lannea* and the lowest mean value under *Ceiba* (Tables 14, 15, 16, 17 and 18). None of these parameters varied significantly between locations under any of the four tree species studied (see Appendix 5.3 for ANOVA tables).

The exchangeable Fe and NO_3^-N content of soil are two other parameters which showed significant variation between tree species. The highest mean value for Fe (0.354 ppm) was recorded under *Ceiba* while the lowest mean value (0.154 ppm) was recorded under *Cola* (Table 19). On the other hand, the highest mean value for NO_3^-N (82.56 µg) was recorded under *Lannea* whereas the lowest mean value (71.74 µg) was recorded under *Ceiba* (Table 20). Interaction between tree species and location also resulted in significant variation between the Fe and NO_3^-N content of soil (Appendix 5.4). The different tree species therefore exhibited significantly different trends in change in these two parameters with increasing distance away from their trunks.

The NH_4^+N and available P content of soil varied considerably not only between locations but also between tree species. The highest mean value of NH_4^+N (20.4 µg) was recorded under *Ceiba* (Table 21) while the highest (46.5 µg) and lowest (11.6 µg) mean values of available P were recorded under *Lannea* and *Cola* respectively (Table 22). The ANOVA tables in Appendix 5.5 indicate that the NH_4^+N and available P content of soil were also influenced by 'tree x location' interaction. Consequently, *Ceiba*, *Cola* and *Lannea* exhibit varying trends in change in NH_4^+N and available P content of soil with increasing distance away from their trunks.

Table 23 is a summary of the results of linear regression analyses carried out on the soil parameters that varied significantly between locations. The regression analyses were done based on the null hypothesis that the observed variations in soil nutrient content were dependent on changes in distance away from the trunks of the different tree species.The t-distribution was used to test the significance of the association between distance and the various soil parameters, at 5 % level of significance. The line fit plots for the regression analyses, which are presented in Figs. 13 (a- f) to 16 (a - f) show different trends in change in soil nutrient status under different tree species as one moves from the 'midway' location through the 'periphery' location to the 'away' location. The actual distances (in meters) of these locations from the various tree trunks are presented on the x axes of the line fit plots.

The results of the regression analyses indicate that although the K and Fe content of soil varied significantly between locations, the observed variations were not due to the changes in distance away the tree trunks. The variations in soil NO_3^-N and NH_4^+N content were, however, found to be dependent on variations in distance away from *Ceiba* but independent of distance away from the other tree species. Table 23 shows that for each 1 m increase in distance away from *Ceiba*, soil NO_3^-N content increases by 0.55 µg while soil NH_4^+N content decreases by 1.61 µg.

Similarly, variations in soil Mg and available P content were dependent on changes in distance away from *Milicia* but independent of distance away from the other tree species . For each 1 m increase in distance away from *Milicia*, the Mg content of the soil decreases by 0.10 Cmol/kg soil while the available P content increases by 1.75 %.

Table 7: Tree influence on CN ratio of soil

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	31.3	29.22	31.32	30.61
Cola	30.9	33.43	30.92	31.75
Lannea	28.08	29.83	30.37	29.43
Mean	30.09	30.83	30.87	30.6
**Milicia*	31.77	33.8	31	32.19

Table 8: Tree influence on total N content of soil (%)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	0.212	0.203	0.197	0.204
Cola	0.207	0.203	0.21	0.207
Lannea	0.232	0.222	0.21	0.221
Mean	0.217	0.209	0.206	0.211
**Milicia*	0.237	0.22	0.24	0.232

Table 9: Tree influence on organic carbon content of soil (%)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	6.567	5.969	6.075	6.203
Cola	6.374	6.665	6.478	6.506
Lannea	6.336	6.619	6.301	6.419
Mean	6.425	6.418	6.285	6.376
**Milicia*	7.403	7.39	7.415	7.403

Table 10: Tree influence on organic matter content of soil (%)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	11.32	10.29	10.48	10.7
Cola	10.99	11.49	11.17	11.22
Lannea	10.92	11.41	10.86	11.07
Mean	11.08	11.07	10.84	10.99
**Milicia*	12.76	12.74	12.78	12.76

Table 11: Tree influence on exchangeable Na content of soil (Cmol/kg soil)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	0.119	0.113	0.107	0.113
Cola	0.11	0.112	0.095	0.106
Lannea	0.112	0.123	0.11	0.115
Mean	0.113	0.116	0.104	0.111
**Milicia*	0.129	0.126	0.116	0.124

Table 12: Tree influence on exchangeable K content of soil (Cmol/kg soil)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	1.121	0.974	0.776	0.957
Cola	0.827	0.895	0.648	0.79
Lannea	0.914	0.995	0.797	0.902
Mean	0.954	0.955	0.74	0.883
LSD = 0.1415 (Location)				
**Milicia*	0.98	0.81	0.81	0.867

Table 13: Tree influence on exchangeable Mg content of soil (Cmol/kg soil)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	3.17	3	2.8	2.99
Cola	3.17	3	2.6	2.92
Lannea	4.13	4.43	3.03	3.87
Mean	3.49	3.48	2.81	3.26
LSD = 0.586 (Tree, Location)				
**Milicia*	3.2	2.67	2.47	2.78

Table 14: Tree influence on exchangeable Ca content of soil (Cmol/kg soil)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	13.53	12.77	11.17	12.49
Cola	12.97	14.87	12.5	13.44
Lannea	16.37	16.93	16	16.43
Mean	14.29	14.86	13.22	14.12
LSD = 2.413 (Tree)				
**Milicia*	14.93	16.2	18.27	16.47

Table 15: Tree influence on moisture content of soil (%)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	13.05	11.73	11.55	12.11
Cola	12.88	12.8	13.43	13.04
Lannea	14.78	14.57	13.68	14.34
Mean	13.57	13.03	12.89	13.16
LSD = 1.163 (Tree)				
**Milicia*	15.4	14.1	15.53	15.01

Table 16: Tree influence on soil pH (in calcium chloride)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	6.883	7.05	6.967	6.967
Cola	7.067	7.383	7.283	7.244
Lannea	7.167	7.233	7.3	7.233
Mean	7.039	7.222	7.183	7.148
LSD = 0.1622 (Tree)				
**Milicia*	7.3	7.267	7.267	7.278

Table 17: Tree influence on soil pH (in water)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	7.267	7.383	7.283	7.311
Cola	7.367	7.7	7.6	7.556
Lannea	7.533	7.6	7.683	7.606
Mean	7.389	7.561	7.522	7.491
LSD = 0.1611 (Tree)				
**Milicia*	7.6	7.567	7.7	7.622

Table 18: Tree influence on CEC of soil (Cmol/kg soil)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	24.8	21.36	20.77	22.31
Cola	23.55	21.8	24.87	23.41
Lannea	27.81	26.92	28.24	27.65
Mean	25.38	23.36	24.62	24.46
LSD = 1.734 (Tree)				
**Milicia*	28.88	28.39	28.76	28.68

Table 19: Tree influence on exchangeable Fe content of soil (ppm)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	0.326	0.442	0.294	0.354
Cola	0.147	0.191	0.124	0.154
Lannea	0.236	0.127	0.141	0.168
Mean	0.236	0.253	0.186	0.225
LSD = 0.0595 (Tree); 0.1031 (Tree x Location)				
**Milicia*	0.391	0.167	0.337	0.298

Table 20: Tree influence on Nitrate-N content of soil (µg)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	68.02	73.25	73.97	71.74
Cola	77.12	82.37	78.87	79.45
Lannea	91	74.67	82.02	82.56
Mean	78.71	76.76	78.28	77.92
LSD = 4.882 (Tree); 8.456 (Tree x Location)				
**Milicia*	107.33	107.33	106.4	107.02

Table 21: Tree influence on Ammonium-N content of soil (µg)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	31.1	17.1	12.9	20.4
Cola	12	14.3	11.3	12.6
Lannea	15.3	8.7	13.2	12.4
Mean	19.5	13.4	12.5	15.1
LSD = 5.01 (Tree, Location); 8.68 (Tree x Location)				
**Milicia*	13.1	13.8	15.2	14

Table 22: Tree influence on available P content of soil (%)

Tree species	Location			
	Midway	Periphery	Away	Mean
Ceiba	32.2	26.1	14.8	24.4
Cola	8.7	13.9	12.3	11.6
Lannea	78.6	43.3	17.7	46.5
Mean	39.8	27.7	14.9	27.5
LSD = 10.86 (Tree, Location); 18.81 (Tree x Location)				
**Milicia*	17.1	25.8	29.5	24.1

Table 23: Analysis of linear regression of soil content of different nutrient elements on distance (x in meters) away from different tree species

Tree species	Data from analysis	Soil nutrient element					
		K (Cmol/kg)	Mg (Cmol/kg)	Fe (ppm)	NO_3^-N (µg)	NH_4^+N (µg)	Available P (%)
Ceiba	Equation	K = -0.03x + 1.38	Mg = - 0.03x + 3.45	Fe = 0.002x + 0.324	NO_3^-N = 0.55x + 63.07	NH_4^+N = -1.61x + 45.83	P = -1.29x + 44.82
	R^2 (%)	81.95	84.81	2.14	99.65	99.73	74.93
	t Statistic	-2.13	-2.36	0.15	16.95	-19.14	-1.73
	P - value	0.28	0.25	0.91	0.04	0.03	0.33
Cola	Equation	K = -0.02x + 0.95	Mg = -0.07x + 3.58	Fe = -0.001x + 0.162	NO_3^-N = 0.40x + 75.75	NH_4^+N = 0.01x + 12.43	P = 0.60x + 6.03
	R^2 (%)	25.34	78.77	0.89	30.34	0.06	70.08
	t Statistic	-0.58	-1.93	-0.09	0.66	0.03	1.53
	P - value	0.66	0.3	0.94	0.63	0.98	0.37
Lannea	Equation	K = -0.01x + 1.00	Mg = -0.13x + 4.92	Fe = -0.016x + 0.301	NO_3^-N = -1.75x + 97.02	NH_4^+N = -0.51x + 16.65	P = -9.00x + 121.02
	R^2 (%)	15.6	33.77	83.39	51.79	26.33	98.31
	t Statistic	-0.43	-0.71	-2.24	-1.04	-0.6	-7.62
	P - value	0.74	0.61	0.27	0.49	0.66	0.08
Milicia	Equation	K =-0.03x + 1.10	Mg = -0.10x + 3.72	Fe = -0.01x + 0.433	NO_3^-N = -0.11x + 108.0	NH_4^+N = 0.27x + 11.61	P = 1.75x + 8.22
	R^2 (%)	92.42	99.98	21.15	51.7	82.25	99.97
	t Statistic	-3.49	-94.95	-0.52	-1.03	2.15	62.34
	P - value	0.18	0.01	0.7	0.49	0.28	0.01

Note: t Statistic (p = 0.05, 1 d.f.) = 12.706; Null hypothesis = Soil content of the various nutrient elements is dependent on distance.

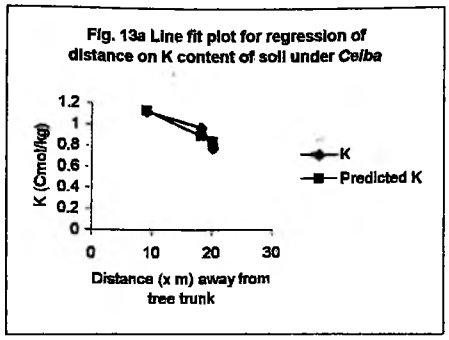


Fig. 13a Line fit plot for regression of distance on K content of soil under *Ceiba*

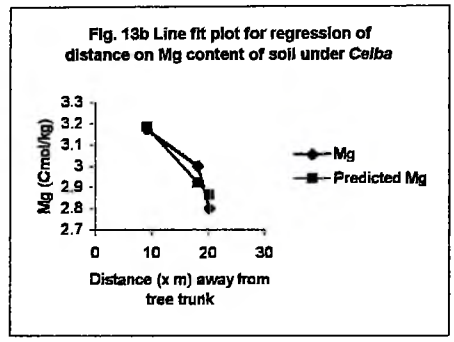


Fig. 13b Line fit plot for regression of distance on Mg content of soil under *Ceiba*

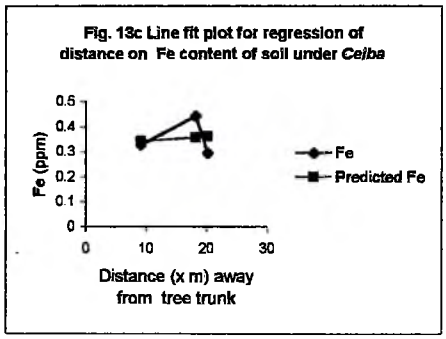


Fig. 13c Line fit plot for regression of distance on Fe content of soil under *Ceiba*

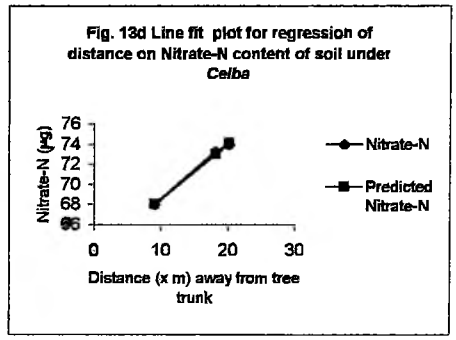


Fig. 13d Line fit plot for regression of distance on Nitrate-N content of soil under *Ceiba*

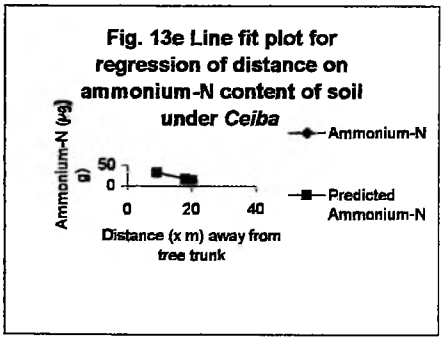


Fig. 13e Line fit plot for regression of distance on ammonium-N content of soil under *Ceiba*

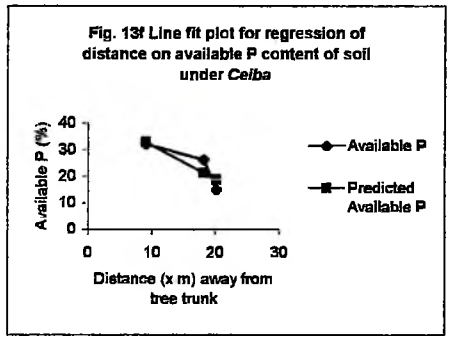


Fig. 13f Line fit plot for regression of distance on available P content of soil under *Ceiba*

Fig. 14a Line fit plot for regression of distance on K content of soil under *Cola*

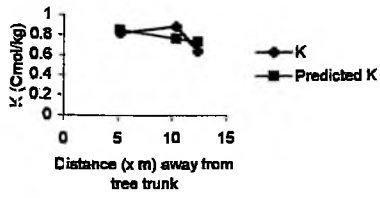


Fig. 14b Line fit plot for regression of distance on Mg content of soil under *Cola*

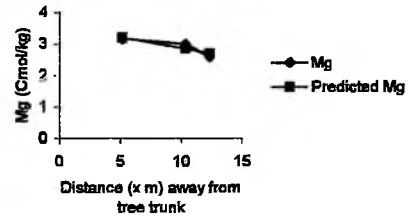


Fig. 14c Line fit plot for regression of distance on Fe content of soil under *Cola*

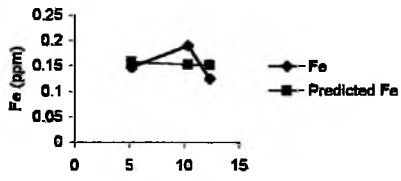


Fig. 14d Line fit plot for regression of distance on Nitrate-N content of soil under *Cola*

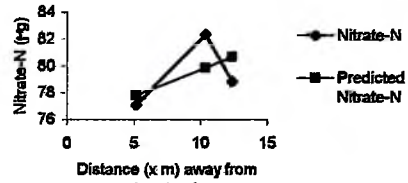


Fig. 14e Line fit plot for regression of distance on ammonium-N content of soil under *Cola*

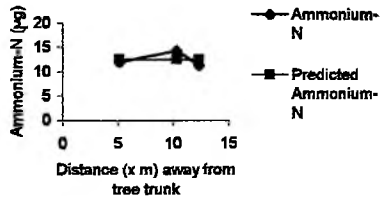
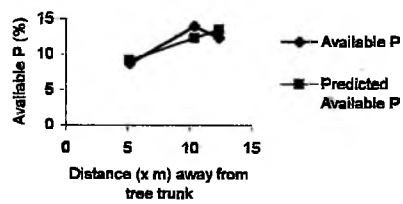
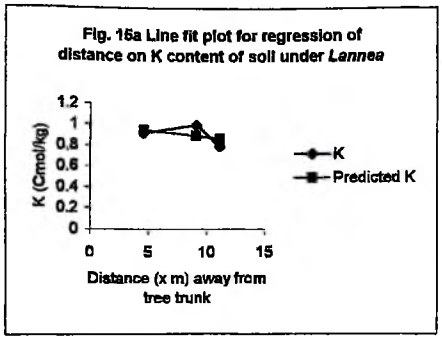
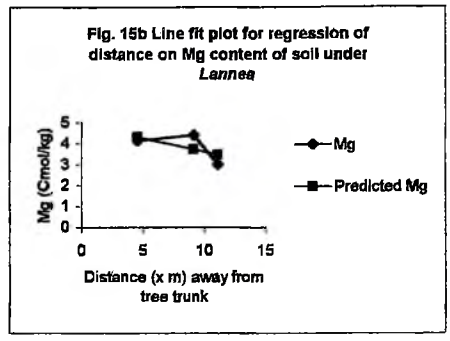
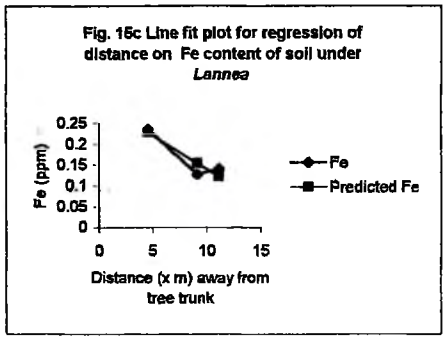


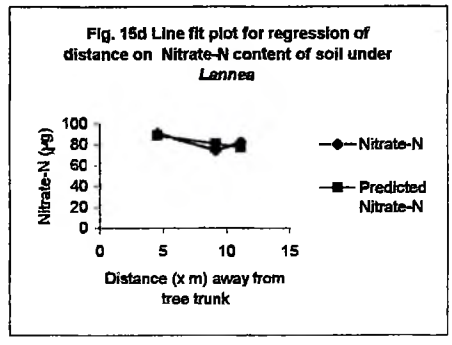
Fig. 14f Line fit plot for regression of distance on available P content of soil under *Cola*

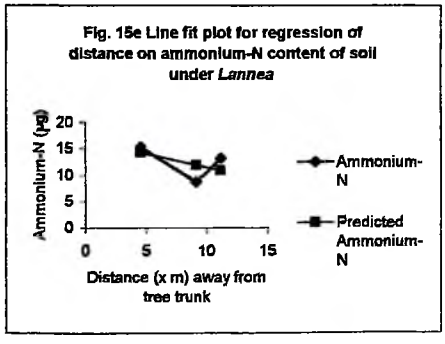


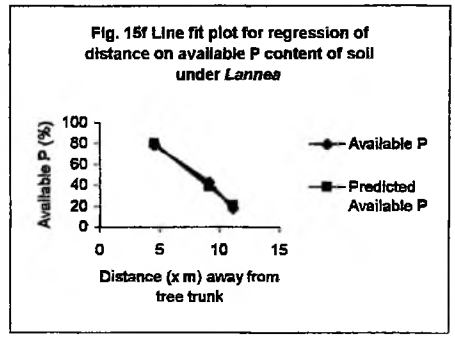


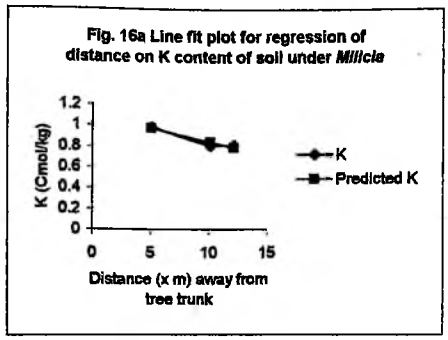


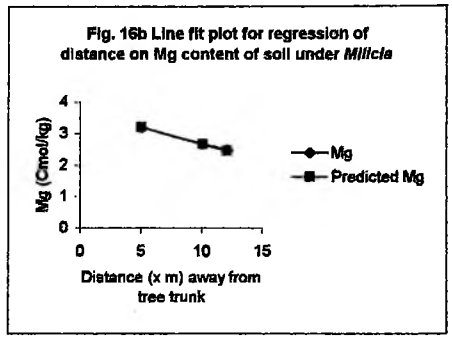


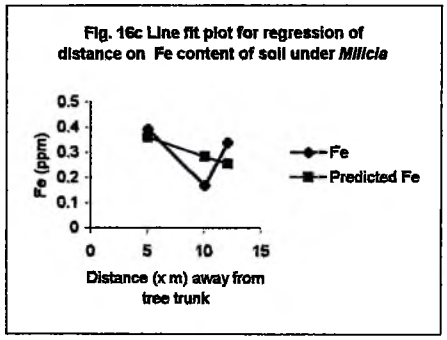


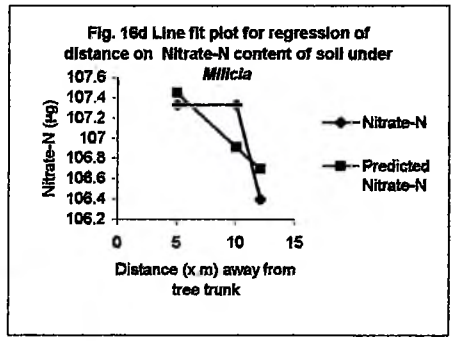


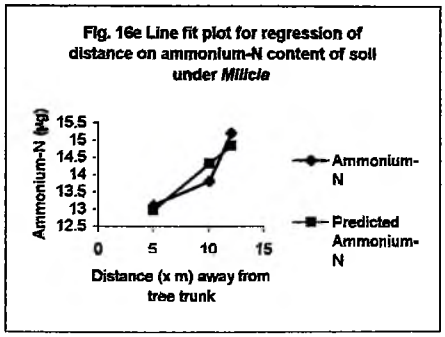


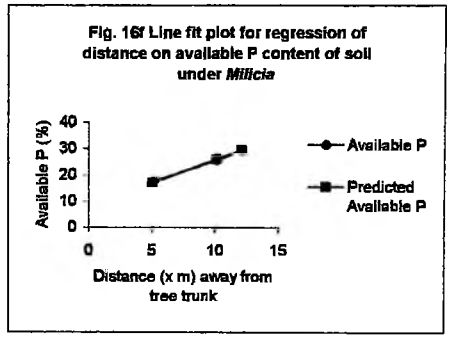












4.9 Effect of Leaf Litter on Growth, Biomass Yield and Macronutrient Content of Maize (*Zea mays*)

4.9.1 Leaf formation

The ANOVA table in Appendix 6.1 indicates that the number of leaves formed by maize plants grown in different soil treatments was influenced significantly by the type of treatment, the age of the plant and also by the interaction between treatment and age. The LSD values in Table 24, however, show that although the mean number of leaves (6.06) formed in the soil to which no leaf litter had been added (Control #1) was significantly higher than that formed in *Cola* leaf litter (5.47), leaf formation in the three other types of litter was comparable to that in Control #1. There was no significant difference in the mean number of leaves formed by maize grown in the soil to which ureate of potash - NPK - was added (i.e. Control #2) and that of maize grown in the four different types of leaf litter. Leaf formation in Control #2 was also similar to that in Control #1. On the average, leaf formation increased with age of the plant although the increase was not significant in some cases.

4.9.2 Shoot height

The shoot height of maize varied significantly between treatments and between ages of the plant (Appendix 6.2). Generally, shoot height increased with age in all the six treatments. The LSD value for treatment in Table 25, however, shows that mean shoot height of maize in Control #1 (72.57 cm) was insignificantly higher than that in Control #2 (71.59 cm). There was also negligible variation in shoot height of maize grown in the four leaf litter types. The maize shoots grown in both controls, however, grew significantly taller than those grown in leaf litter.

Table 24: Number of leaves formed by maize seedlings in different soil treatments

Type of leaf litter	No. of leaves formed 2, 4, and 6 weeks after planting (WAP)			Mean
	2 WAP	4 WAP	6 WAP	
None (Control #1)	5.00	6.17	7.00	6.06
Ceiba leaves	5.33	5.67	6.75	5.92
Cola leaves	4.83	5.83	5.75	5.47
Lannea leaves	5.17	6.17	6.00	5.78
Milicia leaves	5.00	5.67	6.25	5.64
NPK (Control #2)	5.33	6.33	6.25	5.97
Mean	5.11	5.97	6.33	5.81
LSD = 0.330 (treatment); 0.233 (WAP); 0.571 (treatment x WAP)				

Table 25: Shoot height of maize seedlings in different soil treatments

Type of leaf litter	Shoot height (cm) measured 2, 4 and 6 weeks after planting (WAP)			Mean (cm)
	2 WAP	4 WAP	6 WAP	
None (Control #1)	50.43	72.37	94.90	72.57
Ceiba leaves	44.53	59.20	83.55	62.43
Cola leaves	39.83	57.97	76.25	58.02
Lannea leaves	41.67	60.10	79.50	60.42
Milicia leaves	41.43	60.23	85.40	62.36
NPK (Control #2)	43.87	75.07	95.85	71.59
Mean	43.63	64.16	85.91	64.56
LSD = 5.107 (treatment); 3.611 (WAP)				

4.9.3 Biomass yield

The dry weight of both shoot and root biomass of maize (and hence the total plant biomass) increased significantly with age of plant. Although root biomass of the treatments did not differ significantly, shoot biomass of the treatments differed significantly ($p < 0.05$, Appendix 6.3).

A comparison of mean biomass yield based on the LSD values in Table 26 indicated that mean shoot biomass yield in Control #1 (4.80 g) was significantly higher than that in leaf litter produced by *Cola* (3.64 g) and *Lannea* (3.38 g). On the other hand, mean shoot biomass yield in Control #2 (5.94 g) was significantly higher than in all the other treatments. There was, however, no significant variation in mean shoot biomass yield between the four types of leaf litter. Similarly, there were no significant differences in the total biomass yield of maize plants grown in the four types of leaf litter. Total biomass yield in Control #2 (7.63 g) was, however, significantly higher than in all the other treatments.

Table 26: Biomass yield of maize seedlings in different soil treatments

Type of leaf litter	Dry weight of shoot and root biomass (g) - 4 and 6 weeks after planting (WAP)								
	Shoots			Roots			Total		
	4 WAP	6 WAP	Mean	4 WAP	6 WAP	Mean	4 WAP	6 WAP	Mean
None (Control #1)	2.99	6.62	4.8	1.03	1.84	1.43	4.02	8.46	6.24
Ceiba leaves	1.7	6.07	3.88	1.09	2.4	1.74	2.79	8.46	5.63
Cola leaves	2.24	5.04	3.64	1.21	1.82	1.52	3.45	6.86	5.15
Lannea leaves	1.62	5.14	3.38	0.87	1.88	1.37	2.49	7.02	4.76
Milicia leaves	2.04	5.47	3.75	1.24	2.27	1.75	3.28	7.74	5.51
NPK (Control #2)	3.73	8.16	5.94	1.11	2.27	1.69	4.84	10.43	7.63
Mean	2.39	6.08	4.23	1.09	2.08	1.58	3.48	8.16	5.82
LSD	Treatment = 0.635 WAP = 0.367			WAP = 0.257			Treatment = 0.961 WAP = 0.555		

4.9.4 Total N content

There were no significant differences in root N content whether based on age or treatment or both. Shoot N content, on the other hand, increased with age and differed significantly between treatments (Appendix 6.4). The LSD values in Table 27 indicate that shoot N content in Control #2 was significantly higher than shoot N content in Control #1, which in turn was higher than in all four leaf litter types. The total N content of maize grown in *Milicia* leaf litter was, however, comparable to that in Control #1 (Table 27).

4.9.5 Total P content

The P content of both the roots and shoots of maize increased significantly with age, but the root P content of the treatments did not differ significantly (Appendix 6.5). A comparison of mean shoot P content based on the corresponding LSD value for treatment (3.490 mg) indicated that mean shoot P content of maize in Control #2 (20.53 mg) was significantly higher than in *Ceiba*, *Cola* and *Lannea* leaf litter (Table 28). The mean P content of maize shoots grown in Control #1 and in *Milicia* leaf litter were, however, comparable to that of maize shoots grown in Control #2. Besides, shoot P content in Control #1 was comparable to that in all the four leaf litter types. Similar variation was exhibited in the total P content of the entire maize plant.

Table 27: Total N content of maize seedlings in different soil treatments

Type of leaf litter	N content (mg) - 4 and 6 weeks after planting (WAP)								
	Shoots			Roots			Total		
	4 WAP	6 WAP	Mean	4 WAP	6 WAP	Mean	4 WAP	6 WAP	Mean
None (Control #1)	42.8	76.1	59.45	9.75	8.75	9.25	52.55	84.85	68.7
Ceiba leaves	22.5	57.65	40.08	10.7	9.65	10.18	33.2	67.3	50.25
Cola leaves	27.8	49.0	38.4	10.55	8.35	9.45	38.35	57.35	47.85
Lannea leaves	22.15	50.4	36.28	7.95	7.1	7.53	30.1	57.5	43.8
Milicia leaves	25.65	63.6	44.63	16.35	12.7	14.53	42	76.3	59.15
NPK (Control #2)	53.5	98.05	75.78	11	10.05	10.53	64.5	108.1	86.3
Mean	32.4	65.8	49.1	11.02	9.43	10.24	43.45	75.23	59.34
LSD	Treatment = 6.251 WAP = 3.609 Treatment x WAP = 8.840			-			Treatment = 9.115 WAP = 5.263		

Table 28: Total P content of maize seedlings in different soil treatments

Type of leaf litter	P content (mg) - 4 and 6 weeks after planting (WAP)								
	Shoots			Roots			Total		
	4 WAP	6 WAP	Mean	4 WAP	6 WAP	Mean	4 WAP	6 WAP	Mean
None (Control #1)	9.3	21.8	15.55	2.15	3.8	2.98	11.45	25.6	18.53
Ceiba leaves	5.3	20.35	12.83	2.1	3.65	2.88	7.4	24	15.7
Cola leaves	6.35	16.65	11.5	2.15	3.25	2.7	8.5	19.9	14.2
Lannea leaves	5.9	18.8	12.35	1.8	3.35	2.58	7.7	22.15	14.93
Milicia leaves	7.15	24.5	15.83	3	4.8	3.9	10.15	29.3	19.73
NPK (Control #2)	10.8	30.25	20.53	2.05	4.25	3.15	12.85	34.5	23.68
Mean	7.47	22.06	14.76	2.21	3.85	3.03	9.68	25.91	17.79
LSD	Treatment = 3.490 WAP = 2.015			WAP = 0.636			Treatment = 4.122 WAP = 2.380		

4.9.6 Total K content

As in the case of biomass yield and P content of maize roots, the amount of K in the roots increased with age but did not differ significantly between treatments. The K content of maize shoots as well as the total K content of the whole plants, however, differed significantly with age and between treatments. Besides, the total K content of maize was significantly influenced by the interaction between treatment and age of the plant (Appendix 6.6).

Considering the LSD (treatment) value for total K content of maize, the amount of K in the whole plant was found to be significantly higher in Control #2 than in all the other treatments (Table 29). Although shoot K content in Control #1 was significantly higher than that in *Cola* and *Lannea* leaf litter, no such variation was observed when the K content of the whole plant was considered. Furthermore, there was no significant variation in the total K content of maize plants growing in all four types of leaf litter.

4.9.7 Total Ca content

The amount of Ca in both the roots and shoots of maize increased with age and showed significant variation between treatments (Appendix 6.7). The mean Ca content of maize roots growing in Control #2 and in *Lannea* leaf litter (0.06 µg) was significantly higher than that of maize roots growing in *Milicia*, *Ceiba* and *Cola* leaf litter, but comparable to that in Control #1 (Table 30). The highest mean Ca content of maize shoots was also recorded in Control #2 (8.19 µg). This value was significantly higher than the mean Ca content of maize shoots growing in the four litter treatments, but comparable to that in Control #1. The total amount of Ca in the whole plant was substantially higher in Control #2 than in the other five treatments.

Table 29: Total K content of maize seedlings in different soil treatments

Type of leaf litter	K content (mg) - 4 and 6 weeks after planting (WAP)								
	Shoots			Roots			Total		
	4 WAP	6 WAP	Mean	4 WAP	6 WAP	Mean	4 WAP	6 WAP	Mean
None (Control #1)	1.1	2.3	1.7	0.3	0.55	0.43	1.4	2.85	2.13
Ceiba leaves	0.65	1.85	1.25	0.35	0.6	0.48	1	2.45	1.73
Cola leaves	0.9	1.5	1.2	0.4	0.55	0.48	1.3	2.05	1.68
Lannea leaves	0.7	1.75	1.23	0.25	0.7	0.48	0.95	2.45	1.7
Milicia leaves	0.8	1.8	1.3	0.35	0.65	0.5	1.15	2.45	1.8
NPK (Control #2)	1.65	3.2	2.42	0.35	0.7	0.52	2	3.9	2.95
Mean	0.97	2.07	1.52	0.33	0.63	0.48	1.3	2.69	2
LSD	Treatment = 0.258 WAP = 0.149			WAP = 0.080			Treatment = 0.2814 WAP = 0.162 Treatment x WAP = 0.398		

Table 30: Total Ca content of maize seedlings in different soil treatments

Type of leaf litter	Ca content (µg) - 4 and 6 weeks after planting (WAP)								
	Shoots			Roots			Total		
	4 WAP	6 WAP	Mean	4 WAP	6 WAP	Mean	4 WAP	6 WAP	Mean
None (Control #1)	4.05	7.54	5.79	0.04	0.06	0.05	4.09	7.6	5.84
Ceiba leaves	2.38	6.75	4.56	0.02	0.04	0.03	2.4	6.78	4.58
Cola leaves	3.03	6.79	4.91	0.02	0.02	0.02	3.05	6.81	4.93
Lannea leaves	2.23	6.89	4.58	0.03	0.08	0.06	2.26	6.97	4.61
Milicia leaves	2.85	7.87	5.36	0.01	0.05	0.03	2.86	7.92	5.39
NPK (Control #2)	5.32	11.05	8.19	0.05	0.07	0.06	5.37	11.12	8.25
Mean	3.31	7.81	5.56	0.03	0.05	0.04	3.33	7.87	5.6
LSD	Treatment = 1.359 WAP = 0.785			Treatment = 0.027 WAP = 0.015			Treatment =1.377 WAP = 0.795		

Table 31: Total Mg content of maize seedlings in different soil treatments

Type of leaf litter	Mg content (ug) - 4 and 6 weeks after planting (WAP)								
	Shoots			Roots			Total		
	4 WAP	6 WAP	Mean	4 WAP	6 WAP	Mean	4 WAP	6 WAP	Mean
None (Control #1)	0.54	1.22	0.88	0.13	0.22	0.18	0.67	1.45	1.06
Ceiba leaves	0.33	1.03	0.68	0.11	0.28	0.2	0.44	1.32	0.88
Cola leaves	0.43	0.98	0.71	0.13	0.19	0.16	0.56	1.18	0.87
Lannea leaves	0.33	1	0.67	0.13	0.27	0.2	0.46	1.27	0.86
Milicia leaves	0.4	1.13	0.77	0.13	0.27	0.2	0.53	1.4	0.97
NPK (Control #2)	0.73	1.59	1.16	0.15	0.35	0.25	0.88	1.94	1.41
Mean	0.46	1.16	0.81	0.13	0.26	0.2	0.59	1.42	1.01
LSD	Treatment = 0.135 WAP = 0.078			WAP = 0.036			Treatment = 0.172 WAP = 0.099		

4.9.8 Total Mg content

The Mg content of both the roots and shoots of maize increased significantly with age. While the Mg content of the roots did not vary significantly between treatments, that of the shoots (and the total Mg content of the whole plants) varied significantly (Appendix 6.8). A comparison of the mean Mg content of maize shoots in the various soil treatments indicated that maize shoots growing in Control #2 contained significantly higher amounts of Mg than those growing in the other five treatments. The latter contained comparable amounts of Mg (Table 31). A similar variation was observed in the Mg content of the whole plant.

4.10 Growth, Biomass Yield, Macronutrient Content and Nodulation of *Millettia zechiana* in 3 Soil Series

4.10.1 Shoot height and leaf formation

Shoot height and leaf formation were both significantly influenced by the type of soil in which *M. zechiana* was grown (see Appendices 7.1 and 7.2 for ANOVA tables). Shoot height in all the three soil types, increased with age and was significantly higher in the Aburi series than in the Legon and Adenya series (Table 32).

Number of compound leaves formed, as well as the maximum number of leaflets per compound leaf were also significantly higher in the Aburi series than in the Legon and Adenya series (Table 33). The biggest leaflets in the Aburi and Legon series had comparable length and width. The dimensions of the biggest leaflet in the Adenya series was, however, significantly lower than in the Aburi series although its width was comparable to that of the biggest leaflet in the Legon series.

On the whole, plant growth was much better in the Aburi series than in the other soil series and this was evident in the appearance of the plants (Plate 10).

4.10.2 Biomass yield and macronutrient content

The biomass yield and macronutrient content of *M. zechiana* seedlings varied significantly between soil series (Appendices 7.3 and 7.4). Considering the LSD values in Table 34, the dry weight of *M. zechiana* shoots as well as their total N, P and K content were found to be significantly higher in the Aburi series than in the Legon and Adenya series. Root biomass yield was also significantly higher in the Aburi series than in the other two series (Plate 11).

Table 32: Shoot height (cm) per seedling *of M. zechiana* after 4, 6 & 8 weeks of growth

Soil Series	Age of Plant			Mean
	4 weeks	6 weeks	8 weeks	
Adenya	8.13	9.43	10.27	9.28
Legon	11.4	16.9	17.7	15.33
Aburi	20.23	27.33	30.9	26,16
Mean	13.26	17.89	19.62	16.92
LSD = 3.154 (soil, age)				

Table 33: Leaf formation in *M. zechiana* seedlings 8 weeks after planting

Soil Series	Number of compound leaves per plant	Maximum No. of leaflets per compound leaf	Length of biggest leaflet (cm)	Width of biggest leaflet (cm)
Adenya	3.17	5	4.97	3.03
Legon	4.33	6.33	8.3	3.93
Aburi	7.33	9	10.5	4.87
LSD	1.29	1.762	2.745	1.279

4.10.3 Nodulation

Out of the six seedlings of *M. zechiana* uprooted from each of the 3 soil series, five of those grown in the Aburi series nodulated and three of those grown in the Legon series nodulated, but there was no nodulation in any of the seedlings grown in the Adenya series (Table 35). When a few of the nodules from the Legon and Aburi soils were halved, they were found to be light pink in section. This probably signifies that they had the ability to fix nitrogen. The nodules in the Legon soil were irregular in shape while those in the Aburi soil were spherical.

Table 35 indicates that although the mean number of nodules formed in the Aburi series (8.33) was higher than in the Legon series (6.17), the mean dry weight of the former was lower because the nodules formed in the Legon series were bigger than those formed in the Aburi series (Plate 12). The observed differences in number and dry weight of nodules between soil series were, however, statistically insignificant as is evident in the ANOVA tables in Appendix 7.5.

Plate 10: Seedlings of *Millettia zechiana* growing in 3 soil series. NDOb - Aburi series; NDAd - Adenya series; NDLeg - Legon series.

Plate 11: Roots of *Millettia zechiana* seedlings growing in 3 soil series.

Table 34: Biomass yield per plant and macronutrient content per shoot of *M. zechiana* 8 weeks after planting

Soil Series	Dry weight of biomass per plant (g)			Total N content per shoot (mg)	Total P content per shoot (mg)	Total K content per shoot (mg)
	Shoots	Roots	Total			
Adenya	0.43	0.22	0.65	14.55	1.58	0.13
Legon	1.21	0.27	1.48	19.84	5.00	0.25
Aburi	3.06	0.48	3.54	93.00	13.12	0.62
LSD	0.654	0.210	0.838	21.244	3.983	0.137

Table 35: Nodulation per seedling of *M. zechiana* 8 weeks after planting

Soil Series	Number of nodules						Mean Number of nodules/ plant	Mean Dry weight of nodules (mg)
	1st replicate		2nd replicate		3rd replicate			
	Plant 1	Plant 2	Plant 1	Plant 2	Plant 1	Plant 2		
Adenya	0	0	0	0	0	0	0	0
Legon	0	12	0	0	14	11	6.17	7.2
Aburi	5	4	7	0	32	2	8.33	1.8

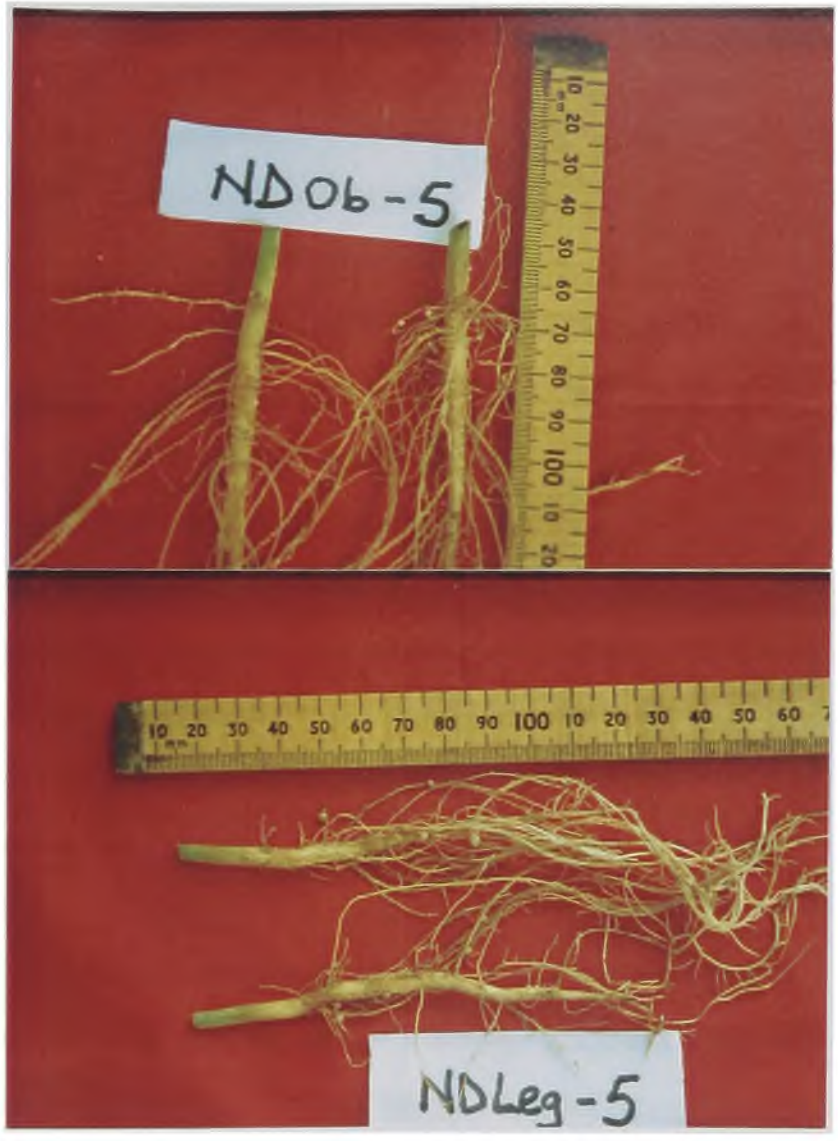


Plate 12: Roots of *Millettia zechiana* showing nodulation in Aburi (NDOb) and Legon (NDLeg) soil series. Note the relatively bigger nodules on the roots from the Legon series (bottom).

CHAPTER 5 - DISCUSSION

5.1 The Timing of Phenophases

Ceiba, *Lannea* and *Milicia* exhibited leaf fall in the dry season. *Cola*, on the other hand, did not shed leaves only in the dry season but also in the minor rainy season. The observation of a peak leaf fall period in the dry season corroborates reports by other researchers (e.g. Taylor, 1960; Daubenmire, 1972; John, 1973). According to Ewusie (1992), there is a general consensus that the adaptive significance of leaf fall in the tropics is the reduction of water loss due to transpiration. Thus the deciduousness of the tree species in the agroforestry system in question results ultimately in conservation of soil moisture. As a result, growth of food crops like *Xanthosoma sagittifolium* (cocoyam) is sustained even during the dry season. Besides, the occurrence of leaf fall in the dry season results in litter accumulation since decomposition rates are slower in dry weather. The accumulated litter is, however, broken down rapidly with the onset of the rains resulting in the release of nutrients for use by food crops, which are normally planted in the rainy season.

Various workers have reported the tendency for leaf flushing to increase toward the end of the major dry season, just before the onset of the rains (Daubenmire, 1972; Ewusie, 1992). This is confirmed by the fact that flushing in *Cola*, *Lannea* and *Milicia* increased in March - one month before the start of the major rainy season. The production of new leaves in the dry season indicates that high soil moisture is not the predominant factor in leaf flushing.

The observed times of flowering and fruiting in *Cola* and of flowering in *Lannea* lie within the time ranges documented by Taylor (1960). The fact that *Lannea* flowered during the dry season confirms

reports that periods of peak flowering are usually observed during or at the end of the dry season (Daubenmire, 1972; Whitmore, 1975). The time of flowering in *Lannea* also confirms a report by Croat (1969; cited by Ewusie, 1992) that members of the family Anacardiaceae tend to flower in the dry season.

The time of flowering in *Cola* (September - November), which coincided with the minor rainy season, confirms an observation by Ewusie (1992) in the semi-deciduous forest of southern Ghana of two major flowering peaks which coincided with the short rains and the beginning of the long rainy season. Although *Cola* began to flower at the start of the minor rainy season, it did not fruit until the beginning of the dry season. Flowering and fruiting peaks observed in the dry season have been explained on the basis of the dry weather being more conducive for pollination and fruit/seed dispersal by insects and other animals (Ewusie, 1992).

5.2 Litter Production and Soil Nutrient Availability

The finding that leaves and twigs respectively contributed 79 % and 15 % of the total litter collected over the study period corroborates work done by John (1973), who found that litter caught in traps over a two-year period in a moist semi-deciduous forest at Kade (Ghana) composed of 77 % leaf litter, 10 % twig, 4 % fruit, seed and flower and 9 % unidentifiable trash. The fact that leaf litter constituted the largest percentage of the total litter suggests that leaf fall plays a vital role in litter accumulation in the agroforestry ecosystem in question. As already mentioned in section 4.6, although *Ceiba* leaf litter contained the highest percentage of C, N, Fe and Cu and leaf litter from *Milicia* contained the highest percentage of Ca, it was *Cola* that exhibited the potential of contributing the highest amounts of these mineral elements to the soil nutrient pool through litterfall.

Thus it can be deduced that the ability of a tree species to produce litter all year round is crucial to the contribution of that species to soil nutrient availability.

If there were a way of ensuring that all the nutrients present in the leaf litter produced by *Cola* are returned to the soil, this tree species would be invaluable to the agroforestry system in question. The actual contribution of the different types of leaf litter to the soil nutrient pool is, however, dependent on the rates of decomposition and mineralisation patterns. Thus the actual contribution of fallen *Cola* leaves to soil nutrient availability could be much lower than their potential contribution, especially since they have a rather slow rate of decomposition.

5.3 Litter Decomposition

It has been shown in section 4.7 that if decomposition rates were to be constant over time, *Ceiba*, *Cola* and *Lannea* leaf litter would respectively require 244, 256 and 161 days for 50 % disappearance. It is worth noting, however, that such steady rates of litter disappearance do not occur in nature. According to Anderson and Ingram (1993), litter mass losses often show a fast initial phase due to leaching of water-soluble materials, which is largely an experimental artifact of drying and re-wetting the litter. There is a slower second phase dominated by the decomposition of cell wall constituents (e.g. cellulose and hemicellulose) and an even much slower phase regulated by lignin and microbial products. Evidently, the time period for investigating litter decomposition in this particular study was too short to bring out the different phases of litter disappearance.

The finding that the leaf litter produced by *Cola* and *Ceiba* have similar decomposition rates contradicts the claim by some farmers that plant growth is luxuriant under the canopy of *Ceiba* because its leaves decompose much quicker than those of *Cola*. A more probable explanation for the

persistent mat of *Cola* leaves under the canopy of the *Cola* tree is the fact that this tree produces appreciable amounts of leaf litter all year round. Consequently, long after the leaves of deciduous species like *Ceiba* have fallen and decomposed, newly shed leaves of *Cola* are still being added to the partially decomposed ones.

5.4 Effects of the Presence of Trees on Soil Properties

The results in section 4.8 indicate that the following soil properties did not differ significantly between locations: total N, OC, OM, Na, Ca and moisture content as well as pH, CEC and CN ratio. This implies that none of the four tree species studied exhibited significant influence on the above-mentioned properties of the soil under their canopies. This finding contradicts reports that the total N and OM content as well as the CEC of soil are higher under tree canopies than outside them (Aggarwal, 1980; Radwanski and Wickens, 1981; Jaiyeoba, 1996).

The K and Mg content of soil were, however, found to be significantly higher under the tree canopies of *Ceiba*, *Cola* and *Lannea* than outside them. Since the results of the regression analyses showed that the observed differences were not due to variations in distance, it could be inferred that the increase in the K and Mg content of soil under the canopies of these tree species was caused by other factors such as leaf litter accumulation, which have no linear relationship with distance.

Cola exhibited no significant influence on the NH_4^+N, NO_3^-N or exchangeable Fe content of the soil under its canopy. *Ceiba*, on the other hand, caused an increase in the soil NH_4^+N content, which was understandably accompanied by a decrease in the NO_3^-N content of the soil under its canopy. In sharp contrast to *Ceiba*, the NO_3^-N content of the soil under the canopy of *Lannea* was much higher than

outside its canopy although the amounts of NH_4^+N contained in the soil at these locations were similar. Besides, while the exchangeable Fe content of soil at the canopy edge of *Ceiba* was significantly higher than under or outside the canopy, that at the canopy edge of *Lannea* was significantly lower than under or outside its canopy.

The finding that the available P content of soil under the canopies of *Lannea* and *Ceiba* was significantly higher than outside their canopies in spite of the lack of association with distance suggests that factors that influence P availability under these tree species (e.g. litter accumulation, moisture) are not dependent on distance. Soil available P content, however, increased with increasing distance away from *Cola*. Thus, it could be inferred that P-uptake by the *Cola* tree decreases with increasing distance away from its trunk.

The observed variations in the trends of change in the NH_4^+N, available P, NO_3^-N or exchangeable Fe content of the soil exhibited by the different tree species may be due to differences in their crown architecture, which may have resulted in variations in the amounts of sunlight and moisture that reach the soil in their immediate environs.

The results of the soil analyses indicate that the following soil parameters also varied significantly between tree species: pH, CEC, NH_4^+N, NO_3^-N, available P, exchangeable Ca, Mg and Fe, as well as moisture content of the soil. This suggests that the influence of some of the tree species on soil properties extended beyond their canopies, hence causing the properties of soil in their immediate environs to be significantly different from the soil in other parts of the study site.

Soil pH and moisture content were found to be significantly high in the vicinity of *Lannea*. This may have resulted in the observed increase in the availability of P, NO_3^-N, Ca and Mg. Since the Na and K content of soil did not differ significantly between tree species, the observed increase in the CEC of soil in the vicinity of *Lannea* can also be attributed to the increased availability of Ca and Mg.

Ceiba, on the other hand, caused an increase in NH_4^+N and exchangeable Fe content of soil in its immediate surroundings. The extremely high influence of *Ceiba* on the availability of NH_4^+N in the soil is a likely explanation for the farmers' claim that food crops perform better under the canopy of this species.

Although the results of this study indicated that *Cola* has the highest potential contribution of Mg and Fe and the second highest potential contribution of K and P to the soil nutrient pool, the soil in the immediate environs of this species contained the lowest amounts of available P, exchangeable K, Mg and Fe. This probably explains the stunted growth of cassava plants found under the canopy of this species, as observed on a farm in the study area. This explanation is on the basis that cassava has a high requirement of potash (Kassam, 1976) and that plants deficient in P exhibit stunting of their leaf, stem and root systems since P is essential for cell division especially in meristematic tissue (Simpson, 1986).

5.5 Availability of the Nutrients in Leaf litter for Plant Growth

From the results presented in section 4.9, it can be deduced that the number of leaves, shoot height, total biomass yield and total P content of maize seedlings grown in soil only (Control #1) was similar to those of seedlings grown in soil to which the mixed fertiliser - NPK - was added (Control #2). This

suggests that the soil had enough available P to support the growth of maize and thus did not use the additional P in the fertiliser. Presumably, cell division in the meristematic tissue of maize seedlings grown in soil only was similar to that in seedlings grown in the artificially fertilised soil since they contained similar amounts of P; hence the similarities in shoot height, number of leaves formed and total biomass yield.

The total N, K, Ca and Mg content of maize seedlings grown in the fertilised soil was, however, much higher than those of seedlings grown in soil only. It stands to reason that the maize seedlings required more N than could be provided by the soil and hence utilised the extra N made available to them by the fertiliser. The increased uptake of N probably enhanced uptake of the cations K^+, Ca^{2+} and Mg^{2+}

The total N content of seedlings grown in soil containing the different types of leaf litter was significantly lower than that of seedlings grown in soil only, except for those grown in soil containing *Milicia* leaf litter, whose total N content was similar to those grown in soil only. The apparent decrease in N content of the soil to which leaf litter from *Ceiba*, *Cola* and *Lannea* were added confirms findings by Tisdale and Nelson (1956) and Jenkinson (1988). According to these authors, when organic materials with high CN ratios are added to soil, the nitrifying bacteria (in order to assimilate the high amounts of carbon) first make use of the available N in the soil solution, which gets tied up in their bodies and so is unavailable to higher plants. Ammonium salts could, however, be released later when the CN ratio of the different types of leaf litter approach that of the body of the nitrifying bacteria, which ranges from about 4:1 to 12 :1.

Interestingly, the loss of soil N due to utilisation by nitrifying bacteria seems to be negligible in the soil containing leaf litter from *Milicia*, which has the highest CN ratio of 37.8 : 1. According to Tisdale and Nelson (1956), when either C or N is in short supply the activity of the nitrifying bacteria decreases gradually until the level of activity that prevailed before the addition of the organic material is attained. Besides, an adequate supply of Ca, P and a proper balance of the microelements Fe, Cu and Mn are required for effective nitrification. The fact that the leaf litter produced by *Milicia* contained the lowest percentage of C and the highest percentage of Ca possibly explains the earlier release of N from *Milicia* leaf litter. It is, however, possible that the *Milicia* leaf litter per se had no biochemical advantage over the other types of litter. Instead, since unsterilised litter was used, the apparent release of N could be due to microbial products exclusive to the leaf litter produced by *Milicia*.

Although the total biomass yield and the total P, K, Ca and Mg content of the maize seedlings grown in soil containing the different types of leaf litter were comparable to those of the seedlings grown in soil only, the former seedlings were significantly shorter. The number of leaves formed by seedlings grown in soil containing *Cola* leaf litter was also significantly lower than that formed by the seedling grown in soil only. Since water is required for the decomposition of litter, it is likely that less water was available for plant growth in the soil containing the different types of leaf litter and hence shoot elongation (and to some extent leaf formation) was suppressed.

Since total biomass yield was highest in seedlings planted in the soil amended with fertiliser, it is not surprising that this soil produced the tallest seedlings with the highest amounts of N, P, K, Ca and Mg. The ability of the artificial fertiliser to readily provide N to the maize seedlings gave it an advantage over all the four types of leaf litter.

5.6 Growth and Nodulation Ability of *Millettia zechiana*

It is evident from the results presented in section 4.10 that with regard to growth, biomass yield and macronutrient content, *M. zechiana* seedlings performed poorly in the Adenya series. Liebig's Law of the Minimum provides an explanation for this finding. The Law states that 'Plant growth is regulated by the factor present in minimum amount and rises or falls according as this is increased or decreased in amounts' (Simpson, 1986). Appendix 8 indicates that the Adenya soil series contained the lowest amount of available P (3.95 ppm), which evidently was low enough to limit growth of the *M. zechiana* seedlings. The available P content of the Legon (6.63 ppm) and Adenya (7.70 ppm) soil series was, however, substantially higher and thus resulted in better plant growth.

The fact that shoot biomass yield was better in the Legon series than in the Adenya series (although the former contained a relatively lower amount of total N) suggests that the extra N in the Adenya soil had virtually no effect on growth and biomass yield because the soil was P-deficient. This further implies that the two mineral elements (N and P) had a synergetic effect on the growth of the *M. zechiana* seedlings. It is not surprising therefore that the *M. zechiana* seedlings planted in the Aburi soil series - which contained the highest amounts of N and P (0.34 % and 7.70 ppm respectively) - exhibited better growth and hence higher biomass yield and macronutrient content.

M. zechiana seedlings did not nodulate in the Adenya soil presumably due to the absence of compatible rhizobia. The above findings on the growth of the *M. zechiana* seedlings, however, indicate that this may not necessarily be the case. A plausible explanation is the low available P content of the soil because acute deficiency of P can prevent nodulation by legumes (Giller and Wilson, 1991).

The variations in the size of nodules formed in the Aburi and Legon soils are as a result of variations in the soil conditions. The variations in shape, on the other hand, indicate that the rhizobial strains responsible for nodulation in the two soils were different (Lynch and Wood, 1988).

CHAPTER 6 - SUMMARY AND RECOMMENDATIONS

6.1 Summary

(1) Leaf fall accounts for more than 70 % of the total litter produced in this agroforestry system.

(2) The leaf litter producing ability of a tree species and the nutrient content of the leaf litter produced are crucial to the contribution of that species to nutrient recycling in any ecosystem.

(3) *Cola gigantea* produced the highest mean leaf litter per tree over the period of the study and hence has the potential to return relatively high amounts of nutrients to the soil via the leaf litter produced.

(4) Tree influence on soil properties varies from one species to the other, most probably as a result of variations in patterns of growth and branching.

(5) Ceiba *pentandra* exhibited a positive influence on the NH_4^+N, P, K, Mg and Fe content of the soil in its vicinity with the influence being greatest under its canopy.

(6) *Lannea welwitschii* had a positive influence on soil pH and moisture content as well as the availability of NO_3^-N, P, K, Ca and Mg in the soil in its immediate surroundings. Although its influence on soil pH, moisture and Ca content was uniform over the sampling distance, its influence on the other soil parameters was greatest under its canopy.

(7) *Cola gigantea* had a positive influence on the K and Mg content of the soil under its canopy, but in comparison with *Ceiba* and *Lannea* this influence was relatively low. Plant growth in the vicinity of *Cola* could be stunted especially if the plant has a high requirement of nutrients such as P, K, Mg and Fe.

(8) Much cannot be said about the influence of *Milicia excelsa* on soil properties since the soil analyses results obtained for this species were based on only one tree. Nonetheless, results of the pot

experiments with maize suggest that leaf litter from *Milicia* may, in the long term, promote plant growth.

(9) The rate of mineralisation of organic materials decreases with increase in the CN ratio. An adequate supply of Ca and P and a proper balance of Fe, Cu and Mn may, however, serve as a catalyst for this biochemical process.

(10)Although the tree species studied are potentially capable of contributing considerable amounts of certain nutrient elements to the soil nutrient pool via their leaf litter, these nutrients are not readily available for plant growth when the leaf residues are used as mulch. This indicates that the observed contributions of *Ceiba* and *Lannea* to soil fertility enrichment are the result of a long term process of nutrient capture.

(11) Mulch materials require moisture for decomposition and this can result in a decrease in the availability of soil moisture for plant growth.

(12) *Millettia zechiana* nodulates in the presence of a compatible rhizobial strain. It could therefore reduce soil nitrogen deficits through biological nitrogen fixation. Nodulation in this legume plant is, however, inhibited in P-deficient soils such as the Adenya soil.

6.2 A Note to the Traditional Farmer

In view of the findings of this study, it is concluded that the decomposition rate of *Cola* is similar to that of *Ceiba* and that *Cola* has no negative influence on the properties of the soil in its vicinity. In comparison with *Ceiba* and *Lannea*, *Cola* also appears to have little or no positive influence on soil properties. Consequently, the soil properties in the immediate environs of *Cola* are very likely to reflect the soil properties of the wider area in which the species is located. Thus on a farm where plant growth under the canopy of *Cola* is poorer than under the canopies of other tree species, the areas

with luxuriant growth are actually reflecting the positive influence of the other species on soil properties. To promote growth under the canopy of *Cola*, the farmer may have to apply artificial fertilisers, if short-term results are expected. Otherwise, the farmer could cultivate the habit of transferring some of the leaf litter produced by the tree species that have a positive influence on soil properties to the immediate surroundings of the *Cola* tree. Although this practice may not yield short-term results due to slow rates of mineralisation - as indicated by the results of the pot experiments with maize - it is envisaged that it will prove useful in the long term.

6.3 Linkages of Study Components

Fig. 17 shows the linkages between the various components of this study. Climatic factors (e.g. temperature and rainfall) influence the growth and phenology of both leguminous and non-leguminous plants.

By influencing phenology, climatic factors also affect the production of litter (especially leaf litter) by plants. Both leguminous and non-leguminous plants contribute to the soil nutrient pool through litter decomposition and mineralisation and thus they return to the soil nutrient pool some of the nutrients they take up through their roots.

Climatic factors also have an influence on the status of the soil nutrient pool. During heavy rains, the availability of nutrients in the topsoil - the part of the soil that is most important for plant growth - is often reduced through soil erosion and leaching.

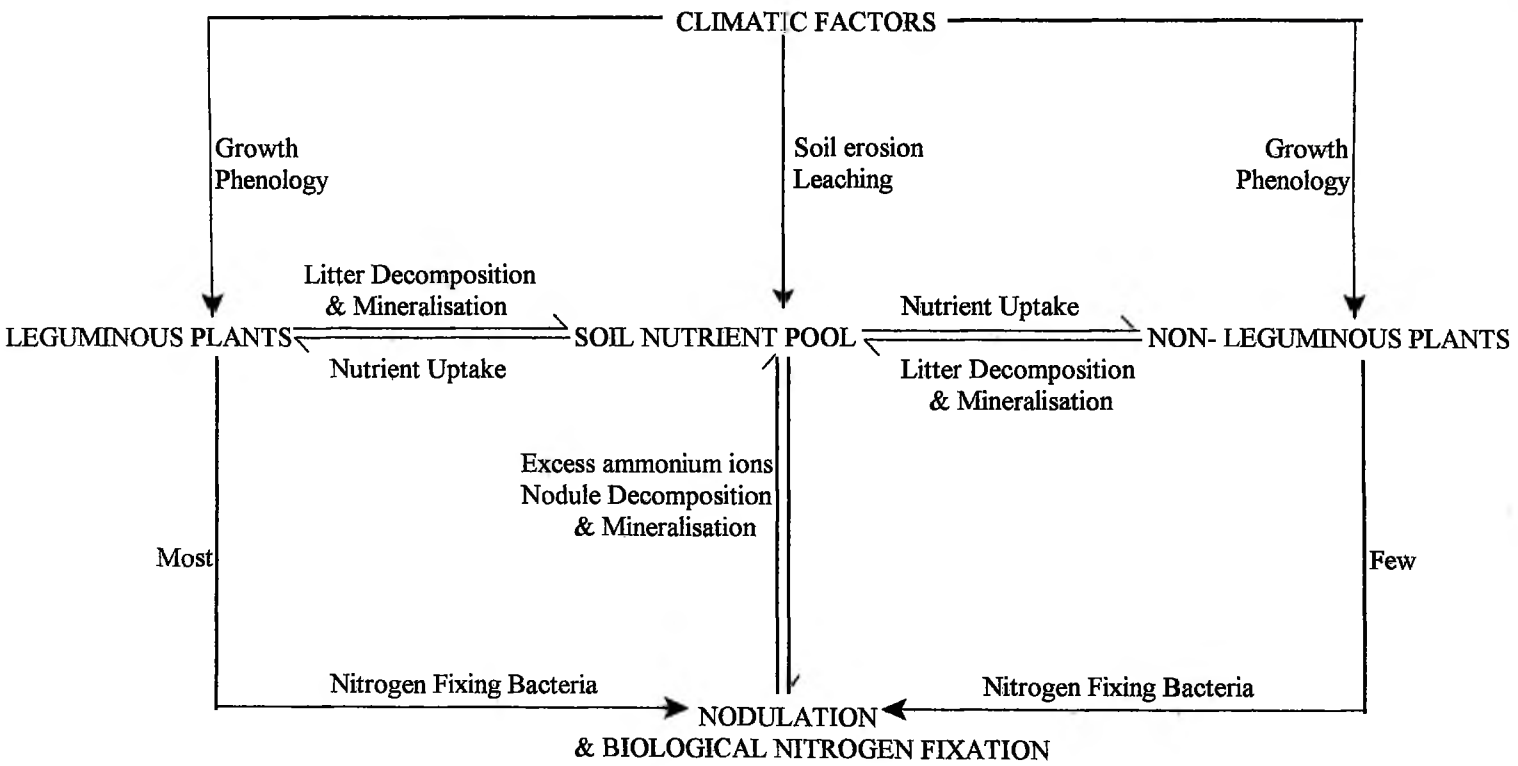


Fig. 17 Linkages of the various components of the study

Most leguminous plants and a few non-leguminous ones form symbiotic associations with nitrogen fixing bacteria and thus exhibit nodulation and biological nitrogen fixation - two phenomena that are influenced in no small way by the status of the soil nutrient pool. Nitrogen fixing bacteria in root nodules convert atmospheric nitrogen to ammonium ions. When root nodules produce ammonium ions in excess of a plant's needs, the ions are released into the soil. More nutrients are released into the soil nutrient pool when dead root nodules undergo decomposition and mineralisation.

The linkages of the various components of the study also reflect the interrelationships between the main components of the homegarden system, which was the focus of this study. In order to manage this system effectively to ensure sustained production, it is important to understand all the ecological processes that occur within it. Arguably, a full understanding is impossible without an in-depth study of the various components of the system. Although this study has covered the main components, there remain a number of gaps that need to be filled and it is hoped that future researchers would take up the challenge.

6.4 Recommendations for Future Research

It will be worthwhile in future studies to undertake the following:

(1) Determine the nutrient content of the different types of leaf litter studied at different stages of decomposition.

(2) Compare the effects of the different types of leaf litter on plant growth in different soils.

(3) Compare the effects of sterile and unsterile leaf litter on plant growth.

(4) Compare the effects of different methods of application of leaf litter (e.g. surface application and incorporation) on plant growth.

(5) Determine how much nitrogen is fixed by *Millettia zechiana*, if any.

(6) Compare the nitrogen content of leaf litter produced by *M. zechiana* with that of the non-leguminous species used in this study.

(7) Compare the effect of the leaf litter produced by *M. zechiana* on plant growth with the effects of the leaf litter produced by the non-leguminous species under the same environmental conditions.

APPENDICES

Appendix 1: List of woody species retained on cropping fields by farmers in Adenya and Gyamfiase in the Eastern Region of Ghana.[2]

SPECIES	LOCAL NAME	FAMILY	LOCAL USES
Alstonia boonei	Nyamedua	Apocynaceae	medicinal (malaria)
Antiaris toxicaria	Kyenkyen	Moraceae	hoe/axe handles
*Blighia sapida**	Akye	Sapindaceae	soap making
*Bombax sp.**	Akonkodie	Bombacaceae	fodder (leaves & fruits)
*Ceiba pentandra**	Onyina	Bombacaceae	pillow stuffing
*Cola gigantea**	Watapuo	Sterculiaceae	shade tree
Deinbollia pinnata	Woagye-akoa	Sapindaceae	aphrodisiac (leaves)
Euadenia eminens	Dinsinkoro	Capparidaceae	aphrodisiac (fruit pulp)
*Funtumia africana**	Okae	Apocynaceae	fuelwood
Holarrhena floribunda	Sese	Apocynaceae	medicinal (dysentery)
*Lannea welwitschii**	Aberewa nyansin	Anacardiaceae	fuelwood
Lecaniodiscus cupanioides	Dwindwera	Sapindaceae	purgative/ laxative
*Milicia excelsa**	Odum	Moraceae	medicinal (toothache)
Millettia zechiana	Fafraha	Papilionaceae	medicinal (bronchitis)
Morinda lucida	Konkroma	Rubiaceae	medicinal (haematuria)
Newbouldia laevis	Sasramansa	Bignoniaceae	fuelwood
Rauvolfia vomitoria	Kakapenpen	Apocynaceae	medicinal (skin rashes)
Sterculia tragacantha	Akronko	Sterculiaceae	fuelwood, food wrapper
*Trichilia heudelotii**	Tanuro	Meliaceae	fuelwood

[2] Species marked with an asterisk are represented on the study site.

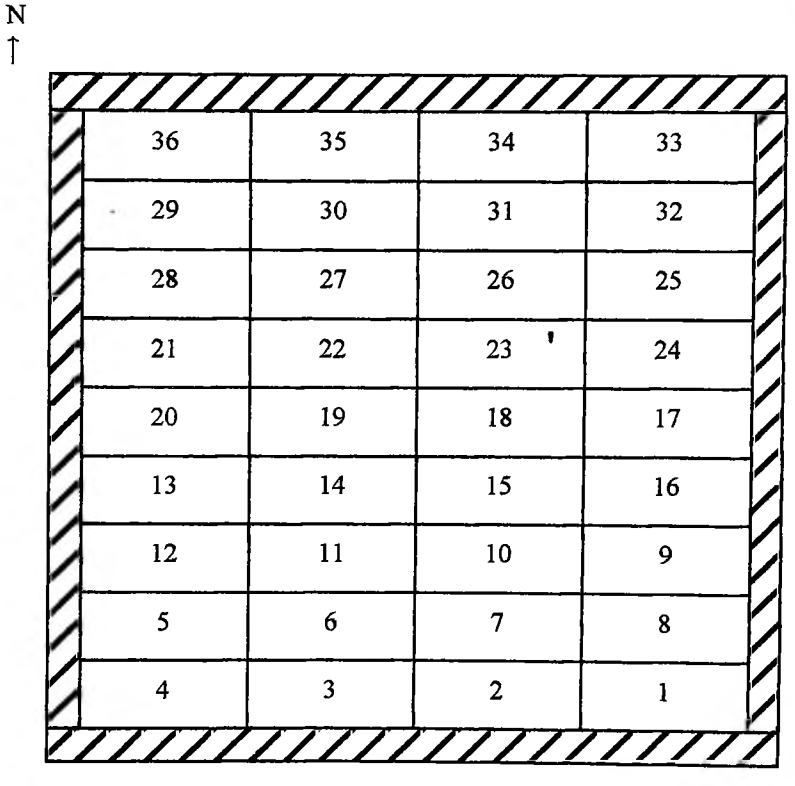
Appendix 2a: Random assignment of litter bags to subplots

Subplot Number	Litter Bag Code	Subplot Number	Litter Bag Code
1	16 - L	19	3 - C
2	25 - Co	20	31 - Co
3	33 - Co	21	28 - Co
4	13 - L	22	36 - Co
5	18 - L	23	6 - C
6	11 - C	24	35 - Co
7	7 - C	25	14 - L
8	2 - C	26	30 - Co
9	12 - C	27	34 - Co
10	8 - C	28	23 - L
11	10 - C	29	15 - L
12	29 - Co	30	1 - C
13	4 - C	31	32 - Co
14	20 - L	32	24 - L
15	17 - L	33	26 - Co
16	22 - L	34	19 - L
17	27 - Co	35	9 - C
18	21 - L	36	5 - C

Appendix 2b: Random retrieval of litter bags from subplots

Litter bag contents	Subplot numbers for retrieval			
	1st Retrieval	2nd Retrieval	3rd Retrieval	4th Retrieval
Ceiba leaf litter	7, 8, 9	10, 30, 36	6, 13, 35	11, 19, 23
Cola leaf litter	3, 21, 24	20, 27, 33	12, 17, 22	2, 26, 30
Lannea leaf litter	4, 14, 15	5, 18, 24	16, 25, 32	1, 28, 29

Appendix 2c: Demarcation of subplots on study site



Appendix 3: ANOVA tables for amounts of various nutrient elements in leaf litter produced by *Ceiba*, *Cola*, *Lannea* and *Milicia*

(a) ANOVA table for C content of leaf litter produced by different tree species

Source of variation	DF	SS	MS	F	P-value
Between Groups	3	86.51186	28.83729	675.21	0
Within Groups	8	0.34167	0.04271		
Total	11	86.85353			

Significance level = 5 %

(b) ANOVA table for N content of leaf litter produced by different tree species

Source of variation	DF	SS	MS	F	P-value
Between Groups	3	0.57067	0.19022	53.96	0
Within Groups	8	0.0282	0.00352		
Total	11	0.59887			

Significance level = 5 %

(c) ANOVA table for P content of leaf litter produced by different tree species

Source of variation	DF	SS	MS	F	P-value
Between Groups	3	0.08857	0.02952	590.44	0
Within Groups	8	0	0.0001		
Total	11	0.08897			

Significance level = 5 %

(d) ANOVA table for K content of leaf litter produced by different tree species

Source of variation	DF	SS	MS	F	P-value
Between Groups	3	0	0	89	0
Within Groups	8	0	0		
Total	11	0			

Significance level = 5 %

(e) ANOVA table for Ca content of leaf litter produced by different tree species

Source of variation	DF	SS	MS	F	P-value
Between Groups	3	50.282	16.7607	130.47	0
Within Groups	8	1.02773	0.12847		
Total	11	51.3097			

Significance level = 5 %

(f) ANOVA table for Mg content of leaf litter produced by different tree species

Source of variation	DF	SS	MS	F	P-value
Between Groups	3	69.6858	23.2286	294.94	0
Within Groups	8	0.63007	0.07876		
Total	11	70.3159			

Significance level = 5 %

(g) ANOVA table for Fe content of leaf litter produced by different tree species

Source of variation	DF	SS	MS	F	P-value
Between Groups	3	0.34184	0.11395	72.55	0
Within Groups	8	0.01256	0.00157		
Total	11	0.3544			

Significance level = 5 %

(h) ANOVA table for Cu content of leaf litter produced by different tree species

Source of variation	DF	SS	MS	F	P-value
Between Groups	3	0.00861	0.00287	34.33	0.0001
Within Groups	8	0.0007	0.0001		
Total	11	0.00928			

Significance level = 5 %

(i) ANOVA table for Mn content of leaf litter produced by different tree species

Source of variation	DF	SS	MS	F	P-value
Between Groups	3	0.01808	0.00603	127.77	0
Within Groups	8	0.0004	0		
Total	11	0.01846			

Significance level = 5 %

(j) ANOVA table for Zn content of leaf litter produced by different tree species

Source of variation	DF	SS	MS	F	P-value
Between Groups	3	0.0001	0	0.93	0.4691
Within Groups	8	0.0004	0.0001		
Total	11	0.0005			

Significance level = 5 %

(k) ANOVA table for CN ratio of leaf litter produced by different tree species

Source of variation	DF	SS	MS	F	P-value
Between Groups	3	151.8533	50.61778	31.50484	0.0001
Within Groups	8	12.85333	1.606667		
Total	11	164.7067			

Significance level = 5 %

Appendix 4: ANOVA tables for weight of different types of leaf litter remaining after 6, 10, 14 and 18 weeks of decomposition

(a) ANOVA table for weight of different types of leaf litter remaining after 6 weeks of decomposition

Source of variation	DF	SS	MS	F	P-value
Between Groups	2	17.5804	8.79021	29.13	0.0008
Within Groups	6	1.81047	0.30174		
Total	8	19.3909			

Significance level = 5 %

(b) ANOVA table for weight of different types of leaf litter remaining after 10 weeks of decomposition

Source of variation	DF	SS	MS	F	P-value
Between Groups	2	4.62642	2.31321	1.15	0.3777
Within Groups	6	12.0654	2.0109		
Total	8	16.6918			

Significance level = 5 %

(c) ANOVA table for weight of different types of leaf litter remaining after 14 weeks of decomposition

Source of variation	DF	SS	MS	F	P-value
Between Groups	2	27.5238	13.7619	2.07	0.2077
Within Groups	6	39.9669	6.66116		
Total	8	67.4908			

Significance level = 5 %

(d) ANOVA table for weight of different types of leaf litter remaining after 18 weeks of decomposition

Source of variation	DF	SS	MS	F	P-value
Between Groups	2	57.8189	28.9094	7.11	0.0261
Within Groups	6	24.3835	4.06392		
Total	8	82.2024			

Significance level = 5 %

Appendix 5.1: ANOVA tables for CN ratio, total N, OC, OM and Na content of soil at different locations under *Ceiba*, *Cola*, *Lannea* and *Milicia*

(a) ANOVA table for CN ratio of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	0	0	0	
Tree	2	48.54	24.27	1.89	0.163
Location	2	6.81	3.41	0.27	0.768
Tree . Location	4	53.31	13.33	1.04	0.399
Residual	44	565.23	12.85		
Total	53	673.9			

Significance level = 5 %

(b) ANOVA table for CN ratio of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	12.56222	6.281111	0.517627	0.620318
Within locations	6	72.80667	12.13444		
Total	8	85.36889			

Significance level = 5 %

(c) ANOVA table for total N content of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	0.070417	0.704167	96.32	
Tree	2	0.00308	0.001539	2.11	0.134
Location	2	0.00114	0.00057	0.78	0.463
Tree . Location	4	0.00108	0.00027	0.37	0.83
Residual	44	0.032167	0.00073		
Total	53	0.1078833			

Significance level = 5 %

(d) ANOVA table for total N content of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	0.0007	0.00034	0.534483	0.611485
Within locations	6	0.00387	0.00064		
Total	8	0.00456			

Significance level = 5 %

(e) ANOVA table for OC content of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	59.1409	59.1409	245.04	
Tree	2	0.8718	0.4359	1.81	0.176
Location	2	0.2253	0.1127	0.47	0.63
Tree . Location	4	1.6234	0.4058	1.68	0.171
Residual	44	10.6196	0.2414		
Total	53	72.481			

Significance level = 5 %

(f) ANOVA table for OC content of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	0.001	0.00048	0.514598	0.621923
Within locations	6	0.00562	0.00094		
Total	8	0.00658			

Significance level = 5 %

(g) ANOVA table for OM content of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	175.9334	175.9334	245.37	
Tree	2	2.5892	1.2946	1.89	0.176
Location	2	0.6735	0.3367	0.47	0.628
Tree . Location	4	4.8399	1.21	1.69	0.17
Residual	44	31.5479	0.717		
Total	53	215.5839			

Significance level = 5 %

(h) ANOVA table for OM content of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	0.0024	0.0012	0.4	0.686953
Within locations	6	0.018	0.003		
Total	8	0.0204			

Significance level = 5 %

(i) ANOVA table for Na content of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	0.00522	0.005222	16.24	
Tree	2	0.0008	0.0004	1.26	0.294
Location	2	0.00151	0.00076	2.35	0.107
Tree . Location	4	0.0006	0.00016	0.5	0.739
Residual	44	0.014144	0.00032		
Total	53	0.022323			

Significance level = 5 %

(j) ANOVA table for Na content of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	0.0003	0.00014	0.303714	0.748783
Within locations	6	0.00275	0.00046		
Total	8	0.00302			

Significance level = 5 %

Appendix 5.2: ANOVA tables for K and Mg content of soil at different locations under *Ceiba*, *Cola*, *Lannea* and *Milicia*

(a) ANOVA table for K content of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	0.03435	0.03435	0.77	
Tree	2	0.26071	0.13036	2.94	0.063
Location	2	0.55113	0.27556	6.21	0.004
Tree . Location	4	0.12429	0.03107	0.7	0.596
Residual	44	1.95175	0.04436		
Total	53	2.92223			

Significance level = 5 %

(b) ANOVA table for K content of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	0.058141	0.02907	0.234105	0.798181
Within locations	6	0.745059	0.124177		
Total	8	0.8032			

Significance level = 5 %

(c) ANOVA table for Mg content of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	20.9067	20.9067	27.51	
Tree	2	10.0015	5.0007	6.58	0.003
Location	2	5.4237	2.7119	3.57	0.037
Tree . Location	4	2.5185	0.6296	0.83	0.514
Residual	44	33.44	0.76		
Total	53	72.2904			

Significance level = 5 %

(d) ANOVA table for Mg content of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	0.862222	0.431111	1.25974	0.349313
Within locations	6	2.053333	0.342222		
Total	8	2.915556			

Significance level = 5 %

Appendix 5.3: ANOVA tables for Ca and moisture content, pH (in both calcium chloride and water) and CEC of soil at different locations under *Ceiba*, *Cola*, *Lannea* and *Milicia*

(a) ANOVA table for Ca content of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	86.13	86.13	6.67	
Tree	2	152.43	76.22	5.91	0.005
Location	2	24.76	12.38	0.96	0.391
Tree . Location	4	14.25	3.56	0.28	0.892
Residual	44	567.82	12.9		
Total	53	845.39			

Significance level = 5 %

(b) ANOVA table for Ca content of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	16.98667	8.493333	1.832215	0.23929
Within locations	6	27.81333	4.635556		
Total	8	44.8			

Significance level = 5 %

(c) ANOVA table for moisture content of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	170.311	170.311	56.79	
Tree	2	45.318	22.659	7.56	0.002
Location	2	4.669	2.335	0.78	0.465
Tree . Location	4	8.861	2.215	0.74	0.571
Residual	44	131.964	2.999		
Total	53	361.123			

Significance level = 5 %

(d) ANOVA table for moisture content of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	3.762222	1.881111	0.398728	0.687724
Within locations	6	28.30667	4.717778		
Total	8	32.06889			

Significance level = 5 %

(e) ANOVA table for pH ($CaCl_2$) of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	0.90741	0.90741	15.56	
Tree	2	0.89037	0.44519	7.63	0.001
Location	2	0.33593	0.16796	2.88	0.067
Tree . Location	4	0.11519	0.0288	0.49	0.74
Residual	44	2.56593	0.05832		
Total	53	4.81481			

Significance level = 5 %

(f) ANOVA table for pH ($CaCl_2$) of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	0.00222	0.001111	0.090909	0.914334
Within locations	6	0.073333	0.012222		
Total	8	0.075556			

Significance level = 5 %

(g) ANOVA table for pH (H_2O) of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	1.815	1.815	31.57	
Tree	2	0.8937	0.44685	7.77	0.001
Location	2	0.2937	0.14685	2.55	0.089
Tree . Location	4	0.17296	0.04324	0.75	0.562
Residual	44	2.53	0.0575		
Total	53	5.70537			

Significance level = 5 %

(h) ANOVA table for pH (H_2O) of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	0.028889	0.014444	1	0.421875
Within locations	6	0.086667	0.014444		
Total	8	0.115556			

Significance level = 5 %

(i) ANOVA table for CEC of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	277.259	277.259	41.62	
Tree	2	286.6	143.3	21.51	<.001
Location	2	37.645	18.823	2.83	0.07
Tree . Location	4	52.788	13.197	1.98	0.114
Residual	44	293.084	6.661		
Total	53	947.376			

Significance level = 5 %

(j) ANOVA table for CEC of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	0.389756	0.194878	0.126509	0.883455
Within locations	6	9.242533	1.540422		
Total	8	9.632289			

Significance level = 5 %

Appendix 5.4: ANOVA tables for exchangeable Fe and NO_3^-N content of soil at different locations under *Ceiba*, *Cola*, *Lannea* and *Milicia*

(a) ANOVA table for exchangeable Fe content of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	0.945654	0.945654	120.53	
Tree	2	0.448895	0.224447	28.61	<.001
Location	2	0.043211	0.021606	2.75	0.075
Tree . Location	4	0.085088	0.021272	2.71	0.042
Residual	44	0.345215	0.007846		
Total	53	1.868062			

Significance level = 5 %

(b) ANOVA table for exchangeable Fe content of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	0.082178	0.041089	6.583802	0.030673
Within locations	6	0.037445	0.006241		
Total	8	0.119623			

Significance level = 5 %

(c) ANOVA table for NO_3^-N content of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	23757.01	23957.01	453.62	
Tree	2	1116.33	558.16	10.57	<.001
Location	2	37.82	18.91	0.36	0.701
Tree . Location	4	977.54	244.39	4.63	0.003
Residual	44	2323.76	52.81		
Total	53	28412.46			

Significance level = 5 %

(d) ANOVA table for NO_3^-N content of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	1.742222	0.871111	0.054054	0.947837
Within locations	6	96.69333	16.11556		
Total	8	98.43556			

Significance level = 5 %

Appendix 5.5: ANOVA tables for NH_4^+N and available P content of soil at different locations under *Ceiba*, *Cola*, *Lannea* and *Milicia*

(a) ANOVA table for NH_4^+N content of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	265.34	265.34	4.76	
Tree	2	755.47	377.74	6.78	0.003
Location	2	520.05	260.03	4.67	0.014
Tree . Location	4	733.48	183.37	3.29	0.019
Residual	44	2450.65	55.7		
Total	53	4724.99			

Significance level = 5 %

(b) ANOVA table for NH_4^+N content of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	6.86	3.43	0.28	0.765142
Within locations	6	73.5	12.25		
Total	8	80.36			

Significance level = 5 %

(c) ANOVA table for available P content of soil at different locations under *Ceiba*, *Cola* and *Lannea*

Source of variation	DF	SS	MS	F	P-value
Reps stratum	1	1112.5	1112.5	4.26	
Tree	2	11218.7	5609.4	21.26	<.001
Location	2	5585.3	2792.6	10.69	<.001
Tree . Location	4	6675.2	1668.8	6.39	<.001
Residual	44	11499.1	261.3		
Total	53	36090.8			

Significance level = 5 %

(d) ANOVA table for available P content of soil at different locations under *Milicia*

Source of variation	DF	SS	MS	F	P-value
Between locations	2	244.2336	122.1168	1.475981	0.301092
Within locations	6	496.416	82.736		
Total	8	740.6496			

Significance level = 5 %

Appendix 6.1: ANOVA table for number of leaves formed by maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	2.18056	0.43611	3.57	0.0119
Age of Plant (B)	2	14.1944	7.09722	58.07	0
A * B	10	2.91667	0.29167	2.39	0.0321
Residual	30	3.66667	0.12222		
Total	47	22.9583			

Significance level = 5 %

Appendix 6.2: ANOVA table for shoot height of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	1646.39	329.278	11.22	0
Age of Plant (B)	2	16093.3	8046.66	274.24	0
A * B	10	367.434	36.7434	1.25	0.3001
Residual	30	880.242	29.3414		
Total	47	18987.4			

Significance level = 5 %

Appendix 6.3: ANOVA tables for shoot, root and total biomass of maize plants grown in different soil treatments

(a) ANOVA table for shoot biomass of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	18.7256	3.74512	18.58	0
Age of Plant (B)	1	81.8073	81.8073	405.87	0
A * B	5	1.89299	0.3786	1.88	0.172
Residual	12	2.41875	0.20156		
Total	23	104.845			

Significance level = 5 %

(b) ANOVA table for root biomass of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	0.54742	0.10948	1.1	0.4079
Age of Plant (B)	1	5.8707	5.8707	59.19	0
A * B	5	0.30962	0.06192	0.62	0.6846
Residual	12	1.19025	0.09919		
Total	23	7.918			

Significance level = 5 %

(c) ANOVA table for total biomass of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	20.6975	4.1395	8.96	0.001
Age of Plant (B)	1	131.508	131.508	284.81	0
A * B	5	3.55323	0.71065	1.54	0.25
Residual	12	5.5409	0.46174		
Total	23	161.3			

Significance level = 5 %

Appendix 6.4: ANOVA tables for N content of maize plants grown in different soil treatments

(a) ANOVA table for N content of shoots of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	4796.5	959.3	49.1	0
Age of Plant (B)	1	6693.36	6693.36	342.61	0
A * B	5	323.46	64.692	3.31	0.0414
Residual	12	234.44	19.5367		
Total	23	12047.8			

Significance level = 5 %

(b) ANOVA table for N content of roots of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	109.688	21.9377	2.41	0.0984
Age of Plant (B)	1	15.6817	15.6817	1.72	0.2139
A * B	5	6.20833	1.24167	0.14	0.9806
Residual	12	109.26	9.105		
Total	23	240.838			

Significance level = 5 %

(c) ANOVA table for total N content of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	5082.51	1016.5	24.47	0
Age of Plant (B)	1	6061.08	6061.08	145.89	0
A * B	5	334.228	66.8457	1.61	0.2312
Residual	12	498.54	41.545		
Total	23	11976.4			

Significance level = 5 %

Appendix 6.5: ANOVA tables for P content of maize plants grown in different soil treatments

(a) ANOVA table for P content of shoots of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	220.694	44.1388	7.25	0.0024
Age of Plant (B)	1	1277.5	1277.5	209.81	0
A * B	5	57.0771	11.4154	1.87	0.1727
Residual	12	73.065	6.08875		
Total	23	1628.34			

Significance level = 5 %

(b) ANOVA table for P content of roots of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	4.45708	0.89142	1.47	0.2699
Age of Plant (B)	1	16.1704	16.1704	26.67	0.0002
A * B	5	0.64708	0.12942	0.21	0.9501
Residual	12	7.275	0.60625		
Total	23	28.5496			

Significance level = 5 %

(c) ANOVA table for total P content of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	257.528	51.5057	6.06	0.005
Age of Plant (B)	1	1581.13	1581.13	186.09	0
A * B	5	68.8633	13.7727	1.62	0.2282
Residual	12	101.96	8.49667		
Total	23	2009.48			

Significance level = 5 %

Appendix 6.6: ANOVA tables for K content of maize plants grown in different soil treatments

(a) ANOVA table for K content of shoots of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	4.64833	0.92967	27.89	0
Age of Plant (B)	1	7.26	7.26	217.8	0
A * B	5	0.485	0.097	2.91	0.0601
Residual	12	0.4	0.03333		
Total	23	12.7933			

Significance level = 5 %

(b) ANOVA table for K content of roots of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	0.02208	0.00442	0.46	0.798
Age of Plant (B)	1	0.51042	0.51042	53.26	0
A * B	5	0.05208	0.01042	1.09	0.4157
Residual	12	0.115	0.00958		
Total	23	0.69958			

Significance level = 5 %

(c) ANOVA table for total K content of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	4.91708	0.98342	24.84	0
Age of Plant (B)	1	11.6204	11.6204	293.57	0
A * B	5	0.69708	0.13942	3.52	0.0343
Residual	12	0.475	0.03958		
Total	23	17.7096			

Significance level = 5 %

Appendix 6.7: ANOVA table for Ca content of maize plants grown in different soil treatments

(a) ANOVA table for Ca content of shoots of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	37.6441	7.52882	8.15	0.0015
Age of Plant (B)	1	121.905	121.905	131.95	0
A * B	5	3.40529	0.68106	0.74	0.6099
Residual	12	11.0868	0.9239		
Total	23				

Significance level = 5 %

(b) ANOVA table for Ca content of roots of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	0.00687	0.00137	3.79	0.0272
Age of Plant (B)	1	0.00454	0.00454	12.52	0.0041
A * B	5	0.00114	0.00023	0.63	0.6824
Residual	12	0.00435	0.00036		
Total	23	0.0169			

Significance level = 5 %

(c) ANOVA table for total Ca content of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	38.2786	7.65572	8.08	0.0015
Age of Plant (B)	1	123.397	123.397	130.2	0
A * B	5	3.44585	0.68917	0.73	0.6163
Residual	12	11.3732	0.94777		
Total	23	176.495			

Significance level = 5 %

Appendix 6.8: ANOVA tables for Mg content of maize plants grown in different soil treatments

(a) ANOVA table for Mg content of shoots of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	0.71202	0.1424	15.61	0.0001
Age of Plant (B)	1	2.9751	2.9751	326.19	0
A * B	5	0.05012	0.01002	1.1	0.4101
Residual	12	0.10945	0.00912		
Total	23	3.8467			

Significance level = 5 %

(b) ANOVA table for Mg content of roots of maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	0.01652	0.0033	1.68	0.2129
Age of Plant (B)	1	0.1027	0.1027	52.33	0
A * B	5	0.01252	0.0025	1.28	0.3359
Residual	12	0.02355	0.00196		
Total	23	0.1553			

Significance level = 5 %

(c) ANOVA table for total Mg content maize plants grown in different soil treatments

Source of variation	DF	SS	MS	F	P-value
Treatment (A)	5	0.88443	0.17689	11.92	0.0003
Age of Plant (B)	1	4.18335	4.18335	281.87	0
A * B	5	0.10405	0.02081	1.4	0.2914
Residual	12	0.1781	0.01484		
Total	23	5.34993			

Significance level = 5 %

Appendix 7.1: ANOVA table for shoot height of *Millettia zechiana* in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Age of Plant (A)	2	195.02	97.51	8.71	0.0023
Soil series (B)	2	1315.95	657.974	58.78	0
A * B	4	59.4044	14.8511	1.33	0.298
Residual	18	201.473	11.193		
Total	26	1771.85			

Significance level = 5 %

Appendix 7.2: ANOVA tables for leaf formation in *Millettia zechiana* in 3 soil series

(a) ANOVA table for number of compound leaves of 8-week old *M. zechiana* seedlings in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Between Soils	2	27.7222	13.8611	33.27	0.0006
Within Soils	6	2.5	0.41667		
Total	8	30.2222			

Significance level = 5 %

(b) ANOVA table for maximum number of leaflets per compound leaf of 8-week old *M. zechiana* seedlings in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Between Soils	2	24.8889	12.4444	16	0.0039
Within Soils	6	4.66667	0.77778		
Total	8	29.5556			

Significance level = 5 %

(c) ANOVA table for length of biggest leaflet of 8-week old *M. zechiana* seedlings in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Between Soils	2	46.5689	23.2844	12.33	0.0075
Within Soils	6	11.3267	1.88778		
Total	8	57.8956			

Significance level = 5 %

(d) ANOVA table for width of biggest leaflet of 8-week old *M. zechiana* seedlings in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Between Soils	2	5.04222	2.52111	6.15	0.0353
Within Soils	6	2.46	0.41		
Total	8	7.50222			

Significance level = 5 %

Appendix 7.3: ANOVA tables for dry weight of biomass of 8-week old *M. zechiana* seedlings in 3 soil series

(a) ANOVA table for dry weight of shoot biomass of 8-week old *M. zechiana* seedlings in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Between Soils	2	10.9109	5.45543	50.86	0.0002
Within Soils	6	0.64353	0.10726		
Total	8	11.5544			

Significance level = 5 %

(b) ANOVA table for dry weight of root biomass of 8-week old *M. zechiana* seedlings in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Between Soils	2	0.11947	0.05973	5.42	0.0452
Within Soils	6	0.06613	0.01102		
Total	8	0.1856			

Significance level = 5 %

(c) ANOVA table for dry weight of total biomass of 8-week old *M. zechiana* seedlings in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Between Soils	2	13.3013	6.65063	37.77	0.0004
Within Soils	6	1.05653	0.17609		
Total	8	14.3578			

Significance level = 5 %

Appendix 7.4: ANOVA tables for total N, P and K content of shoots of 8-week old *M. zechiana* seedlings in 3 soil series

(a) ANOVA table for total N content of shoots of 8-week old *M. zechiana* seedlings in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Between Soils	2	11534.3	5767.16	51.01	0.0002
Within Soils	6	678.368	113.061		
Total	8	12212.7			

Significance level = 5 %

(b) ANOVA table for total P content of shoots of 8-week old *M. zechiana* seedlings in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Between Soils	2	210.572	105.286	26.49	0.0011
Within Soils	6	23.8483	3.97472		
Total	8	234.42			

Significance level = 5 %

(c) ANOVA table for total K content of shoots of 8-week old *M. zechiana* seedlings in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Between Soils	2	0.38167	0.19083	40.41	0.0003
Within Soils	6	0.02833	0.00472		
Total	8	0.41			

Significance level = 5 %

Appendix 7.5: ANOVA tables for number and dry weight of nodules of 8-week old *M. zechiana* seedlings in 3 soil series

(a) ANOVA table for number of nodules of 8-week old *M. zechiana* seedlings in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Between Soils	2	112.167	56.0833	1.76	0.2506
Within Soils	6	191.333	31.8889		
Total	8	303.5			

Significance level = 5 %

(b) ANOVA table for dry weight of nodules of 8-week old *M. zechiana* seedlings in 3 soil series

Source of variation	DF	SS	MS	F	P-value
Between Soils	2	84.24	42.12	2.62	0.152
Within Soils	6	96.4	16.0667		
Total	8	180.64			

Significance level = 5 %

Appendix 8: Total N, available P and exchangeable K content of 3 soil series used to study nodulation in *M. zechiana* seedlings

Soil Series	N (%)	P (ppm)	K ($Cmolkg^{-1}$)
Adenya	0.25	3.95	0.67
Legon	0.18	6.63	0.9
Aburi	0.34	7.7	0.28

Significance level = 5 %

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