DECOMPOSITION AND NITROGEN RELEASE FROM *Leucaena leucocephala*, *Senna siamea*, and *Flemingia macrophylla* LITTER IN MANAGED ALLEYS FOR MAIZE IN ZAMBIA: INFLUENCE OF INORGANIC-N AND LITTER QUALITY

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DECLARATION

I, KASIRAYI MAKAZA, hereby declare that this dissertation represents my own work and it has not been submitted for a degree at this or any other University.

SIGNATURE: .....

DATE: 28-10-02

APPROVAL

This dissertation of KASIRAYI MAKAZA is approved as fulfilling the requirements for the award of the degree of Master of Science in Agronomy (Crop Science) by the University of Zambia.

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DEDICATION

To my late father Hasha Wilson, my mother Joyce, my wife Irene, daughter Rackel, son Tinotenda and the rest of the family.

ABSTRACT

The effects of litter quality and inorganic nitrogen (N) on rate of decomposition and N release pattern by three leguminous woody species were investigated under field conditions by the litterbag technique. The species studied in 1994/1995 were *Leucaena leucocephala, Senna siamea* and *Flemingia macrophylla*. This study was superimposed on an existing alley cropping trial. In the on-going experiment, maize (variety MM 603, 3-way cross), was the companion crop and the leguminous species comprised the alley hedgerows. Nylon litterbags with 4 mm mesh size were each filled with 20 g of dry leaf prunings of each species. Five litterbags of each pruning type were randomly buried in a subplot of each treatment. At each sampling time, one bag representing each pruning type was removed from each subplot. The samples were cleaned, dried weighed and analysed for N, polyphenol and lignin contents. Decomposition rate constants (kD) and N release rate constants (kN) were calculated from exponential decomposition equations. The mean (kD) of the plant litter ranged from 0.30 to 0.12 wk^{-1}, decreasing in the order, *L. leucocephala* > *S. siamea* > *F. macrophylla*. Analysis of variance of the mean kD values showed that *L. leucocephala* and *S. siamea* decomposed significantly ($P \leq 0.01$) faster than *F. macrophylla*. It was also observed that the level of inorganic N had a significant effect on decomposition rate. Residues in plots which received 68 and 112 kg N ha^{-1} had similar decomposition rates which were faster ($P \leq 0.05$) than those for 0 and 34 kg N ha^{-1}. Negative partial correlations were recorded between kDs, on one hand and lignin and polyphenol contents ($P \leq 0.01$), C:N ratio ($P \leq 0.01$), polyphenol:N ratio ($P \leq 0.01$) and lignin + polyphenol:N ratio ($P \leq 0.01$). Positive partial correlations ($P \leq 0.01$) were recorded with initial residue N content ($P \leq 0.01$) and inorganic N level ($P \leq 0.01$). These results show that both the chemical composition of plant residues and level of inorganic fertiliser N applied increased the rate of plant residue decomposition. The mean (kN) ranged from 0.151 to 0.114 wk^{-1}, decreasing in the order *L.*

leucocephala > *S. siamea* > *F. macrophylla*. There were however, no significant species or N level effects on kN. Generally, net N release was obtained in the first 2-3 weeks followed by immobilisation thereafter in all species. Positive partial correlations($P \leq 0.05$) were recorded with initial N-content ($P \leq 0.05$) suggesting that it affects decomposition rates. Negative partial correlations were recorded between initial lignin and polyphenol contents and kN. Lignin and polyphenols are thought to have caused N immobilisation through the formation of resistant complexes. There was no significant species effect on maize yields. A significant N fertiliser effect on yield was obtained at 68 kg N ha^{-1}. This result probably indicates the need for moderate fertiliser N addition to incorporated residues in alley cropping.

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CHAPTER ONE

1.0 INTRODUCTION

Farming systems requiring low external inputs are being developed as alternatives to shifting cultivation in many parts of the tropics where declining soil fertility is a major constraint to crop production. The need for alternative systems is especially great for small scale farmers with limited access to fertilizers (SPRP, 1989). One alternative approach to mitigating the soil fertility constraints is alley cropping or hedgerow intercropping system (Chirwa *et al.*, 1994).

Handayanto *et al.* (1994) defined alley cropping/hedgerow intercropping as an agroforestry system where food crops are grown between rows of trees, preferably leguminous trees. The trees are periodically pruned to prevent shading of the companion crop and to reduce competition. The prunings are utilised as green manures, particulary as sources of N and mulching material. The objectives of agroforestry technologies are to increase soil fertility, conserve moisture, and in some cases, suppress weeds (Kang *et al.*, 1984). Ladd *et al.* (1981) reported that the main value of leaves from N-fixing agroforestry trees was the accumulation of soil organic N from the litterfall, which eventually is made available to companion crops in the alley after mineralisation of the litter. Successful use of alley cropping for soil fertility improvement depends largely on the understanding of biological factors that affect decomposition and nutrient release from the resource material. The factors include the residue C: N ratio, polyphenol and lignin concentrations (Palm, 1988; Constantenides and Fownes, 1994; Tian *et al.* 1992; Handayanto *et al.*, 1994).

Results of various alley cropping experiments in Zambia and Nigeria have indicated that sustained food crop production is feasible using a combination of legume residues and judicious amounts of

inorganic nutrient input (Kamara *et al.*, 1994; Xu *et al.*, 1993). Xu *et al.*, (1993), working on N cycling in semi- arid tropics, established that the N supply by the hedgerow legume was not sufficient to achieve optimum companion crop yield. In order to manage the N mineralised from organic residues for crop uptake, there is need to understand decomposition and N mineralisation patterns of the organic inputs in relation to their chemical composition.

Data on the influence of inorganic N and biomass chemical composition on nutrient release and decomposition are not currently available in Zambia (C.S. Kamara, personal communication 1994). Studies on decomposition of surface litter that were conducted at Chipata, Zambia showed significant differences in rates of decomposition among three species (*L. leucocephala* = *S. siamea* > *F. macrophylla)*, and N-release rates (*L. leucocephala* > *S. siamea* > *Flemingia macrophylla)* (Mwiinga *et al.*, 1994). This work, however, did not relate the decay patterns to the chemical quality of the leguminous material. Studies by Palm (1988), in the Peruvian Amazon on various alley leguminous trees established among other factors that high lignin, high polyphenol content and high C: N ratios in leaves tended to slow litter decomposition and nutrient release. Similar conclusions were also drawn by Constantinides and Fownes (1994), Tian *et al.* (1992), Handayanto *et al.* (1994).

The proposed study seeks to improve the selection and management of green manures in order to synchronise N release and crop demand. This study will also help in determining the timing of pruning incorporation to synchronise periods of high release rate with peak crop nutrient demand (Mwiinga *et al.*, 1994; Palm, 1988). Multipurpose trees (MPTs) which are low in polyphenols, can provide a rapid flush of N during mineralisation, and may therefore be a good choice for use with annual crops such as maize which requires large amounts of N in a short period of time.

Nitrogen release by plant litter with high contents of polyphenols, lignin and C:N ratios is slow so that decomposition occurs over a long period of time . The latter may be the better choice for tree or perennial production systems (Palm, 1988). Thus, in order to sustain production in hedgerow intercropping systems, a better understanding of the effects of litter quality on decomposition and N release is essential.

A field experiment using the litterbag method (Anderson and Ingrams, 1989) was established with the objectives of determining (1) the N, lignin and polyphenol contents in leaves of *L. leucocephala, S. siamea* and *F. macrophylla*, (2) the influence of litter chemical composition on decomposition and N release rates by the leguminous tree species under investigation; (3) the influence of added fertilizer N on decomposition and N release rates by the litter and; (4) maize response to a combination of fertilizer N and leaf biomass from the three leguminous tree species.

CHAPTER TWO

2.0 LITERATURE REVIEW

The alley cropping concept for soil fertility improvement emerged from work conducted at the International Institute of Tropical Agriculture (IITA), in Nigeria with woody legumes in the early 1970s (Kang *et al.*, 1984). This agroforestry technology was designed to allow a higher intensity of land use while maintaining the basic merits of the bush-fallow system (Chitemene in Zambia). Alley cropping is a practice in which annual crops are grown between rows of leguminous trees. The trees are pruned periodically and the prunings are placed as mulch or green manure for the crop between the rows (Kang *et al.*, 1981b). It is assumed that the prunings and litterfall from the leguminous hedgerow plants provide a readily available source of N for the crop.

In addition, the soil physico-chemical properties are also presumably greatly improved. Thus alley cropping has both economic and ecological gains. The ecological benefits accrue from a more efficient nutrient cycling system, reduced soil erosion and the maintenance or enhancement of the soil organic matter content, leading to a more sustainable form of land use than continuous cropping. Economic gains arise from the technology's potential for reducing inorganic inputs and in improving yields. When N fertilizers are expensive and unaffordable, as is the case in Zambia, especially for small scale farmers, green manure and mulch from leguminous hedgerows can be used as cheaper alternatives and cheaper sources of N and other nutrients (C.S. Kamara, personal communication, 1994). In addition, farmers may also obtain extra benefits from products of the hedgerow trees. These may be fuelwood, building poles, medicines and fodder for feeding animals during the dry season (Rocheleau *et al.*, 1988; Kang *et al.*, 1984).

In Zambia, alley cropping appears to have potential to help reduce the need for inorganic fertilizers especially N (Mathews *et al.*, 1992a). It can also be a good source of the much needed fuelwood and a substitute for the destructive shifting cultivation practice known as Chitemene. Alley cropping is particulary important in the wake of the ever escalating population (2.5 to 3.3% per annum for SADC, Ngugi, 1993) and the resultant land pressure. It has a high potential for adoption because alley cropping retains the basic principles of traditional bush fallowing and attempts to keep all land productive at the same time (Mathews *et al.*, 1992b; Mtonga, 1993). According to Kang *et al.* (1984), the major advantage of alley cropping over shifting cultivation and bush fallow systems is that the cropping and fallow phases can take place concurrently on the same piece of land thus allowing the farmer to crop for an extended period without returning the land to bush fallow.

2.1 Alley cropping research

Alley cropping is attracting considerable interest as a stable alternative to shifting cultivation (Kang *et al.*, 1984), primarily because it provides sufficient quantities of mulch to maintain soil fertility, to reduce nutrient losses through leaching and to add biologically fixed N. Numerous experiments conducted by IITA and the International Centre for Research in Agroforestry (ICRAF) are in progress. According to Ngugi (1993), ICRAF and the governments of various countries in Sub-Saharan Africa have developed collaborative agroforestry research projects under the Agroforestry Research Networks for Africa (AFRENA). These are intended to generate agroforestry technologies by addressing problems unique to agroforestry research.

Results from these research activities, especially with maize show that yields under alley cropping significantly improved in field trials conducted at IITA in the sub humid zone of Nigeria (Kang *et*

al., 1981b). The addition of Leucaena prunings between 5-8 tha^{-1} from fully grown hedgerows sustained maize grain yields at about 3.8 t ha^{-1} for two consecutive years with no inorganic N additions. Where prunings were not added, yields declined 1.0 tha^{-1} to less than 0.3 tha^{-1} during the same period. However, maize yields were increased when Leucaena prunings were supplemented with low amounts of N at the rates of 20-80 kg N ha^{-1} depending on maize variety and season. Yamoah *et al.* (1986) and Kang *et al.* (1984) recommended addition of low amounts of inorganic fertiliser N to obtain higher yields where prunings are incorporated. Clay and Clap (1990) citing Woods *et al.* (1983) reported that application of ammonium fertilizers under N-limited conditions can increase microbial respiration, population and N mineralisation potential.

The reduction of inorganic N input and the maintenance of stable yields is an advantage of this technology. Beneficiaries are the resource poor farmers in the third world who are unable to purchase fertiliser inputs due to poor financial resources. In the high rainfall areas of Zambia, economic studies by Mathews (1992b) indicated that as fertiliser prices continue to increase in relation to crop prices, alley cropping particulary with Leucaena, may become a realistic alternative for small scale farmers.

2.2 Alley cropping research in Zambia

Research in agroforestry technologies in Zambia was initiated in 1984 at Misamfu Research Station in Kasama, with NORAD funding and in 1987, with funding from the Swedish Agency for Cooperation with Developing Countries (SAREC) at Msekera Research Station in Chipata and at Chalimbana in Lusaka, (Ngugi, 1993). At the semi-arid Chalimbana site, a positive effect of hedgerow intercropping on maize grain yield was recorded, with *L. leucocephala* being the most effective species (SADC/ICRAF, 1993). Maize grain and stover yields in the Leucaena treatments

were significantly superior to *F. macrophylla* and *S. siamea* alleys after five years. Leucaena managed alleys with prunings alone yielded about 1.0 tha^{-1} as compared to less than 0.4 tha^{-1} for the *F. macrophylla* and *S. siamea* managed alleys and control plots. Combination of fertilizers with prunigs produced significantly more maize grain yield than applying prunings alone, an effect also reported by Kang *et al.*, (1981b). However, since establishment of the alley cropping trials using the three multipurpose tree species in 1987, no studies have been carried out on the effect of inorganic fertiliser N and chemical quality of prunings on the decomposition and N release rates. Decomposition studies carried out by Mwiinga *et al.*, (1994) in Chipata, did not focus on chemical composition of the tree leaves as they relate to decomposition and N release.

2.3 Decomposition and N release

In order to improve soil fertility, the litter from hedgerows has to undergo decomposition and mineralisation to make nutrients available for plant uptake. House and Stinner (1987) defined decomposition as the decrease in the mass of a substrate resulting from leaching of soluble materials, catabolism or oxidation of organic matter, and the resultant physical breakdown or comminution. Substrate quality in terms of lignin, polyphenols and C:N ratio, among other factors, has been known to influence the rate of decomposition and N release (Palm and Sanchez, 1991; Palm 1988). The critical N content needed for immediate net mineralisation of N from litter is quoted as 1.73% by Frenkenberger and Abdelmagid (1985) and as 2% by Palm (1988). The critical polyphenol:N ratio is quoted as 0.5 and C:N ratio of less than 30 (Palm and Sanchez 1991; Oglesby and Fownes, 1992; Handayanto *et al.*, 1994).

2.4 Role of polyphenols and lignin in decomposition and N mineralisation.

Polyphenols are water soluble phenolic compounds that are capable of binding plant proteins

(Haslam, 1989). The binding effect reduces the release of N from decomposing plant materials (Baldwin *et al.*, 1983). In general, polyphenols, which are secondary metabolites in plants, are reactive compounds. Some form complex structures by H-bonding with basic N-containing groups, others form stable cross linkages with amino groups, making the material recalcitrant and resistant to decomposition. In addition, polyphenols are readily oxidised to quinones either by autooxidation at neutral pH conditions, or by enzymes. The quinones react with other polyphenols, amino acids and amino sugars to form stable polymers (Kelly and Stevenson, 1987). The stable polymers formed between polyphenols and N containing compounds have characteristics similar to and considered precursors to the fulvic and humic acids found in soil organic matter (Stevenson, 1982). Another interaction between polyphenols and N that may be especially important in acid soils is referred to as nitrosation, a chemical reaction of nitrite with polphenols, forming organic N compounds. Palm (1988), citing Nelson and Bremner (1969) reported that nitrite can be fixed by organic matter leading to gaseous losses of N in soils with neutral pH and by the formation of stable organic compounds in acidic soils. Formation of these resistant complexes reduces the availability of N from plant material, in which case immobilisation of N by microbes would be expected. Silvapalan *et al.*, (1985) as cited by Palm(1988) found lower net mineralisation from tea leaves that had high soluble N and high polyphenol content compared with leaves containing high soluble N but with low polyphenols. This finding suggests that the polyphenols make soluble N unavailable.

Lignin is also capable of reducing the availability of both carbohydrates and proteins by complexing them in much the same way as polyphenols (Swain, 1979). It is likely that lignin also plays an important role in influencing litter decomposition. Various reports also indicate that lignin may degrade to simpler polyphenol compounds, which in combination with other microbial and

plant polyphenols, may increase the presence of insoluble protein complexes (Palm, 1988).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

The study was carried out during the 1994/95 cropping season at the SADC/ICRAF Zonal Agroforestry Research Project at Chalimbana Research Station in Lusaka, Zambia. The site is situated 28^0 29' 56" East, 15^0 21' 32" South, and its elevation is 1280 m above sea level. Rainfall for 94/95 season was 520 mm and the mean minimum and mean maximum temperatures were 18 ^{0}C and 31 ^{0}C, respectively. The soil is derived from quartz muscovite schist with surface soil being acidic, pH- $CaCl_2$ (4.8), while subsoil is neutral to alkaline. Chemical composition of major nutrients shows 0.13% N, 1.97 mg kg^{-1} P and 0.66 cmol K kg^{-1} soil. The soils have been classified as plinthic Lixisols or in Soil Taxonomy as fine loamy, mixed iso-hyperthermic plinthic kandiustalf (Chirwa *et al.*, 1994). The experiment was superimposed on an alley cropping experiment established in 1987. The hedgerow species were *Leucaena leucocephala, Senna siamea* and *Flemingia macrophylla*. The companion crop has been maize since establishment of the alleys. This experiment was conducted on those plots which had not received fertiliser treatments since establishment of the alley cropping experiment.

3.2 Plant residues

Prunings of three leguminous woody species of *L. leucocephala, S. siamea* and *F. macrophylla* were used in this study. The prunings were sun-dried and incorporated into the soil at the rate of 5 t ha^{-1} in the alleys of each species. Where a species could not yield a 5 t ha^{-1} target, the shortfall was from litter banks of the same species and same age at the station so as to minimise source of error. Part of the dried litter, a total of 1200 g for each species, was confined in nylon litterbags each containing 20 g to monitor decomposition and N release.

3.3 Field layout and plot management.

A split plot in a randomised complete block design replicated three times was used. Plant residues made up the main plot factor while N levels were the subplot factor. The experiment was carried out in the outer three rows of the hedgerows. Each of the three species in a block delineated an alley 4.5 m wide and 10 m long with 6 rows of maize (MM 603, 3- way cross) in the main alley and 3 rows on either side of the hedgerows. The outer rows were divided into two, measuring 2.25 m wide x 4.5 m long to give four subplots of each species per block. Subplots received 0, 34, 68 and 112 kg N ha^{-1} plus 5 t ha^{-1} dry prunnings of the tested tree species. One third of the N fertiliser treatments was applied as D compound (10N:20P:10K) at planting.The balance was applied as urea (46% N) four weeks latter.The 0 kg N ha^{-1} plots did not receive any fertiliser at all because soil analysis results revealed that Potasium Phosphorous and Sulphur were above critical levels and hence the 0 kg N ha^{-1} were not compensated with other sources. The rate of 5 t ha^{-1} was used since it was the expected average prunning yield from the trees. The treatments were as outlined below;

(1) 5 t ha^{-1} *L. leucocephala* + 0 kg N ha^{-1} + 5 litterbags

(2) 5 t ha^{-1} *L. leucocephala* + 34 kg N ha^{-1} + 5 litterbags

(3) 5 t ha^{-1} *L. leucocephala* + 68 kg N ha^{-1} + 5 litterbags

(4) 5 t ha^{-1} *L. leucocephala* + 112 kg N ha^{-1} + 5 litterbags

(5) 5 t ha^{-1} *S. siamea* + 0 kg N ha^{-1} + 5 litterbags

(6) 5 t ha^{-1} *S. siamea* + 34 kg N ha^{-1} + 5 litterbags

(7) 5 t ha^{-1} *S. siamea* + 68 kg N ha^{-1} + 5 litterbags

(8) 5 t ha^{-1} *S. siamea* + 112 kg N ha^{-1} + 5 litterbags

(9) 5 t ha^{-1} *F. macrophylla* + 0 kg N ha^{-1} + 5 litterbags

(10) 5 t ha^{-1} *F. macrophylla* + 34 kg N ha^{-1} + 5 litterbags

(11) 5 t ha^{-1} *F. macrophylla* + 68 kg N ha^{-1} + 5 litterbags

(12) 5 t ha^{-1} *F. macrophylla* + 112 kg N ha^{-1} + 5 litterbags

3.4 Litterbags

Decomposition and disappearance of the prunings were followed in the field by employing the litterbag method as described by Anderson and Ingram (1989). Nylon litterbags measuring 20 cm x 20 cm with a 4mm mesh were used for this study. Mesh size of 4 mm was assumed to allow access to all mesofauna such as termites, colembola, mites and enchytraeids, and virtually all macro-invertebrates such as earthworms, millipedes, insects, and isopods, (Tian *et al.*, 1992). A total of 180 litterbags were prepared each containing 20 g dry prunings (equivalent to 5 t ha^{-1}). Each of the three species had 60 litterbags. Five litterbags per type of pruning were randomly incorporated a soil depth of 10 - 15 cm in each of the four sub-plot treatments in a replicate. A sample of dry prunings from each species was retained for the determination of the initial N, lignin, and polyphenol contents.

Sampling was done at 2, 4, 8, 12 and 16 weeks after the incorporation of litterbags. At each sampling time (ie, harvesting/lifting of buried litterbags), a total of 36 litterbags, one from each subplot treatment, were placed in separate plastic bags and transported to the laboratory. Soil and other contaminants were washed off using distilled water, and the roots were sorted by hand and discarded. The material was then oven- dried at 80 ^{0}C for 48 hours before weighing. After drying the material was weighed and then ground in a Willey Mill to pass through a 1mm sieve. Subsamples weighing 1 g were used to determine the ash-free dry weight by incineration in a muffle furnace at 500 ^{0}C for three hours. Ash-free dry weight was used to correct for

contamination of undecomposed litter. The remaining samples were set aside for determination of N, lignin, and polyphenol content.

3.4.1 Leguminous tree species plant analysis

Harvested leaf samples were analyzed for initial contents of N, lignin, and polyphenols. Total N was analyzed by Macro-Kjeldahl digestion, followed by distillation and titration (Anderson and Ingram 1993; Bradstreet 1965). Lignin and cellulose were determined by the Acid Detergent Fibre (ADF) method as outlined in Anderson and Ingram, (1993). The polyphenols were extracted in hot (80 ^{0}C) 50% aqueous methanol and determined calorimetrically with tannic acid as a standard (Anderson and Ingram 1993; Hagerman, 1988).

3.4.2 Decomposition and N-release

One litterbag, from each subplot was removed at 2, 4, 8, 12, and 16 weeks after incorporation into the soil and the samples used for mass loss determination and chemical analysis, as described in 3.6 above.

3.4.3 Estimation of Decomposition and N-release

An exponential decomposition constant (kD) was derived from the following decomposition equation (Budelman, 1988);

$Y = Y(0)e^{-kt}$ (1)

where; Y(0) is the original amount of material (litter dry weight); Y is the amount of incorporated residue left undecomposed after a period of time (t) in weeks and k is the release constant. This decomposition rate equation was determined, *a priori*, to be the appropriate model to describe decomposition.

Equation (1) was also inverted to obtain the nutrient release function developed by Budelman (1988) as follows:

$R(t) = (DP)(1-e^{-kt})$ (2)

in which R(t) is the amount of a specific nutrient released in kg ha^{-1} after a certain period of time (t) in weeks; D is the foliage dry matter quantity initially applied in kg ha^{-1} and assumed to be 5000 kg; P is initial nutrient concentration of the foliage, and k is the release constant. Since the litterbag size and weight of foliage packed used were 20 cm x 20 cm and 20 g per bag, respectively, the value of D was 5000 kg ha^{-1} (from 250 000 x 20 g litter per 1000). P was the mean N content in the foliage of each species.

3.5 Companion maize crop

3.5.1 Plant height

Maize plant height was measured at 45 and 90 days after planting from the harvest area and their heights was measured in centimetres from the ground to the top of the last leaf (45 DAP) and to the apex of the tassel (90 DAP). The respective mean values were considered to be the plant heights for the periods.

3.5.2 Leaf area index (LAI)

An automatic portable leaf area metre was used to measure the leaf area (cm^2) of five randomly selected middle row maize plants at 90 DAP. The mean value was then divided by the area covered by the maize plant (1875 cm^2).

3.5.3 Grain yield

3.5.3 Grain yield

Cobs from five randomly selected plants in the harvest area (3.375 m^2) were harvested, threshed and the grain dried in an oven (105 ^{0}C) to a constant weight (assumed to be 0% moisture content). The yield was then adjusted to a hectare basis. All yield figures were corrected to 12.5% moisture content at the time of weighing.

3.5.4 Harvest index (HI)

3.5.5 Harvest index was determined at harvest, and it was expressed as a percentage of the ratio of grain yield to the total biological yield (DM). Only the above ground portion of the crop, dried to constant weight at 105 ^{0}C was considered after harvest. The mathematical relationship between grain yield and dry matter yield is described by Stoskopf (1981) and Milthorpe and Moorby (1979):

$$HI = (EY/BY)100$$

where HI is the harvest index value as a percentage, EY is the grain yield in kg ha^{-1}, and BY is the total biological yield in kg ha^{-1}.

3.6 Statistical analysis

Data was analyzed using the MSTAT computer package. The following statistical analyses were done according to Steel and Torrie (1960), Little and Hills, (1990), Gomez and Gomez, (1984), Montgomery (1991).

(i) Analysis Of Variance (ANOVA) was used to check treatment effects on maize yields, (LAI), (HI), maize heights at 45 (DAP) and 90 DAP. In addition, ash free dry weights of remaining plant material, kD and N release constants (kN) were also subjected to analysis

of variance to determine treatment effects on decomposition and N release patterns of the three plant residues.

(ii) The kD and kN rate constants were also subjected to multiple regression and partial correlation analysis to determine effects of initial chemical composition and N level.

(iii) The Duncan's Multiple Range Test was used to separate means where significant treatment effects were obtained from the Analysis of Variance.

CHAPTER FOUR

4.0 RESULTS

4.1 Litterbag study

4.1.1 Initial chemical composition of the plant residues

The initial chemical compositions of the litter from the three leguminous tree species used in this study are shown in Table 1.

4.1.1.1 Nitrogen

L. leucocephala was characterised by a relatively higher N content (3.5%), as compared to the other two residues which had a similar N content of 2.31%.

4.1.1.2 Lignin

The lignin content for *L. leucocephala* (29.94%) was higher than that for *S. siamea* (28.29%) but lower than that for *F. macrophylla* (35.43%).

4.1.1.3 Polyphenol

The polyphenol content was highest in *L. leucocephala* (4.6%) followed by *F. macrophylla* (3.5%) and *S. siamea* (1.6%) respectively.

4.1.1.4 Other components

The C: N ratios were all below 30:1 decreasing in the following order *S. siamea* > *F. macrophylla* > *L. leucocephala*. Cellulose contents ranged from 8.43% *(L. leucocephala)* to 40.29% *(F. macrophylla)*. The differences in the contents of N, polyphenols and lignin contents among the three species provided a basis for determining factors influencing decomposition rates and nutrient release patterns.

Table 1. Initial chemical composition of litter from the three leguminous plants.

Component	*L. leucocephala*	*S. siamea*	*F. macrophylla*	*Mean*	*SD±*
% water	6.92	5.53	9.18	7.21	1.80
% Ash	7.22	5.28	5.82	6.11	1.46
% Carbon	62.03	68.70	57.61	62.78	5.57
% N	3.50	2.31	2.31	2.71	0.69
% Lignin	29.94	28.29	35.43	31.22	3.74
% Polyphenol	4.60	1.60	3.50	3.20	1.52
% Cellulose	8.43	13.57	40.29	20.73	17.10
C:N Ratio	17.72	29.74	24.94	24.13	6.05
Lignin:N ratio	8.55	12.25	15.33	12.04	3.39
Polyphenol;N	1.31	0.69	1.51	1.17	0.43
Polyphenol+ Lignin:N	9.87	12.94	16.85	13.22	3.50

SD - Standard deviation

4.1.2 Decomposition patterns of plant residues

Generally there was a rapid loss of mass from the litterbags during the first two weeks among all the three species (Fig. 1), in the order *L. leucocephala* > *S. siamea* > *F. macrophylla.* By the end of the second week , *L. leucocephala* and *S. siamea* had lost about 60% of their original ash-free dry weight, whereas only 35% of the original litter of *F.marophylla* had been decomposed. After the second week, the rate of mass loss due to decomposition declined for all species. Even then, *L. leucocephala* continued to decompose faster compared to *S. siamea. F. macrophylla.* on the other hand, showed a consistently slow decomposition throughout the incubation period as determined by mass loss (Table 2).

4.1.2.1 Main effect of species on mass loss over time

Results shown in Table 2 indicated that species had a significant influence on the amount of undecomposed residue at all sampling times. After two weeks of incubation, the undecomposed litter of *L. leucocephala* was significantly less than that of either *S. siamea* or *F. macrophylla* suggesting faster rate of decomposition. When the latter two species were compared it was found that the amount for *S. siamea* was also lower than that for *F. macrophylla.* After four weeks until the end of the incubation period *L. leucocephala* and *S. siamea* consistently had significantly lower undecomposed matter. At the same time, *F. macrophylla* showed consistently more undecomposed matter as compared to the other two (Table 2).

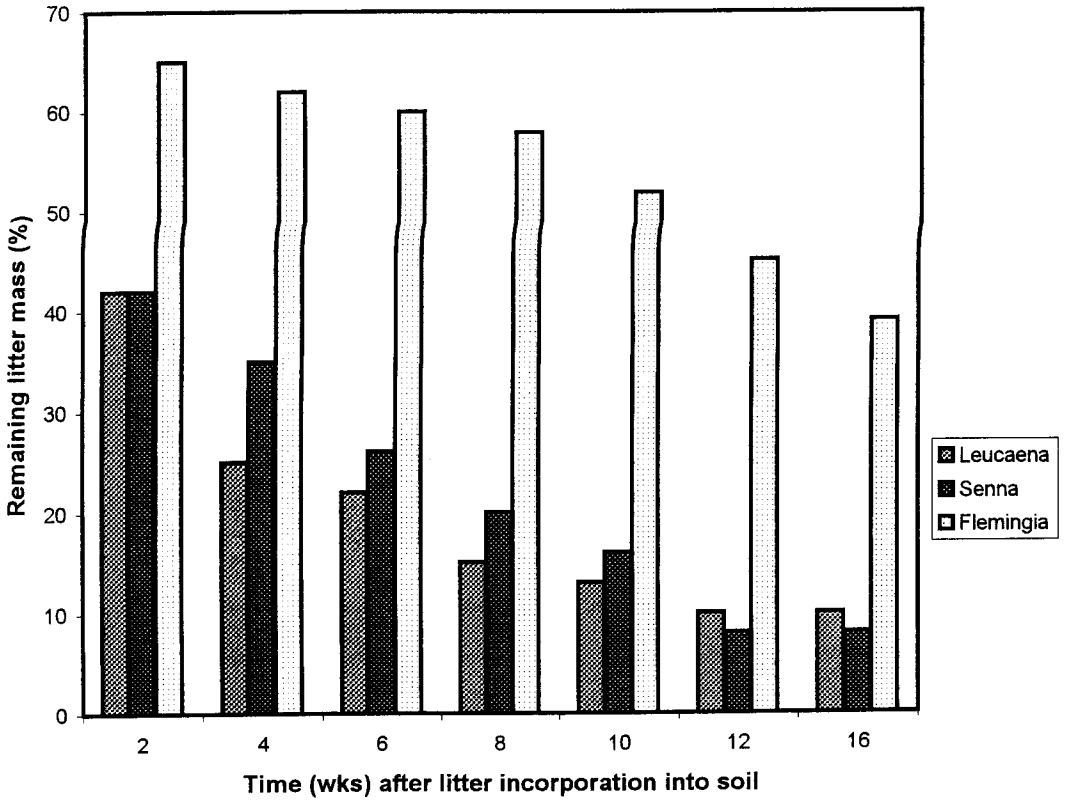

Fig.1. Decomposition of *L. leucocephala*, *S. siamea* and *F. macrophylla* over a period of 16 weeks

Table 2. **The effect of leguminous tree species on remaining mass (g) during 16 weeks of incubation.**

Species	Incubation Time (weeks)				
	2	**4**	**8**	**12**	**16**
	(g)				
L. leucocephala	*6.72b*	*4.40b*	*2.59c*	*1.79b*	*1.60b*
S. siamea	7.01b	5.65b	3.42b	1.44b	1.24b
F. macrophylla	11.17a	10.64a	9.83a	7.68a	6.60a
Analysis of variance					
Species	**	**	**	*	**
*cv (%)	14	25	44	65	115

§Means in the same column followed by the same letter are not significantly ($P \leq 0.05$) different from each other by the Duncan's Multiple Range Test..

4.1.2.2 Main effect of inorganic N rate on mass loss over time

The analysis of variance showed no significant influence of inorganic N on ash-free remaining mass of the residues. However, the 68 kgN/ha rate, though not significant, had a consistantly lower remaining mass after the second week onwards.

4.1.2.3 Main effect of species on decomposition rate constant (kD) at the various sampling times

Mean decomposition rate constants (kD) due to species ranged from 0.30 to 0.12 per week in the following order *L. leucocephala* > *S. siamea* > *F. macrophylla* (Table 3 and Fig.2) . Mean separation showed that overall, *L. leucocephala* and *S. siamea* had significantly higher rate constants ($P \leq 0.01$) than *F. macrophylla* (Table 3).

4.1.2.4 Main effect of species on mean decomposition rate constant (kD)

Species significantly ($P \leq 0.05$) influenced the decomposition rate constants (kD) of the residues during the first eight weeks of incubation. At two weeks, *L. leucocephala* and *S. siamea* showed similar kD which was significantly higher than that of *F. macrophylla*. At four weeks *L. leucocephala* had a significantly higher kD than *S. siamea* which in turn had a kD higher than *F. macrophylla*. The higher kD value for *L. leucocephala* suggests a higher decomposition rate. After 8 weeks, the rates of decomposition were the same for the three species (Table 3).

4.1.2.5 Main effect of inorganic N level on overall decomposition rate constant (kD)

Fertiliser N level significantly influenced kD during the fourth and twelfth week only (Table 4). During the fourth week, the 68 kg N ha^{-1} level gave a higher kD which was significantly different from 0 kg N ha^{-1} level but similar to 34 and 112 kg N ha^{-1}. By the twelfth week, the 68 kg N ha^{-1} treatment had a kD value which was significantly higher than 0 and 34 kg N ha^{-1} but similar to 112

kg N ha^{-1} level. During weeks two and eight the effect was not significant..

Mean decomposition rate constant (kD) due to fertiliser N ranged from 0.198 to 0.304 wk^{-1} with peak kD at the 68 kg N ha^{-1} rate (Table 4). The 68 kg N ha^{-1} rate gave the highest kD which was significantly ($P \leq 0.5$) higher than that for 0 and 34 kg N ha^{-1} but similar to that for the 112 kg N ha^{-1} rate (Table 6).

4.1.2.6 Effect of residue quality on decomposition rate constants (kD) of three residues

Multiple regression and partial correlation analysis (Table 5) showed that decomposition rate constants of the three leguminous tree litter types were positively correlated with initial N content, C:N ratio and inorganic N fertiliser rate ($P \leq 0.01$), and negatively correlated ($P \leq 0.01$) with lignin, polyphenols, polyphenols + lignin:N ratio and polyphenol:N ratio.

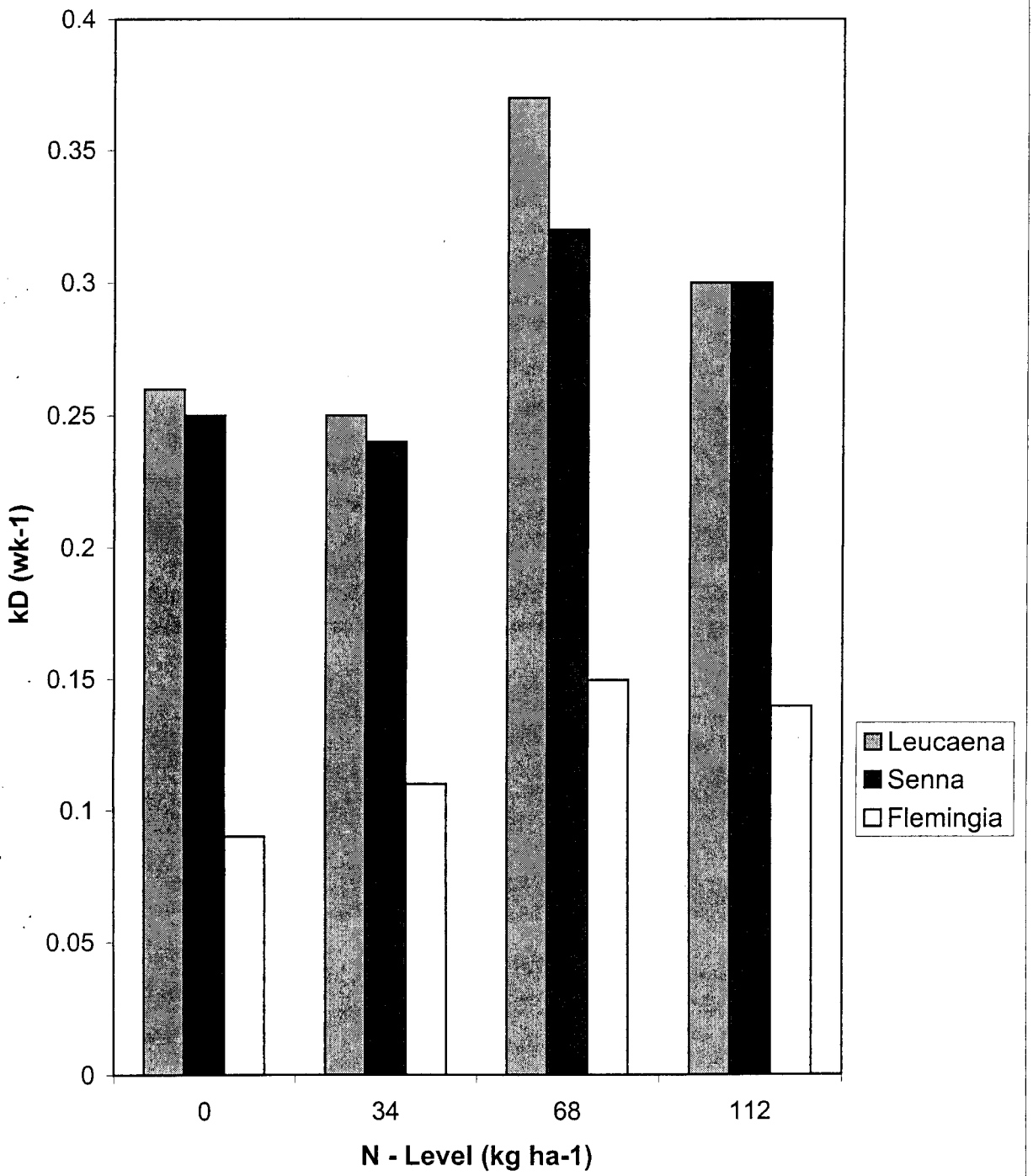

Fig.2. Effect of inorganic N on decomposition rate constant (kD) for *L. Leucocephala*, *S.siamea* and *F. macrophylla*

Table 3. The effect of species on decomposition rate constant (kD) at various sampling times

	Litter incubation Time (weeks) in Soil					
Speices	2	4	8	12	16	Mean
	(kD wk^{-1})					
L. leucocephala	0.45a§	0.37a	0.23a	0.23a	0.19a	0.30a
S. siamea	0.44a	0.28a	0.19ab	0.16a	0.12a	0.24a
F. macrophyalla	0.23b	0.10c	0.08b	0.20a	0.14a	0.12b
*cv (%)	20	34	49	45	69	31

§ Means in the same column followed by the same letter are not significantly ($P \leq 0.05$) different from each other by the Duncan's Multiple Range Test.

Table 4. The effect of inorganic N on decomposition rate constant (kD) per week averaged over species

	Time(weeks)					
N Applied (kg ha^{-1})	2	4	8	12	16	Mean
	----------	---------- (kD wk^{-1})----------				
0	0.36a§	0.19b	0.17a	0.14b	0.15a	0.20b
34	0.36a	0.24ab	0.19a	0.16b	0.14a	0.22b
68	0.36a	0.31a	0.14a	0.26a	0.18a	0.30a
112	0.42a	0.26ab	0.16a	0.20ab	0.14a	0.24ab
*cv (%)	45	34	34	45	35	31

§ Means in the same column followed by the same letter are not significantly ($P \leq 0.05$) different from each other by the Duncan's Multiple Range Test.

Table 5. **The effects of selected parameters on decomposition rate constants (kD) of leguminous tree litters**

Parameter	r^2†	F-value	p-level§	p, r¶
N content	0.0377	21.51	0.01	0.748
Lignin	-0.0253	21.51	0.01	-0.702
Polyphenols	-0.0309	21.52	0.01	-0.702
C:N	0.0644	21.51	0.01	-0.745
PP:N	-0.2208	21.52	0.05	-0.703
L + PP:N	-0.0463	21.52	0.05	-0.704
Inorganic N	0.0377	9.84	0.01	0.698
Constant (k)	2.4389			

†Regression coefficient, §Probability level, ¶ Partial correlation

N Nitrogen C Carbon PP Polyphenols L Lignin

4.1.3 Nitrogen release pattern

Nitrogen release from the three leguminous plant litter partly followed the same pattern as decomposition for the first three weeks (Fig 3). Over 45% of N in the litter was released during the first three weeks of the incubation for all litter. Thereafter, the N content in the remaining undecomposed litter generally increased with time for all litter types (Fig. 3).

Nitrogen release rates varied with plant residues and N levels. The mean N release rates ranged from 0.114 to 0.151 wk^{-1} but were not significantly different (Table 7). The N release rate constants for *L. leucocephala* and *S. siamea* were almost half of the corresponding litter decomposition rate constants whilst for *F. macrophylla* the two rates were equal. After 16 weeks, the N concentration remaining in *L. leucocephala*, *F. macrophylla* and *S. siamea* prunings had decreased on average by 46%, 15% and 13%, respectively (Fig. 3).

4.1.3.1 Main effect of species on N release rate constant over time

Although *L. leucocephala* and *S. siamea* released N faster than *F. macrophylla* during the first three weeks, analysis of variance showed no significance i.e. ($P \leq 0.05$) at all sampling times. There was also no significant species effects on mean kN.

4.1.3.2 Main effect of inorganic N on N release rate constant (kN) over time

Analysis of variance results showed no significant N fertiliser effect on kN at all sampling times on mean kN values averaged over species. There was also no interaction effect of N and species on kN.

4.1.3.3 Effect of initial litter quality on N release rate constant

Positive partial correlations ($P \leq 0.05$) were recorded with initial N content. Negative partial correlations ($P \leq 0.01$) were recorded between initial lignin and polyphenol contents and kN.

4.2 Alley cropped maize performance

4.2.1 Maize grain yield

Since the litterbag experiment was part of an alley cropping trial where maize was the companion crop, maize growth and yield parameters were also evaluated as a measure of response to the N release from litter and fertiliser rate. Maize grain yields for the hedgerow species at the four N fertiliser levels are as shown in Table 8. Maize grain yields increased with increasing fertiliser rate irrespective of litter type. Separation of means revealed significant differences in yield among the N levels (Table 9). There was no species effect (Table 10). The 112 kg N ha^{-1} fertiliser rate gave the highest yield which was significantly different from the rest (Table 9). The interaction of species and fertiliser rate was not significant at 5% level. The maize yields were comparable to the previous year's results at the same site at least for the 0 and 68 $kgNha^{-1}$ rates.

4.2.2 Maize height 45 Days After Planting (DAP)

Maize heights 45 DAP were not affected by the three species treatment (Table 10). However, significant differences ($P \leq 0.05$) existed among fertiliser levels (Table 9). Maize heights for the 112 kg N ha^{-1} rate were significantly ($P \leq 0.05$greater compared to the 0 $kgNha^{-1}$ treatment, but these were not significantly different from the 34 kg N ha^{-1} and 68 kg N ha^{-1} (Table 9). There were no significant differences, however, between 0 $kgNha^{-1}$, 34 $kgNha^{-1}$ and 68 $kgNha^{-1}$ (Table 9).

4.2.3 Maize height 90 DAP

Analysis of variance revealed significant species ($P \leq 0.01$) and N rate ($P \leq 0.05$) differences. Maize plants in *L. leucocephala* alleys were significantly taller than those from *F. macrophylla* and sole crop (Table 10). This observation was also reported in the previous year (SADC/ICRAF, 1994). As for *S. siamea* alleys, maize heights were not significantly different from the plants in the *L.*, *Flemingia* alleys and sole crop. The 112 kg N ha^{-1} rate had significantly taller plants ($P \leq 0.01$) than 34 kg N ha^{-1} and 0 kg N ha^{-1} , but not significantly different from 68 kgNha^{-1} plants which was not significantly different from 34 kg N ha^{-1} for all species (Table 9).

4.2.4 Leaf Area Index (LAI)

Leaf area index was significantly affected by N rate ($P \leq 0.01$) (Table 9), which generally increasing with increasing N fertilizer rate, but not affected by species. Species by N rate interaction was also insignificant (Appendix 4). The 112 kg N ha^{-1} rate gave significantly ($P \leq 0.05$) greater LAI than the other N levels, although there were no significant differences between 34 and 68 kg N ha^{-1} rates (Table 9). Generally LAI increased with increasing N-fertiliser rate.

4.2.5 Harvest Index (HI)

Harvest index showed significant ($P \leq 0.05$) responses to N application (Table 9) ($P \leq 0.05$) and species (Table 10). Maize in *L. leucocephala* alleys had the largest HI which was significantly higher than that from the *F. macrophylla* alleys but not significantly different from *S. siamea* and sole crops.

Table 6. The effects of selected parameters on N release rate constants of leguminous tree litters

Parameters	Partial correlation
N content	0.664*
Lignin	-0.774**
Polyphenol	-0.863**
C:N ratio	-0.432 ns
Polyphenol:N ratio	-0.522 ns
Lignin + polyphenol:N ratio	-0.311 ns
Inorganic N	0.459 ns

**, * and ns = significant at $P \leq 0.01$, $P \leq 0.05$, and not significant, respectively.

Table 7. Nitrogen release rate constants of prunings of three woody species as affected by inorganic N

Plant residues	N-level (kg ha^{-1})				
	0	34	68	112	Spp mean
	(kN)				
L. leucocephala	0.163	0.104	0.186	0.152	0.151a
S. siamea	0.125	0.113	0.150	0.126	0.129a
F. macrophylla	0.112	0.117	0.113	0.112	0.114a
N-level mean	0.133a	0.111a	0.150a	0.130a	
*cv (%)	42.8%				

Means in the same column (species) and in the same row (N-level) followed by same letter are not significantly different from each other at ($P \leq 0.05$) by the Duncan's Multiple Range Test.

Table 8. **Mean maize grain yeild at Chalimbana as influenced by N rates and hedgerows of *L. leucocephala, S. siamea* and *F. macrophylla* pruned at 50 cm height**

N rate	Maize grain yield under			
	Sole crop	Leucaena	Senna	Flemingia
	(kg ha^{-1})			
0	3007	2806	1788	2222
34	3650	3602	3885	2952
68	4204	5186	4365	3192
112	6406	6500	5752	5359

Analysis of variance	
Species	ns¶
N-level	**
Species x N-level	ns
cv (%)	18

¶ ** and ns = significant and not significant at 1 and 5% levels, respectively.

Table 9. The effect of fertiliser N rate on maize parameters

N-rate ($kgha^{-1}$)	Yield ($kgha^{-1}$)	Height (cm)		HI	LAI
		45 DAP	90 DAP		
0	2455.67d	60.53b	189.53c	0.37b	1.64c
34	3521.75c	72.33ab	205.38b	0.41ab	2.10b
68	4236.58b	70.48ab	214.44ab	0.42a	2.20b
112	6004.08a	79.95a	222.31a	0.43a	2.68a
*cv (%)	17.55	18.97	5.40	10.49	18.15
$LSD_{(0.05)}$	599.48	11.32	9.46	0.04	0.39

Means followed by the same letter in the same column are not significantly different from each other at 5% probability level according to Duncan's Multiple Range test.

DAP Days After Planting; HI Harvest Index; LAI Leaf Area Index

Table 10. Effect of species on maize yield parameters

Species	Yield (kg ha^{-1})	Height (cm)		HI	LAI
		45 DAP	90 DAP		
L. leucocephala	4523.42a	75.60a	220.25a	0.44a	2.18a
S. siamea	3946.92a	72.15a	212.13a	0.42ab	2.19a
F. macrophylla	3431.08a	64.53a	201.43b	0.37b	2.09a
Sole crop	4316.67a	71.02a	197.84b	0.40ab	2.16a
*cv (%)	17.55	18.97	5.40	10.49	18.15

Means followed by the same letter in the same column are not significantly different from each other at 5% probability level according to Duncan's Multiple Range test.

DAP Days After Planting; HI Harvest Index; LAI Leaf Area Index

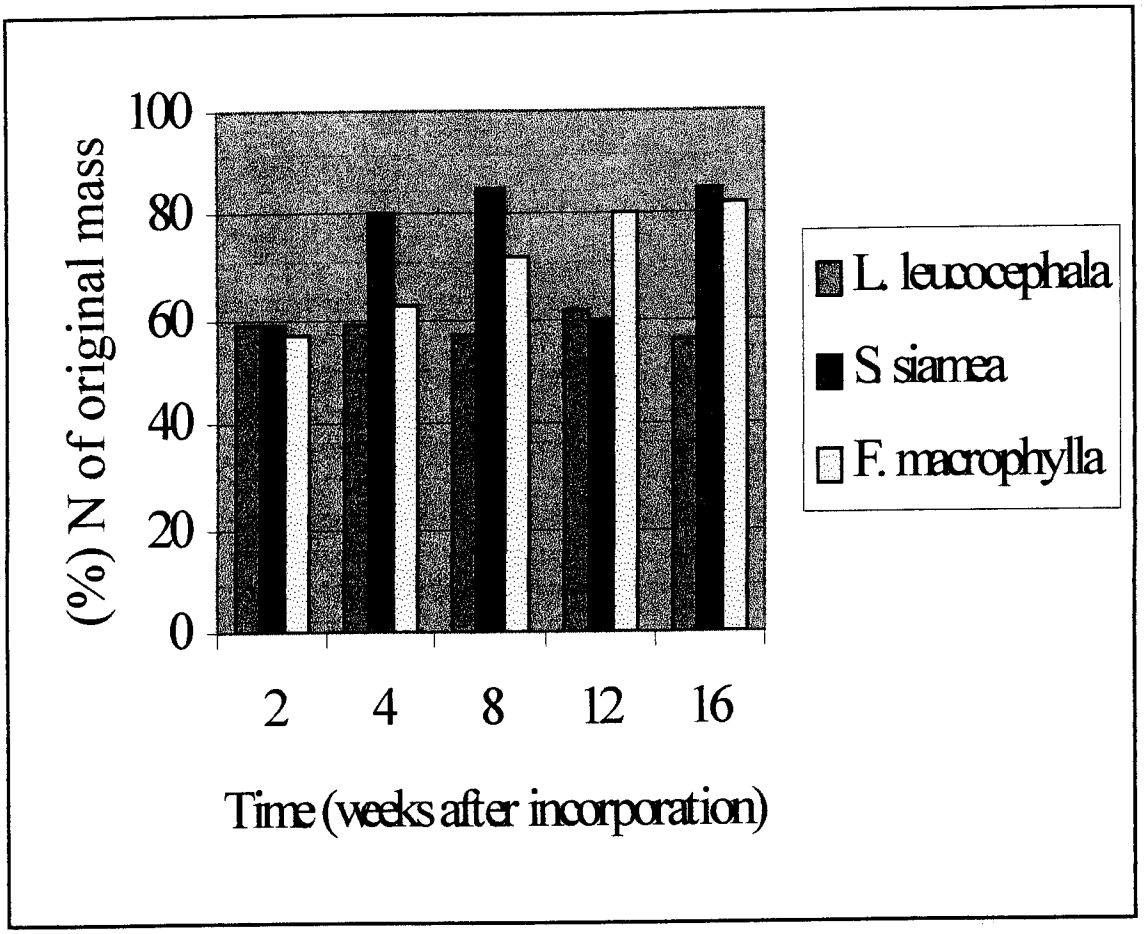

Fig. 3. Nitrogen release trends from *L. leucocephala, S. siamea* and *F. macrophylla* over a period of 16 weeks

CHAPTER FIVE

5.0 DISCUSSION

5.1 Litterbag study

5.1.1 Experimental limitations

The litterbag method used in this study for monitoring decomposition and nutrient release as described by Anderson and Ingram (1993), has been criticised as not providing a realistic description of decomposition and nutrient release. One of the major criticisms is that enclosure in fine mesh and/or compaction of leaf packs in the bags can create different microclimates to ambient conditions in unconfined litter, resulting in different rates of decomposition (Anderson and Ingram, 1993). In confined litter, the conditions under which the organisms operate are defined, but the fate of materials lost from the bags cannot be monitored.

Although another criticism is that the mesh size of the bag often excludes soil macrofauna that are important to decomposition processes especially comminution, the mesh size used for this study, 4 mm, was considered to be accessible to all decomposers. Tian *et al.* (1992), discovered that there were no significant differences in decomposition between 2 mm and 7 mm mesh sizes.

The fact that litterbags are harvested without replacement, meaning that at each sampling time a different litterbag is harvested for analysis for the same treatment, is another potential source of worry. This limitation could be responsible for some of the exceptionally high coefficients of variation obtained in the analysis of variance for undecomposed matter. Despite these and other limitations to the various methods of confining experimental litter, the litterbag method remains one of the most convenient methods for comparing decomposition processes between sites or experimental units, hence its adoption in this study.

It is also necessary to keep in mind that both old and young leaves were used in this study. Decomposition in such mixed samples will most likely be slower than those of young leaves alone because of retranslocation of N and phosphorous in older leaves to young and actively growing tissues resulting in a plant material of lower quality (Palm, 1988). With this and other limitations mentioned, the results obtained in this study will be discussed and where possible compared to those of others.

5.1.2 Decomposition patterns

Decomposition rates obtained from this study ranging from 0.118 to 0.299 wk^{-1} (Table 4), fall within the range reported from Nigeria by Tian *et al.* (1992). Although some of the variations in decomposition rates between sites is due to macroclimatic differences, analytical methodology differences can also be a source of error. Appendix 5 shows kD values from various researchers. Palm (1988), citing Meentemeyer (1978) suggested that the quality of the plant material controls the rate of decomposition in the tropics more than climatic factors. Plant residues with high initial N content have been known to show high correlations between N content, N release and biomass loss (Tian *et al.*, 1992).

In this study, the three residue types had high N contents, well above the critical level of 2% (Table 1). Among the three species studied *L. leucocephala* and *S. siamea* decomposed significantly faster than *F. macrophylla.* In this study *L. leucocephala* and *S. siamea* had similar decomposition rates although they differed in C:N ratios and in contents of N and polyphenols. They however had similar lignin contents. *S. siamea*, on the other, had similar N content as *F. macrophylla* but contained lower lignin and polyphenols.

From the foregoing discussion, it is possible to attribute slow decomposition of *F. macrophylla* to lignin as being the limiting factor, thus making it a better predictor. This observation is in conformity with Meentemeyer (1978) cited by Palm (1988), who observed that within a site, lignin content is a good predictor of decomposition rates. Although a lower polyphenol content for *S. siamea* resulted in faster decomposition and a higher content for *F. macrophylla* resulted in a slower rate, the situation was different for *L. leucocephala*. This multi-purpose tree had the highest polyphenol content yet decomposed faster than *F. macrophylla* with a comparatively high polyphenol content also. This suggests that other chemical factors favoured the decomposition of *L. leucocephala* than polyphenols.

Despite the high polyphenol content, *L. leucocephala* had the highest N content, lignin similar to *S. siamea* and the lowest C:N ratio. The C: N ratio did not serve as good an indicator as lignin content because *F. macrophylla* with a lower C: N ratio decomposed significantly slower than *S. siamea* which had a higher C:N ratio. The lignin + polyphenol:N and lignin:N ratios served as good predicters. The higher the ratio, the less the decomposition rates. This suggests the level of decomposition of plant residues is a function of the integrated effects of chemical characteristics of the residue. In fact, going by the respective values of regression coefficients, the lignin + polyphenol:N ratio and may be lignin:N ratio, probably a better indicator than just lignin content (Table 5). However, there is insufficient ancillary data on the chemical characteristics of the leaves to determine the relative importance of N, lignin and polyphenol content and other characteristics on decomposition in these studies (Palm, 1988).

The C: N ratio is a good indicator of whether net mineralisation or decomposition will occur

during decomposition. Since all materials had C: N ratios less than 30:1, it can be assumed that net mineralisation took place during litter decomposition. Materials with C: N ratios greater than 30 : 1, can decompose just as rapidly as those with low C:N ratios provided adequate N is available in the soil (R. Nyemba, personal communication, 1995).

The decomposition rate constant equation for the materials studied were established during the investigations (Table 5). The positive correlation between the decomposition rate constants and rate of inorganic N fertiliser applied justifies the reason why companion crop yields (in this case maize) in alley cropping experiments where fertiliser N is added, are superior to those yields where no fertiliser has been added. Although decomposition rates increased with increasing amount of fertiliser N, no significant differences were observed between 68 and 112 kg N ha^{-1} rate (Table 4). This implies that the 68 kgN ha^{-1} had the same effect as 112 kg N ha^{-1} on decomposition rates. This observation justifies the reason why the recommended N-fertiliser rate for hybrid maize companion crop in alley cropping at Chalimbana is 68 kg N ha^{-1}. N levels beyond this are not only uneconomical but tend to retard decomposition of incorporated leguminous plant residues probably due to luxury microbial biomass synthesis using inorganic N. Fertiliser N above this tends to be wasteful since it encourages luxury microbial N immobilisation at the expense of degradation of residue substrate (SADC/ICRAF, 1994).

The decomposition of leguminous leaves or litter in the tropics has received little attention (Palm, 1988). Values reported in the literature indicate fast but variable rates of decomposition ranging from 91% to 848% per year (Appendix 5). In this study, the range was higher, from 614% to 1560% per year.

The fact that there were significant differences between kD and inorganic N level in which the bags were incorporated, suggests the existence of the effect of N amendments on faunal activity on residues. This could be due to increased available inorganic N in the soil which makes N not limiting for soil microorganisms which are responsible for degrading the residues. However, Knapp *et al.*, (1983) reported conflicting evidence where some studies found mixed results from the effect of N additions on straw decomposition. The varied results could be attributed to the effect of chemical composition, soil environmental factors and duration of incubation. If environmental conditions are optimal for maximum microbial activity, N and C will be utilised and microbial biomass synthesized during the initial stages of crop residue decomposition. Soil microbial biomass can serve as both sink or source of soil nutrients or as a "driving force" in nutrient availability, where microbes promote the decomposition process. It is not only the microbial pool, but also the turnover rate that is important for nutrient availability. The kinetics of the system during this period is of agronomic interest in that they may be ultimately useful for residue management.

5.1.3 Nitrogen release pattern

In general, absence of net N release after two weeks suggests N immobilisation. N release rate constants obtained in this study (Table 7), fall within the range reported by Tian *et al*, (1992), but below those reported by Palm (1988). These differences are probably due to differences in residue species, quality or macroclimatic conditions. In the studies by Palm (1988), for example, the N contents were greater or equal to 3.18% and the lignin contents were smaller or equal to 16.3% for *Inga edulis, Cajanus cajan* and Erythrina spp. The absence of significant differences in N release rate constants amongst the three residues and across the four fertiliser N levels was unique. The high lignin and polyphenol contents (Table 1) could be major contributing factors on

N immobilisation in *L. leucocephala* and *F. macrophylla*, while as for *S. siamea*, the lignin content and the rather high C: N ratio could be responsible.

It is important to remember that the N release by the three species after two to three weeks began to show net immobilisation following the initial rapid loss (Fig. 3). This change in N release coincides with an increase in the N concentration in the tissue remaining. This second phase could be explained by the lignin and polyphenols in these species (Palm, 1988). In the first phase (2-3 weeks) the soluble N fraction is either leached, mineralised or taken up by the alley companion maize crop. At the same time, some of this N may bind to the lignin fraction leaving a resistant form of N (Handayanto *et al*, 1994; Swain, 1979). Another possibility is that N which is mineralised binds to the polyphenols forming a resistant form of N (King and Heath, 1967; Palm, 1988; Handayanto *et al.*, 1994). The latter explanation is more likely for *L. leucocephala* and *F. macrophylla* which have both high lignin and polyphenol contents. Spain and Le Feuvre (1987), however reported that it is difficult to distinguish between the two because polyphenolic-N complexes end up in the same fraction as lignin, or acid soluble fraction in most laboratory procedures. Other researchers, Palm and Sanchez (1991), and Oglesby and Fownes (1992), concluded that the ratio of polyphenols to N was the parameter which could best be used to predict N mineralisation of various tropical legumes with a critical value of 0.5. The plant residues in this study were all above this critical figure (Table 1) which might explain the pattern obtained.

The presence of inorganic N fertiliser did not significantly affect N release constants although it was anticipated that the presence of applied N would increase microbial activity since N would not be limiting. There is a possibility that the inorganic N was complexed by polyphenols and lignin from the decomposing residues after two weeks.

5.2 Alley cropped maize study

Results of alley cropped maize performance are varied and diverse. Kang *et al.* (1981b) found that addition of 10 tha^{-1} fresh weight of prunings of *L. leucocephala,* containing about 100 kgN/ha produced similar maize yields as that fertilized with 100 $kgNha^{-1}$. Similar promising results were also reported by Kang *et al.*, (1984). Others have reported less promising results with alley cropping (Yamoah *et al.*, 1986b; Kass and Diaz-Romeu, 1985). These varied results are due to several factors and must not necessarily be interpreted as explicit failures of alley cropping in maintaining crop production. Some of these factors include tree/crop competition, amount and quality of residues, placement method and climatic and soil conditions. Yamoah *et al.* (1986b), found little differences in maize yields between plots without and plots with prunings of *Gliricidium sepium, Flemingia congesta* or *Cassia siamea.*

The present study did not establish significant effects of species treatment (Table 9). Mean yields averaged over N rate decreased in the following order, Leucaena > Sole > Senna > Flemingia. though the differences were not significant despite differences in chemical composition (Table 1) and decomposition rates among the species (Table 3). This was probably due to complexing of N by lignins and polyphenols which might have limited N release for crop uptake. The other reason could be the low pruning rates of 5 tha^{-1} which were incorporated in this study. Another reason could be that only a small proportion of the N added as part of plant residues was taken up by the maize following incorporation. Xu *et al* (1993), working on N cycling in leucaena alley cropping in semi-arid tropics found that the recovery of ^{15}N by maize was less than 9% in the first cropping season. This view was also shared by Chirwa *et al.* (1994), who reported that the effect of prunings as a source of N was not even evident when prunings were considered as a N source in

the absence of inorganic fertiliser during one season. Kang *et al* (1981b) observed that although prunings from leguminous trees can supply N for crop production. N utilisation efficiencies are reportedly low as compared to inorganic N sources. Possible reasons for the inefficiency include NH_3 volatilisation due to surface incorporation, inappropriate timing of pruning applications, delayed release of N and competition with hedgerow trees. Palm (1988) observed that efficiency of N utilisation by crop plants might be improved if release of N from the prunings was synchronised with crop demands. The same researcher suggests that this synchrony will depend on the timing of application of the prunings relative to crop uptake patterns. In this study the material was incorporated into the soil meaning that loss of N by volatilisation was therefore considered to be minimal.

The significant increase in yield in response to inorganic fertiliser in combination with leguminous plant residues has been reported by many researchers (Xu *et al.*, 1993; SADC/ICRAF, 1994; Chirwa *et al.*, 1994; Yamoah *et al* ., 1986b; Kang *et al.*, 1984). Where inorganic fertiliser was applied in combination with prunings, the readily available inorganic N may have been a more effective source of N compared to prunings which take some time before they are decomposed and subsequently mineralised. For example, in this study, 5 tha^{-1} of *L. leucocephala* residues (3.50% N) and *S. siamea* and *F. macrophylla* (2.31% N) could have supplied 175 $kgNha^{-1}$ and 115.5 $kgNha^{-1}$, respectively in the unfertilised plots and the maize yields could have increased accordingly. This strongly suggest that N availability and crop uptake were apparently affected by factors other than just the N supplying potential by the leguminous legumes. The significant increase in maize yields with increasing fertiliser N rates (Table 9) suggests that the nutrient was limiting performance even in the presence of prunings. This is probably because N from residues was not readily available in the short term.

5.2.1 Alley cropped maize height and leaf area index (LAI)

Maize plant height at anthesis were significantly taller ($P \leq 0.05$) in *L. leucocephala* alleys than in the other species although this was not translated into yield (Table 9). Overall, the 68 and 112 $kgNha^{-1}$ rates had taller plants averaged over species than 0 and 34 $kgNha^{-1}$. This implies that increased N supply affected growth rate in terms of height. Increased N supply also increased leaf area (Table 9) or, the photosynthetic surface area which was probably responsible for the corresponding yield increase as the N levels increased.

5.2.2 Alley cropped maize harvest index (HI)

Harvest index (HI) is the ratio of economic yield to the total above ground dry matter yield and is an important indicator of the efficiency of photosynthate partitioning between source and sink (van Averbeke and Marais, 1994). Maize in *L. leucocephala* alleys had larger HI though not significantly different from *S. siamea* alleys and the sole crop (Table 10). This suggests that growth and biomass production under Leucaena alleys were more pronounced. In fact, *L. leucocephala* residues decomposed faster, though not significantly different from *S. siamea*, thus suggesting better synchrony with crop demand. Combination of residue and fertiliser N produced higher HI due to improved N nutrition and hence biomass production in favour of the sink.

CHAPTER SIX

6.0 CONCLUSIONS

Results obtained in this study provide guidelines for the selection and management of alley cropping systems. From this study it is apparent that not all leguminous leaves, despite their high N content are of high quality in terms of rates and pattern of decomposition and N release. All the three tree litter materials had N contents above the critical value of 2% and their C: N ratios were all below the critical 30:1 ratio. On the other hand, the lignin contents were higher than those commonly reported by researchers while the polyphenol contents were within the commonly reported ranges. The polyphenol:N ratios were higher than the critical value of 0.5. This implies that while the residues were considered to be of high quality in terms of initial N content and C:N ratios, the amount of polyphenols and lignins reduced the quality with respect to decomposability and nutrient release.

Decomposition and N release are influenced by lignin and polyphenol content of the leaves. Residues high in lignins and polyphenols showed a rapid initial release followed by net accumulation or immobilisation. It is proposed that the lignins and polyphenols are prohibitive factors that bind to N thereby forming resistant complexes which lock up the N. These are important factors to consider when selecting legumes as N sources in agroforestry systems. Legumes low in lignins and polyphenols will provide a more rapid flush of N from mineralisation, and may therefore be a better choice for use with annual crops that require large amounts of N for short periods of time. Nitrogen release by legumes higher in lignins and polyphenols will be slower and decompose over a long period of time and may be the better choice for tree production systems.

Combination of pruning residues and inorganic N fertiliser is recommended where annual crops are involved. This is encouraged because inorganic N fertiliser has been shown to enhance decomposition rates of the residues in this study. Also nutrient contribution from residue has been seen to be very minimal in the short term. The 68 $kgNha^{-1}$ in combination with prunings has been proved to be attractive in terms of effect on decomposition and on the yields of the alley cropped maize. *L. leucocephala* and *S. siamea* had more positive attributes in terms of quality (save for the high polyphenol content for Leucaena), decomposition and N release constants and greater influence on companion crop performance than *F. macrophylla.*

The low decomposition of Flemingia litter make them very effective as mulch. This mulching effect may be more crucial for conserving moisture during dry conditions.

However, further research for more than one season and including some non leguminous residues for comparison is needed. The fate of the resistant complexes formed by polyphenols and lignins with N should also be investigated. More interestingly, the use of tracer/radio isotope techniques in N dynamics in alley copping or pot experiments would yield more conclusive results on the influence of inorganic N on decomposition and N release in alley cropping. Otherwise the limitations of this technology may outweigh those of alternative technologies like improved fallows especially in subhumid tropics including Zambia. Also an assay of microbial population dynamics and N nutrition during decomposition would also be useful background information.

7.0 REFERENCES

AFRINA REPORT, 1994: Agroforestry Research Project. Annual Report, No 80. Chalimbana. Lusaka, Zambia. pp 88

Anderson J.M. and Ingram J.S., 1989: Tropical Soil Biology and Fertility. A Handbook of Methods. Commonwealth Agricultural Bureau, Oxon. pp 171.

Anderson J.M. and Ingram J.S., 1993: Tropical Soil Biology and Fertility, A Handbook of Methods. CAB International, Wallingford. pp 45-49.

Baldwin J.T., Olson R.K. and Reiners W.A., 1983: Protein binding phenolics and inhibition of nitrification in subalpine balsan fir soils. Soil Biol. Biochem. 15:419-423.

Bradstreet R.D., 1965: Kjeldahl method for organic N. Academic Press. London. pp 85.

Budelman N., 1988: The decomposition of leaf mulches of *Leucaena leucocephala, Gliricidia sepium* and *Flemingia macrophylla* under humid tropical conditions. Agroforestry Systems 7(1):37- 45.

Chirwa P.W., Nair P.K.R. and Nkedi-Kizza P., 1994: Pattern of soil moisture depletion in alley cropping under semi-arid conditions in Zambia. Agroforestry Systems 26:89-99.

Clay D.F. and Clap C.F., 1990: Mineralisation of low C to N ratio corn residue in soil fertilised with ammonium fertiliser. Soil Biology Biochemistry. 22(3):355-360.

Constantinides M. and Fownes J.H., 1994: N mineralisation from leaves and litter of tropical plants; Relationship to N, lignin, and soluble polyphenol concentrations: Soil Biol. Biochem. 26:(1):49-55.

Frankenberger W.T. and Abdelmagid H.M., 1985: Kinetic parameters of N mineralisation rates of leguminous crops incorporated into soil. Plant and Soil 87:257-271.

Gomez K.A. and Gomez A.A., 1984: Statistical Procedures for Agricultural Research. An International Rice Research Institute Book. John Wiley, Brisbane. Australia pp 188-266.

Hagerman A., 1988: Extraction of tannin from fresh and preserved leaves. Journal of Chemical Ecology 2(2):95-121.

Handayanto E., Cadisch G. and Giller K.E., 1994: N release from prunigs of legume hedgerow trees in relation to quality of the prunings and incubation method. Plant and Soil, 160:237-248.

Haslam E., 1989: Plant polyphenols: Vegetable tannins revisited. Cambridge University Press. Cambridge. pp 230.

House G.J. and Stinner R.E., 1987: Decomposition of plant residues in no-tillage agroecosystems: influence of litterbag mesh size and soil arthropods. Pedobiologica, 30:351-360.

Kamara C.S., Chikasa P. and Mateke S.M. 1994: SADC/ICRAF Agroforestry Research Project. Annual Report no 80. Chalimbana, Lusaka, Zambia. pp 64-75.

Kang B.T., Wilson G.F. and Sipkens L., 1981b: Alley cropping maize (*Zea mays L.*) and *Leucaena (Leucaena leucocephala Lam*) in Southern Nigeria. Plant and Soil 63:165-179.

Kang B.T., Wilson G.F. and Lawson T.L., 1984: Alley cropping, A stable alternative to shifting cultivation. IITA, Ibadan, Nigeria. pp 99.

Kass D.C.L. and Diaz-Romeu R., 1985: Effects of prunings of woody legumes on nutrient losses in sustained crop production on a Typic Humitropept (Humic Cambisol). Transactions of the International Society of Soil Science 3:801-802.

Kelly K.R. and Stevenson F.J., 1987: Effects of carbon source on immobilisation and chemical distribution of fertiliser N in soil. Soil Science Society of America Journal 51:946-951.

King H.G. and Heath G.W., 1967: The chemical analysis of small samples of leaf material and the relationship between the disappearance and composition of leaves. Pedobiologica, Bd. 7:192-195.

Knapp E.B., Elliott L.F. and Campbell G.S., 1983: Microbial respiration and growth during the decomposition of wheat straw. Soil Biology and Biochemistry 13(3):319-323.

Ladd J.N., Oades J.M. and Amalo M., 1981: Distribution and recovery of N from legume residues decomposing in soils sawn to wheat in the field. Soil Biology and Biochemistry 13:251-

256.

Little T.M. and Hill F.J., 1980: Agricultural Experimentation. Design and Analysis. John Wiley and Sons. New York. pp 311

Mathews R.B., Holden S.T., Volk J. and Lungu S., 1992a: The potential of alley cropping in improvement of cultivation systems in the high rainfall areas of Zambia. 1. Chitemene and Fundilika. Agroforestry Systems, 17(3):219-240.

Mathews R.B., Lungu S., Volk J., Holden S.T. and Selberg K., 1992b: The potential of alley cropping in improvement of cultivation system in the high rainfall areas of Zambia. II Maize production. Agroforestry Systems 17(3):241-260.

Milthorpe F.L. and Moorby J., 1979: An introduction to crop physiology. Cambridge University Press. London. pp 211.

Montgomery D.C., 1991: Design and Analysis of experiments. John Wiley and Sons. New York.

Mtonga R.M., 1993: Alley cropping as a promising agroforestry technology for Luapula Province: In Kamara C. S., Gossage S. J., and Kwesiga F., (Eds): Agroforestry in Zambia. A summary Proceedings of the first Zambia National Agroforestry Workshop. ICRAF, Nairobi. Kenya. p 26.

Mwiinga R.D., Kwesiga F.R. and Kamara C.S., 1994: Decomposition of leaves of six multipurpose tree species in Chipata, Zambia. Forest, Ecology and Management 64:209-216.

Ngugi D.N., 1993: Keynote address: Agroforestry Research Networks For Africa (AFRENA) programme in the SADC region: In Kamara C.S., Gossage S.J., and Kwesiga F., (Eds): Agroforestry in Zambia. A summary Proceedings of the first Zambia National Agroforestry Workshop. ICRAF, Nairobi, Kenya. pp 26.

Oglesby K.A. and Fownes J.H., 1992: Effect of chemical composition in N mineralisation from green manures of seven tropical leguminous trees. Plant and Soil. 143:127-132.

Palm C.A., 1988: Mulch quality and N dynamics in alley cropping system in the Peruvian Amazon. PhD Thesis, North Carolina State University, Raleigh N.C. pp 33-40.

Palm C.A. and Sanchez P.A., 1991: Nitrogen release from leaves of some tropical legumes as affected by their lignin and polyphenolic contents. Soil Biology and Biochemistry 23:83-88.

Pauwelyn P.L. and Songolo H.L., 1986: Practical manual for soil sciences, UNZA. pp 26 -30.

Rocheleau D., Weber P. and Field-Juma A., 1988: Agroforestry in Dryland Africa. ICRAF, Nairobi, Kenya. pp 311.

SADC/ICRAF, 1992: Agroforestry Research Project. Annual report No 51. Chalimbana, Zambia. pp 78.

SADC/ICRAF, 1993: Agroforestry Research Project. Annual Report No 70. Chalimbana, Zambia. pp 89.

Spain A.V. and Le Feuvre R.P., 1987: Breakdown of four litter of contrasting quality in a tropical Austraulian rainforest. Journal of Applied Ecology 24:279-288.

SPRP, 1989: Annual Research Report, Misamfu Regional Research Station. Kasama, Zambia. p 3.

Steel R.G.D. and Torrie J.H., 1960: Principles and procedures of statistics. McGraw-Hill Book Company. New York. pp 122-150.

Stevenson F.J., 1982: Humus chemistry; Genesis, Composition, Reactions. John Wiley and Sons. New York. pp 443.

Stoskopf N.C., 1981: Understanding crop production. Reston Publishing Company. Virginia. pp 351.

Swain T., 1979: Tannins and Lignin. In: Rosenthal G.A., and Janzen D.H., (Eds). Herbivores. Their Interaction with secondary plant metabolites. Academic Press, New York. pp 657-822.

Tian G., Kang B.T. and Brussaard L., 1992: Biological effects of plant residues with contrasting chemical composition under humid tropical conditions - Decomposition and nutrient release. Soil Biol. Biochem. 24(10):1051-1060.

van Averbeke W. and Marais J.N., 1994: Maize response to plant population and soil water supply II. Plant barrenness and harvest index. South Africa Journal of Plant and Soil 11(2): 84-89.

Xu Z. H., Myers R.J.K., Saffigna P. G. and Chapman A.L., 1993: Nitrogen cycling in Leucaena (*Leucaena leucocephala*) alley cropping in semi-arid tropics. II. Response of maize growth to additions of N fertiliser and plant residues. Plant and Soil 148:73-82.

Yamoah C.F., Agboola A.A. and Wilson G.F., 1986b: Nutrient contribution and maize performance in alley cropping systems. Agroforestry Systems 4:247-254.

Appendix 1. Analysis of variance for ash-free remaining mass for all sampling times

Sources	Time (weeks after incorporation)				
	2	4	8	12	16
REPS	Ns	ns	Ns	ns	ns
SPECIES (A)	**	**	**	*	**
N-LEVEL (B)	Ns	ns	Ns	ns	ns
AB	Ns	ns	Ns	ns	ns
CV%	13.91	24.67	43.52	65.23	114.72

**, *, ns = significant at 1%, 5% level and not significant, respectively.

Appendix 2. Analysis of variance for decomposition rate constants (kD) and nutrient release rate constants (kN) for all sampling times

Source	kN (wk)					kD (wk)				
	2	4	8	12	16	2	4	8	12	16
REPS	ns§	ns	ns	ns	ns	Ns	Ns	ns	ns	ns
SSP (A)	Ns	ns	ns	ns	ns	*	*	*	ns	ns
N-LEVEL (B)	Ns	ns	ns	ns	ns	Ns	Ns	ns	ns	ns
AB	Ns	ns	ns	ns	ns	Ns	Ns	ns	ns	ns
CV%	24.9	66.8	80.2	98.8	80.16	20.2	34.1	45.8	44.9	68.9

§, * ns = significant and not significant, respectively at 5% level.

Appendix 3. Analysis of variance for mean kD and mean kN per week

SOURCE	Mean kD	Mean kN
REPS	Ns	Ns
SPECIES (A)	**	Ns
N-LEVEL (B)	*	Ns
AB	Ns	Ns
CV%	31.35	42.83

** Significant at 1%

* Significant at 5%

ns Not significant

Appendix 4. Analysis of variance for alley cropped maize parameters.

Source	Yield (kgha-1)	Height (cm)		HI	LAI
		45 DAP	90 DAP		
REPS	Ns	ns	Ns	Ns	ns
SPP (A)	Ns	ns	*	*	ns
N-LEVEL (B)	**	*	*	*	**
AB	Ns	ns	Ns	Ns	ns
CV%	17.55	18.97	5.40	10.49	18.15

* Significant at 5%

** Significant at 1%

ns Not significant at 5%

Appendix 5: Decomposition rate constants (kD) for tropical legumes

SPECIES	LOCATION	MEAN (mm)	ANNUAL (°C)	ID (yr^{-1})	REFERENCE
G. sepium	Ibadan, Nigeria	1250	21-31	8.48	Yamoah *et al.*, 1986
F. congesta	Ibadan, Nigeria	1250	21-31	3.66	"
C. siamea	Ibadan, Nigeria	1250	21-31	2.17	"
L. cyanescems	Ibadan, Nigeria	1250	21-31	8.87	"
I. vera	El Verde, Puerto Rico	4000	22	1.66	LaCaro and Rudd, 1985
Inga spp and *Erythrina* (mixed)	Caracus, Venezuela	1200	20	3.01	Aranguren *et. al.*, 1982a
Erythrina spp mixed with non-legume	"	"	"	3.81	Aranguren *et. al.*, 1982b
I. edulis	Yurimaguas, Peru	2200	26	0.91	Palm, 1988
C. cajan	"	"	"	1.45	"
Erythrina spp	"	"	"	3.72	"
C. calothyrsus	Haren, Netherlands	2580	26.3	1.74	Handayanto *et al.*, 1994
P. pterocarpa	"	"	"	1.53	"
G. sepium	"	"	"	2.16	"
L. leucocephala	"	"	"	1.79	"
L. leucocephala	Chalimbana, Zambia	1000	24-27	15.55	This study
S. siamea	"	"	"	14.71	"
F. macrophylla	"	"	"	6.14	"

Sources: Palm (1988), Handayanto *et al.*, (1994)

Appendix 6. Soil profile description and its classification of the soils at the experimental site.

DATE	30th June, 1992
FAO	Plinthic lixisols
USDA	Fine loamy, isohyperthermic Plinthic Kandiustalf.
AUTHOR	Ronald Msoni
LOCATION	At Chalimbana Agricultural Research Station. 20 km South East of Lusaka Along the Lusaka-Chipata road. Approximately 28°29'56"E and 15°21'32"S
ELEVATION	1280m
LAND FORM	Degraded Central African Plateau
LAND ELEMENT	Interfluve
SLOPE	Upper slope, simple gentle sloping
LAND USE	Agroforestry Research
PARENT MATERIAL	Undifferentiated
SURFACE RUN-OFF	Medium
INTERNAL SOIL DRAINAGE	Medium
SOIL DRAINAGE CLASS	Moderately well drained
SEEPAGE	None
INCIDENCE OF FLOODS	No floods
SOIL EROSION	No appreciable erosion
SHRINK SWELL POTENTIAL	Medium
SALINITY/SODICITY	Free

Source: SADC/ICRAF (1993)

Appendix 7. Seasonal means of maximum and minimum temperature for Chalimbana over a seven year period

Season	MAXIMUM TEMPERATURE ^{0}C	MINIMUM TEMPERATURE ^{0}C
	Mean	Mean
1988/89	27.94	16.53
1989/90	28.97	16.93
1990/91	28.91	16.86
1991/92	29.70	16.96
1992/93	28.69	16.74
1993/94	29.66	16.34
1994/95	30.88	17.75

Source: SADC/ICRAF (1995)

Appendix 8. Rainfall data (mm) for Chalimbana over a period of seven years

Season	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
88/89	2.2	20.0	145.8	385.9	527.6	163.0	5.5	1087.0
89/90	0.0	40.8	123.5	312.9	222.0	24.9	52.0	776.1
90/91	46.1	17.7	244.3	268.1	91.5	62.5	10.2	740.4
91/92	22.9	100.2	82.5	101.2	58.3	137.4	23.1	525.6
92/93	2.8	98.2	269.7	185.7	231.8	66.7	9.9	864.8
93/94	46.6	109.2	135.2	146.4	102.4	1.2	0.0	540.8
94/95	0.0	0.0	213.6	63.8	187.6	55.0	0.0	520.0

Source: SADC/ICRAF (1995)

Appendix 9. Composition (%) of fertilizers used in Zambia

Fertiliser	N	P_2O_5		K_2O		S	B
Mixture A	2	18		15		10	0.1
Mixture B	4	18		15		10	0.1
Mixture C	6	18		12		10	0.1
Mixture D	10	20		10		10	-
Mixture R	20	20		-		10	-
Mixture X	20	10		5	10		-
Urea	46	-	-	-	-		
Sulphate of Ammonia	21	-	-	24		-	
Ammonium nitrate	34	-		-	-	-	
Single supers	-	19		-	12		-
Tripple Supers	-	44		-	-	-	
Potassium Chloride	-	-	60		-	-	
Potassium sulphate	-	-	50		16		
Soluber	-	-	-	-		20	

Source: Wellving, A. H. A., (1984).

maintain the purple colour.

f. Filter under suction.

g. Place crucible in a clean pan and fill half full with demineralising solution.

h. Allow to stand for 15 minutes and then filter under suction.

i. Wash the fibre with demineralising solution until white.

j. Filter and thoroughly wash with 80% ethanol. Filter under suction and repeat twice.

k. Wash twice in a similar manner with acetone.

l. Dry the crucible for two hours at 105 ^{0}C, cool in a desiccator and weigh (W4).

Ash the contents of the crucible at 550 °C, for 1 hour. Allow to cool in a desiccator and weigh (W5).

Calculations.

$$\text{Lignin (\%)} = \frac{(W3 - W4) \times 100}{W1}$$

$$\text{Cellulose (\%)} = \frac{(W4 - W5) \times 100}{W1}$$

Appendix 11. Polyphenol determination. The Folin Denis Method (Anderson and Ingram, 1989)

Standards.

a. Tannic acid, 0.1 $mgml^{-1}$: dissolve 0.050 g tannic acid in 500 ml of water in a volumetric flask, and make up to volume.

b. Using 0, 1, 2 and 4 ml of the tannic acid standard instead of unknown, follow the procedures below from step f.

Procedure.

c. Weigh about 0.75 ± 0.001g (W) of material into a 50 mlbeaker.

d. Add 20 ml 50% methanol, cover with parafilm and place in a water bath at 77 - 80 ^{0}C for one hour.

e. Quantitatively filter (Whatman No 1) the extract into a 50ml volumetric flask using 50% aqueous methanol to rinse, and make up with water. Mix well.

f. Pipette 1 ml of the unknown or standard into a 50ml volumetric flask, add 20 ml water, 2.5 ml Folin Denis reagent and 10 ml of 17% sodium carbonate.

g. Make to the mark with water, mix well and stand for 20 minutes.

h. Read the standard and unknown absorbency at 760 nm.

Calculation.

Plot a graph of absorbency against standard concentration. Determine solution concentrations for each unknown and the blanks. Subtract the mean blank value from the unknowns; this gives a value for corrected concentration, C.

$$\text{Total extractable polyphenols (\%)} = \frac{C \times 5}{W} \times 100$$

Appendix 12. Nitrogen determination. Macro-Kjedahl Method (Pauwelyn and Songolo, 1986)

Procedure

Pretreatment

Place 1 g of plant sample in a 500 ml Kjeldahl flask. Add 10 ml of concentrated sulphuric acid and swirl thoroughly.

Digestion

(a) Add 2 g of the catalyst mixture and place the flask on to the Kjeldahl digestion stand.

(b) Heat cautiously until water is removed and frothing has ceased after about an hour.

(c) Then allow to cool, add about 100 ml of water and allow to cool.

Distillation

(a) Carefully transfer the digest into a 250 ml volumetric flask. Make up to the mark with distilled water.

(b) Add 30 ml Boric acid indicator solution into a 250 ml flask which is then placed under the condenser of the distillation apparatus.

(c) Transfer 20 ml of 10M NaOH into the distillation flask.

(d) Transfer 10 ml of digest into the distillation flask gently and quickly attach the Kjeldahl flask to the distillation apparatus.

(e) The end of the condenser should be just dipping into the Boric acid solution.

(f) Commence distillation. Keep condenser cool (<30 °C) allowing sufficient cold water to flow through and regulate heat to minimise frothing and prevent flow-back.

(g) Distil for 15 minutes and collect the distillate for titration.

Titration

Titrate the distillate with 0.01 M standard HCl until colour changes from green to pink.

Calculations and Result

$\%N = (a - b)\ 0.14 \times 10^{-3} \times 100$

Where, a and b is HCl (ml) used to titrate the sample and the blank, respectively.