EFFECT OF ALLEY CROPPING WITH CALLIANDRA CALOTHYRSUS (MEISSM) ON SEQUENTIALLY GROWN MAIZE AND COWPEAS

BY

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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This thesis has been submitted for examination with our approval as University and IITA supervisors respectively

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DEDICATION

This thesis is dedicated to my dear parents,

Mr. Amos Karinge Kigo, and
Mrs. Lucy Wanjiku Karinge

Glory be to GOD the Father, JESUS the Son and to the HOLY SPIRIT

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To all of you who contributed towards this study, may the most high God touch your lives in a more practical, profound and personal way. And let all the glory and honour be unto Him forever, in Jesus name. Amen.

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ABSTRACT

A series of trials were conducted at the International Institute of Tropical Agriculture, Ibadan, Nigeria, between January and December 1988 to evaluate the potential of calliandra for alley cropping. In a field experiment, the growth, biomass production and nutrient yield of calliandra and the growth and yield performance of sequentially grown maize and cowpea were assessed. Six treatments were used comprising three nitrogen rates (0, 45 and 90 kg N ha^{-1}) factorially combined with and without prunings in a randomized complete block design. Concurrently, a comparison of the decomposition rates and nitrogen release of calliandra and maize stover, and that of green and dry wood of calliandra, leucaena, calliandra, cassia and acioa was made using the same experimental field and design. In a greenhouse study, the N-manuring value and residual effects of dry and green leaves of calliandra and calliandra maize production were also investigated and compared with inorganic N-source in a randomized complete block design. Nitrogen from legume leaves and calcium ammonium nitrate (CAN) was supplied at 0, 50 ppm and 100 ppm N rates and the plant height, dry matter production and N-content in tops determined.

Calliandra recorded an impressive one year's growth of 306.7 cm, a maximum of 35 coppices per tree and a biomass production of 5.0 tons Dm ha^{-1} from four prunings contributing an estimated nutrient yield of 185 kg N, 13.3 kg P, 64.2 kg K, 55.2 kg Ca and 16 kg Mg ha^{-1}. Maize plant height and leaf area index were increased

by pruning and inorganic N application, but not significantly. Levels of N, P and Mg in maize earleaves increased with increasing nitrogen and with pruning application, but only N was significant while K and Ca remained largely unaffected. Without prunings, the application of 45 and 90 kg N ha^{-1} increased total grain yield by 108 and 176% respectively. With pruning application, however, the respective yield increases were only 6 and 12%. Prunings alone double maize yield while the addition of 45 kg N increased yields by 12% and that of 90 kg N depressed yields by 8%. The effect of pruning applicaiton was approximately equivalent to the application of 45 kg N ha^{-1}. Hedgerows significantly reduced per plant grain yield of plants grown adjacent to them, but the latter accumulated more N in grain than the former.

Pruning application, residual N and calliandra hedgerows did not significantly influence cowpea plant height or leaf area index. Plants near hedgerows showed higher nutrient status than those in middle of alleys. Application of prunings significantly affected weed growth and flora in cowpea crop. Prunings slightly increased total seed yields and the proximity of cowpea to hedgerows had a significant positive effect on both number of pods and yield, with a significant interaction with residual N.

Calliandra prunings decomposed four times faster than maize stover and green wood faster than dry wood, rates which were proportional to their respective C:N ratios. The order of decomposition was leucaena > gliricidia > calliandra > cassia >

acioa. The decomposition rates of *cassia* and *acioa* were significantly different from the rest.

Under greenhouse conditions, inorganic N was a better N-source than dry leaves of *calliandra* at same N-rates while *calliandra* was inhibitory at increasing application rate. Incubation of green and dry leaves for periods of 9, 6 and 3 weeks did not improve performance significantly, but green leaves were better than both inorganic N and dry leaves and gave a greater residual effect on subsequent maize crop.

CHAPTER ONE

1.0 INTRODUCTION

Kenya is reported to have the world's fastest growin population, with an annual growth rate of about 4%. The country population is projected to grow from 20 million in 1985 to 3 million by 2000 A.D. (The Beijer/Scandinavian Institute, 198 Europa Year Book, 1987). This rapid population growth, wit concomitant increases in dema.ıd for food, fodder, fuel and othe tree products has greatly constrained the limited land resourc base for sustained agricultural production.

Nearly all the arable land in Kenya, comprising only about 25% of the total land area of 580,367 km^2 is now already unde continuous cultivation, with or without the use of inorgani fertilizers. Serious encroachments have already been made int marginal and gazetted forest lands (Wangati, 1984; Mwangi anc Ruigu, 1984). The lack of fallow periods and heavy grazing in newl settled lands has accelerated degradation of already fragile ecosystems.

The decline of land productivity under continuous cultivatior in the tropics is rapid, even with supplementary fertilizer use (Allan, 1965 Moorman and Greenland, 1980). Yet, the greater part of the needed increases in agricultural production must come from increasing yields per unit area in the existing cultivated land, large areas of which are subject to degradation (Okigbo, 1983 UNEP/ICRISAT, 1986). The challenge to produce adequate food for the country's rapidly growing population is therefore real and urgent.

The conventional practice for maintaining and increasing crop yields under continuous cultivation systems is the use of inorganic chemical fertilizers, of which nitrogen is the most important element. This is shown by its increased use between 1950-1974 when world cereal grain production was doubled (Hardy, 1975). Since it is required in large quantities, nitrogen deficiency is a major cause for declining soil fertility and crop production. Its high production costs and transportation problems makes it barely affordable or available to the subsistence farmer who, according to Andrews and Kassam (1976), must produce most of the needed food increases under conditions of low capital, unfavourable prices, unsophisticated markets and rudimentary infrastructures. In order to reduce risk and create self-sufficiency, the farmer must utilize land between competing uses for crops, trees and livestock production. This presupposes the existence or development of ecologically sound, tree-based multiple-cropping food production systems. This is especially important considering that Kenya spends approximately 36% of the total Gross Domestic Product on fuel imports alone and where fuelwood constitutes the main source of domestic energy for 75% of the population (The Beijer/Scandinavian Institute, 1984).

Future agricultural and rural development strategies must therefore envisage changes in the land use patterns for improved farming and cropping systems which should not only be stable and sustainable but also economically viable and socially acceptable. Such systems should have the ability to maintain or improve the resource base while increasing production and profitability through increased use of renewable farm resources and reduction in the dependence on external inputs. The most developed of such systems to-date are referred to as agroforestry systems.

Alley-cropping is an agroforestry system where crops are grown in spaces between rows of planted woody shrubs. The woody spp. are periodically pruned during the cropping season to prevent shading; to provide green manure and mulch for associated crops; to minimize intercrop competition for moisture, light and nutrients and to provide fodder, fuelwood or staking material (Getahun, 1980; Kang et al; 1981; IITA, 1982). Alley-cropping with leguminous species has been shown to provide an alternative nitrogen source which seems to offer great potential to help farmers reduce their dependence on commercial fertilizers by partially or wholly substituting their inorganic nitrogen requirements.

Among the woody spp. that have been used for alley- cropping, some with considerable success, are leucaena (Leucaena leucocephala), gliricidia (Gliricidia sepium) and calliandra (Calliandra calothyrsus). Leucaena and gliricidia are the most extensively studied while calliandra is the least studied among them. Specific investigations into the potential of calliandra for alley-cropping are virtually lacking globally or they have not been reported, leaving wide gaps in knowledge regarding its growth, yield characteristics and nutrient cycling potential. In particular, there is a great need to identify and evaluate alternative tree spp. adaptable to a wide range of soils, environments and elevations for diversified alley-cropping situations. Calliandra has indicated some good potential in these respects (NAS, 1980; IITA, 1986, 1987; EDI, 1987). More study into its potential contribution towards improvement of current farming systems in the tropics is required.

This study examines the potential of calliandra in enhancing or conserving soil fertility and sustaining or increasing crop production under an alley cropping system with sequentially-cropped maize and cowpeas. In particular, the study dwells on the ability of the plant to produce biomass and contribute nitrogen and other nutrients to the associated crops, as well as the ability of the latter to make use of these nutrients.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Calliandra calothyrsus

Calliandra is a member of the Acacia family mimosaceae, sub-family leguminosae. It is a genus of approximately 140 species, most of which occur in the tropical and sub-tropical regions of America, Madagascar and India (Renvoize, 1981). They are short trees or tall shrubs bearing white, pink or red flowers, pinnate paired leaflets, dehiscent fruit pods and usually grow to a height of 4-6m with a stem diameter of up to 20cm (NAS, 1983).

There are two common species of calliandra i.e. red calliandra (Calliandra calothyrsus Meissm) and white calliandra (Calliandra tetragona B. et H.). There is a third spp., red-white calliandra (Calliandra surinamensis), commonly used as an ornamental plant. Calliandra calothyrsus Meissm is the best known and most important spp. in this genus. It grows taller, has bigger trunk, a more dense crown and is more resistant to disease, pests and drought than white calliandra. It also has deeper root system with more branches and more nodules. A native of Guatemala in South America, it has now been widely spread throughout the dry and wet tropics, notably in Indonesia where it was introduced in 1936, and more recently in Kenya in the 1980's (NAS, 1983; EDI, 1987). The reported uses of calliandra include, fodder, green manure windbreaks, firebreaks, honey-production, ornamental, fire, wood pulp and for tool handles (Carlowitz, 1986).

Calliandra grows successfully in a range of environments with widely differing soils, elevations, precipitation and shading levels. It survives on infertile, acid and compacted soils, where it is used as a species to fertilize the land (Soejono, 1981). In Indonesia, it is grown on Andisols, Vertisols, Latosols and Regosols, with a preference for light-textured, slightly acid clay soils (NAS, 1980; 1983). The altitudinal range is 0-2000m above sea level, with annual precipitation between 700-4000mm. The best performance is recorded at medium altitudes and with total annual rainfall in excess of 1000mm. In Kenya, it has been reported that calliandra growth and performance under alley-cropping at high altitude is better than leucaena (EDI, 1987). Other reports indicate that it may even be superior to other well known hedgerow species with respect to tolerances to stresses, cool temperature, and extremes of soil pH, aluminium and manganese toxicities (Douglas, 1972; NAS, 1975; 1979). Calliandra can tolerate 3-6 months drought and no disease attack has yet been observed. However, it is susceptible to frost and waterlogging conditions.

Calliandra is best established by seedling, but can also be propagated by direct seeding and stem cuttings. Seedlings can grow to 3m in a year, while regrowth reach up to 4m in a year (EDI, 1987). Fruit is produced within one year, but seed production is low in Kenya, as is reflected in the 1986 local market price equivalent to US $13.0 per kg dry seed. This puts a major drawback to widespread production and expansion of calliandra planting. Seeds have no dormant period and can be planted immediately without pretreatment. Baggio and Heuveldop (1982) achieved 50-70% germination with untreated seeds over a period of 10-24 days respectively. The seedlings develop both numerous, heavily nodulated superficial roots and, deep growing roots which can be used to control erosion and runoff. Leaf decomposition is rapid and the shady crown creates a favourable microclimate (Satjapradja and Taulana, 1981).

Calliandra has been listed among the eight nitrogen-fixing tree spp. suitable as source of green manure (Brewbaker, et al. 1982) and for soil improvement. Soil improvement may be achieved through the combined effect of litter fall, green manure, erosion control and weed suppression. Calliandra plays this role effectively due to its fast growth, high biomass production, high nodulation capacity and its deep and well-developed root system. Annual biomass production of 200-250m^3 ha^{-1} was reported by Satjapradja et al. (1981), and a firewood harvest of 35-65 m^3 ha^{-1} $year^{-1}$ (NAS, 1979). Kidd and Taogaga, (1984) and EDI, (1987) have reported fresh and dry fodder production of 46.2 tons ha^{-1} $year^{-1}$ and 7-10 tons ha^{-1} $year^{-1}$ respectively. Close spacing is recommended for maximum biomass production. Data from Catchpole et al., (1986) and Baggio and Heuveldop, (1982) indicate, that increasing inter-row spacing increased yield per tree but decreased the yield per unit area and that closer inter-row spacing significantly increased biomass production. As a hedgerow species for biomass production, calliandra has been used successfully to replace leucaena and gliricidia in the Philippines in areas where they performed poorly (Keny, 1985). In Indonesia, it has been used to regenerate the fertility of degraded soils and for erosion control on slopy areas and for control of gullies (Soerjono and Suhaendi;

1981). In addition, farmers routinely enrich worn out agricultural land through a highly efficient rotation system of 4 years calliandra followed by 4 years sugarcane and 2 years maize.

Except perhaps in Indonesia, the potential of calliandra in agroforestry remains largely uninvestigated and unexploited. There is little or no information on its growth under different soil and climatic conditions, performance under alley-cropping systems or in comparative trials with other spp.

2.2 Soil fertility and maintenance

Shifting cultivation and related bush fallow systems are the predominant food production systems in the tropical world. These systems are based on land rotation whereby a few years of cultivation is alternated with several years of natural or planted fallow during which time exhausted soil fertility is restored (Nye and Greenland, 1960). God, in his great wisdom and concern for environmental degradation, has from ancient days recommended fallowing as a sound agricultural practice. According to the Bible, the land also needs a sabbath rest every seventh year for soil fertility regeneration (Leviticus 25: 1-7). In addition to improving soil fertility and conserving soil and water resources, different tree species used in fallow have various multiple uses including food, fodder, firewood and others, all of which have great economic, social and cultural values in a subsistence economy (Okigbo and Lal, 1979). Wilson and Kang (1981) have stated, that no method of food production more superior than the natural fallow system has been developed for the tropics to date.

However, shifting cultivation systems are presently being destabilized by rapid population growth and the associated pressures on land as observed in some regions. This has for example, resulted in reduced fallow periods in Eastern Nigeria (Nye, 1966;) and drastic transformation of the traditional farming and cropping systems in Kenya (Auckland, 1971; Winston and Lipscomb, 1972; Wangati, 1984). In the absence of appropriate conservation and restoration techniques, extension of cultivation periods and increased grazing intensity on marginal lands results in frequent crop failure, soil erosion and land degradation (FAO, 1974).

Even with use of inputs, decline in soil productivity has been reported with continuous cultivation (Allan, 1965; Moorman and Greenland, 1980; FAO, 1985). An additional problem is that much of arable food production in tropical Africa is practiced on highly weathered and low activity clay (LAC) soils whose inherent low fertility present serious production constraints (Kang and Juo, 1981; 1983; Pendleton and Kang, 1986). Under these circumstances, it may be necessary to fallow or put the land to some other uses depending on soil and climatic conditions. However, Ahn (1979) indicates that continuous farming with sustained production is indeed possible in all soils of the tropics, provided that the physical soil conditions are maintained at an optimum level and nutrient balance provided by adequate fertilization.

Alternative ways of ensuring good soil fertility under continuous cropping include use of organic matter, green manures mulches and grass/legume mixtures (NAS, 1979; Padwick, 1983;

Akobundu and Okigbo, 1984). Ahn (1979) has observed that the decline in soil organic matter levels during cropping could contribute substantially to soil depletion and exhaustion as a result of reduced rate of addition of new humus and consequent decrease in mineralization rate. These processes are reversed when organic materials such as animal manure, compost, mulches and green manures are added to the soil. The increased humus content improves the soil cation exchange capacity, and the subsequent mineralization releases major and minor soil nutrients. Addition of organic materials also improve soil structure, waterholding capacity and moisture infiltration rate (Crowder, 1970-71; Agboola, 1975; Lal et al, 1979). Mulching has been reported to reduce soil temperature and erosion, soil moisture evaporation and weeds growth (Akobundu, 1980; Akobundu and Okigbo, 1984). The use of herbaceous legumes as green manures for soil fertility in Africa has been limited despite their success, mainly because of incompatibility with tropical climates and low green matter production (Milsum and Bunting, 1928; Vine 1953). But some woody shrubs and legumes have been successfully used as cover crops, shade trees, browse or as green manures and mulch. gliricidia and Cordia abbysinica have been used as shade trees in cocoa and coffee. Crotolaria spp., Sesbania spp. and Tephrosia spp. have been used as green manures while Anthonata macrophylla and gliricidia have been used as natural and planted fallows respectively (Okigbo, 1975). To overcome the management problems of upland LAC soils and to incorporate the fallow component in current cropping systems, the use of woody spp. in agroforestry systems such as alley cropping has been developed (Kang and Juo, 1983).

This has resulted from an increased awareness of the role of trees in the ecologies of the tropics within the past two decades (Getahun et al., 1982; Huxley, 1983) and many agroforestry concepts aimed at increasing food production while retaining trees in a stable ecosystem have been developed (Mongi and Huxley, 1979). Trees and shrubs have long been used as multiple components in most tropical agriculture systems. They are a dominant feature of the major farming systems in the humid and subhumid tropics (IITA, 1978; Getahun, 1979). Examples of intensive tree-based production systems in the tropics are the multi-storey homegardens of Indonesia (Michon et al., 1986), and compound farms of south-eastern Nigeria (Okafor and Fernades, 1986) which can provide the farmer with a combination of food and cash crops, that can offer a degree of self-sufficiency (Watson, 1982). In addition, because of their deep root systems, trees and shrubs are more effective in taking up and recycling plant nutrients from greater depths than herbaceous fallows or grass fallows (Nye and Greenland, 1960; Jaiyebo and Moore, 1964).

Agroforestry is a collective term that denotes land use practices which integrate crop, livestock and tree production systems. It has been considered as a sustainable land management system which increases the overall yield of the land combining the production of crops and forest plants and/or animals, simultaneously or sequentially, on the same unit of land, using traditional management practices (Bene et al., 1977; King and

Chandler, 1978;). Depending on the system components that are combined, Nair (1985) has broadly categorized agroforestry systems as either agri-silviculture (Crops and trees), silvo-pastoral (trees and animals) or agri-silvo-pastoral (crops, trees and animals). A comprehensive review of agroforestry systems is given by Combe and Budowski (1979). They classify them according to distribution in time and space, the role of the components and by the production aims and outputs.

Since most agroforestry systems in the tropics are found on smallholder farms where the major concern is to increase productivity and other economic returns, (Chandler and Spurgeon, 1980) the management intensities are generally low and the potential of the systems have not been fully exploited. The situation is compounded by the fact that agroforestry is an emerging discipline and research in the field is still in its infancy. Among the most studied, most developed and most promising agroforestry system is one called alley cropping.

2.3 Alley-cropping

The potential of selected tree species in land and soil management for increased or sustained food production is being exploited through an improved bush fallow system called alley-cropping. Alley-cropping is the growing of food crops in alleys formed by hedgerows of trees or shrubs that are periodically pruned during the crop growing season to minimize the adverse effects of shading and to reduce competition with food crops (Kang et al., 1981b; IITA, 1982). It embodies the agroforestry concept of intercropping trees and crops (agri-silviculture). The concept of alley-farming has been introduced (Sumberg and Okali, 1983) where trees are managed to provide both high-protein livestock fodder and nitrogen-rich green manure or mulch (agrisilvo-pastoral system). The prunings from hedgerows are put back into the soil either as surface mulch or incorporated as green manure. They provide nitrogen and other nutrients to the companion crop and conserve the soil. Shading by trees and mulch suppresses weeds. The woody biomass may be used as fuelwood, construction materials or stakes for climbing plants. The main advantage of alley-cropping is, that it permits the combination of both cropping and fallow phases, thereby allowing a longer cropping period and increased land use intensity. According to Kang et al. (1989), the bush fallow systems, from which the concept was developed, are extravagant in resource use since the land is kept unproductive for an extended period of time.

Extensive studies on species like leucaena and gliricidia have recognized their superiority in biomass production; plant nutrient regeneration and efficiency in soil fertility restoration Guevarra, 1976; IITA, 1982-84; (Kang et al., 1981a; 1981b; 1984; 1985; Rachie, 1983; IITA 1985-86; NAS, 1979). Similarly, the potential of alley cropping for food production in the tropics has been widely investigated (Kang et al. 1984; 1985; Kang and Duguma, 1985; Ngambeki, 1985; Wilson et al. 1986; Kang, 1987). Most of these studies have reported sustained or improved yields and better soil chemical and physical conditions than other systems under comparison.

The ability of a particular tree species to recycle nutrients and to exert positive effects on associated annual crop will largely depend on its biomass production capacity. It will also depend on the root volume, root activity, nutrient concentration and age of plant (Huxley, 1986). Biomass production is in turn influenced by plant characteristics, plant population, environmental conditions and the management regimes (Benge, 1983; Pathak and Patel, 1983; Sanginga, 1988). Biomass production and nutrient yield have been shown to be greater under lower pruning frequencies, higher cutting heights and closer spacing (Krishnamurthy and Munegowda, 1982; Koudoro, 1982; Duguma et al., 1985), but conflicting and widely differing figures have been reported even within single spp. For example, on a sandy entisol in southern Nigeria, Kang et al. (1984) have shown that leucaena variety K-28 can produce 5-6.6 tons dry matter ha^{-1} $year^{-1}$ to yield 160 kg N, 15 Kg P, 150 kg K, 40 kg Ca and 15 kg Mg. Guevarra et al. (1978) reported N-fixation for the same species as high as 500-600 kg N ha^{-1} $year^{-1}$ in Hawaii, while Rachie (1983) reported a yield of 172 kg N ha^{-1} $year^{-1}$ in Cali, Columbia. Large differences in nutrient percentage and their composition in various plant parts have also been noted between and within same species as shown by recent data from Kang et al. (1989). The data indicate, that nutrient concentrations are higher in leguminous than non-leguminous species and that their compositions are higher in younger plant tissues irrespective of tree spp.

Published work on calliandra indicate, that it can produce substantial biomass and nitrogen yield. Baggio and Heuveldop,

(1982) reported biomass yields of between 2.6 and 4.4 tons DM ha^{-1} $year^{-1}$ at intrarow spacings of 2 meters and 25 cm respectively for 10-month old hedgerow plants. IITA (1987/88) reported biomass yields of upto 6 tons DM ha^{-1} $year^{-1}$ with nitrogen yield of 189 kg N ha^{-1} $year^{-1}$ in an alley-cropping system with hedgerows spaced 4 x 1 metres with 4 successive prunings of 5-year old plants. The nutrient yield in the prunings was estimated at 169 kg N, 8 kg P, 83 kg K, 423 kg Ca and 26 kg Mg ha^{-1} $year^{-1}$. The amount of nutrients that could have been removed by harvested if the wood biomass was not returned to the soil would be 69 kg N, 4 kg P, 97.7 kg K, 26.9 kg Ca and 11.7 kg Mg. These facts emphasise the need to return both prunings and woody stems of calliandra to the soil for maintenance of the soil fertility and crop yield improvement. This view is supported by work done in Rwanda where calliandra gave comparable yield performance and nitrogen contribution, but significantly higher woody stem production than either leucaena or cassia (IITA, 1986).

In alley-cropping, the management of the N contributed through pruning application is considered a crucial factor for its optimization and efficient utilization by associated crops. This is in view of the fact that, nitrogen is the most expensive, most easily exhausted nutrient in the soil and the major element limiting crop production in many tropical countries. High cost is coupled with lack of availability and low utilization efficiency in many tropical developing countries (Greenland 1975; Subbiah and Sachdev, 1982). In addition, the low-activity alfisols and related soils which are widely distributed in the tropics are prone to soil acidification and rapid decline in the productivity with continuous use of higher rates of N-fertilizers (Bache and Heathcote, 1969; Allan, 1965; Nnadi and Arora, 1985). In contrast, continuous and long term addition of N in form of prunings has less effect on soil acidity (Kang and Duguma, 1985) and soil productivity can be maintained at a more sustained level. Okigbo (1975) Wilson and Kang (1981) Kang and Duguma (1985) and Sanginga (1988) have all pointed to the need for an effective management of biological nitrogen fixation as a viable N-source for resource-poor farmers. When the optimal plant population and pruning regime have been obtained, it is important to consider the relative efficiencies of the prunings when incorporated into the soil as either green manures or retained on the surface as mulch. The implications of applying fresh versus dried leaves may also be important.

The application of leucaena as green manure for maize and rice production has been reported to approximate the application of 90-40-40 and 80-30-3 kg NPK, respectively (Prusner, 1983). Further, Kang (1987), estimated the nitrogen contribution from leucaena and gliricidia to intercropped maize at about 40 kg N ha^{-1}. Kang et al. (1981a) also reported that both leucaena and gliricidia prunings were a more effective N-source for maize when incorporated as green manure than when applied as mulch. They obtained yield increases from 1.3-3.2 tons/ha^{-1} with application of 10 tons leucaena prunings, equivalent to about 100 kg N ha^{-1}.

The potential nutrient contribution from trees and shrub species is determined by their nutrient composition and rate of decomposition and nutrient release (Yamoah et al., 1986a).

Decomposition of organic matter by micro-organisms liberates NH_4+ and $N0_3-$ nitrogen which increases the total available N in the soil for plant uptake (Weeraratna, 1979). In addition, other plant nutrients like K, Ca and Mg are released and the soil is enriched. Plant materials with a narrow C:N ratio generally decompose faster than those with high C:N ratio and, as reported by Van Schreven (1968), fresh plant materials releases N more readily than dried materials. For example, Kang and Duguma (1985) have shown that prunings of leguminous trees or shrubs (Low C:N ratio) decompose faster than maize stover (high C:N ratio). Read et al. (1985) also observed that fresh leucaena leaves decomposed faster than dried leaves and buried materials more than surface-applied leaves. In pot experiment, N-uptake of maize plants was higher from fresh than dry leucaena leaves whether they were incorporated or surface applied.

The decomposition levels of gliricidia, cassia and flemingia (Flemingia congesta) prunings after 120 days have been reported at 100%, 85% and 73% respectively (Yamoah et al., 1986a). The N-release levels were respectively 71%, 77% and 26% of the total N required for maize. Their results suggest, that the release of large amounts of nitrogen by prunings contribute significantly to N nutrition of maize crop. However, the efficiency of utilization of N released from prunings is reportedly low, 33% for leucaena (Guevarra, 1976). It is therefore likely that most of the N released is not fully utilized by the crops and supplementation with inorganic N will still be needed to optimize yields under alley cropping situations as reported by several authors (Kang et al., 1981b and Yamoah et al., 1986b).

Results obtained thus far from the humid and subhumid tropics indicate, that alley-cropping is a very promising, low-input technology for sustained and improved crop production (Kang et al., 1981a; 1981b; 1984; 1985; 1986; IITA, 1981-1984; Wilson et al. 1986; Yamoah et al., 1986b; Ngambeki, 1985; Reynolds and Atta-krah, 1986; Duguma et al., 1988).

Higher maize and cassava yields have consistently been obtained under alley-cropping than in controls of sole crops, but cowpea has not shown any significant increase or reduction (Kang et al., 1984; Kang and Duguma, 1985; Ngambeki, 1985). Cropping maize and cowpeas sequentially with leucaena or gliricidia has been shown to be an appropriate alley cropping system on alfisols and entisols in southern western Nigeria. According to Kang et al. (1984), the prunings from these hedgerows are able to meet the N requirement of the maize crop and the subsequent cowpea crop does not require any fertilizer application. Grain yields of maize have been maintained at 3.8 tons ha^{-1} for 2-3 years and at 2.0 tons ha^{-1} for 6 years with addition of leucaena prunings only.

Preliminary results from work on calliandra at IITA, Ibadan, Nigeria have shown that calliandra prunings increased maize yields and that addition of fertilizer on plots where prunings were applied did not significantly affect yields (IITA, 1986, 1987/88). In addition the yield of the second season cowpea crop was not affected by either prunings or fertilizer application. The removal of prunings was observed to depress maize grain yields while a 45% yield increase was recorded when prunings were retained. The application of 45 and 90 kg N ha^{-1} alone increased maize yields by 41 and 51% respectively. Retention of prunings produced slight negative residual effects in cowpeas and plants near hedgerows were observed to yield less than those further away.

Other studies have reported on the effect of alley cropping on other crop yield characteristics such as dry matter production and nitrogen uptake (Read et al. 1982; Koudoro, 1982; Yamoah et al. 1986b). Koudoro (1982) noted that maize yields and maize ear-leaf nutrient composition were significantly improved by alley cropping with leucaena and gliricidia with or without fertilizer application. The levels of N, P and K in maize earleaf were higher where prunings and fertilizer was applied, though Zn, Mg and Ca were unaffected. Read et al. (1985) reported that application of leucaena prunings significantly increased the maize ear-leaf N-status (17%) and grain yield (15%) over treatments receiving no N.

Yamoah et al. (1986b) indicated, that the overall performance of maize alley-cropped with gliricidia, cassia and flemingia was better than in control plot. However, growth performance of maize plants close to the hedgerows was depressed. The growth depression was attributed to shading and possible competition for water and nutrients. However, in plots without N application and prunings removed, maize plants grown adjacent to the hedgerows performed better than those in the middle of the alleys; as was also noted by Kang et al. (1981b). This was attributed to N contributed from leaf litter in areas adjacent to hedgerows.

Studies on the effect of alley cropping on soil properties indicate, that addition of hedgerow prunings improve the soil chemical, physical and biological properties (Kang et al. 1985; Yamoah et al. 1986c). Yamoah et al. (1986c) observed significant improvement in the nutrient status (N, P, K) and organic carbon, bulk density, water-holding capacity and aggregate diameter by cassia, flemingia and gliricidia. Long-term alley cropping studies on a sandy apomu soil by Kang et al. (1985) indicated higher organic matter, higher N, K, Ca and Mg. Increased humus carbon, as reported in alley-cropping studies, is associated with improvement in soil structure which lowers bulk density and improves aeration, rainfall acceptance, permeability and waterholding capacity (Agboola, 1975; Lal et al., 1979). In some situations, it has been observed that soil physical changes resulting from an increase in humus levels may even be more important than chemical changes in increasing or sustaining productivity (Ahn, 1979; Yamoah et al., 1986c). Supporting this view, Richards (1985) quoted Ahn (1970) and Lal and Greenland (1979) who argued that soil physical properties in the tropics are more crucial to sustained production than nutrient supply. This position is attested to by the fact that nutrient restoration for an exhausted soil is far much easily achieved than the reconstruction of the soils' physical condition.

Evidence from the literature review suggests that calliandra is a promising tree spp. for soil fertility improvement and improved crop production, but its potential for alley-cropping remains largely uninvestigated and unexploited. Its potential for biomass production, nutrient cycling and use as green manure or mulch for crop production needs better quantification. Comparative studies on growth and decomposition are also lacking and information on nutrient uptake and utilization efficiencies by associated crops is scanty.

A series of experiments were therefore designed to investigate the potential roles of calliandra for improved crop production under current farming systems. The first experiment was an evaluation of growth and yield performances of the tree and crop components in an alley-cropping system with the following objectives:

1. To determine the growth, biomass production and nutrient cycling potential of calliandra.

2. To determine the effect of calliandra prunings and inorganic nitrogen fertilizer on growth and yield performance of sequentially-cropped maize and cowpeas.

3. To determine the effect of calliandra prunings and inorganic nitrogen fertilizer on soil chemical properties.

The second experiment was a field decomposition study whose objectives were:

1. To determine the rate at which calliandra prunings decompose to release nutrients to companion crops.

2. To compare the decomposition rates of calliandra wood and other woody shrubs currently being used for alley cropping.

The third and fourth experiments were greenhouse trials. The objective of the third experiment was to determine and compare the effect of calliandra and gliricidia leaves on dry matter production and N-uptake of maize and to evaluate their possible allelopathic effects on maize growth. The objectives of the fourth experiment were:

1. To determine and compare the effects of dry and fresh leaves of calliandra and gliricidia on dry matter production and N-uptake of maize.

2. To determine the effect of decomposition time on dry matter production and N-uptake of maize and to evaluate any residual effects of dry and fresh leaves on subsequent crop.

CHAPTER THREE

3.0 MATERIALS AND METHODS

Studies to investigate the potential of calliandra for alley cropping were conducted at the International Institute of Tropical Agriculture (IITA), Ibadan, in South-western Nigeria from February to December, 1988. The Institute is located on latitude 7°30'N and longitude 3°54'E at an elevation of about 250m above sea level. The mean annual rainfall is 1250mm and is bimodal in distribution. The first rainy season starts from March to July while the second season lasts from September to November. The weather data during the experimental period are presented in the Appendix Table 1. The soils at the experimental site are classified as Oxic paleustalf (USDA) or Ferric Luvisol (FAO). Four experiments, comprising two field trials and two pot trials were conducted.

Experiment 1. Alley-cropping calliandra with maize and cowpeas

The potential of calliandra for alley-cropping was investigated by superimposing maize and cowpeas grown in sequential cropping system on a calliandra plantation established at a 4 x 1m spacing (2500 trees ha^{-1}) in 1983. There were five calliandra hedgerows and three alleys. Only the two outer alleys were used for the experiment. Preliminary investigations had been carried out in the previous two years. The hedgerows were last pruned in October 1987 and the present study initiated in April, 1988. Six treatments were tested consisting of factorial combinations of three nitrogen (N) rates and two rates of calliandra prunings (PR) arranged in a randomized complete block design using three replications. The experimental field measured 12 x 65m (810m^2) and the size of each plot was 4 x 7.5m (30m^2). The treatments for the experiment were:

1. No nitrogen, without prunings (ON-PR), control
2. No nitrogen, with prunings (ON + PR)
3. 45 kg N ha^{-1}, without prunings (45N - PR)
4. 45 kg N ha^{-1}, with prunings (45N + PR)
5. 90 kg N ha^{-1}, without prunings (90N - PR)
6. 90 kg N ha^{-1}, with prunings (90N + PR)

Initial land preparation was done by spraying paraquat (1.5 Kg active chemical ha^{-1}) for weed control and cutting back the dry season coppice growth of calliandra hedgerows. Prunings were retained in the plots or removed according to treatment specifications. Four rows of maize (CV.TZPB Suakoko) were planted in each 4m alley at a spacing of 0.80 x 0.25m (40,000 plants ha^{-1}) in mid April. Nitrogen fertilizer was applied as Calcium ammonium nitrate (CAN) in two split doses, $^{1}/3$N broadcast at planting and $^{2}/3$N banded at 4 weeks after planting (WAP). No potassium or phosphorous fertilizer was applied. The crop was handweeded twice at 4 and 6 WAP. Harvesting was done 118 days after planting (DAP).

Cowpeas was planted in the second season in mid August. Land preparation was done as before and the pruning treatment repeated. Maize stover was retained in all plots, but no fertilizer was applied to the cowpea crop. Seven rows of cowpea (CV. IT945-2264-4), a brown-seeded short maturing variety (65 days) was planted at a spacing of 0.5 x 0.25m (70,000 plants ha^{-1}). The crop was weeded once with hoe at 2 WAP and sprayed 4 times with Dimethoate-cypermethrin, mainly for control of thrips.

For both maize and cowpeas, grain yield was determined on a 4 x 4m harvest area and a separation by proximity of rows to calliandra hedgerows made to check for any variability. Data was collected on plant height, leaf area, dry matter production, nutrient uptake, weed growth, grain and stover yield for maize and cowpeas and the plant height, biomass production and nutrient contribution of the calliandra hedgerows. Soil chemical properties of the 0-5 and 5-15cm surface layers were also determined at the beginning and end of the cropping period.

Plant heights of the agricultural crops were measured at 4, 6 and 8 WAP for maize and at 2, 4 and 6 WAP for cowpeas. Ten plants from each plot were randomly measured using five each from rows adjacent and five from rows furthest from the hedgerows. Plant heights of the calliandra trees were taken on five randomly selected plants in each plot before each pruning and at 2, 4 and 8 weeks after first pruning.

Leaf samples were taken on three randomly selected plants from each plot at 4 and 8 WAP for maize and at 2, 4 and 6 WAP for cowpeas. All leaves from each plant were removed and passed through an automatic leaf area meter. The leaf area index was calculated by dividing the leaf area meter reading by the land area occupied by the plant.

Plant dry matter production for maize was assessed by sampling five whole plants from each plot at 6 WAP. The plants were weighed and oven-dried till constant weight was achieved. Nutrient uptake was determined after sub-samples were ground in a 2mm Wiley mill and analysed for N, P, K, Ca and Mg concentrations. In addition, ten maize-earleaf samples were similarly taken from each plot, ground and analysed for the same nutrients to determine the plant nutrient status. Dry matter production for cowpeas was evaluated by taking whole plant samples of three plants from each plot at 2, 4, and 6 WAP and determining the dry weights. The nitrogen content in plant samples was used to assess nutrient status at each growth stage.

Weed flora type and growth was determined on a $1m^2$ area in each plot during the second cropping season. Four random quadrat areas each measuring 25 x 25cm were clean weeded and the dominant weed spp. identified. The fresh and dry weights were determined and used to estimate the weediness levels caused by the various treatments.

Grain yield determination was made on a 4 x 4m harvest area and expressed at 14% moisture content. A separation was made according to proximity of maize or cowpeas rows to the hedgerows. The grain was manually separated from stover and pods, sun-dried, weighed and subsamples ground for nitrogen analysis. For cowpeas, the number of pods per plant was also determined.

To determine the grain:stover ratio for maize, ten physiologically matured plants were selected from each plot, five each from rows adjacent and five from middle rows. The stover and maize cob were separated, sun-dried to constant weights, and the dry weight of shelled grain and the stover used to determine the grain:stover ratio. Subsamples of grain and stover were taken for analysis of nitrogen to determine the partitioning of nitrogen uptake by grain and stover.

Biomass production by calliandra hedgerows was determined at each of the four pruning times during the cropping cycle. The number of coppices per plant was determined by counting on five random plants from each plot. The fresh and dry weight of prunings were taken and subsamples were ground and analysed for N, P, K, Ca and Mg contents. Additional samples of old and young calliandra wood were also analysed for the same nutrients. The nutrient concentrations of these materials and the dry matter production were used to estimate the nutrient yield from calliandra prunings.

Soil sampling and analysis was done at the beginning and end of the cropping cycle. Composite soil samples taken from 15 core samples in each plot were air-dried, ground, sieved and analysed for pH, organic carbon, total nitrogen, available phosphorous and for exchangeable bases (calcium, magnesium, sodium and potassium).

All plant and soil analysis were done using procedures described in Juo (1979) as follows: Soil pH was determined in a 1:1 soil to water ratio. Organic carbon was determined by Walkley and Black dichromate method. Total nitrogen was determined by micro-kjedhal method where N-content in the digest is measured by distillation and titration. Available phosphorous was determined using Bray-1 extractant and exchangeable bases extracted by 1N AM Acetate. Na and K were measured by flame photometer and Ca, Mg and Mn by atomic absorption spectrophotometer.

Experiment 2: Decomposition studies of calliandra prunings, maize stover and green and dry wood of calliandra, leucaena, gliricidia, cassia (Cassia siamea) and acioa (Acioa barterii).

The decomposition rate of fresh calliandra prunings and maize stover and that of green and dry wood of various alley-cropping shrubs were compared in two separate trials. In the first trial, fresh calliandra prunings and dried maize stover were studied using a randomized complete block design with three replications. The moisture content of the prunings was evaluated by oven-drying to constant weight and the C:N ratio for both materials determined by ashing in an electric furnace at 500°C for carbon, and by standard procedures for nitrogen as outlined in experiment 1 above. Eighteen samples each of chopped dried maize stover and calliandra prunings and weighing 300g were put in 1.0mm mesh-size nylon decomposition bags and randomly distributed in the field. Six samples were used for each replicate and treatment. Samples were collected after 7, 14, 21, 35, 49 and 63 days for dry weight and nitrogen content determination. The dry matter loss and nitrogen concentration were used to estimate the decomposition rate and nitrogen release over time.

In the second trial, the decomposition rate of green and dried wood of calliandra was compared to that of four other leguminous and one non-leguminous shrub species using ten treatments replicated three times in a randomized complete block design. The treatments were as follows:

1. *Calliandra* green sticks
2. *Calliandra* dry sticks
3. *Leucaena* green sticks
4. *Leucaena* dry sticks
5. *Gliricidia* green sticks
6. *Gliricidia* dry sticks
7. *Cassia* green sticks
8. *Cassia* dry sticks
9. *Acioa* green sticks
10. *Acioa* dry sticks

For each treatment, 1 kg of young wood measuring 25cm long but less than 2mm in diameter were used. The moisture content of the green wood was determined by drying to constant weight. The dry wood was previously kept in the green house until sufficiently dry. The C:N ratio and nutrient concentrations of each wood spp. was also determined. The wood was loosely tied, distributed randomly in the field and left to decompose for 4 months. Dry weight was determined monthly and the decomposition rates evaluated on the basis of weight loss over time.

Experiment 3. Effect of nitrogen rates and dried leaves of *calliandra* and *gliricidia* on dry matter production and nitrogen uptake of maize

A comparative study on the N-manuring value of *calliandra* and *gliricidia* dried leaves for maize was conducted in the greenhouse using a randomized complete block design and replicated five times. The trial was carried out using pots filled with 3 kg air-dried Apomu surface soil (Psammentic urtorthent). Some physical and chemical properties of the soil are shown in the appendix Table 2. Nitrogen as calcium ammonium nitrate (CAN), calliandra and gliricidia dry leaves were applied at two rates of 50 ppm N and 100 ppm N. The following seven treatments were compared.

1. Control (No nitrogen)
2. 50 pm N, CAN
3. 100 ppm N, CAN
4. 50 ppm N, calliandra dry leaves
5. 100 ppm N, calliandra dry leaves
6. 50 ppm N, gliricidia dry leaves
7. 100 ppm N, gliricidia dry leaves.

All treatments received a basal application of 50 ppm P and 62 ppm, K (as KH_2P0_4), 20 ppm Mg (as $Mg\ S0_4.7H_20$) and 5 ppm Zn (as $ZnS0_4.7H_20$) to ensure that these nutrients were adequate. Ten maize seeds (Hybrid var. 8321-21) were planted in each pot and thinned to six plants at one week after germination. Height measurements were taken weekly for 3 weeks when the top crop biomass was harvested. The plants were oven-dried at 65^{o}C to determine dry weight, then ground in a Wiley Mill and subsamples taken for nitrogen analysis. Nitrogen content was calculated as the product of dry matter production per pot and the percentage nitrogen concentration.

A quick laboratory test was then run to evaluate the possible allelopathic potential of dried calliandra and gliricidia leaves using a randomized block design with four replications. Initially, 1% acqueous extracts of each species was prepared by dissolving 1g of dried material in 100 ml distilled water, shaking for 2 hours and extracting by suction-filtration. The effects of these extracts on germination, radicle and plumule growth of maize seed was then determined using distilled water as control, through germination percentage and the length of radicle and plumule over a 3-day period. Subsequently, varying concentrations of calliandra extracts (1,5 and 10%) were tested using same procedure with additional data taken on number and length of secondary roots.

Experiment 4: Effect of incubation period of fresh and dried leaves of calliandra and gliricidia on dry matter production and nitrogen uptake of maize.

This trial was set up to compare nitrogen release of dried and fresh calliandra and gliricidia leaves over time and their effect on dry matter production and nitrogen uptake of maize. Three kilograms of Apomu surface soil was used in each pot as in the previous trial using a split-plot experimental design. Fresh leaves of calliandra and gliricidia at the two N-rates were added, making a total of 11 treatments as sub-plots while maintaining the basal applications of other nutrients. Three series were prepared, incubated for 3 time-periods (3, 6 and 9 weeks as main plots), and then simultaneously cropped. Height measurements were taken weekly and the crop harvested after 3 weeks. A second crop was grown to evaluate any residual treatment effects. For both crops the dry matter production, nitrogen concentration and nitrogen uptake were determined as in experiment 3 above.

Data collected in both field and pot trials were analysed using the Statistical Analysis Systems (SAS) package. Analysis of variance was used to determine treatment effects. Mean separation was done by Duncan's Multiple Range Test (MRPT) or the Least Significant Difference (LSD) method at 5% level. The standard errors and coefficient of variation were used as needed to assess reliability of the data and the result of the analysis of variance.

CHAPTER FOUR

4.0 RESULTS

4.1.0 Calliandra productivity

4.1.1 Calliandra growth

The mean height, stem number and fresh biomass production per tree for pruned and unpruned trees at various stages of growth are shown in Table 1. At first pruning, calliandra trees left to fallow for five months mainly during the dry season had attained a mean growth of 168.6 cm, an average of 16 stems and fresh biomass yield of 1.7 Kg per tree. During the rainy season after 8 weeks, pruned trees had attained a remarkable growth of 143.3 cm as compared to a height increase of only 16 cm for unpruned trees which was only comparable to a week's growth for the pruned trees. The number of stems per tree was more but the fresh biomass yield was less than for unpruned trees. At the third pruning stage, four weeks later, pruned trees maintained a higher growth rate of about 25 cm/week over that of unpruned trees of about 10 cm/week. Though pruned trees had more stems than unpruned trees, the forage biomass production from the latter was 9 times higher. At the fourth pruning four weeks later, growth rates were slightly reversed, with unpruned trees growing twice as fast as pruned trees although pruned trees produced 35 stems/tree compared to 20 for unpruned trees. However, the fresh biomass production over the whole period was 5.2 and 9.7 Kg/tree respectively.

It would appear that pruning promotes coppicing, and the number of coppices increases with decreasing pruning interval. It is also observed that coppice regrowth is very rapid, but repeated pruning reduced potential biomass production.

Table1 Mean height, stem number and fresh biomass production of pruned and unpruned calliandra trees at various stages of growth.

Growth stage (weeks)	Pruning date[1])	Plant height (cm)		No. of stems		Fresh Biomass(Kg/	
		pruned	unpruned	pruned	unpruned	pruned	unprunec
0	1st pruning 15/4/88	168.6	168.6	16	16		
2		28.6		28.			
4		56.8		32.			
8	2nd pruning 20/6/88	143.3	180.6	22	20		
10		25.8		18.			
16	3rd pruning 19/8/88	98.9	224.3	24	20		0.7
18		18.1		28.			
20	4th Pruning 22/9/88	35.6	306.7	35	20		0.3
				Total biomass		5.2	9.7

[1]) Pruning height of trees 50 cm

4.1.2 Biomass production and nutrient contribution

The biomass production and nutrient contribution from calliandra prunings for the four successive prunings during the cropping period is shown in Table 2. The total annual dry matter production was about 5 tons ha^{-1} with an estimated nutrient yield of 185.1 Kg N, 13.3 Kg P, 64.2 Kg K, 55.2 Kg Ca and 16.9 Kg Mg ha^{-1}. The highest dry matter production and nutrient yield was produced during the second pruning, and the amounts decreased rapidly with subsequent prunings. In contrast, concentrations of N, P and K in prunings was observed to increase at each successive prunings while those of Ca and Mg declined in the opposite order (Table 2). Nitrogen content increased from 3.25 to 3.82%, P from 0.16 to 0.36% and K from 0.77 to 1.31. Ca decreased from 1.17 to 0.65% and Mg from 0.34 to 0.22. Large variations in nutrient concentrations of young and old wood of calliandra were observed (Table 3). The concentrations of N, P, K, Ca and Mg in young wood was approximately twice that in old wood. The concentrations of Mn and Zn was high in both young and old wood. The data also indicate, that young wood developed during the dry period has higher nutrient concentrations than that developed during wet season while the opposite is true for old wood.

Table 2. Biomass and nutrient yield of calliandra prunings with successive prunings and mean nutrient concentration (in brackects) in biomass[1].

Pruning date	Dry matter yield (Kg/ha^{-1})	Nutrient yield (kg ha^{-1}) and concentration (%)				
		N	P	K	Ca	Mg
15/4/88[1]	1880	74.4 (3.25)	4.5 (0.16)	24.1 (0.77)	27.4 (1.77)	8.1 (0.34)
20/6/88	2464	85.4 (3.47)	7.1 (0.29)	32.2 (1.31)	24.7 (1.00)	7.7 (0.31)
19/8/88	517	19.7 (3.81)	1.2 (0.23)	4.9 (0.94)	2.7 (0.41)	0.8 (0.16)
22/9/88	147	5.6 (3.82)	0.5 (0.36)	3.0. (0.49)	1.0 (0.65)	0.3 (0.22)
Total	5008	185.1 (3.59)	13.3 (0.26)	64.2 (0.88)	55.2 (0.96)	16.9 (0.26)

1) Nutrient yield by harvested wood was 13.3 N, 1.4 P, 9.7 K, 5.4 Ca and 1.7 Mg Kg ha^{-1} respectively and is included in the first pruning figure. No wood was produced in subsequent prunings.

Table 3. Nutrient concentration in young and old wood of calliandra at first pruning and for trees left to grow until 4th pruning

Nutrient element	1st pruning[1]		unprune trees[2]	
	Young	Old	Young	Old
N (%)	2.08	0.73	2.73	0.83
P (%)	0.25	0.04	0.22	0.1
K (%)	1.27	0.82	0.97	0.87
Ca (%)	0.80	0.35	0.57	0.31
Mg (%)	0.28	0.09	0.17	0.10
Mn (PPm)	28.3	64.1	-	-
Zn (PPm)	41.4	8.0	-	-

1) Sampled, at first pruning

2) Sampled, 5 months later at fourth pruning time

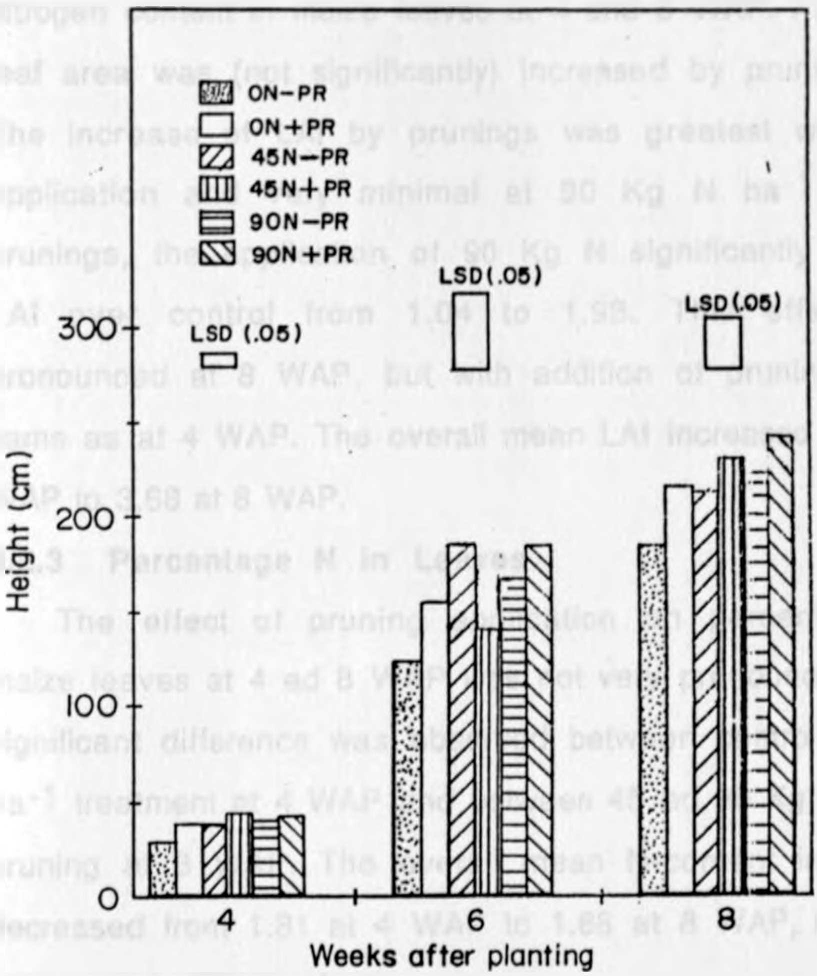
4.2.0 Alley-cropping calliandra with maize

4.2.1 Plant height

The effect of calliandra prunings and nitrogen rates on maize height 4, 6 and 8 WAP is shown in figure 1. At 4 WAP, treatment differences were significant over control and application of pruning and increasing nitrogen rate increased plant height. The mean plant height with and without prunings at 0, 45 and 90Kg N ha^{-1} were 36.7, 42.8, 40.6 and 27.8, 35.1, 39.1 cm respectively. This effect was also observed at 6 WAP but application of 45 Kg N ha^{-1} alone depressed maize plant height significantly from other treatments except over control. The mean plant height with and without prunings at 0, 45 and 90 Kg N ha^{-1} were 154.8, 186.3, 183.8 and 123.7, 140.7, 167.2 cm respectively. At 8 WAP, the same trend continued with no significant differences between treatments. The mean plant height with and without prunings at 0, 45 and 90 Kg N ha^{-1} were 216.7, 230.1, 243.4 and 184.8, 212.4, 223.5 cm respectively.

At all stages of growth, data was also analysed by relative position to calliandra hedgerows. Position did not have a significant effect on plant height, but the hedgerow seemed to depress the height of maize plants grown adjacent to them. The mean plant height for plants grown near hedgerows were 36.1, 157.9 and 218.5 cm at 4, 6 and 8 WAP respectively compared to 37.8, 160.9 and 218.4 cm for maize plants in middle rows.

Fig. 1. Effect of Calliandra prunings and nitrogen rates on maize plant height at 4, 6 and 8 weeks after planting a).



a). An explanation of each treatment is given on page 24.

4.2.2 Leaf area index (LAI)

Table 4 shows effect of application of calliandra prunings and inorganic nitrogen fertilizer on leaf area index and percent nitrogen content in maize leaves at 4 and 8 WAP. At 4 WAP maize leaf area was (not significantly) increased by pruning application. The increase of LAI by prunings was greatest without nitrogen application and very minimal at 90 Kg N ha^{-1}. Without the prunings, the application of 90 Kg N significantly increased the LAI over control from 1.04 to 1.98. This effect was more pronounced at 8 WAP, but with addition of prunings, it was the same as at 4 WAP. The overall mean LAI increased from 1.66 at 4 WAP to 3.68 at 8 WAP.

4.2.3 Percentage N in Leaves

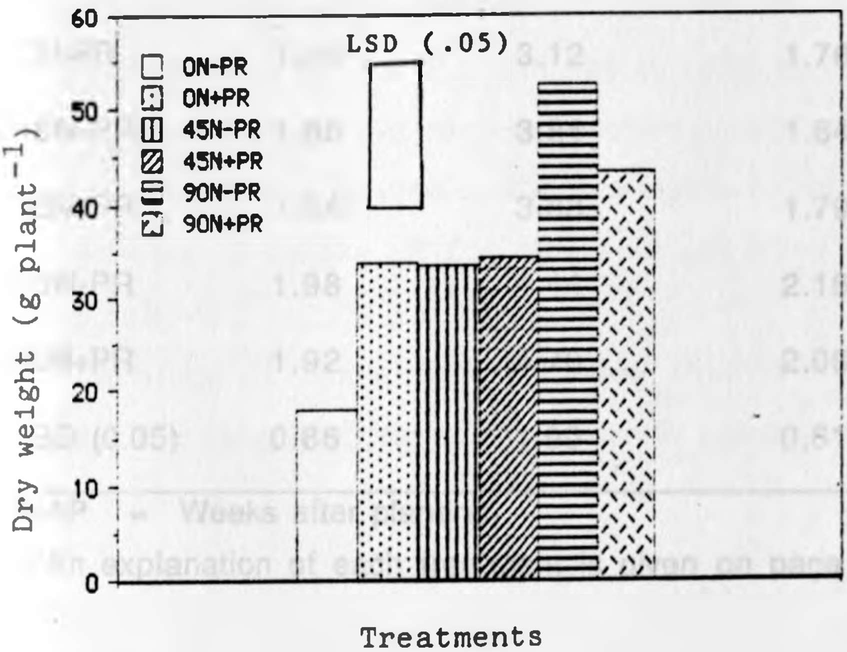
The effect of pruning application on percent N-content of maize leaves at 4 ad 8 WAP was not very pronounced. However, a significant difference was observed between control and 90 Kg N ha^{-1} treatment at 4 WAP and between 45 ad 90 Kg N ha^{-1} without pruning at 8 WAP. The overall mean N-content in maize leaves decreased from 1.81 at 4 WAP to 1.68 at 8 WAP, which concided with maize silking stage.

4.2.4 Dry matter production

The effect of calliandra prunings and nitrogen rates on maize dry matter production at 6 WAP is shown in figure 2. where no nitrogen was applied, application of prunings significantly increased maize dry matter from 17.7 to 33.9 g/plant. The effect of pruning application alone was almost the same as that of 45 kg

N ha^{-1} with or without prunings. There was a further significant increase of dry matter production by application of 90 kg N ha^{-1} to 52.6 g/plant but this was slightly reduced by addition of prunings to 43.5.

Fig. 2. Effect of Calliandra prunings and nitrogen rates of maize dry matter production at 6 weeks after planting a).



a).

An explanation of each treatment is given on page 24.

Table 4. Effect of calliandra prunings and nitrogen rates on maize leaf area index and % N in maize index leaves at 4 and 8 WAP[a].

Treatment[b]	Leaf area index		% N in maize leaves	
	4 WAP	8 WAP	4 WAP	8 WAP
ON-PR	1.04	2.04	1.45	1.75
ON+PR	1.44	3.12	1.76	1.76
45N-PR	1.66	3.84	1.64	1.80
45N+PR	1.84	3.88	1.79	1.59
90N-PR	1.98	4.44	2.16	1.41
90N+PR	1.92	4.70	2.08	1.75
LSD (0.05)	0.86	1.90	0.61	0.36

WAP = Weeks after planting

b) An explanation of each treatment is given on page 24

4.2.5 Earleaf nutrient composition

The maize earleaf nutrient composition at silking is given in Table 5., N, P, and Mg concentrations increased with pruning and N application but K and Ca were not affected. The application of 90 Kg N ha^{-1} significantly increased earleaf N-content. Application of prunings significantly increased N and P levels at 0 and 45 Kg N application rate but not at 90 Kg N ha^{-1}. The concentration of magnesium was only significantly increased by a combination of prunings and 90 Kg N ha^{-1} with values ranging from 0.17-0.21%. The levels of K and Ca remained largely unaffected by treatments from 2.00-2.21% and 0.44-0.49% Increasing N application seemed to enhance P uptake of the other nutrient even without pruning application.

Average N concentration ranged from 1.77 for control to 2.58% for 45 and 90 Kg N ha^{-1} and P values from 0.19-0.29%. respectively.

Table 5. Effect of application of calliandra prunings and nitrogen fertilizer on nutrient composition of maize earleaves at late silking stage

Treatment[a]	Nutrient concentration (%)				
	N	P	K	Ca	Mg
ON-PR	1.77	0.19	2.05	0.44	0.17
ON+PR	2.02	0.26	2.21	0.49	0.19
45N-PR	1.77	0.20	2.17	0.52	0.20
45N+PR	2.18	0.21	2.08	0.47	0.19
90N-PR	2.51	0.24	2.11	0.49	0.20
90N+PR	2.58	0.29	2.00	0.49	0.21
LSD (0.05)	0.41	0.15	0.10	0.04	0.33

a) An explanation of each treatment is given on page 24

4.2.6 Grain yield, stover yield and grain stover ratio

The effect of calliandra prunings and nitrogen rates on maize grain yield, stover yield and grain stover ratio is shown on Table 6. Grain yield was significantly increased by increasing nitrogen rate and pruning application. The application of 45 and 90 kg N ha^{-1} alone increased total grain yield by 108 and 176% respectively over control but differences among themselves were not significant. However, in combination with prunings, the respective yield increases were only 5 and 13%. Application of prunings alone increased maize yield by 125%, while combination of prunings and 45 kg N ha^{-1} caused a yield increase of 13% and that of 90 kg N ha^{-1} depressed yield by 8%. The effect of calliandra prunings on maize grain yield was almost equivalent to the application of 45 kg N ha^{-1}.

Similarly, stover yield was significantly affected by calliandra pruning and nitrogen application (Table 6). Application of 45 and 90 kg N ha^{-1} increased stover yield by 76 and 139%, respectively over control. Differences between the two nitrogen rates were significant. When combined with prunings, the respective yield increases were 76 and 81% which were higher than for grain yield. Application of prunings alone signicantly increased stover yield by 97%. The yield level was unaffected by pruning application at 45 kg N ha^{-1} but a yield decline of 32% was observed at 90 kg N ha^{-1}.

The effect of prunings, nitrogen rates and position of maize plants to calliandra hedgerows on per plant maize grain yield is shown in Table 7. For both positions to hedgerows with no nitrogen application, addition of prunings significantly increased per plant grain yield. There was no significant effect on grain yield due to addition of prunings and N application.

However, the mean per plant grain yields was significantly higher for plants grown in the middle of the alleys (108 g) than for those grown adjacent to the hedgerows (91.5 g).

An increase in grain stover ratio with pruning application at each nitrogen application rate and by increasing nitrogen application was observed (Table 6). This effect was non significant except between 90 kg N ha^{-1} and control. The lowest value of 0.70 was recorded where neither nitrogen nor prunings were applied while the highest value of 0.98 was recorded with application of 90 kg N ha^{-1} with prunings.

Table 6. Effect of calliandra prunings and nitrogen rates on grain yield, stover yield and grain stover ratio (var. TZPB).

Treatment[a]	Yield (tons ha^{-1}) Grain	Stover	Grain: stover ratio
ON-PR	1.80	2.58	0.70
ON+PR	4.05	5.09	0.80
45N-PR	3.76	4.55	0.83
45N+PR	4.27	4.53	0.94
90N-PR	4.98	6.17	0.81
90N+PR	4.59	4.67	0.98
Mean	3.91	4.60	0.84
C.V. %	16.5	20.2	17.9
LSD (0.5)	1.40	1.25	0.27

a)An explanation of each treatment is given on page 24

Table 7. Effect of prunings, nitrogen rates and position of maize plant to calliandra hedgerows on grain yield of maize (Var. TZPB).

Treatment[a]	Position: Adjacent to	Position: Middle of alley	Mean
	(g plant^{-1})		
ON-PR	49.7	64.7	57.2
ON+PR	97.0	105.7	101.3
45N-PR	80.3	107.7	94.0
45N+PR	106.3	107.3	106.8
90N-PR	113.3	135.7	124.5
90N+PR	102.3	127.0	114.7
Mean	91.5	108.0	

LSD 0.05 For treatment means, 30.6
For hedgerow position, 11.5
For subtreatments within same mainplot treatment 28.3
For subtreatments between different mainplot treatment 36.6

a) An explanation of each treatment is given on page 24

4.2.7 Nitrogen content in grain and stover

The effect of prunings, nitrogen rates and position of maize plants to calliandra hedgerows on nitrogen status in maize grain and stover is shown on Table 8. The N level in grain was slightly increased by either pruning or nitrogen fertilizer application. A higher mean N-content was observed in grains of plants grown adjacent to the hedgerow than those grown in middle of alleys. The values were 1.19 and 1.02% respectively. For maize stover, treatment differences due to hedgerow position were not significant. The mean N-level was less (1.11) in plants grown adjacent to hedgerow than those grown in middle of alleys. The increased % N in maize stover with pruning and nitrogen application show the same trend as observed in maize grain.

Table 8. Effect of calliandra prunings, nitrogen rates and position of maize plants to calliandra hedgerows on % N in maize grain and stover.

	% N in Maize grain in maize grain and stover					
	Adjacent to hedgerow		Middle of alley		Mean	
Treatment[a]	Grain	Stover	Grain	Stover	Grain	Stover
ON-PR	0.96	1.00	1.00	0.89	0.98	0.95
ON+PR	1.12	1.06	0.80	1.16	0.96	1.11
45N-PR	1.14	0.92	1.18	1.21	1.16	1.07
45N+PR	1.37	0.92	1.08	1.21	1.23	1.07
90N+PR	1.33	1.20	0.97	1.34	1.15	1.27
90N+PR	1.20	1.27	1.06	1.24	1.13	1.26
Mean		1.11	1.19	1.19	1.02	

LSD (0.05%) grain: For treatment means, 0.47 for hedgerow positionmeans, 0.17
For subtreatment within same mainplot treatment 0.42
For subtreatment between different mainplot treatment 0.56

LSD (0.05%) stover: For treatment means, 0.23 for hedgerow positionmeans, 0.14
For subtreatment within same mainplot treatment 0.34
For subtreatment between different mainplot treatment 0..33

a)An explanation of each treatment is given on page 24

4.3.0 Alley-cropping calliandra with cowpeas

4.3.1 Plant height

Cowpea plant height was not significantly influenced significantly by either pruning application or residual inorganic N applied to the previous maize crop (Fig. 3). Similarly, no differences were observed when data was analysed by relative position to hedgerows. Slight increases in plant height by application of prunings at all growth stages were noted but it was not significantly different from that attained by plants in fertilizer treatments. The average plant heights at each growth stage for all treatments were quite similar i.e 28, 39 and 45 cm at 2, 4 and 6 WAP, respectively.

4.3.2 Leaf area index

The effect of calliandra prunings and residual nitrogen on leaf area index of cowpea plants at 2, 4 and 6 WAP is shown in figure 4. The leaf area index was not significantly affected by either addition of prunings or with residual fertilizer N, though there was a marked increase in LAI with pruning application at all stages of growth. The mean LAI at 2, 4 and 6 WAP with and without pruning application were respectively 0.80, 2.66, 7.23 and 0.75, 2.42, 6.5. On plots receiving fertilizer N in the previous maize crop, the LAI were lower than those with pruning treatment.

4.3.3 Dry matter production

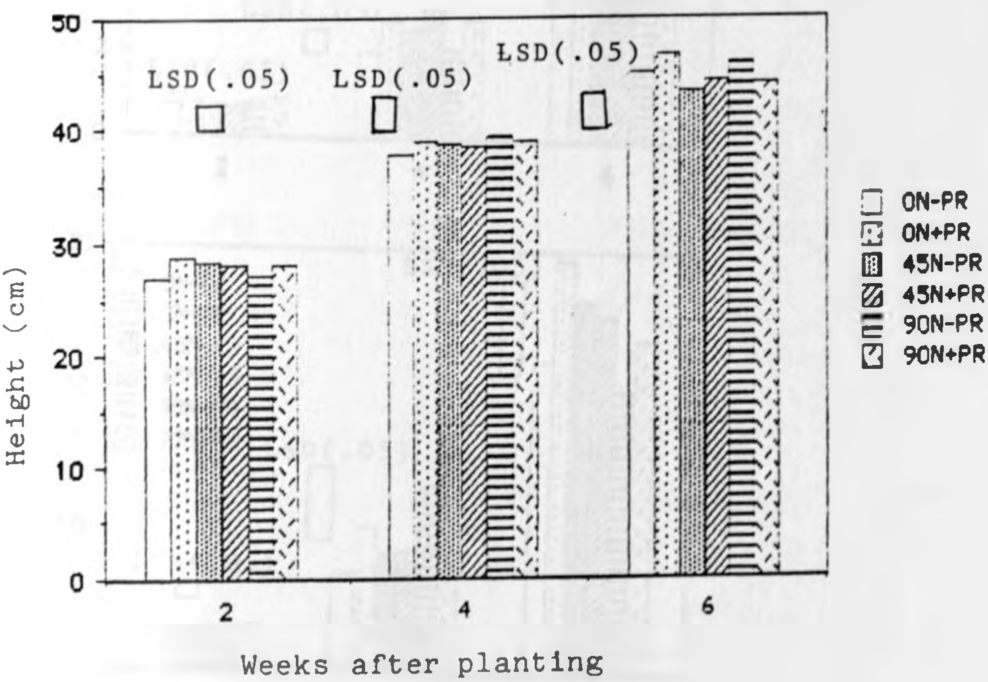
The effect of pruning and nitrogen application on cowpea dry matter production at 2, 4 and 6 WAP is shown on figure 4. At 2 and 6 WAP, difference between treatments were not significant but it was observed that dry matter production was increased by prunings and by increasing rates of nitrogen application. At 4 WAP, the same trend was observed with significant differences between all treatment and the control. Dry matter production was highest at 90 Kg N ha with prunings (16.7 g $plant^{-1}$) and lowest for control (7.2 g $plant^{-1}$).

4.3.4 Nutrient composition of whole plant

Treatment differences in N level in cowpea plant were not significant concentration at 2, 4 and 6 WAP with residual 90 Kg N ha^{-1}. N application significantly decreased N concentration compared to control (Table 9). At all growth stages with N application, N level in plants receiving pruning was higher than without pruning application. The N level in whole cowpea plants increased with growth stage from 3.78 at 2 WAP to 3.94 at 4 WAP and 4.02 at 6 WAP.

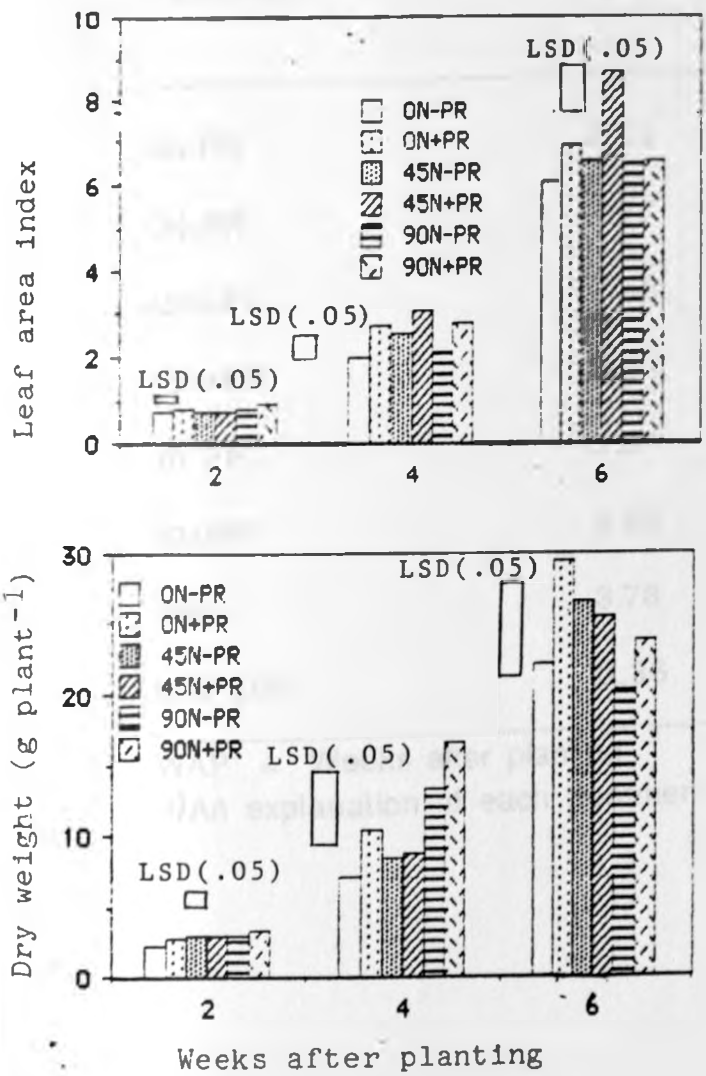
The nutrient composition of whole cowpea plants at flowering stage did not vary significantly due to treatment effects. However, analysis of the data by relative position to hedgerows indicated higher nutrient status for plant grown near the hedgerows (Table 10).

Fig. 3. Effect of Calliandra prunings and residual N fertilizer on cowpea plant height at 2, 4 and 6 weeks after planting [a]



a) An explanation of each treatment is given on page 24.

Fig. 4. Effect of Calliandra prunings and residual N fertilizer on cowpea leaf area index and dry matter production at 2, 4 and 6 weeks after planting a).



a). An explanation of each treatment is given on page 24.

Table 9. Effect of calliandra prunings and residual N fertilizer on N level in cowpea plants at 2, 4 and 6 WAP[a].

Treatment[b]	2 WAP	4 WAP	6 WAP
		(% N)	
ON-PR	3.83	3.90	3.95
ON+PR	3.77	3.85	3.91
45N-PR	3.58	4.46	4.06
45N+PR	3.94	3.47	4.03
90-PR	3.91	4.14	4.39
90+PR	3.66	3.81	3.76
Mean	3.78	3.94	4.02
LSD (.05)	0.36	0.81	0.40

WAP = Weeks after planting

a)An explanation of each treatment is given on page 24

Table 10. Effect of calliandra hedgerows on % nutrient composition of whole cowpea plants at flowering stage (6 WAP).

Nutrient Level (%)	-------- Position -------- Adjacent to hedgerow	Middle of alley	LSD (0.05)	C.V %
N	3.04	3.08	0.03	4.0
P	0.36	0.26	0.10	43.6
K	0.96	0.92	0.08	10.8
Mg	0.13	0.11	0.02	17.9
Ca	0.16	0.13	0.04	34.3
K	0.96	0.92	0.09	12.5

4.3.5 Weed growth

The effect of prunings and nitrogen fertilizer on weed growth during the cowpea crop is shown on Table 11. Pruning application had a significant effect on weed growth but the effect of residual fertilizer N was insignificant. The mean fresh weed weights in plots with and without pruning application were respectively 399.7 g m^{-2} and 211.3 g m^{-2}. Differences in weed flora due to prunings and fertilizer were also observed. In plots where prunings and/or nitrogen fertilizer were applied, the weed flora was dominated by broad leaved weeds, mainly Talinium triangulare, Commelina erecta, Acalypha ciliata and Oldenlandia corymbosa. Except the last spp, these weeds were conspicously absent from treatments without prunings and fertilizer application. The dominant weed spp in these treatments were mainly grasses and sedges such as Digitaria horizontalis and Mariscus alternifolius. Oldenlandia corymbosa and two leguminous spp, Boerhavia erecta and Desmodium scorpiurus, were particularly common on plots without pruning or fertilizer application.

Table 11. Effect of calliandra prunings and residual N fertilizer on dry weed growth on cowpea crop at 4 WAP[a].

calliandra Prunings	Residual Nitrogen rate (Kg N ha^{-1}) O	45	90	Mean
	------------ g m^{-2} ------------			
Without prunings	212.7	182.3	239.0	211.3
With prunings	430.0	345.3	423.7	399.7
Mean	321.3	263.8	331.3	
LSD (.05) for pruning means	118.6			
for nitrogen rate means	145.2			

a) An explanation of each treatment is given on page 24

4.3.6 Seed yield

The effect of calliandra prunings and residual nitrogen on cowpea seed yield is shown in Table 12. None of the treatments had any significant effect. Pruning application slightly increased yields even in combination with nitrogen but residual nitrogen alone tended to decrease grain yield. The mean yields with and without prunings were respectively 857.7 and 783.4 Kg ha^{-1}, while those for 0, 45 and 90 Kg N ha^{-1} treatments were 893.8, 781.3 and 786.5 Kg ha^{-1} respectively. Highest cowpea yields were obtained in the absence of nitrogen application with or without prunings.

A yield assessment by number of pods per plant and by relative position of plants to calliandra hedgerows, however, indicated some significant differences. Position of plants to hedgerows had a significant influence on both number of pods and cowpea yield and the interaction with pruning and fertilizer application were significant too (Table 13 and 14).

The mean number of pods in middle of alleys and in the two rows adjacent to the hedgerows were 20 and 16, while the yields were 256 and 212 Kg ha^{-1} respectively. Pruning application also increased the number of pods and yield by position, though not significantly. Residual inorganic nitrogen did not affect the number of pods but slightly decreased the cowpea yield at increasing rate. The lowest yield was in plots where 90 Kg N ha^{-1} had been applied while highest yield was recorded where no nitrogen had been applied.

Table 12. Effect of <u>calliandra</u> prunings and residual nitrogen on cowpea seed yield (Var. IT 845-2246-4)[a].

calliandra prunings	Nitrogen rate ($Kg\ N\ ha^{-1}$) 0	45	90	Mean
	------------	$Kg\ ha^{-1}$	------------	
Without prunings	885.7	729.3	735.3	783.4
With prunings	902.0	833.3	837.7	857.7
Mean	893.8	781.3	786.5	
LSD (.05) for pruning means	159.8			
for nitrogen rate means	195.4			

a) An explanation of each treatment is given on page 24

Table 13. Effect of position to calliandra hedgerow, and prunings on number of pods and grain yield (Kg ha^{-1}) of cowpea.

Position	Pruning retained		Prunings removed		Mean	
	No of pods	Yield	No of pods	Yield	No of pods	yield
Two middle rows	20.5	276.9	19.7	236.1	20.1	256.1
Two outer rows	15.7	206.9	16.9	217.7	16.3	212.3
Mean		18.1	241.4	18.3	226.9	

LSD (.05) For positon, mean No. of pods 1.5
For position, mean yield 22.1
For pruning, no. of pods 4.9
For pruning ,yield 60.7

Table 14. Effect of position to calliandra hedgerow and residual N fertilizer on number pods and grain yield (Kg ha^{-1}) of cowpea.

Position	Nitrogen rate (Kg N ha^{-1}) 0		45		90		Mean	
	No. of Pods	Yield	No. of Pods	Yield	No. of Pods	Yield	Pods	Yield
Two middle rows	20.5	269.3	20.2	257.0	19.7	241.8	20.1	256
Two outer rows	14.8	223.8	15.3	207.5	18.8	205.7	16.3	212
Mean	17.7	246.6	17.7	232.2	19.3	223.8	18.2	234
C.V.%	11.5	13.0						

LSD (.05) For position, mean No of pods - 1.5
For position, yield - 22.1
For Fertilizer, no. of Pods - 6.0
For Fertilizer, yield - 74.3

4.4.0 Soil chemical properties

Soil analysis data at the beginning of the experiment is shown in Table 15. The levels of organic C and nutrient status were higher where prunings and fertilizer N had been applied compared to control plot. Addition of pruning was only noticeable in no N plot. The lowest pH was observed on plots where 90 Kg N had been applied. The mean pH was 5.7, 5.8 and 5.6 at 0, 45 and 90 Kg N ha^{-1} respectively. Except for pH, soil nutrient levels at 5-15 cm depth were lower than at 0-5 cm for all treatments. The pH was higher and there was a significant effect due to pruning application (5.8 and 6.0 with and without prunings). There seemed to be a general improvement in the level of all other nutrient in plots where prunings were applied, but this was not consistent.

After cropping with maize and cowpeas, the surface soil (0-5 and 5-15 cm depth) did not indicate significant changes due to treatments. There appears to be an overall decline in pH, organic carbon and P, K, Ca, Mg, levels (Table 16). Prunings slightly increased organic carbon levels with values for the upper soil layer higher (1.5 %) than for the lower soil layer (1.1 %). The levels of P, K, Ca and Mg were significantly affected by pruning application.

Table 15 . Effect of prunings and nitrogen fertilizer application on chemical properties of surface soil at experimental site before cropping maize. [a]

Treatment		pH-H_2O	Org. C (%)	Total N (%)	Extra-Bray P-1 (ppm)	NH_4 OAC. Exch. cations (meq 100 g^{-1}) K	Ca	Mg	ECEC (meq 100 g^{-1})
0N-PR	0-5 cm	5.8	1.37	0.14	7.15	0.38	3.23	0.92	4.71
	5-15 cm	6.2	0.97	0.10	4.20	0.19	1.94	0.59	2.88
0N+PR	0-5 cm	5.8	2.42	0.20	10.10	0.49	4.66	1.18	6.52
	0-15 cm	5.9	1.04	0.13	4.33	0.26	2.89	0.72	4.03
45N-PR	0-5 cm	5.8	1.80	0.19	10.70	0.41	3.91	0.96	5.46
	5-15 cm	6.1	0.95	0.12	9.70	0.22	2.35	0.63	3.36
45N+PR	0-5 cm	5.8	1.69	0.18	9.10	0.43	3.91	0.98	5.51
	5-15 cm	5.8	0.88	0.10	3.67	0.24	2.10	0.58	3.07
90N-PR	0-5 cm	5.8	2.20	0.22	8.70	0.48	4.45	1.13	6.25
	5-15 cm	5.9	1.13	0.13	3.57	0.25	2.84	0.77	4.02
90N+PR	0-5 cm	5.8	1.97	0.18	9.17	0.43	3.71	0.98	5.30
	5-15 cm	5.8	0.79	0.10	4.37	0.24	2.04	0.58	3.01
LSD (.05) For soil sample depth within same mainplot treatment		0.25	0.49	0.05	6.96	0.10	0.97	0.19	1.21
For the same soil sample depth between different mainplot treatments		0.08	0.41	0.04	7.00	0.08	0.93	0.15	1.14

a) An explanation of each treatment is given on page 24.

Table 1e Effect of prunings and nitrogen fertilizer application on chemical properties of surface soil at experimental site after cropping cowpea.[a]

Treatment	Depth	PH-H20	Organic-C %	Extra-Bray-1 P	NH4 OAC. Ech. cations (meq 100 g^{-1}) K	Ca	Mg	CEC (meq 100 g^{-1})
ON-PR	0-5 cm	5.8	1.41	3.63	0.23	2.70	0.81	3.71
	5-15 cm	5.8	1.09	4.37	0.19	1.85	0.61	2.65
ON+PR	0-5 cm	5.7	1.47	4.60	0.30	3.06	1.01	4.37
	5-15 cm	5.7	1.13	4.00	0.23	2.00	0.71	294
45N-PR	0-5 cm	5.6	1.65	5.57	0.26	1.95	0.71	2.94
	5-15 cm	5.6	0.99	2.77	0.24	25.9	0.83	3.66
45N+PR	0-5 cm	5.5	1.40	4.33	0.25	1.80	0.70	2.75
	5-15 cm	5.5	0.97	3.73	0.19	1.27	0.49	1.95
90N-PR	0-5 cm	5.5	1.39	4.87	0.26	2.57	0.92	3.75
	5-15 cm	5.7	1.01	2.93	0.21	1.87	0.71	2.79
90N+PR	0-5cm	5.4	1.51	5.40	0.22	1.81	0.69	2.12
	5-15 cm	5.6	1.11	4.97	0.17	1.21	0.46	1.84
LSD (.05) For soil sample depth within same mainplot treatment		0.1	0.31	3.21	0.53	0.14	0.08	0.75
For the same soil sample depth within different mainplot treatments		0.4	0.75	2.92	0.09	1.94	0.43	2.46

a) An explanation of each treatment is given on page 24.

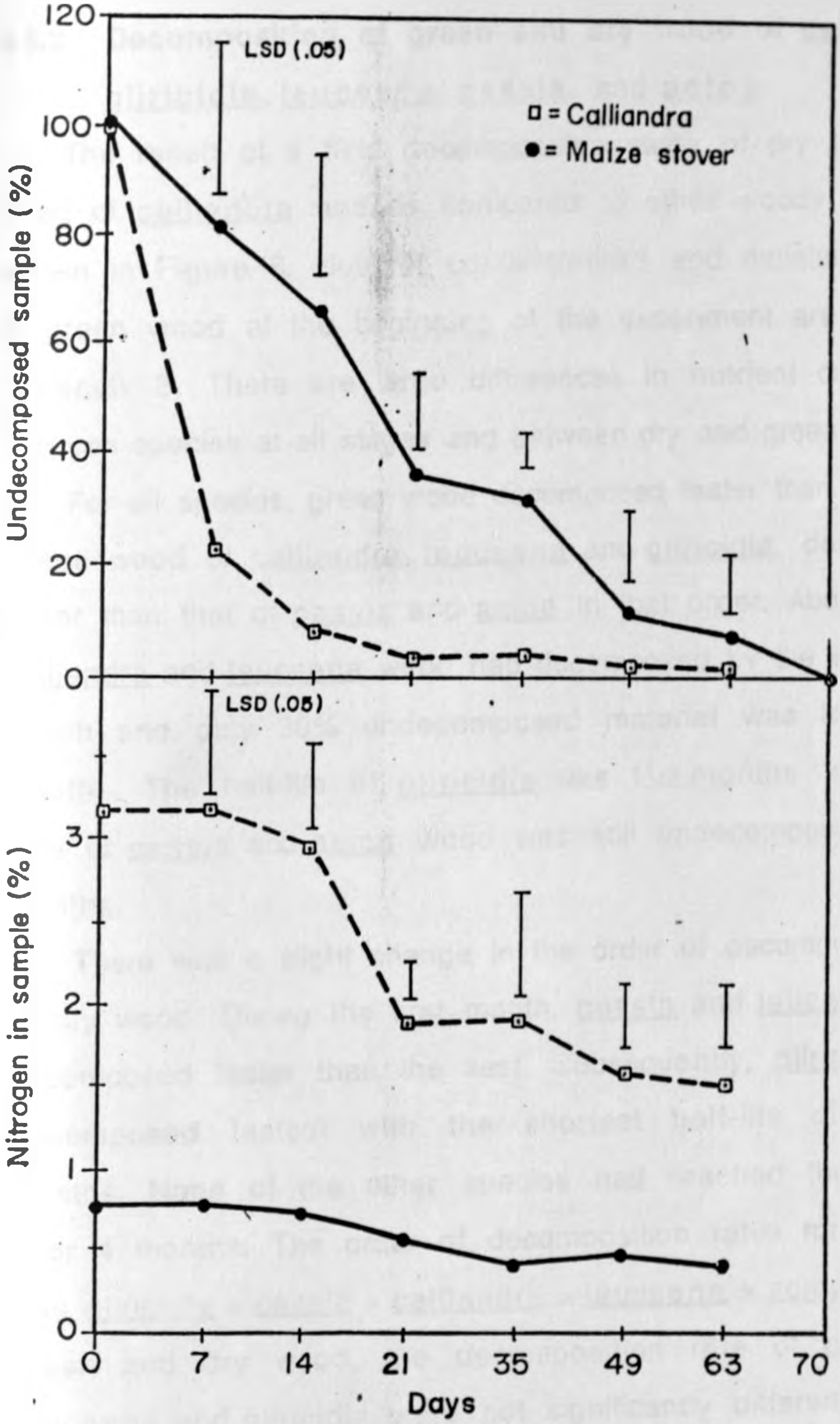
4.5.0 Decomposition study

4.5.1 Decomposition of calliandra prunings and maize stover

The result of the field decomposition trial of fresh calliandra prunings and maize stover is shown in Figure 5. The respective C:N ratios for prunings and stover were 3:1 and 13:1. The decomposition rates between the two materials were observed to differ significantly for the first seven weeks (49 days) but not in the last 2 weeks of the trial. Decomposition of calliandra prunings was very rapid during the first 14 days in which 90% weight loss was recorded with a half life of about one week. The half-life of the remaining undecomposed materials was approximately 4 weeks. Only 34% weight loss was recorded for maize stover in the first 2 weeks with a half life of about 2$^{1}/_{2}$ weeks.

An analysis of the nitrogen percentage in the undecomposed materials indicated a small change in the nitrogen content of both materials in the first two weeks. At the end of 8 weeks, the materials still retained about 50% of the initial nitrogen level. The nitrogen level of calliandra prunings dropped from 3.2 to 1.5% while that of maize stover dropped from 0.77 to 0.40%. The estimated amount of nitrogen that was released by calliandra prunings during this period was 4.4 g which was approximately 50% of total amount added.

Fig. 5. Decomposition and nitrogen release of decomposing Calliandra prunings and maize stover.



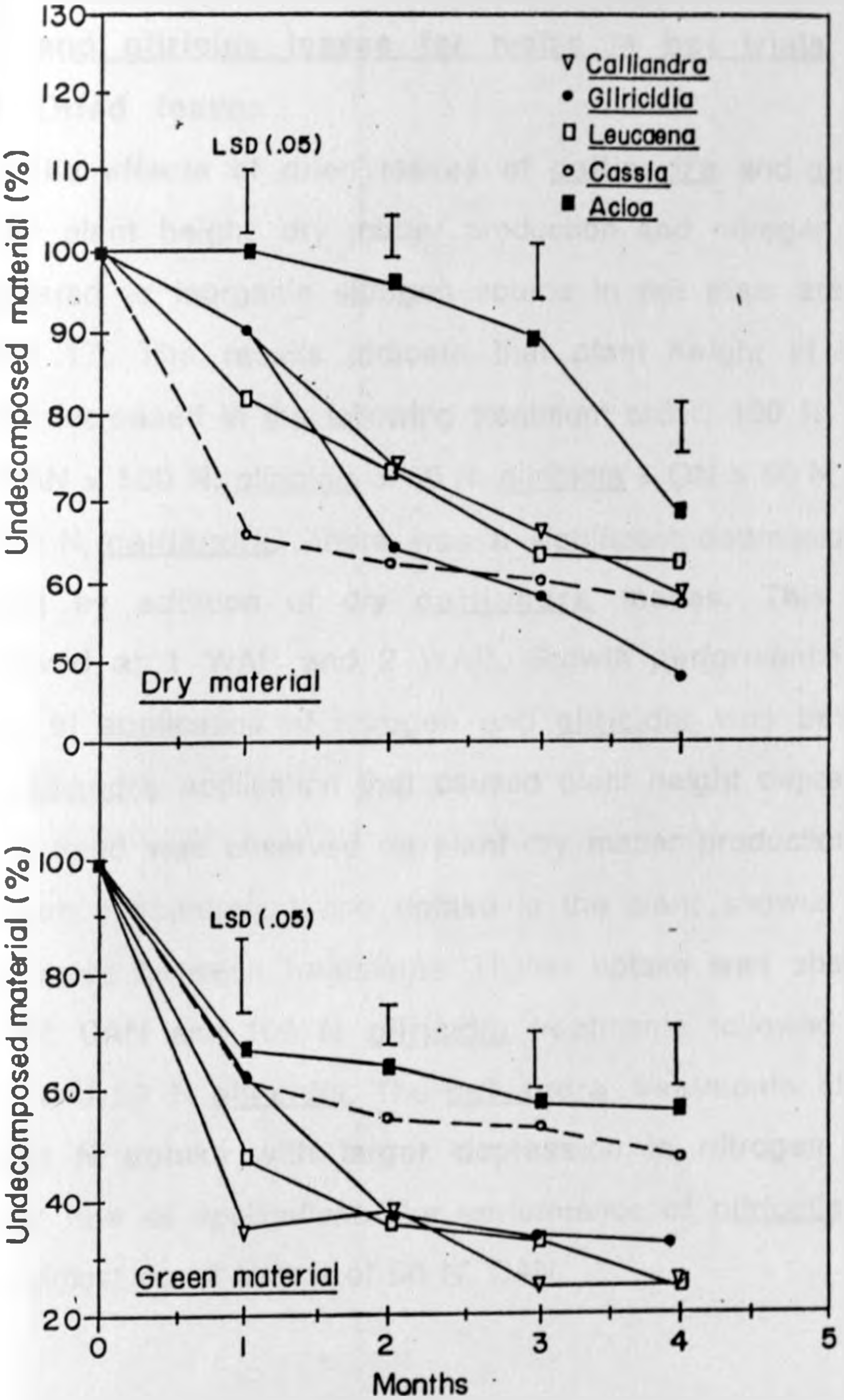
4.5.2 Decomposition of green and dry wood of calliandra, gliricidia, leucaena, cassia, and acioa

The result of a field decomposition study of dry and green wood of calliandra and as compared to other woody shrubs is shown in Figure 6. Nutrient concentrations and moisture content of green wood at the beginning of the experiment are given on Appendix 3. There are large differences in nutrient composition between species at all stages and between dry and green wood.

For all species, green wood decomposed faster than dry wood. Green wood of calliandra, leucaena and gliricidia decomposed faster than that of cassia and acioa in that order. About 50% of calliandra and leucaena wood had decomposed by the end of one month and only 30% undecomposed material was left after 4 months. The half-life of gliricidia was $1^1/_2$ months while over 50% of cassia and acioa wood was still undecomposed after 4 months.

There was a slight change in the order of decomposition rate of dry wood. During the first month, cassia and leucaena wood decomposed faster than the rest. Subsequently, gliricidia wood decomposed fastest with the shortest half-life of about 4 months. None of the other species had reached their half-life after 4 months. The order of decomposition rates for dry wood was gliricidia > cassia > calliandra > leucaena > acioa. For both green and dry wood, the decomposition rate of calliandra, leucaena and gliricidia were not significantly different, but they were significantly different from of acioa.

Fig. 6. Decomposition rates of dry and green wood of Calliandra, Gliricidia, Leucaena, Cassia and Acioa.



4.6.0 Comparative study of N-manuring value of calliandra and gliricidia leaves for maize in pot trials

4.6.1 Dried leaves

The effects of dried leaves of calliandra and gliricidia on maize plant height, dry matter production and nitrogen uptake as compared to inorganic nitrogen source in pot trials are shown in Table 17. The results indicate that plant height at harvest (3 WAP) increased in the following treatment order; 100 N, CAN > 50 N, CAN > 100 N, gliricidia > 50 N, gliricidia > ON > 50 N, calliandra > 100 N, calliandra. There was a significant depression of plant height by addition of dry calliandra leaves. This was also observed at 1 WAP and 2 WAP. Growth performance at higher rates of application of nitrogen and gliricidia was better except for calliandra application that caused plant height depression. The same trend was observed on plant dry matter production. Data on nitrogen concentration and uptake in the plant showed significant differences between treatments. Higher uptake was observed with 100 N; CAN and 100 N, gliricidia treatments followed by 50 N, CAN and 50 N gliricidia. The calliandra treatments showed the lowest N uptake with larger depression in nitrogen uptake at higher rate of application. The performance of gliricidia at 100 N, was almost equal to that of 50 N, CAN.

Table 17. Effect of application of CAN and dry leaves of calliandra and gliricidia on plant height, dry matter production and nitrogen content of maize (hybrid 8321-21) in pot trial.

Treatment (N-rate, ppm N)	Plant height at 3 WAP (cm)	Plant Dry weight (g Pot-1)	Nitrogen concentration (%)	Nitrogen content (mg Pot^{-1})
O N (control)	57.2	3.96	0.94	3.74
50 N, CAN	78.6	9.00	1.31	11.82
100 N, CAN	77.0	10.08	1.75	17.70
50 N, calliandra	53.0	2.40	1.44	2.75
100 N, calliandra	43.8	1.80	1.68	2.10
50 N, gliricidia	70.2	6.00	1.24	7.44
100 N, gliricida	75.2	8.04	1.40	11.28
LSD (.05)		9.88	1.05	0.30

4.6.2 Fresh and dried leaves incubated over different time periods

The effects of addition of green and dried leaves of calliandra and gliricidia incubated at three time periods (9, 6 and 3 weeks before planting maize) on maize plant height, dry matter production and nitrogen uptake as compared to inorganic nitrogen source in pot trials are shown in Appendix Tables 5-10. The result showed that plant height at harvest (3 WAP), dry matter yield and nitrogen content in plant increased with incubation time of the leaves in the order 9 weeks > 6 weeks > 3 weeks. Height differences for 6 weeks incubation period were significantly higher than for 3 weeks incubation as measured at 1 WAP and 2 WAP. However at 3 WAP differences were insignificant. Since differences in height, dry matter production and nitrogen uptake due to incubation period were not significant at 3 WAP, the data was pooled together in the statistical analyses as shown in Table 18. Green leaves of calliandra and gliricidia were more effective than the dry leaves in increasing plant height, dry weight and nitrogen content.

The depressing effect of calliandra dry leaves observed in the previous experiment was not apparent after incubation. There were significant effects on plant height due to treatments. The performance of calliandra and gliricidia was comparable but differences in plant height were observed between dry and green leaves and between rates of application. Green leaves of calliandra increased maize plant height over dry leaves at 100 N rate but at 50 N rates, this difference was not significant.

The highest maize biomass was observed with application of leaves of gliricidia followed by calliandra leaves and CAN at 100 ppm N rate. At both 50 N and 100 N rate dry matter yield was higher with green leaves for both species. The performance of maize with CAN at both levels (50 and 100 N ppm N) was almost equal to that of 50 N, dry calliandra but significantly lower from 100 N, green calliandra and 50 N, green and dry gliricidia leaves.

Nitrogen concentration and nitrogen content in plants was observed to follow similar trends as observed with plant height and dry matter production. The effect of incubation period was notsignificant but 9 weeks > 6 weeks > 3 weeks. Green leaves performed better than dry leaves at all rates in all the periods. Highest N uptake by maize was recorded with application of green dry gliricidia and calliandra at 100 N. This was significantly higher than and of 50 N, gliricidia, 100 N, CAN and 100 N, calliandra. Dry gliricidia leaves, dry and green calliandra leaves and CAN at the lower application rate gave the least performance but were significantly higher than control.

Table 18. Effect of application of CAN and green and dry leaves c calliandra and gliricidia on plant height, dry matter yield an nitrogen content of Maize in pot trial[1].

Treatment (N-rate ppm N)	Plant height at 3 WAP (cm)	Dry weight ($g\ pot^{-1}$)	Nitrogen concentration (%)	Nitrogen con ($mg\ pot^{-1}$)
O N (Control)	56.0	4.55	1.13	5.14
50 N, CAN	66.5	6.99	2.27	15.59
100 N, CAN	70.4	7.01	2.54	17.81
50 N, dry calliandra	70.1	7.17	2.32	16.71
100 N, dry calliandra	72.4	7.34	2.53	18.57
50 N, green calliandra	72.8	7.74	2.29	17.80
100 N, green calliandra	76.8	8.08	2.89	23.35
50 N, dry gliricidia	68.5	8.08	2.42	18.20
100 N, dry gliricidia	73.0	7.52	3.11	26.43
50 N, green gliricidia	70.4	8.28	2.61	21.43
100 N, green gliricidia	72.7	8.73	3.12	27.32
LSD (0.05)	3.92	0.74	0.36	

1) Data represent mean of three incubation (3, 6, 9 weeks) periods of calliandra and gliricidia leaves

When a second maize crop was grown to determine residual effect due to the various treatments, and periods, the results showed only slight differences from the above observations (Table 19). The effect of incubation period on plant height at 1, 2 and 3 WAP and on the dry matter production was not significant but the performance was in the order 9 weeks > 6 weeks > 3 weeks. Treatment effects were better than control in increasing the plant height at all stages of growth. At 3 WAP, 100 N, green leaves of calliandra and both green and dry gliricidia leaves gave the best growth performance with respective mean plant height of 62.2, 60.5 and 60.3cm which were significantly different from the rest. This was followed by dry calliandra leaves at 100 N rate and green and dry gliricidia leaves at 50 N rate whose performance was comparable to 100 N, CAN.

The mean height at O N was 35.0 which was significantly different from other treatment, but comparable to that attained in the first crop. Similarly gliricidia green leaves at 100 N, gave the highest dry matter production of 7.6 g pot^{-1}. This was followed by 100 N, gliricidia dry leaves and 100 N, calliandra green leaves. Differences between these two and the other treatments were significant. The maize dry matter production by dry and green leaves of gliricidia at 50 N was comparable to that of 100 N, calliandra dry leaves. The residual effect of 50 N calliandra green and dry leaves was comparable to that of 100 N, CAN and 50 CAN respectively. There was a marked though insignificant reversal in N concentration in plants due to incubation period. The order was 3 weeks > 6 weeks > 9 weeks and respective values were 1.29, 1.22 and 1.20%. This, however, did not significantly change the trends in N-content from that observed on dry matter production.

Table 19. Residual effects of application of CAN and green and dry leaves of calliandra and gliricidia on plant height, dry matter production and Nitrogen content of second maize crop.

	Plant height 1 WAP	2 WAP	3 WAP	Dry weight	Nitrogen concentration	Nitrogen content
	--------- cm -------			(g pot^{-1})	(%)	(mg pot^{-1}
ON (control)	21.01	32.43	35.04	1.46	9.6	1.40
50 N, CAN	24.37	45.64	50.85	4.27	0.98	4.18
100 N, CAN	26.14	48.70	56.24	5.23	1.25	6.54
50 N, dry calliandra	24.44	43.96	52.54	4.16	0.98	4.08
100 N, dry calliandra	25.18	49.23	56.90	5.37	1.22	6.55
50 N, green calliandra	24.10	46.53	54.84	4.91	1.12	5.50
100 N, green calliandra	26.30	50.87	62.16	6.66	1.65	5.50
50 N, dry gliricidia	26.69	47.90	56.39	5.72	1.10	6.29
100 N, dry gliricidia	28.42	50.66	60.27	6.81	1.46	9.94
50 N, green gliricidia	27.17	48.20	55.68	5.66	1.23	6.96
100 N, green gliricidia	29.63	52.70	60.47	7.64	1.64	12.58
Mean	25.77	46.98	54.67	5.26	1.24	6.52
LSD (.05)	2.18	2.84	2.72	0.66	0.18	

4.6.3 Allelopathic effect of calliandra dry leaves

The result of a preliminary investigation on the effect of 1% aqueous extracts of dried calliandra and gliricidia leaves on radicle and plumule growth and on secondary root development of germinating maize seed over a 3-day period is shown in Table 20. calliandra extract significantly increased plumule and radicle length over gliricidia and distilled water control during the whole period. There were no significant differences between treatments on secondary root development, but calliandra consistenly gave the best performance. Gliricidia extract appeared to have severe negative or toxic effects on radicle and plumule growth and on secondary root development of germinating maize seed.

On further investigations with calliandra leaf extracts at concentrations of 1, 5 and 10%, it was observed that the germination percentage was increased, but not significantly, by increasing concentration of calliandra extract (Table 21). No significant differences in lenght of radicle, plumule and secondary on root development were observed after the first day. Two days after germination, application of 1% extract significantly increased radicle and plumule growth over other treatments except control. At 10% concentration, plumule growth was depressed more than radicle growth. Data collected on the third day confirmed this trend. The length of plumule at 1 and 10% concentrations were repectively, 1.73 an 0.70 cm while that of radicle was 4.80 and 3.03 cm. For both radicle and plumule growth, the effect increased in the order 1% > H_20 > 5% > 10%.

Performance of 1% calliandra was significantly different from 5% and 10% but not from distilled water control.

An assesment of the number of secondary roots, however, indicated that the higher concentration promoted secondary root development. This effect was in the order 10% > 5% > 1% > H_20. The mean number of roots per plant were respectively 5.5, 4.0, 3.1 and 2.8. Differences between 10% and 1% and control were significant but not from 5% concentration. Although there were many small secondary roots at high concentrations, their total length was less than at lower concentration levels.

Table 20. Effect of calliandra and gliricidia dried leaf extracts on radicle and plumule growth and on secondary root development of germinating maize seed

	Lenght of radicle (cm)		
	DAY 1	DAY 2	DAY 3
Distilled H_2O	1.97	3.57	3.34
Calliandra 1%	2.89	4.55	4.21
Gliricidia 1%	1.18	1.37	1.20
LSD (0.5)	0.97	0.49	0.79

	Lenght of plumule (cm)		
	DAY 1	DAY.2	DAY 3
Distilled H_2O	0.49	1.14	1.53
Calliandra 1%	1.07	1.83	1.80
Gliricidia 1%	0.42	0.80	0.93
LSD (.05)	0.25	0.41	0.45
	Number of secondary roots		
Distilled H20	3.42	3.24	2.68
Calliandra 1%	3.67	4.14	3.24
Gliricidia 1%	3.16	3.52	2.62
LSD (.05)	1.02	0.74	0.89

Table 21. Effect of concentration of calliandra dried leaf extracts leaves on germination, radicle and plumule growth and on secondary root development of maize seed.

Treatment DAY 1	Germination %	No. of secondary roots	Lenght of radicle (cm)	Lenght of plumule (cm)
Control (H_20)	85	0.95	1.53	0.35
1% calliandra	85	1.60	1.45	0.68
5% calliandra	90	0.95	1.08	0.43
10% calliandra	90	0.60	1.00	0.25
LSD (.05)	17.7	0.59	0.66	0.25

DAY 2

Control (H_20)	90	2.95	4.10	1.38
1% calliandra	90	3.25	4.80	1.73
5% calliandra	95	3.10	3.38	1.08
10% calliandra	100	3.05	3.03	0.70
LSD (.05)	15.3	0.70	1.08	0.53

DAY 3

	No. of secondary roots	Length of radicle	Length of plumule	Total length of secondar roots
Control (H_20)	2.75	6.15	3.40	4.0
1% calliandra	3.05	6.55	3.40	8.20
5% calliandra	3.95	4.95	3.00	5.40
10% calliandra	5.50	4.00	1.95	4.3
LSD (0.05)	1.58	1.31	0.91	2.50

CHAPTER FIVE

5.0 DISCUSSION

5.1.0 Calliandra growth, biomass production and nutrient contribution

Calliandra is a highly productive, fast growing, leguminous multipurpose tree species suitable for varied agroforestry systems. Its potential use for soil improvement and for increasing crop yield under alley cropping system will be determined not only by seed availability but also by its ability to produce adequate biomass and capacity for nutrient cycling and nitrogen fixation under different environmental conditions and management practices. Previously reported work has placed emphasis on its growth and use for erosion control, biomass and firewood harvests (NAS, 1979; Soerjono and suhaendi, 1981; Baggio and Heuveldop, 1982; Keny, 1985; EDI, 1987). However little effort has been put into quantifying and relating its growth, with biomass production and nutrient contribution in an alley cropping system.

Results from the current study suggest that growth and coppicing ability can be promoted by pruning and shorter the pruning interval at the expense of reducing total biomass production (Table 1). Rachie (1983) indicated that pruning stimulates regrowth and nitrogen fixation in leucaena and other legumes. It is also supported by recent observations at IITA, Nigeria which show that biomass and N-yield of various hedgerow species in alley cropping is increased by less frequent prunings (Duguma et al., 1988). The growth reversal observed between the third and fourth prunings for unpruned and pruned trees was probably due to a higher accumulation of carbohydrates available for growth in unpruned trees than in pruned trees. The dry matter production of 5.0 tons ha^{-1} and nutrient yield of185 kg N ha^{-1} of calliandra compared very well with values reported by Gichuru and Kang (1989) of 6.0 tons and 189 kg N ha^{-1} respectively for the same species. The biomass production can be significantly increased by closer inter-row spacing, better pruning management and environmental conditions. This may explain the high values of 7-10 tons DM ha^{-1} (EDI, 1987) and 46.2 tons fresh fodder (Kidd and Taogaga, 1984). Results from this study also show, that under humid conditions at low altitude and medium rainfall, calliandra grows slowly, produces less biomass and has lower nutrient composition and contributes less nutrient than leucaena (Table 2 and 3). The levels of the major nutrient elements, N, P, K in prunings increased with shortening pruning interval and number of prunings. Levels of Ca and Mg increased with shorter pruning interval and decreased with increasing number of prunings (Table 2). Nutrient levels in young wood was higher than in old wood and in the pruned than the unpruned trees (Table 3). These observations agree with the established fact that accumulation of plant nutrients is higher in younger and actively growing tissues than in older tissues. It was not clear why levels of Ca and Mg declined in pruning with shortening pruning interval.

The higher nutrient concentration of young wood developed during the dry season than the wood developed in the wet season is due to higher percentage dry matter as a result of reduced moisture content. Such changes in moisture content are more dynamic in young wood than in older wood. The variations in nutrient composition with pruning interval, different plant parts and between seasons is, therefore, an important consideration in optimization of biomass and nutrient yield from calliandra in alley cropping.

5.2.0 Maize growth, biomass production and grain yield

5.2.1 Maize plant height

The rate at which the dry weight of the whole plant increases (crop growth rate) is contributed in part by increases in plant height (Sayre, 1948). Results from this study showed that at all stages of growth, maize height increased with increasing fertilizer nitrogen and pruning application (Fig. 1). Since nitrogen is the most limiting element for growth and yield production in maize, increasing N-supply in the soil by pruning or fertilizer application is expected to increase N-uptake. However, this effect was not significant and a disparity was observed at 6 WAP. Application of 45 Kg N ha^{-} alone significantly depressed plant height at this stage, and no explanation could be given. The poor growth rate on control plots with chlorosis is indicative of the inadequate N-supply, which resulted in delayed tasselling and silking by approximately one week. The result also suggests, that calliandra prunings were as effective as application of 45 Kg N ha^{-1} in increasing the plant height. The effect of increasing N application to 90 Kg ha^{-1} was minimal and therefore unnecessary.

Similarly, differences in height between plants growing adjacent and further away from calliandra hedgerows were not significant. The slight depression in height of plants adjacent to hedgerows was probably due to competitive interactions and shading between the hedgerows and maize plants. This height depression had also been observed by Yamoah et al. (1986b) in alley cropping of leucaena and maize who attributed such effects to the possible nutrient and water competition. Perhaps it is inevitable to tolerate a certain amount of shading in alley cropping as long as it does not adversely affect crop grain yields in order to maximize biomass production from hedgerows. This is supported by the studies of Fischer and Palmer (1984) who have concluded that shading is only crucial about two weeks around flowering time when it can significantly decrease the net assimilation rates and grain yields.

5.2.2 Maize leaf area

Mineral nutrition of maize plants appears to influence grain yield mainly by affecting leaf area produced early in the growing period and the length of time leaves remain functional during grain formation. (Hanway, 1962). Results from this study showed that the leaf area index at 4 and 8 WAP was only significantly increased by 90 Kg N application (Table 4). Leaf area index at 4 WAP ranged from 1.04 for control to 1.98 at 90 Kg N ha^{-1}. Respective values at 8 WAP were 2.04 and 4.44. This is attributed to the increased N-supply available for vegetative growth.

Leaf area index values at 8 WAP compares well with those obtained by Fischer (1984) of between zero to 7.5. Hanway (1962a) also found that total dry matter and grain yield per plant were primarily a function of the weight of leaves which in itself is a function of leaf area. In the absence of other limiting factors, it would be expected that increasing leaf area would result in higher maize yields. However, there was a slight decrease in grain yield at the highest leaf area index values which coincided with the highest N-application rate. This could have been due to mutual shading of the upper leaves which resulted in reduced light interception and lower assimilation rate by the leaves. Moss et al. (1961) reported, that photosynthesis in maize leaves increased linearly with increasing incident radiation at a leaf area index of 4.0, which was approximately the upper limit value obtaining in this experiment. The decomposition rate and mulching effect of applied prunings on soil temperature, moisture and nutrient availability could have contributed to these effects.

5.2.3 Percentge N in maize leaves

Although maize leaves constitute only about 13°% of total dry matter before tasseling, they contain more than 30% of the total nitrogen, 20% of total phosphorus and 30% of the potassium taken up by the plants at 8 WAP (Hanway, 1961; Berger, 1962). The concentration of N in particular tissues of maize plant can and has been used to diagnose the N availability in the soil. In the present experiment, the effect of prunings and nitrogen on the nitrogen status of the maize crop was assessed by the analysis of N in index leaves at 4 and 8 WAP (Table 4) and the effect in dry matter production at 6 WAP (Fig. 4.2.2).

There were no pronounced treatment effects on N-content of maize leaves at 4 and 8 WAP. Application of 90 Kg N ha^{-1} was significantly different from control at 4 WAP while a combination of both prunings and nitrogen rates was significant at 8 WAP. Bennet et al (1953) have obtained similar results where N application significantly increased percent N in maize and which was positively correlated with grain yield upto 2.8% N. The effect of application pruning at 4 WAP was not significant probably due to the slow decomposition of the material as a result of low moisture availability during early part of the growing season (Appendix 1). Decomposition and mineralization of prunings at 8 WAP was probably faster probably due to better moisture supply. In addition, N from initial prunings was slowly becoming more available and interacted with inorganic nitrogen to significantly increase %N.

In between the two growth stages, the %N in leaves increased in the no nitrogen and 45 Kg N treatments but decreased steadily with higher nitrogen rate and pruning application. This was because plants supplied with adequate nitrogen reache tasselling and silking stages earlier and translocation of N from leaves to grain formation could have commenced.

5.2.4 Maize dry matter production

Accumulation of dry matter maize plants at 6 WAP was found to respond positively to pruning and increasing nitrogen fertilizer applications (Fig. 2). A stage of linear plant growth and linear increase in dry matter production has been observed by some workers (Hanway, 1962; Bromfield, 1969). At this stage of plant growth, dry matter accumulation is a linear function of time and depends on nutrient availability. In this study, this was reflected in the significant increase in the earleaf nutrient composition with fertilization two weeks later. The response to both prunings and nitrogen fertilizer, however, diminished with increasing N application rate and reached a peak (52.6 g plant^{-1}) at 90 Kg N ha^{-1}. This would perhaps explain why addition of prunings at this N-application rate resulted in a reduced dry matter production (43.5 g plant^{-1}). The results suggest that since dry matter and grain yield are directly related, nutrient addition at this stage can help to prevent expected yield losses.

5.2.5 Maize earleaf nutrient composition

A relatively high proportion of the plant N is found in the leaves prior to grain formation period. The nutrient concentration of maize leaves at silking stage have been used both to determine total nutrient uptake and to diagnose nutrient deficiences resulting from variations in soil fertility (Tyner, 1947; Sayre, 1948; Bennet et al. 1953; Hanway, 1962; Melsted et al., 1969). High and positive correlation with dry matter production and grain yields have been obtained in these studies.

Results from this study indicated clear trends that N, P and Mg concentrations increased, though insignificantly, with increasing nitrogen resulting from increasing nitrogen fertilizer and pruning application (Table 5). This may suggest that increasing N-application facilitates uptake of other nutrients in the earleaf which agrees with the results reported by Krantz and Chandler (1951). They showed that N application increased N, P and K contents in leaves. The fact that pruning application increased both N and P levels at 0 and 45 Kg N ha^{-1} reflects the greater availability of other nutrients in the prunings. These results are consistent with those of Read et al. (1985) who observed a significant (17%) increase in maize earleaf N-status by leucaena prunings. Bennet et al. (1953) obtained similar results and found a definite linear relationships between yield and N and P contents of leaves. Alley cropping studies with similar or slightly differing results from those obtained in this experiment include; Koudoro (1982) who reported that application of leucaena and gliricidia prunings significantly improved N, P and K in maize earleaf both with or without fertilizer applicaiton and Kang et al. (1981a) who found that leucaena prunings and fertilizer application increased K and Ca but decreased P percentage.

That the earleaf N values were higher than those obtained for maize leaves at 4 and 8 WAP, suggest that N-accumulation in the plant was continuous, but this would be expected to decline at the onset of the grain-filling stage. The earleaf N contents (1.77-2.58%) were lower than those considered sufficient in Nigeria (3.10-3.25%) (Agboola, 1972) but the P contents (0.19-0l29%) compared quite favourably (0.23-0.27%). The same trend was observed to be valid when the values were compared with those from Melsted et al. (1969) and Tyner, (1947) who reported critical concentration levels of the two nutrients at 2.60-3.10% and 0.23-0.30%, respectively. However, N-deficiency symptoms were only observed on plots without N application and those treated with 45 Kg N ha^{-1} without prunings.

5.2.6 Maize grain and stover yield

Most alley cropping studies in the humid and subhumid tropics have consistently reported sustained or improved maize yields (IITA, 1981-1984; Kang et al. 1981; 1984; 1985; Ngambeki, 1985;

Yamoah et al. 1986). Indeed, Kang et al. (1984) have demonstrated that grain yields can be maintained at 3.8 tons ha^{-1} for 2-3 years and at 2.0 tons ha^{-1} for 6 years with addition of leucaena prunings alone.

Results from this study indicated that both grain and stover yield were significantly increased by fertilizer and application of calliandra prunings. Application of prunings alone was as effective as the application of 45 Kg N ha^{-1} in increasing maize yields (Table 6). The significant pruning effect was probably enhanced by the prolonged and slow N-release characteristic of decomposing legume tissue. It could also be due to the strategic application of secondary prunings just before the maize tasselling/silking stages. Another factor would have been the additional nutrients supplied by prunings and the beneficial influences of mulch on soil moisture and temperature. The effect of prunings could perhaps be improved by spreading pruning application over a longer period instead of adding all prunings at the same time which is the current practice. Even with the resultant storage problems, the low efficiency of N-utilization from prunings could probably be improved. In support of this, some results from pot trials by Kang et al. (1981a) showed that prunings applied two weeks before planting were more effective than when they were applied at time of planting maize. In contrast with inorganic N, the low utilization efficiency may be more than compensated by additional nutrients (P, K, Ca, Mg) provided by prunings and the possibilities of positive residual effects on succeeding crops due to slower mineralization and less leaching losses.

Increasing the efficiency of nitrogen use from organic sources is reported as a major drawback to the utilization of prunings from hedgerows in alley cropping (Guevarra, 1976; Kang et al. 1981b). Results from this study suggest that application of pruning was more beneficial than increasing fertilizer application because fertilizer apparently promoted excessive vegetative growth at the expense of grain yield. This was reflected in the lower grain stover ratio at each fertilizer application rate without pruning application. In fact, increasing fertilizer rate from 45 to 90 Kg N ha^{-1} slightly reduced the grain stover ratio. This finding supports other results in this study estimating the optimal N-requirement for maize crop at this site at about 96 Kg N ha^{-1}. The range in grain yield (1.8-4.9 ton ha^{-1}) was slightly higher than the 2.0-3.3 tons ha^{-1} reported in IITA (1987/88) under similar calliandra alley cropping.

A consideration of per plant grain yield in relation to position to calliandra hedgerows (Table 7) indicated that in the absence of nitrogen fertilizer, addition of prunings significantly increased yields irrespective of position and that there was a significant effect at each N application level. However, grain yield was not significantly affected by a combination of prunings and nitrogen fertilizer, but the mean per plant grain yield was significantly higher for plants in middle rows than those adjacent to hedgerows. This yield depression was also observed by Yamoah et al. (1986b) and was probably due to the competition for moisture, nutrients and for light due to shading. The trend for per plant grain yield was consistent with the total grain yield results obtained above where prunings and nitrogen application increased grain yields. The fact that yield were depressed by hedgerows expresses the need for further research into the actual mechanisms by which this is caused and specifying tradeoffs that are intrinisically associated with the alley cropping.

5.2.7 Nitrogen concentration in grain and stover

Large proportion of N translocated from stalks and leaves to the grain, with a maximum accumulation rate during the tasselling and silking stage (Sayre, 1948; Hanway, 1962b). The N-nutrition of maize plants at this critical period therefore becomes very important in order to maximize N-uptake and yield.

Results from this study (Table 8), indicating increased N-level in grain with pruning and N-application supports this view. N-uptake increased because of increased N availability in the soil. This effect was more pronounced in plants grown adjacent to hedgerows apparently due to additional biologically fixed N by calliandra roots or that contributed solely by leaf litter. Viets et al (1954) also reported significant increases in grain N-content with increasing N application. The N-content in stover followed the same trend. However, N-content in plants adjacent to hedgerows was lower than those in the middle of the alley. This could be due to higher rates of N-translocation to grain from plants adjacent to hedgerows as a result of the higher N-supply from both fertilizer application and biological fixation.

The relationship between N in grain and stover and the respective yields was positive and linear. There was a greater removal of N by the stover (52.5 Kg N ha^{-1}) than by the grain (43.6

N Kg ha^{-1}) because stover yield was higher than grain yield while the mean N-concentration levels were comparable.

There is no doubt that removal of maize stover from cropland is detrimental to soil nitrogen status and subsequent crop, and that retaining maize stover is a sound management practice for enhancing soil physical and chemical properties. The minimum nitrogen applications to sustain yield levels obtained in this experiments would therefore be equivalent to the total amount removed by stover and grain (96 kg N ha^{-1}). Results from grain yields indicate that about 50% of this nitrogen requirement (45Kg) can be supplied by calliandra prunings alone.

5.3.0 Cowpea plant height, leaf area index and dry matter production

Plant height and leaf area index are good indicators of the rate of cowpea dry matter production during the vegetative and early reproductive stages of development. The main determining factor in plant growth and dry matter accumulation is leaf area development which is largely dependent on the N-nutrition status; but since cowpea is able to fix its own nitrogen, temperature and light interception, rather than nutrition, became more important (Summerfield et al 1977, 1983; Earl and Joao, 1988).

5.3.1 Cowpea plant height

The results from this study showed no significant differences in plant height due to application of pruning and residual nitrogen (Fig. 3). This implied that nitrogen was not a limiting factor, and that levels of shading by the hedgerows was also not critical.

During ththis season, only one pruning was done and this was done early enough in the crop growing period (4 WAP). However, in addition to making pruning and weeding cumbersome, it was observed that cowpeas rows grown adjacent to hedgerows experience substantial shading by virture of their small mature size, suggesting need for earlier or more pruning times. Since additional pruning application would not be beneficial to cowpea growth or yield production, the problem may be countered by reducing plant population. By removing one row of cowpeas from each alley, the plant population could be reduced from 70,000 to 53,000 plants ha^{-1}, corresponding to a yield reduction of approximately 118 Kg ha^{-1}. For the same alley cropping system, IITA (1987/88) has reported an optimum cowpea population of 53,000 plant ha^{-1} with a yield reduction of 120 Kg ha^{-1} from 6 to 5 rows in each alley.

5.3.2 Cowpea leaf area index

Similarly,, leaf area index was increased, though not significantly by pruning and residual nitrogen application (Fig. 4). At all growth stages leaf area index was increased more by prunings at every fertilizer rate. The mean leaf area index range was 0.77, 2.54 and 6.87 respectively at 2, 4 and 6 WAP, the latter value coinciding with the onset of flowering. It appears that the effect of residual nitrogen was to cause a luxurious consumption of N which resulted in greater leaf area development. Summerfield et al. (1985) reported that a maximal light interception under humid conditions is achieved with an LAI greater than 5, which in this study was achieved at 6 WAP. It is also likely that higher residual nitrogen could reduce nodulation and biological nitrogen fixation, as observed by Singh et al (1987), causing excessive vegetative growth which could adversely affect yields. The better performance of prunings was probably due to addition of other nutrients from prunings, especially P, which has multiple effects on cowpea nutrition. These range from nodulation, nutrient composition in leaves and seed production (Muleba and Ezumah, 1985).

5.3.3 Cowpea dry matter production

Trends in dry matter production closely followed those of leaf area except that treatment differences were significant at 4 WAP. This would be expected since rates of dry matter production primarily depend on the proportion of leaf area utilizing intercepted light in addition to the photosynthetic and respiration rates. The very low leaf area index and dry matter production in the absence of nitrogen and pruning application is a positive indication that cowpeas respond to N-application at this location. This agrees with the findings of Donald and Theodore (1984) who indicated that increasing the combined N in the soil solution from zero to 2.0 Mmoles often promotes growth and N_2 fixation of symbiotically grown legumes and that growth of legumes which are entirely dependent on rhizobium for a source of N was primarily N-limited.

5.3.4 Nutrient composition of cowpea plants

The rate and efficiency with which applied nutrients are taken up and utilized by plants is normally diagnosed by tissue analysis. Analysis of whole plant samples in this study indicated that application of 90 Kg N ha^{-1} to previous maize crop significantly decreased % N levels at 4 and 6 WAP while % N levels were increased by pruning application (Table 9). Apparently, high levels of applied N in the soil create nutrient imbalances which inhibit further N-uptake . This is possible since other nutrients, especially P and K, are known to be more limiting to cowpea growth and yield production than nitrogen depending on soil type and cowpea variety (Huxley, 1980). The observed increase in N-contents by pruning application was due to a positive nutrient balancing effect in the soil through addition of other nutrients from pruning decomposition. The higher mineral nutrient composition of plants near hedgerows than those in middle rows (Table 10) lends further support to this hypothesis due to the fact that there is more litter fall and root decay all of which decompose to provide other essential nutrients.

5.3.5 Weediness in cowpea

Many alley cropping studies, for example Kang et al. (1981) and IITA, (1982), have reported its beneficial effect in suppressing weeds through shading by the hedgerows and mulch application.

In cowpea, the critical weeding time is during the first 4-6 WAP when the crop is establishing ground cover. The results obtained from this study at 4 WAP showed that pruning application significantly increased weediness and also affected weed flora (Table 11). Residual nitrogen had a similar though nonsignificant effect. The pruning effect was most likely due to the increased availability of nutrients from decomposing prunings which improved the soil fertility that promoted not only weed growth, but also crop growth as observed earlier on leaf area development and dry matter production.

These observations suggest that pruning application is unnecessary and that residual nitrogen is harmful to a cowpea crop since they both promote weed growth which would compete unfavourably with cowpea for light, water and nutrients. The degree of such competition and its effect on seed yield would depend on crop growth stage and the weed management practice.

5.3.6 Cowpea seed yield

Cowpea yields are influenced by many agronomic practices, including date of planting, plant population, soil fertility status, weed control and cropping patterns.

In this study, inferences were earlier made from soil fertility and weed growth investigations on plant biological characters (leaf area index, dry matter production and nutrient composition in plants) which have a bearing on final grain yield. Results from seed yield followed similar trends. The superiority of prunings over inorganic nitrogen was probably due to addition of other nutrients. It is also possible that reduced nodulation due to excess inorganic N caused excessive vegetative growth at the expense of seed production as was noted earlier with leaf area index and dry matter production. Consequently, highest yields were recorded on plots with lowest dry matter production where no nitrogen had been applied with or without prunings.

Other studies on alley cropping with calliandra, leucaena and gliricidia have also reported nonsignificant or slight negative effects of prunings and nitrogen application on second season cowpea (Kang et al. 1984; Ngambeki, 1985; Gichuru and Kang, 1989).

A significant pruning effect and a spatial variability with respect to calliandra hedgerows was however observed on number of pods per plant and seed yield (Table 13 and 14). Plants grown in middle of alleys performed better than those near hedgerows although this was not reflected in the total seed yields. The reduction in number of pods and yield of plants adjacent to hedgerows was probably due to icnreases in N nutrition from biologically fixed N, litter fall and decomposing roots. This is supported by the fact that lowest yields were recorded on plots where 90 Kg N ha^- had been applied and highest yields on plots without nitrogen application. The possible effect of some shading cannot be completely excluded considering that light is critical in cowpea growth and yield production and that pod formation continued well into a stage where calliandra hedgerows were substantially shading the crop. Perhaps light measurements taken at strategic stages in the growth cycle would have explained these differences more adequately.

5.4.0 Soil properties

The maintenance and improvement of soil physical, chemical and biological properties is a fundamental premise for sustained yield which, in alley cropping is met through organic matter addition in form of prunings. Results of soil analysis data from this experiment at the beginning of the cropping period indicated higher organic C and nutrient status with pruning and increased N-application and a lowering of pH by nitrogen application or pruning removal (Table 15). The increased nutrient status was most likely a result of the organic materials and nutrients added or replacement of leached nutrient by prunings. The lowering of pH was only slight but the effect could become significant in the long term leading to gradual soil acidification and decline on productivity as reported earlier by several workers (Allan, 1965; Bache and Heathcote, 1969; Nnadi and Arora, 1985). The higher availability of nutrients in the top soil layer probably accounts for the ability of the maize and other crops to compete effectively for nutrients with hedgerows without large yield reductions. In this study, this was confirmed by the nonsignificant yield differences between either maize or cowpeas grown adjacent and further away from hedgerows in this study. It is unlikely that nutrient levels due to pruning application can build up to significant levels within the short term of this study, which may explain the inconsistencies observed with individual nutrient elements.

At the end of the cropping cycle, the levels of N, P, Ca, and Mg and organic carbon declined (Table 16) due to removal by crops and probably other losses including leaching, volatilization and immobilization by soil organic biomass. The decline in soil organic matter, leading to soil exhaustion and depletion has been observed by Ahn (1979) and the reduction in N, P, and K levels in alley cropping trials with gliricidia, cassia and flemingia specifically reported by Yamaoh et al. (1986c) and Kang et al. (1985). It seemed that there is a build up of soil organic carbon during the dry season fallow period which probably occurs through litter fall and root biomass decomposition. Indeed, the most recent studies suggest that dry matter production and organic carbon returned to the soil through root biomass and fine root death and decomposition could potentially be as high as that expected from root biomass (Huxley, 1989; Sanginga, Pers. Comm). This would explain the slightly higher organic carbon levels observed before cropping than at the end of cropping. However, the decline in organic carbon and other nutrients was smaller in plots receiving prunings than with the non-pruning treatments (Table 15 and 16). The decline was more in the upper 0-5 cm than in the 5-15 cm soil surface layer. Indications from this study suggest that there are definite beneficial effects of prunings on soil chemical properties, whose impact is probably of a longer term nature. It also shows that favourable physical and biological effects due to pruning application could probably interact positively to contribute to the observed increases in crop production under a calliandra alley cropping system.

5.5.0 Decomposition of calliandra prunings and stover

Calliandra prunings and maize stover are, respectively alternative sources of organic matter on an alley-cropped and a non-alley cropped farms. The nitrogen concentration, lignification levels and other chemical constituents influence decomposition and nutrient release rates of these organic materials and, subsequently, their capacity for enhancing soil fertility. Van Schreven (1968) and Read et al (1985) have observed that woody materials are less readily decomposed than leafy materials and that fresh materials more than dried ones.

Results from this study showed that calliandra prunings decomposed 4 times faster than maize stover (Fig. 5). This was mainly due to large differences in C:N ratio which were respectively 3:1 and 13:1. Read et al. (1985) have also reported that leucaena pruning decompose faster than maize stover. Materials with a narrow C:N ratio provide microbes with the necessary nitrogen to build up their body proteins, and as pointed out by Parr and Papendick (1978), plant residues with less than 1.5-1.7 % N decompose slowly because of N-deficiency and other nutrients necessary to sustain microbial population. The N concentrations of calliandra prunings and maize stover were, respectively 3.2% and 0.8%. In 14 days, 90% of the calliandra prunings and 34% of the maize stover had decomposed. This rapid decomposition eventually slowed down in the following 4 weeks probably due to slower decomposition of stems, leaf veins and other more durable portions of prunings. After 49 days, all calliandra prunings had virtually decomposed while about 32% of the maize stover remained undecomposed. It is likely that there were also quantitative and qualitative differences between arthropod fauna associated with the decomposition of calliandra prunings and maize stover. The time period for complete decomposition of calliandra prunings sharply contrasts with the 120 days reported for gliricidia prunings by Yamoah et al. (1986a).

With an average prunings application of 2 tons DM ha^{-1} from a single pruning, the estimated nitrogen contribution during the period would then have been 64 Kg N ha^{-1} out of which 50% (32 kg) would be released in the first 7 days. The equivalent of 10.6 tons ha^{-1} of dried maize stover would be required in order to have the same effect, with 50% of the nitrogen being contributed in about 18 days. The rapid decomposition of calliandra releases large amounts of nitrogen over a short time while the slow decomposition of maize stover in addition to nitrogen provides good ground cover for a longer period. At farm level, therefore, a combination of calliandra prunings for nutrient contribution and the mulching effect of maize stover may be the most desirable option for improving and sustaining soil chemical and physical properties.

5.6.0 Decomposition of green and dry wood of calliandra gliricidia, leucaena, cassia, and acioa

The decomposition of leaf and stem material of leguminous trees can be of considerable importance in the transfer of symbiotically fixed nitrogen to associated crops. In alley cropping, the woody part of cutbacks from first prunings are usually returned into the soil together with branches, young twigs and leaves. The relative propotions of these components and their decomposition rates vary with species and pruning frequencies, and so does the total nutrient contribution. Woody materials decompose less readily than prunings while green wood decompose more readily than dry wood mainly because of differences in C:N ratio and moisture content. In this study, the decompositon rate of green wood material closely followed this pattern with respect to C:N ratio and moisture content in the order leucaena > calliandra > gliricidia > cassia > acioa (Fig. 6). The respective C:N ratios and moisture content were 4.2:1, 5.6:1, 6.8:1, 10.4:1 and 14.4:1; and 66, 56, 44 and 46%. In related studies on decomposition of prunings, gliricidia cutbacks and prunings have been reported to decompose faster than those of cassia (Yamoah et al; 1986a). The fact that decomposition rates were slightly reversed in dry wood materials was probably due to daily changes in moisture supply causing uneven wetting and drying periods. It could also be due to other factors such as earthworm and termite activity which are less affected by moisture and C:N ratio than other microbial organisms for decomposition.

Compared to calliandra prunings, calliandra green wood takes 4 times as long to reach 50% decomposition and contributes only about 19% as much nitrogen (13 kg N ha^{-1}) from the same amount of biomass (2 tons DM ha^{-1}). It is therefore necessary to retain both pruning and wood portions back to the soil for best nutrient cycling results. The slower release of N from wood ensures availability of plant nutrient over a longer crop growing period. In terms of N-supply from decomposing tissues to associated crop, the main advantage of the legume prunings over inorganic N source is the possibility of maintaining soil organic N concentrations to ensure longterm delivery of N to succeeding crops. It also appears, that calliandra can effectively compete with leucaena and gliricidia in N contribution to soils so long as its biomass production can be increased to match these other species. Available literature indicate little or no efforts at breeding in that direction whereas great achievement have been made with leucaena and gliricidia.

5.7.0 N-manuring value of dried calliandra and gliricidia leaves for maize

In alley cropping, leguminious trees can be intercropped and prunings applied onto the soil as green mulch or manure to benefit associated crops; or tops can be harvested and transported to be applied as fertilizer in other fields. The amount of N released will then be determined by the rate of decomposition which inturn is influenced by the N-concentration of the mulch materials, moisture supply, temperature and the composition and quantity of decomposers (Henzell and Vallis, 1977). The results from pot trials on the use of dried calliandra and gliricidia leaves as green manures when compared to inorganic N source (Table 17) can be explained by some of these factors. CAN was superior to Gliricida at 50N and 100N application rates in increasing plant height, dry matter production and N-content because of the initially higher N availability. Read et al, (1985) also found that CAN was more effective than green or dry leucaena in increasing maize dry matter and that fresh leaves were better than dried leaves. Gliricidia was more effective than calliandra at both rates because as shown in Appendix 5, gliricidia leaves have a higher N-concentration (3.63%) than calliandra (3.01%). However, the depressing effect of calliandra leaves on plant height, dry matter and N-content was possibly due to exudation of toxic substances which inhibited N-uptake by the plants (Table 20 and 21).

5.8.0 N-manuring value of fresh and dried leaves incubated over different time periods

Comparison between incubated green and dried leaves of calliandra and gliricidia as N-sources for maize indicated, that green leaves were better than dry leaves in increasing plant height, dry matter production and N-content, and that this effect increased with increasing incubation time though not significant at 3 WAP (Table 18). Except for calliandra dry leaves at 50 N application rate, differences between 100 N and 50 N rates were also significant both for green and dry leaves at all three incubation time periods (9, 6 and 3 weeks). The effect of drying the legume leaves seem to reduce mineralization of N thus giving a relative advantage of green over dry leaves. Indeed, Henzell and Vallis (1977) have reported that in unpublished work by the first author, dried leaves of Desmodium intortum were found to mineralize only $^{2}/_{3}$ as much N as fresh leaves. In absolute terms, the available N from dried leaves is considerably reduced. An additional factor is the lower N concentration in dried leaves than in green leaves (Appendix 5).

Plant N-uptake and dry matter production were consequently enhanced by increasing availability of N. This is shown by the consistently better performance at higher rates of N-application irrespective of the N-source. The absence of the inhibitory effect of dried calliandra leaves observed in the previous experiment could be attributed to the additional time given for decomposition to take place.

A noteworthy observation, was the increased effectiveness of incubated legume leaves as green manure and the decreased performance of inorganic N-source. At 100 N application rate, gliricidia and calliandra leaves were better than CAN. At 50 N application rate, CAN was comparable to dry calliandra leaves but less than green and dry gliricidia leaves. This implies that there were considerable N-losses from CAN by leaching or other processes and increased N-mineralization from legume leaves during the incubation period.

The distinctive trends of green leaves > dry leaves at all rates and periods were apparent when N-concentration and N-content in plant were compared and could be explained in the same way as plant height and dry matter production. And for similar reasons, dry gliricidia and calliandra leaves and CAN at 50 N rate were comparable but better than control.

Results from subsequent maize crop showed similar effects due to periods and treatments (Table 19). The average height of plants in all treatments was less than in first crop, due to lower nutrient levels. Green leaves of both gliricidia and calliandra at the higher rate of application had respectively the best residual effects on plant height and dry matter production due to initially better maize growth in the first crop with CAN.

In field trials Read et al. (1985) found that dry leaves had a greater residual effect than green leaves due to their slower decomposition and N-mineralization, but the reverse was infact found to be true in this greenhouse study. Because of the lower N concentration in dry leaves used in this experiment, and since most of this N would be released during the first cropping, it is probable that only a very minimal amount was available for the subsequent crop.

An additional factor is the fact that large amounts of N could have been lost by leaching and volatilization during the incubation periods. This, however, does not help to explain why significant residual effects were observed with inorganic N-source, unless N-losses from dry legume leaves proceeded at a higher rate than from CAN. The general but nonsignificant reduction of N-concentration with increasing incubation period is an indication of the fact that legume leaves incubated for a longer period have lost more N than those incubated over a shorter period.

CHAPTER SIX

6.0 SUMMARY AND CONCLUSION

Studies to investigate the potential of calliandra for alley cropping were conducted at the International Institute of Tropical Agriculture (IITA), Ibadan, in South-western Nigeria from February to December 1988. The trials were composed of a field study with sequentially grown maize and cowpea superimposed on a calliandra plot grown in hedgerows. A field decomposition study with calliandra prunings, maize stover and wood of several alley cropping tree species and a greenhouse study on N-manuring value of calliandra and gliricidia leaves were also carried out.

The main objective of the alley cropping trial was to evaluate the growth and yield performances of the tree and crop components in the system. The specific objectives were as follows:

(a) To determine the growth biomass production and nutrient cycling potential of calliandra. Measurements were taken on plant height and dry weight of pruning at first cutback and in subsequent pruning times. Nutrient analysis (N, P, K, Ca and Mg) of pruning and wood was also done.

(b) To determine the effect of calliandra prunings and inorganic nitrogen fertilizer (CAN) on growth and yield performance of sequentially grown maize and cowpeas. For maize, measurements were taken on plant height at 4, 6 and 8 WAP; leaf area index and N-concentration in leaves at 4 and 8 WAP; dry matter production at 6 WAP and nutrient composition of earleaf analysed at silking stage. Grain and stover yield and their respective N-concentrations were determined at harvest. For cowpeas, plant height, percentage N in plant, leaf area index and dry matter production were taken at 2, 4 and 6 WAP. Weed growth was assessed at 4 WAP and the number of pods and seed yield at harvest.

(c) To determine any changes in soil chemical properties due to cropping and the treatments imposed. Soil chemical properties were analysed at beginning and end of the cropping cycle for the two depths of 0-5 cm and 5-15 cm.

The objective of the decomposition study was to determine and to compare the decomposition rates of calliandra prunings and maize stover and those of green and dry wood of calliandra, leucaena, gliricidia, cassia and acioa to obtain a better view on the nutrient release into the soil. For calliandra prunings and maize stover, the dry weight and N-concentration were analysed at weekly or fortnightly intervals for 8 weeks. For woody materials, dry weight was taken at monthly intervals for 4 months.

The greenhouse study was designed to evaluate and compare the effect of calliandra and gliricidia dried and green leaves on the dry matter production and N-uptake of maize and to elucidate possible residual and allelopathic effects of the same. Plant height was measured weekly for 3 weeks and the dry weight and N concentration of harvested crop determined. Possible allelopathic effects were assessed in the laboratory by measuring germination percentage, length of radicle and plumule and the number and length of secondary roots on germinating maize seed.

The following are the highlights from the findings of this study:

The growth of pruned calliandra trees was observed to be rapid in this environment. A height increase of 25 cm per week, a maximum of 35 stems per tree, a one year's growth of 306.7 cm and a biomass production of 5.0 tons DM ha^{-1} from four prunings were recorded. Nutrients contributed through prunings amounted to 185 Kg N, 13.3 Kg P, 64.2 Kg K, 55.2 Kg Ca and 16 Kg Mg ha^{-1}. The nutrient concentrations in pruning were higher than in wood and in younger than older wood, tissue. Pruning the calliandra trees promoted coppicing and increase in number of pruning times reduced total biomass production. Compared to leucaena. calliandra growth was slower, with coppicing ability comparing favourably, but leucaena produced substantially more biomass.

Maize plant height increased with increasing inorganic N and pruning application at all growth stages but this effect was not significant. Plant height was lowest on no fertilizer treatments without pruning application and prunings alone was as effective as 45 Kg N ha^{-1} in increasing plant height. There was a slight but insignificant depression of height in plants growing adjacent to hedgerows.

Leaf area index taken at 4 and 8 WAP was significantly increased by nitrogen and pruning application but this response was observed to diminish at increasing N application rate. The correlation between leaf area and dry matter production was highly positive.

There was no pronounced treatment effects on percentage N in maize leaves at 4 and 6 WAP, but at 4 WAP application of 90 Kg N ha^{-1} was significant from control and the interaction with prunings was significant at 6 WAP. In between the two growth stages, the percentage N in leaves increased in no nitrogen and 45 Kg N ha^{-1} treatments but decreased steadily with further N or pruning application. Earleaf nutrient composition showed that levels of N, P and Mg increased with increasing nitrogen and pruning application but only N was significant while K and Ca remained largely unaffected. Even though values obtained were lower than those considered sufficient in this location, no deficiency symptoms were observed except on control plots.

Maize grain and stover yields were significantly increased by inorganic N and pruning application. The grain stover ratio was however reduced by application of 90 Kg N ha^{-1}. Even though large amounts of N were supplied by prunings, the effect of prunings was only comparable to that of 45 Kg N ha^{-1}. Hedgerows significantly reduced per plant grain yield of plants grown adjacent to them. In contrast, maize plants grown adjacent to hedgerows accumulated more N in grain than those in middle rows. Overall, there was greater removal of N by stover than by maize grain.

Cowpea plant height and leaf area index at 2, 4 and 6 WAP were not influenced significantly by either prunings, residual nitrogen or proximity to calliandra hedgerows. Dry matter was significantly increased by residual nitrogen and pruning application at 4 WAP but the effects were not significant at 2 and 6 WAP. The percentage N in whole plants was significantly increased by residual 90 Kg N ha^{-1} at 4 and 6 WAP and prunings gave higher N-levels than treatments without prunings. Nutrient compostion at flowering time did not show significant treatment effects but plants near hedgerows showed higher nutrient status than those in middle of alleys. Pruning application had a significant effect on weed growth which was not observed with residual inorganic N, but both promoted growth of broad leaved weeds whereas grasses and sedges were more common on no nitrogen treatments. Grain yields were not significantly affected by prunings or residual nitrogen. Pruning application slightly increased yields while residual nitrogen tended to decrease yields. However, position of cowpea plants relative to calliandra hedgerows had a significant positive effect on both number of pods and yield and the interaction with both pruning and residual N was significant too.

Soil analysis results showed, that at the beginning of cropping, there was a small but insignificant increase in organic carbon and nutrient status with pruning application and increased N application and a lowering of pH by nitrogen application or pruning removal. At the end of cropping, the levels of N, P, Ca, Mg and organic carbon declined. This decline was smaller in pruning than no-pruning treatments and in the upper 0-5 cm than the lower 5-15 cm depth.

Results from the decomposition study showed that calliandra prunings decomposed four times faster than maize stover, a rate that was proportional to their respective N-concentrations at the beginning of the trial. After 49 days, calliandra prunings had virtually decomposed while 32% of the maize stover was still undecomposed. Calliandra prunings also decomposed four times faster than calliandra green wood. The decomposition rate of green wood material closely followed their C:N ratios in the order leucaena > calliandra > gliricidia > cassia > acioa. The decomposition rate of green wood was faster than that of dry wood in all cases. For both green and dry wood, the decomposition rates of calliandra, gliricidia and leucaena were not significantly different but they were significantly different from those of cassia and acioa.

Results from the greenhouse trials showed that inorganic nitrogen was better than gliricidia and calliandra dry leaves in increasing maize plant height, dry matter production and N-content. The performance of gliricidia at 100 ppm, N was almost equal to that of CAN at 50 ppm, N rate. Calliandra leaves were found to be inhibitory and this effect increased at the higher rate of application. Incubation of green and dry leaves for periods of 9, 6 and 3 weeks did not improve performance significantly, but fresh leaves were better than dry leaves and gave a greater residual effect on subsequent crop. Calliandra and gliricidia green leaves at 100 ppm, N gave better performance than inorganic N source at same rate and no inhibitory effect of calliandra dry leaves was observed after incubation. The lowest values were obtained in no nitrogen control. Interestingly, extracts from dried leaves of gliricidia were observed to have more inhibitory effects than calliandra on germination, radicle and plumule growth, and on secondary root development of maize seed. In calliandra, however, whether the effect was stimulatory or inhibitory seemed to depend on concentration of leaf extracts and on the plant part. Germination and secondary root development were significantly improved at high concentrations (10%) while the number of roots, radicle and plumule growth were depressed.

On the basis of results obtained in this study, the following conclusions and recommendations for further research can be made on alley cropping with calliandra.

1. Calliandra has a great potential for biomass production and nutrient contribution in alley cropping but it is less adapted or suited than leucaena or gliricidia under the environment of this experiment. More studies on calliandra productivity under different pruning and management regimes and in different ecological zones are needed to close the wide gap in knowledge and information.

2. Calliandra prunings contributed about 45 Kg N ha^{-1} to the maize crop which significantly improved certain plant biological and yield characters. Supplementation with inroganic N is needed to optimize yields but it seems unnecessary to apply additionally more than 45 Kg N ha^{-1} with pruning application, since additional nitrogen does not significantly increase maize yields but instead depressed the subsequent cowpea crop. Studies to quantify the efficiency of pruning N are necessary in order to determine the optimum levels of N supplementation under calliandra alley cropping.

3. *Calliandra* hedgerows invariably interfered with growth and yield production of plants grown adjacent to them either positively or negatively, implying that shading was not the critical factor. Root studies are needed to quantify their contribution and interaction effects with above ground factors in enhancing soil fertility status, nutrient uptake and yield of associated crops.

4. Alley cropping *calliandra* with sequentially grown maize and cowpeas is a viable cropping system because of its positive nitrogen economy and provision of other essential plant nutrients Prunings obtained during the cowpea season can be put to other alternative uses e.g. as livestock fodder or green manure to fertilize other piece of land. Some economic analysis studies are needed to substantiate these observations.

5. Decomposition rates of prunings and wood of alley cropping species are directly related to the N-concentration in these materials and therefore proportionate to the amounts of nutrients that can be released into the soil within a given time. Further decomposition studies with N^{15} are necessary to quantify the fate of N from prunings during and after crop growth in order to formulate pruning management regimes which optimise nitrogen use from prunings and are compatible with crop N requirements.

6. Fresh leaves of calliandra when used as green manure for maize growth are as effective as gliricidia leaves and can substitute upto 50% of the inorganic nitrogen requirements. This contribution is greater if the positive residual effects on subsequent crop are taken into account. Calliandra dry leaves may have to be treated (e.g. incubation) before they can be effectively used to benefit the crop. Studies are needed to isolate and quantify the allelochemical compounds associated with inhibitory or stimulatory effects on N-uptake and maize growth and to explain the mechanisms by which this takes place.

7. The beneficial effects of alley cropping with calliandra cannot be contributed solely to pruning application and presence of hedgerows. There are attendant changes in soil chemical, physical and biological properties which can only be evaluated in long term studies or under more intensively managed systems in the short term.

8. The substantial wood produced at first cutback indicate the versatility of calliandra in adapting to alternative management systems to produce other tree by products such as firewood and construction materials which may be socially and economically as important as improving soil fertility or increasing crop yields.

In summary, the aim of this study was to evaluate calliandra for alley cropping, with a view to indicating both its potential contribution in improving crop production and the alternative management strategies for its utilization under low input production systems. The results have shown that calliandra has good potential as green manure or mulch for crop production. It compares favourably with other alley cropping tree species in biomass production and nutrient yield and can be exploited for other economic tree by products. There are also positive indications from the results which might help in understanding some nutrient dynamics and plant growth responses under calliandra alley cropping. The study is by no means conclusive and further investigations and testing under different agroecological conditons are deemed necessary.

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Appendix 1. SUMMARY OF CLIMATIC DATA FOR IITA, CENTRAL STATION 1988

MONTH	TOTAL RAIN FALL mm	TOTAL EVAPO-RATION mm	MEAN WIND SPEED km/h	SOLAR RADIA-TION Gm-cal/ Cm^2/day	TEMPERATURE °C			RELATIVE HUMIDIT %			NO. OF RAIN DAYS
					MAX	MIN	MEAN	MAX	MIN	MEAN	
JAN	0.3	139.05	2.9	322.06	32.1	21.3	26.8	88	41	65	1
FEB	32.0	145.47	4.1	411.63	33.7	23.4	28.6	91	38	64	2
MAR	93.6	139.69	3.7	397.29	32.0	23.4	27.0	95	52	74	4
APR	203.9	150.69	4.1	394.91	31.2	22.7	27.0	95	55	75	15
MAY	115.0	133.60	3.2	403.71	29.9	22.2	26.1	98	63	81	8
JUN	293.5	111.43	3.8	350.19	29.1	22.4	25.8	98	69	84	13
JUL	168.1	91.17	4.6	302.22	27.9	22.5	25.2	95	71	83	13
AUG	86.1	80.65	4.4	257.31	27.3	22.2	24.8	96	71	84	16
SEPT	274.5	97.89	3.9	371.61	29.4	22.9	26.1	96	66	81	17
OCT	259.0	123.04	3.2	426.57	29.7	22.2	26.0	97	62	80	15
NOV	14.3	135.32	3.3	414.72	32.3	23.5	27.9	98	47	72	1
DEC	10.4	123.06	3.9	357.43	32.2	21.9	26.6	90	42	66	1

Source: Weather Bulletin, IITA, 1988

Appendix 2. Some physical and chemical properties of Apomu (Psammentic urstrothent) surface soil (1-5 cm) used in greenhouse trials.

Greenhouse experiment 1:

pH	OC (%)	T.N. (%)	Avail. Bray-1 P (ppm)	NH4 OAC. Exch. Cations ($meq100g^{-1}$) K	Ca	Mg	Na
5.4	0.57	0.05	2.8	0.11	1.50	0.66	0.19

% Sand	88
% Silt	8
% Clay	4
Texture	sand

Greenhouse experiment 2:

pH	OC (%)	T.N. (%)	Avail. Bray-1 P (ppm)	NH4 OAC. Exch. Cations ($meq100g^{-1}$) K	Ca	Mg	Na
5.4	0.69	0.05	3.4	0.22	0.59	0.31	0.20

% Sand	83
% Silt	5.5
% Clay	11.5
Texture	Loamy sand

Appendix 3. Nutrient concentrations, C:N ratios and moisture content of green wood materials used in decomposition trial at beginning of experiment.

	Nutrient composition %							C:N ratio	Moisture content (%)
	C	N	P	K	Ca	Mg	Mn(ppm)		
Calliandra	3.43	0.61	0.12	0.42	0.04	0.02	19.5	5.6	56
Gliricidia	3.61	0.53	0.09	1.44	0.17	0.03	25.0	6.8	56
Leucaena	2.85	0.68	0.09	0.76	0.06	0.03	19.5	4.2	66
Cassia	2.92	0.28	0.07	0.19	0.15	0.06	15.0	10.4	44
Acioa	2.01	0.14	0.05	0.42	0.02	0.05	21.0	14.4	46

Appendix 4. Nutrient composition of calliandra and gliricidia leaves used in greenhouse trials.

Leaf Material	Nutrient composition %				
	N	P	K	Ca	Mg
Dry calliandra	3.10	0.16	0.73	1.77	0.33
Green calliandra	3.68	0.18	0.95	1.38	0.27
Dry gliricidia	3.63	0.17	1.42	0.92	0.24
Green gliricidia	3.81	0.18	2.77	1.89	0.35

Apendix 5. The effect of incubation period and green and dry leaves of <u>calliandra</u> and <u>gliricidia</u> on plant height of first maize crop at 3 WAP in pot trial.

Treatment	Plant height (cm) for different incubation periods 3 weeks	6 weeks	9 weeks	Mean
O N Control	55.7	55.8	56.7	56.0
50 N, CAN	65.0	67.8	66.8	66.5
100 N, CAN	69.8	72.9	68.5	70.4
50 N, dry calliandra	67.2	70.8	72.2	70.1
100 N, dry calliandra	68.8	74.5	73.9	72.4
50 N, green calliandra	68.1	76.1	74.2	72.8
100 N, green calliandra	72.1	79.0	79.4	76.8
50 N, dry gliricidia	64.1	68.9	72.6	68.5
100 N, dry gliricidia	69.2	71.7	78.1	73.0
50 N, green gliricidia	67.3	69.0	74.9	70.4
100 N, green gliricidia	66.1	76.8	75.1	72.7
Mean	66.7	71.2	72.0	

LSD (.05) For period means 7.1
For treatment means 3.9
For treatment means within same period 6.8
For treatments means between different periods 9.5

Apendix 6. The effect of incubation period and green and dry leaves of calliandra and gliricidia on dry matter production of first maize crop at 3 WAP in pot trial.

Treatment	Plant weight (g plant $^{-1}$) for different incubation periods			
	3 weeks	6 weeks	9 weeks	Mean
O N Control	4.63	4.17	4.87	4.56
50 N, CAN	6.83	7.40	6.73	6.98
100 N, CAN	7.00	7.43	6.60	7.00
50 N, dry calliandra	7.00	7.00	7.50	7.17
100 N, dry calliandra	7.00	7.50	7.53	7.34
50 N, green calliandra	7.80	7.77	7.67	7.74
100 N, green calliandra	8.00	7.90	8.33	8.08
50 N, dry gliricidia	7.80	6.83	7.93	7.52
100 N, dry gliricidia	8.23	8.87	8.30	8.45
50 N, green gliricidia	8.27	8.23	8.33	8.28
100 N, green gliricidia	7.77	8.90	9.53	8.73
Mean	7.30	7.50	7.60	

LSD (.05)		
	For period means	0.34
	For treatment means	0.75
	For treatment means within same period	1.29
	For treatments means between different periods	1.27

Appendix 7. The effect of incubation period and green and dry leaves of calliandra and gliricidia on nitrogen concentration of first maize crop at 3 WAP in pot trial.

Treatment	Nitrogen concentration in plants (%) for different incubation periods			
	3 weeks	6 weeks	9 weeks	Mean
O N Control	1.07	1.14	1.17	1.13
50 N, CAN	2.27	2.23	2.18	2.23
100 N, CAN	2.69	2.54	2.40	2.54
50 N, dry calliandra	2.50	2.18	2.31	2.33
100 N, dry calliandra	2.62	2.46	2.51	2.53
50 N, green calliandra	2.58	2.08	2.23	2.29
100 N, green calliandra	2.76	3.08	2.83	2.89
50 N, dry gliricidia	2.31	2.39	2.56	2.42
100 N, dry gliricidia	3.15	3.09	3.11	3.11
50 N, green gliricidia	2.19	2.58	3.09	2.62
100 N, green gliricidia	3.16	3.24	2.99	3.13
Mean	2.48	2.46	2.49	

LSD (.05)		
	For period means	0.34
	For treatment means	0.36
	For treatment means within same period	0.63
	For treatments means between different periods	0.69

Apendix 8. The effect of incubation period and green and dry leaves of calliandra and gliricidia on plant height of second maize crop at 3 WAP in pot trial.

	Plant height (cm) for different incubation periods			
Treatment	3 weeks	6 weeks	9 weeks	Mean
O N Control	32.4	35.9	36.9	35.0
50 N, CAN	50.6	50.9	51.1	50.9
100 N, CAN	57.2	53.8	57.7	56.2
50 N, dry calliandra	55.0	50.8	51.8	52.5
100 N, dry calliandra	58.7	54.1	57.9	56.9
50 N, green calliandra	53.7	54.9	56.1	54.8
100 N, green calliandra	61.7	63.4	61.3	62.2
50 N, dry gliricidia	55.1	53.8	60.3	56.4
100 N, dry gliricidia	59.5	58.9	62.3	60.3
50 N, green gliricidia	53.4	55.8	57.9	55.7
100 N, green gliricidia	58.3	58.8	64.3	60.5
Mean	54.1	53.7	56.1	

LSD (.05)	For period means	4.1
	For treatment means	2.7
	For treatment means within same period	4.7
	For treatments means between different periods	5.9

Apendix 9. The effect of incubation period and green and dry leaves of calliandra and gliricidia on dry matter production of second maize crop at 3 WAP in pot trial.

Treatment	Plant dry weight (g $Plant^{-1}$) for different incubation periods 3 weeks	6 weeks	9 weeks	Mean
O N Control	1.03	1.63	1.73	1.47
50 N, CAN	4.23	4.60	3.97	4.27
100 N, CAN	5.37	5.27	5.07	5.23
50 N, dry calliandra	4.27	4.37	3.83	4.16
100 N, dry calliandra	5.87	4.93	5.30	5.37
50 N, green calliandra	4.60	5.07	5.07	4.91
100 N, green calliandra	6.57	6.70	6.70	6.66
50 N, dry gliricidia	5.27	6.07	5.83	5.72
100 N, dry gliricidia	7.30	7.06	6.07	6.81
50 N, green gliricidia	5.10	5.77	6.10	5.66
100 N, green gliricidia	7.37	7.43	8.13	7.64
Mean	5.18	5.35	5.25	

LSD (.05)	For period means	0.98
	For treatment means	0.66
	For treatment means within same period	1.14
	For treatments means between different periods	1.45

Apendix 10. The effect of incubation period and green and dry leaves of calliandra on nitrogen concentration of second maize crop at 3 WAP in pot trial.

Treatment	Nitrogen cocentration in plants (%) for different incubation periods 3 weeks	6 weeks	9 weeks	Mean
O N Control	1.03	0.85	1.01	0.96
50 N, CAN	1.04	1.00	0.89	0.98
100 N, CAN	1.19	1.44	1.11	1.25
50 N, dry calliandra	0.98	0.97	0.99	0.98
100 N, dry calliandra	1.11	1.13	1.42	1.22
50 N, green calliandra	1.27	0.98	1.12	1.12
100 N, green calliandra	1.69	1.67	1.59	1.65
50 N, dry gliricidia	0.88	1.08	1.35	1.10
100 N, dry gliricidia	1.71	1.55	1.12	1.46
50 N, green gliricidia	1.38	1.21	1.10	1.23
100 N, green gliricidia	1.85	1.58	1.47	1.64
Mean	1.28	1.22	1.20	

LSD (.05)	For period means	0.23
	For treatment means	0.18
	For treatment means within same period	0.31
	For treatments means between different periods	0.37