KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

FACULTY OF RENEWABLE NATURAL RESOURCES

DEPARTMENT OF AGROFORESTRY

POTENTIAL NUTRIENT INPUTS AND SOIL PROPERTY CHANGES IN WOODLOTS OF *Leucaena leucocephala* AND *Senna siamea* FIFTEEN YEARS AFTER ESTABLISHMENT

BY

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MASTER OF SCIENCE IN AGROFORESTRY

BY
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DECLARATION

I declare that except references to other people's work which have been duly cited, this thesis submitted to school of Postgraduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi for the degree of Master of Science in Agroforestry is my own investigation.

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ABSTRACT

Quantitative estimates of litter and potential nutrient inputs and release and changes in selected soil chemical properties of *Leucaena leucocephala* and *Senna siamea* woodlots fifteen years after establishment were studied in three experiments as follows;

i. Litter and potential nutrients inputs in *Leucaena leucocephala* and *Senna siamea* woodlots.

ii 'In situ' decomposition and mineralization of *Leucaena leucocephala* and *Senna siamea* foliage.

iii Soil chemical properties in woodlots of *Leucaena leucocephala* and *Senna siamea* fifteen years after establishment.

Experiment I compared litter and potential nutrient inputs in *Leucaena leucocephala* and *Senna siamea* woodlots. Litter inputs were estimated by installing 12 trap nets in each woodlot randomly. Total litter collected from June to December, 2003 in *Leucaena leucocephala* woodlot was 400 kg/ha with average monthly collection of 67 kg/ha. In the *Senna siamea* woodlot, a total of 455 kg/ha of litter was collected with an average monthly collection of 76 kg/ha. Total litter inputs did not differ significantly between the woodlots hence, *Leucaena leucocephala* or *Senna siamea* species could be used in Agroforestry practice where litter input is a management objective.

Potential nutrient inputs in leaves, twigs and branches for the six month period were computed by multiplying the values of component oven dry weights by the respective nutrient element concentration. *Senna siamea* could potentially contribute in its litter components (leaves, twigs and branches) N, 1024 kg/ha; P, 290 kg/ha; K, 824 kg/ha; Ca,

719 kg/ha and Mg, 441 kg/ha whereas *Leucaena leucocephala* could contribute N, 843 kg/ha; P, 164 kg/ha; K, 657 kg/ ha, Ca, 347 kg/ha and Mg, 233 kg/ha. Potential N and K inputs did not differ significantly between the woodlots ($P > 0.05$). However, potential P, Ca and Mg inputs were significantly ($P < 0.05$) higher in *Senna siamea* litter compared to *Leucaena leucocephala* litter. *Senna siamea* could therefore, be a preferred species to improve soil fertility if nutrient inputs are part of management objective.

In experiment II, rates of decomposition and mineralization of N, P, K, Ca and Mg in *Leucaena leucocephala* and *Senna siamea* foliage were compared using nylon bags from August to December, 2003. Decomposition rate of *Leucaena leucocephala* foliage was significantly ($P > 0.05$) faster than that of *Senna siamea* foliage. The decomposition rate constants (K_d) of *Leucaena leucocephala* foliage varied between 0.013 and 0.069. That of *Senna siamea* foliage varied between 0.001 and 0.076. For long term effect on soil, *Senna siamea* had a better potential as soil cover due to the slower decomposition of its foliage.

Between species, mineralization of Mg was significantly faster in decomposing foliage of *Leucaena leucocephala* whereas mineralization of N, P, K and Ca were similar. Within species N, P, K and Ca release were faster in decomposing foliage of *Senna siamea* whereas Mg release was faster in decomposing foliage of *Leucaena leucocephala*. Nutrient release constant (K_n) of decomposing foliage of *Leucaena leucocephala* varied between 0.004 and 0.011 and in decomposing foliage of *Senna siamea* K_n varied between 0.003 and 0.007. Based on the K_n values the pattern of release in *Leucaena leucocephala*

foliage was in the order N > Ca > Mg > K= P. In *Senna siamea* foliage the pattern of release was in the order K > Mg > N = P = Ca.

Experiment III compared selected soil chemical properties between and within the woodlots and changes in selected soil chemical properties between the woodlots fifteen years after establishment. Using soil auger, soil samples were collected from two depths; 0-15 cm and 15-30 cm within three quadrats of size 15 cm × 25 cm randomly laid in the woodlots. These were analyzed for soil pH, % OM, % OC, total N, available P, exchangeable K, Ca and Mg, exchangeable acidity (Al + H), effective CEC and % base saturation. Within 0-15 cm depth, available P and exchangeable K were significantly higher within *Senna siamea* woodlot compared to *Leucaena leucocephala* woodlot. All other soil properties did not differ significantly (P > 0.05) in both woodlots. Within 15-30 cm depth, only available P was significantly higher in the *Senna siamea* woodlot compared to *Leucaena leucocephala* woodlot.

Within 0-15 cm depth, there were appreciable increases in soil pH, % OC, exchangeable Ca and effective CEC in both woodlots fifteen years after establishment. However, levels of total N, available P and exchangeable K decreased in both woodlots. Within 15-30 cm, soil pH decreased within *Senna siamea* woodlot whereas % OC, total N and available P decreased within *Leucaena leucocephala* woodlot. Harvests that remove greater portions of *Senna siamea* and *Leucaena leucocephala* woody biomass could potentially deplete N, P, and K fertility.

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CHAPTER 1

1.1 GENERAL INTRODUCTION

Soil fertility maintenance is a major concern in tropical Africa. Existing farming systems, based mostly on shifting cultivation, continuous land cropping with little or no use of fertilizers and manure and poor soil conservation practices are inefficient and lead to rapid decline in soil fertility, soil erosion and lastly environmental degradation. Trees contribute to soil organic matter build-up through the supply of litter; foliage, roots, twigs, branches, fruits, barks, and seeds and soil fertility improvement (Young, 1997).

Litter fall plays an important role in the maintenance of soil fertility, protection of soil against erosion and in regulating soil moisture and temperature status. Once litter decomposes into humus, the organic matter contributes significantly to the improvement of soil structural stability, lower bulk density and plays a balance between fine and coarse pores which leads to ease of root penetration, erosion resistance and good soil moisture properties. The organic matter also improves cation exchange capacity (CEC) and organic acids released during decomposition promote the weathering of soil minerals (Young, 1997).

The rate of litter decomposition however, influences the speed at which nutrients become available for renewed uptake by plants and the amount of nutrients which accumulate on the forest floor. Nutrient cycling and incorporation of organic matter into soils are critical result of litter decomposition process and is influenced by

moisture, temperature, litter characteristics and nature of the microflora, microfauna, mesofauna and macrofauna activities in the decomposition process (Witkamp and Olson, 1963; Ovington, 1962).

Agroforestry, the deliberate growing of woody perennials together with crops and/or animals, has emerged as an important land-use activity to reclaim degraded lands and improve soil fertility (Young, 1997). The success of Agroforestry as a viable land use option however, depends on the exploitation potential of the woody perennials or multipurpose tree species (MPTs), many of which relatively little is known outside their native habitat (Nair, 1993).

Multipurpose tree species (MPTs) are major components of any Agroforestry system. The litter produced by MPTs contributes to soil fertility improvement through release of nutrients during decomposition. The increasing interest in MPTs for productive and sustainable land management has also created the urgent need for qualitative information on various trees and shrubs (Robinson, 1986). Hence, information on MPTs is important for making rational decisions relating to the suitability of a particular species for specified sites and functional roles.

Leucaena leucocephala and *Senna siamea* are MPTs with proven ability to improve soil fertility (Nair, 1993). Woodlots of these were established fifteen years ago at the Faculty of Renewable Natural Resources (FRNR) demonstration farm to help restore fertility on land that had been reduced due to intensive farming. Total litter inputs in

the woodlots did not differ significantly twelve years after establishment (Kyerematen, 2000). However, total litter inputs from *Senna siamea* woodlot were significantly higher than total litter inputs from *Leucaena leucocephala* woodlot thirteen years after establishment (Yeboah-Badu, 2001).

Osei (1992) reported that after four years of establishment, soil pH, organic matter, organic carbon, total N, available P, exchangeable K, Ca and Mg, exchangeable acidity (Al + H), effective CEC and percent base saturation within 0-30 cm depth in the woodlots of *Leucaena leucocephala* and *Senna siamea* were significantly higher ($P \leq 0.05$) than in uncropped fallow control plots. There were no significant differences in soil chemical properties between the woodlots. Also, soil pH, organic matter, organic carbon, total N, available P, exchangeable K, Ca and Mg, exchangeable acidity (Al + H), effective CEC and percent base saturation within 0-15 cm depth in the same woodlots increased significantly ($P \leq 0.05$) nine years after establishment (Kaho, 1998).

This study is designed to make quantitative estimates of litter and potential nutrients inputs and release and to detect changes in selected soil chemical properties of *Leucaena leucocephala* and *Senna siamea* woodlots fifteen years after establishment.

1.1.1 Hypotheses and Objectives

The study hypothesizes that;

i. litter and potential nutrients in the woodlots are similar,

ii. rates of decomposition and mineralization of *Leucaena leucocephala* and *Senna siamea* foliage are similar,

iii. selected soil chemical properties within 0-30 cm depth in the *Leucaena leucocephala* and *Senna siamea* woodlots fifteen years after establishment are similar, and

iv. soil chemical properties within 0-30 cm depth in the *Leucaena leucocephala* and *Senna siamea* woodlots will increase fifteen years after establishment.

Based on these hypotheses, the specific objectives of the studies were to compare;

i. litter and potential nutrient inputs between the woodlots,

ii. rates of decomposition and mineralization of N, P, K, Ca and Mg in *Leucaena leucocephala* and *Senna siamea* foliage,

iii. selected soil chemical properties between and within the woodlots, and

iv. changes in selected soil chemical properties within the woodlots fifteen years after establishment.

The research hypotheses were tested in three experiments and are reported in this thesis as follows.

Chapter 3: Litter and potential nutrient inputs in *Leucaena leucocephala* and *Senna siamea* woodlots.

Chapter 4: 'In situ' Decomposition and Mineralization of *Leucaena leucocephala* and *Senna siamea* foliage,

Chapter 5: Soil chemical properties in the woodlots of *Leucaena leucocephala* and *Senna siamea* fifteen years after establishment.

Chapter 6: General discussion, conclusion and recommendations.

CHAPTER 2

2. 0 LITERATURE REVIEW

INTRODUCTION

This chapter reviews literature on litter production and includes litter fall, physiology of litter fall, factors affecting litter production and litter accumulation, decomposition and mineralization. Also reviewed are literature on the role of trees in soil fertility improvement through nitrogen fixation, reduction in losses through leaching and erosion, improvement of soil physical and chemical properties and characteristics of the species monitored.

2.1 LITTER PRODUCTION

2.1.1 Litter Fall

Young (1982) defines the term litter as materials lying on the soil surface which is mainly composed of dead plants or their shed organs. The components of litter are leaves, twigs, bud scales, bark, inflorescence, fruit or seeds and branches. Litter fall is an adaptation of plant that serves to remove senile leaves, ripe fruits and flowers that did not set. Litter fall occurs through complex physiological developments triggered by many factors which include low light intensity, change in temperature and photoperiod, mineral nutrient deficiency and water stress. Older leaves, fruits and flowers are more likely to be abscised than those which have recently expanded (Longman and Jenik, 1992).

2.1.2 Physiology of Litter Fall

In the tropics, broad-leaved trees shed their leaves regularly. This is brought about by the development at the base of the leaf petiole, a special layer of cells called the abscission layer. The slightest pressure from environmental factors such as air current may cause the vascular tissue to break and the leaf to fall. Striking changes in leaf colour (chlorosis) often precede leaf abscission (Adam and Greuluch, 1967).

The change of colour termed senescence appears to be mediated by alterations in the balance of several endogenous growth substances. This signals the wholesale breakdown of chlorophyll, ribonucleic acid and protein and the rapid translocation out into the stem of some of its organic and inorganic nutrients (Longman and Jenik, 1992).

2.1.3 Factors Affecting Litter Fall

There are variations in the amount of litter collected in both natural and plantation forest stands. Factors strongly influencing litter fall quantity include season, age, species composition and period over which litter are collected (Stohlgren, 1988). Also, stand density and altitude influence the rate of litter fall (Bray and Gorham, 1964).

Season

Leaf fall in the tropics has an annual rhythm with the maximum occurring in dry season and the minimum in the long wet season. It fluctuates during the dry season months of November to March and peaks during the driest month in the tropics. Classical studies of Bray and Gorham (1964) on seasonal production of litter in the rain forest of Ghana

reported that most litter accumulates in March and least in July. In evergreen seasonal forest, it appears leaf fall peaks in the first half of the dry season as some of the trees become completely leafless in the second half of the season (Longman and Jenik, 1992).

Nye (1961) observed that litter fall in moist tropical forest of Ghana peaks in February. The timing of leafless period in forest trees in Ghana closely follows the rainfall pattern and the proportion of trees without leaves increases to a peak at the height of the dry season in December and February. This proportion declines as flushing occurs in majority of species in late February and early March and falls to a very low level before the onset of rainy season. Taylor (1960) linked this seasonal leaf fall to sexual conditions of trees. The trees shed their leaves to renew vigor in order to flower and fruit between February and May. Litter fall in secondary forests peaks in January and this corroborates the results obtained by Danquah-Menka (1986) from his studies on litter fall in Bobiri Forest Reserve in the humid zone of Ghana. Similarly, litter production in *Leucaena leucocephala* and *Senna siamea* stands in humid zone of Ghana peaked in February (Kyerematen, 2000; Yeboah-Badu, 2001) and in moist semi-deciduous forest in Ghana litter production peaked in January and February (Boateng, 1985).

In Sudan Savanna, Larwonou (1994) observed that *Faidherbia albida* shed its leaves in the rainy season between August and September whereas *Terminalia superba* had its

litter fall peaking in the wet season in Nigeria's Gambari Forest Reserve (Ola-Adams and Egunjobi, 1992).

Age

Bray and Gorham (1964) reported that in tree stands, annual litter fall increases continuously until canopy closure and remains constant over a long period before decreasing in old stands. This pattern in annual litter fall relates to the pattern of current annual growth with age (Kittredge, 1948). The age of a stand influences net production and the relative proportions of the production in stems, leaves and roots.

Net primary production in mature forests could be lower than that in the young forests since most of the gross primary production would be employed in maintenance (Golley, 1972). For instance, litter production in 21 and 29 year-old *Pinus merkusii* stands with about 180-200 trees per hectare were 3,550 and 2,840 kg/ha/yr respectively (Sutjahjo, 1975). Annual above ground litter fall in a 23-year-old stand was 6,500 kg/ha and 4,600 kg/ha in a 180-year-old stand (Grier et al., 1981) whereas litter produced in five and six year-old *Acacia auriculiformis* plantations were 10,900 kg/ha and 13,000 kg/ha, respectively (Thojib, 1981).

Stand density

Stand density appears to make little difference in litter fall. Little variation in either total or non-woody above ground litter fall was observed in four stands in Alaska

ranging from hardwood-conifer stands of 10,000 stems per hectare to Spruce-Hemlock stands of 660 stems per hectare (Hurd, 1971). Several studies have reached the same conclusion, including one that showed constant litter fall in *Eucalyptus* forest varying in density by more than four folds. Understory vegetation contributed 25% of the above ground litter fall in the dense stand but only about 2.5% in the less dense stands (Bray and Gorham, 1964).

Altitude

The quantity of litter fall is less in montane than in low land tropical forest. This could be attributed to change in temperature and moisture conditions at higher altitude. For instance, in Andean forest total litter fall sampled at altitudes 2,550 m and 3,370 m were 7,030 and 4,310 kg/ha/yr respectively (Heaney and Proctor, 1989). At Banco in Côte d'Ivoire, litter fall was 8,100 kg/ha/yr on a plateau and 7,800 kg/ha/yr in a valley at an altitude between 50-100 m (Bernhard- Reversat, 1972). In Puorto Rico, litter production was 2,400 kg/ha/yr at higher elevation and 5,600 kg/ha/yr at lower elevation (Lugo and Brown, 1981). Also, in Nigeria, annual litter fall were 7,200 kg/ha/yr at an altitude of 60 m in an evergreen forest and 4,700 kg/ha/yr at an altitude of 140 m in a seasonal forest. At an altitude of 150 m in Kade-Ghana, annual litter fall was 9,700 kg/ha/yr with leaves making up 7,400 kg (John, 1973).

2.1.4 Estimates of Litter Production

Litter production is the amount of vegetation formed and shed by the ecosystem within a definite period. Litter production has been estimated both as total and as components or fractions. Analyses of litter production usually include leaves, twigs, branches and reproductive organs (UNESCO, 1978). Generally, leaf litter constitutes the highest proportion of litter falling in any particular year in forest ecosystem. Twigs and reproductive organs litter however, vary greatly (Jamuladheen and Kumar, 1999). Mean litter production in equatorial forests was estimated to be 10,900 kg/ha/yr with 6,800 kg/ha or 62% being leaf litter. Litter production in a mixed high forest in Ghana was 10,700 kg/ha/yr and leaf litter was 7,133 kg/ha of the total litter fall (Nye, 1961). Out of total litter inputs of 8,800 kg/ha/yr in Mazimba Forest, 62% were leaves, 20.4% were twigs and 6.9% reproductive organs (Lundgren, 1978).

In the humid zone of Ghana, total litter production under *Senna siamea* woodlot was 8,629 kg/ha/yr with 64.6% as leaf litter and 6.7% as reproductive organs and under *Leucaena leucocephala* woodlot, total litter production was 5,575 kg/ha/yr with 62.4% as leaf litter and 10.5% as reproductive organs (Kyerematen, 2000). In the same woodlots, Yeboah-Badu (2001) reported total litter production of 6,426 kg/ha/yr in *Senna siamea* with 66.0% as leaf litter; 21.3% as twigs and branches and 10.1% as reproductive organs. Total litter production under *Leucaena leucocephala* was 1,511 kg/ha/yr with 31.5% as leaf litter; 23.4% as twigs and branches and 11.4% as reproductive organs.

Bernhard (1970) estimated high leaf fraction of 73.27% from four sites in the tropical evergreen rain forest of Côte d'Ivoire. Total litter production from 42 different forests estimated litter production to be 10,000 kg/ha/yr with leaf litter forming about 52.20% (UNESCO/UNEP/FAO, 1978). Estimates of litter production in four major world forest regions are as follows: 5,500-15,300 kg/ha/yr in equatorial rain forests; 2,900-8,100 kg/ha/yr in warm temperate forests; 1,000-6,900 kg/ha/yr in cool temperate forests and 600-1,500 kg/ha/yr in the arctic regions (William and Gray, 1974).

2.2 LITTER ACCUMULATION

The accumulation of litter on forest floor is largely the function of annual amount of litter fall minus annual rate of decomposition. Total accumulated forest floor litter is determined by collecting all organic materials above a specified area of soil and separating into component layers while periodic litter fall is determined by collecting all debris falling to the forest floor in a litter trap and after drying and weighing, converting it to an area basis (Pritchett, 1979).

Rates of forest floor litter accumulation can differ markedly between species planted on the same site. Forest floor litter accumulation is influenced by the age of the floor or the elapsed time since the last fire or other disturbances (Bray and Gorham, 1964). Available soil moisture influences accumulation of forest floor material as a result of its effect on tree growth. Litter accumulation across broad range of species, stand age, growth rate and locality generally falls within the range of 1,000 to 22,000 kg/ha/yr. On

regional basis, accumulation in African forest range from 1,700 kg/ha in the moist semi-deciduous forest in Nigeria to 13,300 kg/ha in an evergreen forest in Gabon (Hopkins, 1966). In the moist tropical forest annual litter accumulation was 12,500 kg/ha/yr (Nye and Greenland, 1960).

In general, species of *Eucalyptus, Pine* and *Casuarina* accumulate more litter compared to many other plants. Annual litter accumulation in the Southern Backend forest reserve, Cameroon ranged between 12,900 and 14,100 kg/ha; made up of leaves 61-66%, branches 22-28%, fruits and flowers 8-12% and epiphytes about 0.8% (Songwe et al., 1995).

Annual returns of 2,000-6,000 kg/ha appears to hold for most conifers and hardwood in cool temperate regions. However, up to 12,000 kg/ha/yr is produced in tropical rain forest. The accumulation of litter on the forest floor under tropical rain forest is never large except on very wet site due to the rapid rate of turn over of annual litter fall (Bray and Gorham, 1964; Olson, 1963). In the humid zone of Ghana, litter accumulation under *Leucaena leucocephala* and *Senna siamea* woodlots were 1,510 kg/ha/yr and 6,426.0 kg/ha/yr, respectively (Yeboah-Badu, 2001).

2.3. DECOMPOSITION AND MINERALIZATION

The amount and characteristics of forest floor litter depend to a large extent on the rate of decomposition of organic debris. For a forest in equilibrium, the annual litter fall is usually assumed to equal its decomposition. It does not however, follow that the rates of litter fall and decomposition are equal. Decomposition of plant materials can be categorized into two main phases:

a) the rate of disappearance of litter material from the surface which involves the disintegration and incorporation into the organic fractions of the soil and

b) the rate of complete chemical breakdown (mineralization) of the organic litter components (Bocock, 1963).

Litter decomposition and mineralization is mediated by soil and forest floor decomposer community which comprise of microflora, microfauna and macrofauna. The rate of decomposition is regulated by interactions between this decomposer community, the physical environment and litter resource quality (Swift et al., 1979).

2.3.1. Decomposition

Decomposition is defined as biological and chemical disintegration of dead plant material until a stage where the gross cell structure is no longer recognizable. It is usually accompanied by the breakdown of complex organic compounds into carbon dioxide, water and mineral components. Decomposition as a sequence of transfer of chemicals occurs between the time an element enters a particular ecosystem and the time it leaves (Kimmins, 1996). Litter decomposition is a major component of nutrient cycling and it varies among species (Taylor et al., 1989). Species may affect

decomposition either directly through litter quality which is determined by physical conditions of litter residue, their C/N ratio, lignin and polyphenol contents (Berendse et al., 1994) or indirectly through microclimate such as moisture and temperature or decomposer communities (McClaugherty et al., 1985; Vitousek and Walker, 1989). Direct and indirect effects are difficult to separate because both litter and microclimate usually change simultaneously as species vary along environmental gradients.

The process of decomposition often begins even before the plant debris is added to the forest floor. Leaf exudates promote the invasion of pathogens while the leaves are still on the tree and further invasion by fungi occurs during the first few days of weathering after the litter reaches the forest floor (Edwards et al., 1970). Decomposition of leaf litter of different species occurs at different rates. The varying rates of disappearance seemed to be due to the nutrient content and characteristics of the leaves (Songwe et al., 1995).

2.3.2 Factors Influencing Decomposition Rate

The time needed to complete the process of decomposition may range from days to years depending on prevailing physical environment, substrate quality (quality of the accumulated plant residue) and the physical characteristics of litter. These factors determine the residual time of plant detritus and the rate of nutrient cycling. The location of residue in or on the soil also has critical impact on decomposition rates. Surface placement of plant residues as in forest floor usually results in slow variant

rates of decomposition than where similar residues are incorporated into the soil. Besides, surface residues are usually physically out of reach of most organisms and are subjected to drying and extreme temperatures (Swift et al., 1979).

Effect of physical environment

Physical environment may directly intervene in decomposition as well as regulate biological activities (Swift et al., 1979). Physical environment suitable to aid rapid decomposition include; sufficient soil moisture and warm temperatures between 25 to 35 °C, good aeration and altitude. These factors affect microbial activities and in turn affect the rate of decomposition.

Moisture becomes an important regulator of litter decomposition where rainfall is seasonal. Hopkins (1966) observed that the rate of decomposition at Olokemeji forest reserve in Nigeria showed distinct seasonal changes throughout the year. Leaves that fell during the dry season began to decompose only during the next wet season. The highest intensity of organic matter decomposition was observed under conditions of moderate temperature and soil moisture content of about 60-80% of its maximum water holding capacity (Kononova, 1975). The greatest rate of decomposition usually occurs during the warm and wet periods of the year (Das and Ramkrishnan, 1985).

During periods of water stress, the rate of litter fall may be high while decomposition rates may be slower. The onset of wet season accelerates decomposition (Swift et al., 1979). At Olokemeji, leaves disappeared in a month during the wet season and 8

months during the dry season and at Omo, also in Nigeria leaves disappeared in 3-4 months during the wet season and in 6-7 months during the dry season (Hopkins, 1966).

Simultaneous increase or decrease in temperature and moisture to a level below or above the optimal levels required for efficient decomposition leads to a decline in the rate of organic matter decomposition. Mikola (1960) reported that decomposition decreased as altitude increased. Shanks and Olson (1961) studied litter decomposition beneath natural stands at various elevations and concluded that there was an average decrease in breakdown of nearly 2% for each 1°C drop in mean temperature.

Effect of substrate quality

Swift (1985) defines substrate quality as the intrinsic characteristics of a resource or factors that affect the residue decomposition rate. Factors determining the quality of the residue as food resource for microbes include the physical characteristics of the residue and the chemical indices of substrate quality which include nutrient element concentrations and concentrations of various classes of organic compounds. The most influential among these chemical indices are; initial lignin levels, initial N levels, initial polyphenolic levels, initial lignin/nitrogen ratio and C/N ratio. These have long been considered as critical factors in determining the rate of decomposition (Swift et al., 1979; Melillo et al., 1982).

Chemical composition of litter has great significance in determining the rate of decomposition. The rate of decomposition is highest in species with maximum ash and N concentrations and minimal C/N ratios and lignin concentrations (Thaiutsa and Granger, 1979). The foliage of coniferous trees generally decays more slowly than that of deciduous trees because of low content of potassium, phosphorous and the high lignin content in their litter (Gosz et al., 1973; Kimmins, 1996).

Singh (1969) observed that species with medium ash, N and lignin concentrations and an average C/N ratio greater than 30 seem to decompose at an intermediate rate. Fresh leaves of *Leucaena leucocephala*, *Gliricidia sepium* and *Erythrina* species decompose relatively fast under humid tropical conditions due to low C/N ratio, low levels of lignin and low lignin/nitrogen ratio (Nair, 1993). *Senna siamea, Flemingia macrophylla* and *Dactyladenia berteri* are slow decomposers due to high lignin/nitrogen ratios, high C/N ratios and low N concentration (Young, 1997; Swift, 1985).

Chemical indices of substrate quality

Lignin

Lignin is the general name for a large group of molecules that provide strength and stability and help to guard the plants against attack. Melillo et al. (1982) defined plant materials with high lignin concentrations as low quality and these decompose more slowly than those with low lignin concentrations. Lignin retards the overall decomposition of plant material as a result of its ability to serve as a surrogate for many

physical and chemical properties which regulate litter decomposition rate (Singh, 1969; Van Cleve, 1974). Leaves of *Senna siamea* with lignin concentration of 10.4% decomposed slowly than leaves of *Leucaena leucocephala* with lignin concentration of 8.1% (Kachaka et al., 1993). Species like *Inga edulis* which has high lignin levels immobilized N and slows down decomposition (Angel and Palm, 1987).

Nitrogen

During decomposition, N is assimilated into cell proteins and other compounds. Nitrogen concentration of biomass affects decomposition of plant residue. Species with high initial N concentrations are considered to be of high resource quality to micro-organisms and decompose more rapidly than species with low N concentrations. However, high N concentration in litter could slow down decomposition after the initial rapid mass loss (Pandey and Singh, 1982).

Addition of N may inhibit the decomposition of lignin either through suppressing synthesis of ligniolytic enzyme or promoting the formation of additional recalcitrant compounds (Berg, 1986). Nitrogen rich broad leaves decompose faster than resistant needle leaf litter. Taylor et al. (1989) stated that N levels in litter correlate with the rate of mass loss in initial stages of decomposition. Materials high in N and low in C/N ratio decompose rapidly (Nair, 1993). For example, Van Der Meersch et al. (1993) reported that *Leucaena leucocephala* leaves with N concentration of 3.7% and C/N ratio of 11 decomposed faster than *Senna siamea* with N concentration of 1.8%, and C/N

ratio of 24. In general, litter with high N concentration decomposes faster than litter with a low N concentration and equal lignin concentration (Fog, 1988).

Litter physical characteristics

Physical characteristics of litter affect the rate of decomposition in varying ways. Particle size, for instance, is an important physical factor. The smaller the particles the more rapid the decomposition process because decreasing particle size increase surface to volume ratio. Diminution of residue into smaller particles physically expose more surface area to decomposition and breaks up lignacious cell and waxy outer coatings on leaves so as to expose the more readily decomposable tissue and cell content (Brady and Weils, 1999). The size of the residue can be a factor in determining what organisms can colonize or consume the resources (Swift et al, 1979).

Softy pubescent leaves of *Celtis zenkeri* decompose faster than glabrous leathery and tough leaves of *Desbordesia glaucescens* and *Ceiba pentandra* (Songwe et al., 1995). In *Cola lepidota,* the leaf laminae disappear leaving the prominent midribs and veins, which decompose less rapidly. Brittle leaves disintegrate faster in the soil while those with medium and high fiber content disintegrate more slowly. Rigid leaves of *Lutsea spp* with prominent midribs and veins lose less weight than species like *Schizomena* with thick and less rigid leaves without prominent skeletal tissue because of the medium to high fiber content, high lignin concentration and low N concentration of the leaves (Edwards, 1977).

2.3.3 Mineralization

During decomposition, organic materials are broken down and mineral nutrients are released. Mineralization is the process through which nutrients are made available to plants and microbes. Factors affecting mineralization rates are similar to those affecting decomposition and have been reviewed above. Analyzing decomposition at regular intervals to find the loss in mineral content can be used to assess mineralization rates (Bocock, 1963).

Pattern of mineralization

Pattern of mineralization varies from species to species and also among different components of the same species. In a Nigerian rain forest, mineralization was in the order Ca > N > K > Mg > P for leaf, Ca > N > K > Mg > P for wood litter and in the order N > K > Ca > Mg > P for fruit litter. Furthermore, it was observed that nutrients returned to the ecosystem were very low in the wettest months of May to August (Moughalu et al., 1993). Release of nutrients in decomposing *Eucalyptus deglupta* litter was in the order Na > K > Ca > Mg > P (Attiwill, 1967). In the humid zone of Ghana, mineralization was in the order K > Mg > N > P > C > Ca for decomposing leaves of *Leucaena leucocephala;* K > Mg > P > N = Ca > C for decomposing leaves of *Gliricidia sepium* and K > Mg > P > N > Ca = C for decomposing leaves of *Cassia spectabilis* (Sraha and Ulzen-Appiah, 1997).

In general, mineralization of P, K, Ca and Mg is faster from high quality *Erythrina* leaves than those of *Inga edulis* or *Cajanus cajan* due to high content of soluble

polyphenols in their leaves (Palm and Sanchez, 1990). Approximately 40% of initial P and Ca concentrations and 75% of Mg and K concentrations of *Erythrina* leaves were mineralized within four weeks under humid tropical conditions due to the high C and N levels and low levels of lignin concentration in their litter (Nair, 1993; Palm and Sanchez, 1991). Potassium showed a very steep decline from 0.29 to 0.05% after three months and remained approximately stable (Versfeld and Donald, 1991). However, Ca, Mg and P showed little change in percent concentrations with decomposition. Materials that have high N levels and low C/N ratios release relatively large quantities of N (Nair, 1993). Nitrogen released or returned through decomposition occurred throughout the year but the returns occurred most rapidly between May and August (Nwoboshi, 1970). This may be due to increased moisture supply which accelerates decomposition during this period (Swift et al., 1979).

2.3.4 Nutrient Dynamics during Mineralization

Three (3) sequential phases occur during mineralization of nutrients from decomposing plant residue. An initial phase where leaching and nutrient release predominate; a net immobilization phase during which nutrients are imported into the residue by microbes and a net release phase where nutrient mass decreases (Berg et al., 1992). However, not all these phases occur for all nutrients and all types of litter. Litter properties most useful in predicting nutrient dynamics are initial N concentration and bio-chemical properties such as lignin and polyphenol content of the plant residue.

The initial release of N and P is followed by immobilization phase in many types of litter in tropical forest. The relative release of N and P in decomposing litter is caused by non-symbiotic N fixation uptake from surroundings by fungal hyphae growing in litter, deposition of insect frass and plant material from the canopy (Toky and Singh, 1993). In the humid lowlands of Côte d'Ivoire, Budelman (1988) observed that K release was fastest from *Leucaena* followed by *Gliricidia* and *Flemingia* with K percentage from their mulches being 1.52%, 1.52% and 1.19%, respectively.

2.4 TREES AND SOIL IMPROVEMENT

Under natural ecosystem, soils are improved through constant interaction between soils and plant communities with high degree of internal recycling. Trees maintain and/or improve soil through (i) biological nitrogen fixation (BNF), (ii) improvement of soil physical and chemical properties, (iii) atmospheric deposition (wet and dry deposition), (iv) reduction in nutrient losses through erosion and leaching and (v) through nutrient uptake from weathering rocks (Young, 1997). The following sections review literature on biological nitrogen fixation, improvement of soil physical and chemical properties, atmospheric deposition and reduction in nutrient loss through erosion and leaching.

2.4.1 Biological Nitrogen Fixation (BNF)

Nitrogen fixation offers an excellent opportunity for drawing upon the vast reserves of atmospheric N in an inexpensive and environmentally sound manner to plant production. Biological nitrogen fixation takes place by non-symbiotic and symbiotic

means. Non-symbiotic N fixation is carried out by soil organisms and it is not associated with plants including blue-green algae and free living bacteria like *Clostridium* and *Beijerinckia* species. Even though BNF is important in natural ecosystem, the amount of N fixed is small in relation to the greater requirements of agroecosystems (Young, 1997).

Symbiotic nitrogen fixation occurs through association of plant roots with N fixing bacteria called *Rhizobuim* and members of the family Leguminosae and *Frankia* with non-leguminous plants. Many leguminous plants are capable of fixing large amounts of N. Notable among them are *Inga, Erythrina, Gliricidia, Sesbania, Leucaena, Albizia* and *Acacia* species. The non-leguminous N fixers most widely used in the tropics are *Casuarina* and other genera belonging to the family Casuarinaceae.

Nitrogen fixation by properly nodulated legumes averages about 75% of the total N used in plant growth (Danso et al., 1992). *Leucaena* can fix 100-500 kg of N per hectare per year in a pure stand and 75-100 kg when grown in a hedgerow intercropping system (Young, 1997). Also, *Leucaena* grown in an alfisol in Ibadan fixed 98-134 kg of N per hectare in six months (Dommergues, 1987). *Sesbania sesban, Gliricidia sepium, Acacia mangium, Albizia lebbeck, Inga jinicuil,* slower-growing trees like, *Faidherbia albida* and *Acacia senegal* and the non-legume *Casuarina equisetifolia* fix amounts of the order of 20-100 kg of N per hectare per year. *Sesbania rostrata,* grown in association with swamp-rice systems, can also fix 500 kg of N per hectare per year

whereas *Casuarina equisetifolia* fixed 113 kg of N per year per tree during the first nine months following plantation (Danso et al., 1992; Young, 1997).

2.4.2 Improvement of Soil Physical and Chemical Properties

Trees help maintain soil organic matter through the provision of litter and root residue. Soil organic matter is the prime mover from which stem many of other soil improving processes (Young, 1997). Soil organic matter refers to all organic materials that are present in the soil and consist of two parts; fully decomposed organic matter that is already part of the soil colloidal complex and plant and microbial remains that are in various stages of decomposition, commonly called humus (Nair, 1993). The effect of organic matter falls into three groups; (i) effect on biological activities, (ii) effect on soil physical properties and (iii) effect on soil chemical properties.

Soil physical properties

Maintenance of good soil physical properties is an essential element in soil management, not only for its direct effects but also because it leads to more efficient use of nutrient and also improved water management. Many studies of tree-soil transect show better physical properties under trees than surrounding soils. Table 2.1 presents section of recent studies on tree-soil transects. Higher availability of soil water can be maintained under trees because of interception and redistribution of rainwater within the system, reduced evapotranspiration and increased water infiltration (Wallace, 1996). Also, better structure, porosity, permeability and water-holding capacity of soils under

Table 2.1. Tree – soil transects

Country	Environment	Tree species	Soils under trees	Effect on crop yield	Reference
Kenya	Semi-arid; ferralsols, natural savanna	*Acacia tortilis, Adansonia digitata*	Higher N,P,K,Ca except where heavily grazesd	Higher herbaceous layer biomass	Belsky et al. 1993
Nigeria	Dry sub-humid, soil?	*Faidherbia albida, Ziziphus spina-Christi*	Higher fertility to 2× crown radius	Higher yield of interplanted *Leucaena*	Verinumbe,1993
Mali	Dry sub-humid, soil?	*Vitellaria paradoxa, Parkia biglobosa*	Slightly higher C & cations	Mainly c.60% lower	Kater et al., 1992

Source: Young, 1997.

forest is well documented together with decline in these properties on forest clearance (Lal et al., 1986). Under *Acacia tortilis* and *Adansonia digitata* trees in Kenya, soil bulk densities were lower with high rates of water infiltration (Belskey et al., 1993).

Torquebiau and Kwesiga (1996) reported that two-year fallow with *S. sesban* decreased soil bulk density, resistance to penetration and increased water infiltration on an Alfisol in Eastern Zambia. Yamoah et al. (1986) reported that bulk density was significantly lower than mean structural aggregate diameter and water content at saturation was also higher after two years of inter-cropping with tree species in Ibadan, Nigeria. Hulugalie and Kang (1990) in a study that included *L. leucocephala, G. sepium,* and *Dactyladenia barteri* reported that particle size distribution, bulk density, apparent pore size distribution and water infiltration were superior in hedgerow plots compared to control without trees.

The effect of litter as mulch is related to many factors among which reducing soil moisture losses is one (Lal, 1975; Wade and Sanchez, 1983). Other important mulching effects are soil temperature amelioration, weed suppression, improving water infiltration rate, erosion control and protection against rainfall impact thus offering mechanical protection and in some soils increase macrofauna activities (Wooldridge, 1970; Yeboah-Badu, 2001). For example, in the humid lowlands of Cote d'Ivoire, mulching with 5000 kg per hectare of *Leucaena, Gliricidia and Flemingia* reduced soil temperature by 5-19^{0}C and raised soil moisture by 4-6% over 50-90 days (Budelman, 1989).

Soil chemical property

Trees have favourable effect on soil chemical properties through the addition of organic matter. However, the main chemical effect of organic matter in soil depends upon nutrient supply from plant litter which is balanced across the range of primary (Nitrogen, Phosphorus and Potassium), secondary (Calcium, Magnesium, and Sulphur) and micronutrients as well as soil acidity (Brady and Weils, 1999).

Organic matter function as a granulator of the mineral particles being largely responsible for the loose, easily managed condition of productive soil. Organic matter enhances the cation exchange capacity of the clay-humus complex. In highly weathered acid soils, organic matter improves phosphorus availability through blocking of fixation sites by organic complex (Young, 1997).

Nitrogen

Nitrogen is accumulated in soils in the form of plant and animal residue. The amount of N in the soil at any given time depends on climatic and edaphic factors such us rainfall, temperature, soil moisture as well as natural and human disturbances that influence the ratio of plants and animal additions (inputs) to the rate of decomposition (output). Nitrogen in organic materials becomes available to higher plants only after C/N ratio approaches 10:1 (Pritchett, 1979).

Senna siamea holds large amounts of N in its foliage and this is readily made available to plants upon decomposition (National Association of Sciences [N.A.S], 1980). A two-year old *Sesbania sesban* litter decomposed dramatically increasing N availability

and yield of subsequent crops while 15,000-20,000 kg of *Leucaena* leaves contributed about 160 kg of N after a year of planting on sandy Entisol in Nigeria (International Institute for Tropical Agriculture [IITA], 1986). Evaluation of N production by four months old *Leucaena leucocephala* was 127 kg/ha (Rachie, 1983). In the humid tropics, N returns from litter of *Leucaena leucocephala, Gliricidia sepium, Sesbania sesban* were between 25-280 kg/ha/yr (Brewbaker, 1987). In Malawi, 6,000 kg/ha leaf residue from *Calliandra calothyrsus* contributed 175 kg of N per hectare while short term fallow of *Sesbania rostrata* between crops of swamp rice contributed 68-154 kg of N per hectare (George et al., 1994).

Most MPTs particularly, N fixing trees have the ability to add N to soil through the association of plant roots with nitrogen fixing bacteria. In Nigeria, a six month old *Leucaena leucocephala* in a hedgerow intercropping system contributed 100-300 kg of N/ha/yr to the soil (Brewbaker, 1987). *Coriaria arborea* grown as an understory species in plantations of *Pinus radiate* in New Zealand is reported to fix up to 192 kg of N/ha/yr (Silvester, 1983). In an Alfisol in Nigeria, *Senna siamea* mulch has shown to provide 113 kg per hectare of N (Ghuman and Lal, 1990). The total N content of the top soil (0-15 cm) under *Senna siamea* woodlot was significantly higher than those of soil under the natural fallow after fifteen years (Forestry Research Institute of Ghana [FORIG], 1995). In a traditional fallow system in Kisangani region, Zaire total plant N was 170 kg/ha and 300 kg/ha after 6 months and 2 years, respectively (IITA, 1986).

Phosphorus

Phosphorus is one of the essential nutrients for plant growth. It has important effects on photosynthesis, flowering, fruiting, seed formation, root development and strength of straw in cereal crops (Brady and Weils, 1999). In systems with application of litter, substantial returns of P occurs typically in the range of 10-20 kg per hectare in mixed systems and 5-10 kg per hectare in hedgerow intercropping (Young, 1997). *Leucaena leucocephala* can contribute as much as 49 kg of P per hectare per year (Hauser and Kang, 1993). In Malawi, 6,000 kg per hectare leaf residue from *Calliandra calothyrsus* contributed 8 kg of P per hectare (ICRAF, 1994; Palm et al., 1991).

In the tropics, 7.8 kg of P per hectare per year were transformed from trees to soil by the above ground litter fall (Nye, 1961). Also in an Agroforestry system in the humid tropics, 8100 kg of *Leucaena leucocephala,* 8,100 kg of *Erythrina spp,* 12,300 kg of *Gliricidia sepium and* 7,500 kg of *Sesbania sesban* litter and prunnings contributed between 23-358 kg of P per hectare per year (ICRAF, 1994). In a two-year *Sesbania sesban* fallow in Kenya, trees accounted for 36% of total non-woody biomass and contributed 2 kg P per hectare while fallows of *Inga* and *Cajanus* accumulated 20-30 kg P per hectare after 29 months (Palm et al., 1991).

Potassium

Potassium is an essential element of many physiological functions for plant growth and yield. These include carbohydrate metabolism, nitrate reduction, protein synthesis, and

activation of various enzymes and growth of meristematic tissue (Mengel and Kirkby, 1982). Trees are capable of absorbing K from unweathered feldspars and other K bearing minerals with the aid of mycorrhizal roots. Potassium is rapidly and efficiently cycled in established forest stands. Very little K appears to be leached below the surface root mat in undisturbed forests (Pritchett, 1979).

In the tropical forest of Ghana, 68.4 kg of K were transferred from trees to soils by above-ground litter fall and 6,000 kg/ha leaf residue from *Calliandra calothyrsus* in Malawi contributed 25 kg of K per hectare (ICRAF, 1994; Nye, 1961). *Leucaena leucocephala* contributed as much as 264 kg of K per hectare per year (Hauser and Kang, 1993). Also, Cobbina (1995) and FORIG (1995) reported that exchangeable K content of the topsoil (0-15 cm) under *Senna siamea* woodlots were significantly higher than soil under the natural fallow after fifteen years.

Calcium

Calcium is considered to be an immobile element and exists in soils mostly in inorganic forms. Deep rooted trees with high Ca requirement such as hardwoods tap Ca reserved in the lower horizons and build up the concentration in the surface soil through annual leaf fall (Pritchett, 1979). *Leucaena leucocephala* contributed 195 kg of Ca per hectare per year (Hauser and Kang, 1993). In the tropical forest of Ghana, through fall contributed 26 kg of Ca per hectare per year while 206 kg of Ca were transferred from trees to soils by above ground litter fall (Nye, 1961).

Kang et al. (1984) reported that prunnings of *Leucaena leucocephala, Erythrina spp* and *Gliricidia sepium* contributed between 1.40-1.52 kg of Ca per hectare per year to the soil. Ruhigwa et al. (1993) studied the nutrient capacity under a three and half year fallow of three multipurpose tree species and found that *Senna siamea* increased soil Ca in the top 50 cm compared to *Alchornea cordifolia* and *Actyledenia berteni*. Juo et al. (1996) reported that planted fallow of *Leucaena leucocephala* was effective in maintaining soil exchangeable Ca in an Oxic Kandiustalf in Nigeria.

Magnesium

Magnesium is the only mineral constituent of the chlorophyll molecule and is essential to photosynthesis. Most soils contain ample Mg for good tree growth. *Leucaena leucocephala* contributed 52 kg of Mg per hectare per year (Hauser and Kang, 1993). In tropical rain forest, nutrient input from 6,500 kg of *Leucaena leucocephala* leaves per hectare per year contributed 15 kg of Mg per hectare while 8,000 kg of *Erythrina* spp and 12,300 kg of *Gliricidia sepium* contributed 26 kg and 60 kg of Mg per hectare, respectively (ICRAF, 1994). In an Ultisol in Nigeria, *Senna siamea* mulch contributed 13 kg of Mg per hectare and planted fallow of *Leucaena leucocephala* was effective in maintaining soil exchangeable Mg on an Oxic Kandiustalf in Nigeria (Juo et al., 1996).

Soil acidity (pH)

Soil acidity is an indicator of H_3O^+ ions actively present in liquid phase of the soil. Soil pH affects the availability of most nutrient elements which are of importance to plant (Nair, 1984). Nutrient conditions are favourable in soils with intermediate pH range. For instance, P availability is at maximum in soils with intermediate pH range between 6.0 and 7.0 whereas the availability of N is restricted at low pH values (Mengel and Kirkby, 1982).

Trees can check the development of soil toxicities or reduce existing acidity. For instance, soil pH was lowered from 10.5 to 9.5 in five years under *Acacia nilotica* and *Eucalyptus tereticornis* fallow in Karnal, India (Gill and Abrol, 1986). In Togo, *Senna siamea* had superior ability in enriching sandy loam topsoil with Ca and increase topsoil pH from 6.8 to 7.0 in a 5-year-old fallow (Drechsel et al., 1991). Planted fallow of *Leucaena leucocephala* was effective in maintaining soil pH on an Oxic Kandiustalf in Nigeria (Juo et al., 1996) and in a dry high land site in Rwanda, the combined application of litter containing 50-90 kg of Ca per ha and 10,000 kg/ha of cattle manure raised pH of 4.4 by 0.4 - 0.5 units in six years (Balasubramanian and Sakayange, 1991).

2.4.3 Atmospheric Deposition

Atmospheric deposition comprises nutrients dissolved in rainfall (wet deposition) and those carried in dust (dry deposition). Inputs by precipitation and dust vary by location as well as season of the year depending largely on dust load and lightening activity.

Tree canopy is an efficient agent in capturing airborne dust particle (Pritchett, 1979; Young, 1997).

Ovington (1962) reported average inputs of minerals into the ecosystem from precipitation as follows: N, 0.2 to 0.6; K, 1.0 to 10.0; Ca, 3.0 to 19.0 and Mg, 4.0 to 11.0 kg per hectare per year. Potassium, Ca and Mg additions to the forest ecosystems through the atmosphere originate largely as aerosols over the oceans and agricultural lands. In Nigeria, inputs of nutrients in precipitation were: N, 14; K, 17.5; Ca, 12.7; and Mg, 11.3 kg per hectare per year (Nye, 1961).

Under drought conditions, significant part of atmospheric inputs of N and other nutrients come from dust particles. Through electrical discharge, molecular N is converted to ammonium, nitrate or various nitrogen oxides that dissolve in the atmospheric humidity and reach the soil in precipitation (Wollum and Davey, 1975).

2.4.4 Reduction in Nutrient Losses through Erosion and Leaching

The major causes of soil fertility improvement by trees is through maintenance of soil organic matter levels, through the supply of litter and reduction of soil erosion by protecting soil against the direct impact of rainfall. The long term effect of soil erosion is physical removal of the top soil and the consequent thinning of the profile, but most serious effect is the loss of soil organic matter and nutrients thus, impoverishing soils.

A litter cover or mulch of 60% reduced erosion to 10% of its value on bare soil. In a five-year old *Acacia auriculiformis* plantation, litter cover reduced soil erosion by 95% as compared with bare soil (Wiersum, 1985). In Machakos, Kenya, mulch of *Senna siamea* applied at 2,250 kg/ha and 4,500 kg/ha reduced erosion by 11% and runoff by 28% of that of unmulched control (Omoro and Nair, 1993). On the other hand, mulch of *G .sepium* and *S. siamea* applied at 4,500 kg/ha reduced runoff by 9.14% on the crop only control and soil loss by 2-4% (Chiti, 1997). In parts of Indonesia, *Leucaena leucocephala* has been used for decades to create hedgerow terraces for erosion control with widely recognized benefits in terms of soil fertility improvement (Perera, 1989).

Trees with deep roots can intercept nutrients leaching down soil profiles and 'capture' nutrients accumulated in subsoil below the rooting depth of annual crop plant. For example, 4.8 kg of N per hectare per year leached from the forest floor into the upper 3 cm of mineral soil but 0.6 kg of N per hectare per year leached beyond the rooting zone of a matured Douglas-fir stand. Similarly, 10.1 kg of K and 16.6 kg of Ca were leached from forest floor but only 1.0 and 4.5 kg per hectare per year, respectively, were leached beyond 100 cm (Gessel and Cole, 1965). Hedgerow intercropping of *Leucaena leucocephala* with maize and cassava rotation in Benin Republic, reduced nitrate leaching on ferralic–haplic acrisols with 87% sand content (Horst et al., 1995).

2.5 CHARACTERISTICS OF SPECIES MONITORED

2.5.1 *Leucaena leucocephala*

Leucaena leucocephala is an exotic species belonging to the sub-family Mimosoidae in the family Leguminosae. It originated from the mid-lands of southern Mexico and it is restricted to the tropics and sub-tropics. *Leucaena leucocephala* is an aggressive colonizer and occurs naturally in Central America. It is either tall (20 m), slender or a bushy shrub (5 m) depending on the variety. *Leucaena leucocephala* has feathery compound leaves and produces branches of long brown pods and small white powdery pulp flowers (N.A.S., 1984).

Leucaena leucocephala is a nitrogen fixing legume which helps to enrich the soil. It grows fast and coppices well. *Leucaena* has aggressive root system which breaks up impervious sub-soil thus improving water penetration and aeration while decreasing run-off. *Leucaena* has high biomass production and high and balanced nutrient concentration in the foliage thus making the plant a promising Agroforestry multipurpose tree species. *Leucaena* does well on a wide range of soils except on acidic soils. It is suitable in lowland areas with altitude below 500 m and grows best where annual rainfall is 600-3000 mm and pH is 6.0-7.7 (Brewbaker, 1987).

Leucaena leucocephala forage is highly nutritious, palatable and digestible. The foliage contains riboflavin and vitamin K (N.A.S., 1980). However, it also contains mimosine which is toxic to ruminants that feed on it. Amino acid in the mimosine contained in *Leucaena leucocephala* is a chemical known to cause hair loss, thyroid abnormalities

and foetal development in non-ruminants (N.A.S., 1980). *Leucaena leucocephala* shows high resistance to pest and diseases but seedlings can easily be destroyed by goats. Its wood can make good firewood and charcoal. In Central America and South East Asia people eat *Leucaena* leaves and seeds (N.A.S., 1984).

2.5.2 *Senna siamea*

Senna siamea belongs to the Caesalpiniaceae family. It is a native of Southwest Asia and has become naturalized in Accra plains of Ghana. *Senna siamea* is an evergreen and strong light demanding tree with dense crown foliage, smooth gray bark and compound leaves. Though not a nitrogen-fixing tree, it holds large amount of nitrogen in its foliage (Yamoah et al., 1986). It is a fast growing evergreen species which can grow to a height of 5 m in 3 years and 15 m in 10 years. It coppices readily and can have continuous yield for 4 or 5 rotations (N.A.S., 1980).

Senna siamea grows well in a wide range of climate: humid, sub-humid, dry and arid zones. It prefers high water table and thrives well in the tropics in light to medium textured soils. *Senna siamea* is adapted to drained soils, tolerates light soils or neutral to acidic soils and thrives well at altitudes of 1200 mm above sea level. It requires mean annual rainfall and temperature ranges of 650-1500 mm and 21-28^{0}C respectively (N.A.S, 1983).

Senna siamea foliage is used as mulch to increase soil fertility, conserve water, control erosion and suppress weed growth (Ghuman and Lal, 1990). Seeds and foliage are

highly toxic to pigs. It is termite resistant. In Central America, East, West and Southern Africa, *Senna siamea* is planted mainly for poles and fuelwood. The hardwood is an attractive timber for cabinet making. It is used as wind breaks and for land reclamation (N.A.S., 1980).

CHAPTER 3

3.0 LITTER AND POTENTIAL NUTRIENT INPUTS IN *Leucaena leucocephala* AND *Senna siamea* WOODLOTS

3.1 INTRODUCTION

Litter consist of a wide range of materials of different sizes including reproductive organs, leaves, twigs, bud scales, branches, bark, roots and entire bole. Nutrient pools in forest ecosystems are replenished through litter fall, which acts as an input-output system for nutrient cycling in the forest ecosystem. The amount of litter formed and shed by the ecosystem within a definite period is termed litter production and it is related to the species and time of the year (Songwe, 1984). Leaf fall in the tropics has an annual rhythm with the maximum occurring in the dry season and the minimum in the wet season. Studies by Bray and Gorham (1964) on seasonal production of litter in the rain forest of Ghana reported highest litter accumulation in March and lowest accumulation in July.

The potential for site nutrient replenishment is dependent on the amount of nutrients added to the system in the form of residue especially tree foliage. In the rain forest of Ghana, 68.4 kg of K; 7.8 kg of P and 206 kg of Ca were transferred from trees to soils through above ground litter fall (Nye, 1961). Both the quantity of leaf biomass and the concentration of nutrients determine the amount of nutrients returned to the soil (Young, 1989). Therefore, it is important to study litter inputs and nutrient content in order to make quantitative estimates of potential nutrients inputs. This will permit

rational decisions to be made regarding to the potential for a particular species to add nutrients to site.

This study reports on six months litter collected from *Leucaena leucocephala* and *Senna siamea* woodlots. The objective of the study was to assess litter and potential nutrient inputs in *Leucaena leucocephala* and *Senna siamea* woodlots. The study hypothesizes that litter and potential nutrients inputs in the woodlots are similar.

3.2. MATERIALS AND METHODS

3.2.1. Study Site

The experiment was conducted at the Faculty of Renewable Natural Resources demonstration farm located at Kumasi in the humid zone of Ghana. Kumasi lies on longitude 06°, 43'W and latitude 01°, 36'N at an altitude of 278 m above sea level. The area has a bimodal rainfall with an annual mean ranging between 1300 mm and 1600 mm. The mean temperature ranges between 22°C and 34°C. The soil at the study site belongs to the Asuansi series, classified as Ferric Acrisol (Food and Agriculture Organization [FAO], 1976) or Typic Haplustult (United States Department of Agriculture [USDA], 1975) and are characterized as loamy, well drained, moderately deep with pH ranging from 4.2-6.4

3.2.2. Woodlot Description

The *Leucaena leucocephala* and *Senna siamea* woodlots were established in April 1988 and measure 0.26 ha and 0.14 ha, respectively. *Leucaena leucocephala* was planted at 1

m by 2 m spacing and the *Senna siamea* woodlot was planted at 2 m by 2 m spacing. These woodlots were coppiced in 1992 and 1995.

3.2.3. The Experiment

Litter inputs

Twenty four (24) trap nets each of collecting surface area 0.25 m^2 made with nylon net of mesh size 2 mm were used to collect litter inputs (Hughes et al., 1987). Twelve litter trap nets were randomly distributed under the canopy in each woodlot at a height of 0.5 m above the ground to allow good drainage (Hopkins, 1966). The litter trap nets were emptied monthly from July – December, 2003.

The litter collected monthly were sent to the laboratory and sorted out into the various components: leaves, twigs and branches, reproductive organs (seeds, fruits, and flowers) and miscellaneous, that is, litter not belonging to the species under consideration (Hughes et al., 1987). The sorted components were oven dried at a temperature of 65°C to a constant weight and dry weights recorded (Cuevas and Medina, 1986). The dried components (leaves, twigs and branches) were ground in a Wiley mill and sieved using 40 mm mesh size sieve. Sub-samples were analyzed for N, P, K, Ca, and Mg.

3.2.4. Laboratory Analyses of Litter Inputs

Nitrogen, phosphorus, potassium, calcium and magnesium concentrations of leaves, twigs and branches were determined using the methods described below.

Nitrogen

Nitrogen was determined using macro Kjeldahl digestion method (Wilde et al., 1972). This method involved three processes; digestion, distillation and titration. In the digestion process 0.5 g of sieved leaves and 1.0 g of sieved twigs and branches were wrapped in a filter paper. These were digested in sodium sulphate (Na_2SO_4), copper sulphate ($CuSO_4.5H_2O$) and 25 ml of concentrated sulphric acid mixture using selenium as a catalyst to convert organic nitrogen to ammonia. The digests were cooled for 15 minutes when turned green after 2-3 hours of heating and were taken through the distillation process.

The distillation process involved the addition of 200 ml distilled water, 125 ml of 40% sodium hydroxide (NaOH) and four pea size pieces of mossy zinc to the solution. These were heated until about 150 ml of distillate was collected in the collection flask containing 50 ml of 4% boric acid and three drops of methyl red indicator. The boric acid solution changed from bluish purple to bluish green with the introduction of ammonia. The distillate was titrated with 0.1 M Hydrochloric acid till the solution turned from bluish green to pink.

Percentage N was calculated using the formula below:

$$\text{Percent N} = \frac{(T\text{-}B) \times (N) \times 1.4}{\text{Sample wt.}} \qquad \text{Eqn. 1}$$

Where: T = volume titrated for sample B = volume titrated for blank

N = normality of acid

Phosphorus

Phosphorus was determined using the Vanadate-Molybdate yellow colour method (Wilde et al., 1972). This involved ashing 1 g of plant tissue in a muffle furnace at 470°C for 16 hours. The ashed samples were dissolved in 10 ml of 5 N Nitric acid (HNO_3) and after shaking mechanically for 30 minutes, the solution was filtered through Whatman No. 42 filter paper into 50 ml volumetric flask. Two milliliters of HNO_3 – Vanadate-Molybdate solution was added to 2 ml of sample solution. The colour was allowed to develop for exactly 20 minutes and the phosphorus concentration determined calorimetrically by measuring the absorbance with a spectrophotometer at 655 mμ wavelength. Percent P was calculated using the formula below:

$$\%\ \text{P in sample} = \frac{(\text{ppm P in solution}) \times (\text{dilution factor}) \times \text{volume} \times 0.0001}{\text{Sample wt.}} \qquad \text{Eqn. 2}$$

Potassium

The Atomic Absorption Spectrophotometry (AAS) described by Wilde et al. (1972) was used to determine potassium. This involved dry ashing of 1 g of plant material in a muffle furnace at 470°C for 16 hours. The ashed samples were dissolved in 10 ml of 5

N of Nitric acid (HNO_3) and 3 N Hydrochloric acid (HCl) solutions. After shaking mechanically for 30 minutes the solution was filtered through Whatman No. 42 filter paper into 100 ml volumetric flask. The solution was brought to a final volume of 100 ml with deionised distilled water. The filtrate was used for the K determination by the AAS.

Calcium and Magnesium

Calcium and magnesium were determined using Ethylene-diamine tetra-acetic acid (EDTA) method described by Radov et al. (1985). In this method, 1 g of leaves and 5 g of twigs and branches were ashed in a muffle furnace at 470°C for 16 hours and dissolved in 10 ml and 50 ml of 1 M NH_4AC solution at pH of 7, respectively. After shaking the solution mechanically for 30 minutes, it was filtered into 100 ml volumetric flask and brought to a final volume of 100 ml with deionised distilled water. Crystals of cal-red indicator, 10 ml of 10% KOH as buffer solution, 1 ml triethanolamine and 3 drops of KCN solution were added to 25 ml aliquot of the filtrate. The mixture was titrated with 0.02 N EDTA to determine Ca. Calcium was calculated using the formula below;

Me of EDTA used = $0.02 \times T$ Eqn. 3

25 ml of aliquot = $0.1 \times A$ g (weight of sample used) Eqn. 4

$$\text{Exchangeable Ca} = \frac{0.02 \times T}{0.1 \times Ag} \quad \text{Eqn. 5}$$

Where T = mls of EDTA used

For the determination of (Ca + Mg), 5 ml of ammonium chloride-ammonium hydroxide buffer solution, 1 ml of triethanolamine and 3 drops of KCN solution were added to 25 ml aliquot of the filtrate. This was titrated with 0.02 N EDTA solution using a few drops of Eriochrome Black T as an indicator. Exchangeable (Ca + Mg) was calculated using the formula below;

$$\text{Exchangeable (Ca + Mg)} = \frac{0.02 \times T}{0.1 \times Ag} \qquad \text{Eqn. 6}$$

where;

A g is weight of sample used

Magnesium was obtained by subtracting the value of exchangeable Ca from the value of exchangeable (Ca + Mg) as follows;

$$\text{Exchangeable Mg} = \text{exchangeable (Ca + Mg)} - \text{exchangeable Ca} \qquad \text{Eqn. 7}$$

3.2.5 Potential Nutrient Inputs

Rawat and Singh (1988) method for estimating nutrient inputs was employed. Potential nutrient inputs (PNI) in leaves, twigs and branches for the six month period were computed by multiplying the values of component oven dry weights by the respective nutrient element concentration. The formula below was used.

$$\text{PNI} = \text{Component oven dry weight} \times \text{Component nutrient element conc.} \qquad \text{Eqn. 8}$$

3.2.6 Statistical Analysis

Nutrient concentrations in leaves, twigs and branches of *Leucaena leucocephala* and *Senna siamea* and litter and potential nutrient inputs in the woodlots were compared using the Student's T- test. These are presented in section 3. 3. 3 and 3.3.4, respectively.

3.3 RESULTS

3.3.1 Litter Input and Distribution

Total litter collected during the six month period from June-December, 2003 in *Leucaena leucocephala* woodlot was 400.17 kg/ha with an average monthly collection of 66.69 kg/ha. Leaf litter was highest forming 55.7% of the total litter fall; followed by twigs and branches, 23.8%; miscellaneous, 17.7% and reproductive organs, 2.8% (Table 3.1). In the *Senna siamea* woodlot, a total of 454.83 kg/ha of litter was collected over the six month period with an average monthly collection of 75.81 kg/ha. Leaf litter was the highest forming 73.9% of the total litter fall; followed by twigs and branches, 18.5%; miscellaneous, 4.3% and reproductive organs 3.2% (Table 3.2).

Total leaf litter collected from *Leucaena leucocephala* woodlot was 222.9 kg/ha with an average monthly collection of 37.41 kg/ha. In the *Senna siamea* woodlot, a total of 336.27 kg/ha leaf litter was collected with an average monthly collection of 56.04 kg/ha.

3.3.2 Pattern of Litter Inputs

The pattern of monthly litter inputs during July to December, 2003 for *Leucaena leucocephala* and *Senna siamea* woodlots is presented in Figure 3.1. In *Leucaena leucocephala* woodlot, total litter inputs were about the same from July to September and then increased from October to December. For *Senna siamea* woodlot, total litter inputs were about the same in July and August and then increased, peaking in October and thereafter declined.

Table 3.1. Litter inputs from *Leucaena leucocephala* woodlot in Kg/ha in 2003.

Months	Leaves	Twigs & branches	Reproductive organs	Miscellaneous	Total litter	%Leaves
July	35.04	9.96	0.12	4.50	49.62	70.60
August	38.76	12.24	0.33	4.23	55.56	69.80
September	26.31	14.37	3.66	9.51	53.85	48.90
October	25.62	18.36	4.92	14.79	63.69	40.20
November	40.71	14.67	0.99	16.47	72.84	55.90
December	56.46	25.59	1.14	21.42	104.61	54.00
Total	222.9 (55.7)	95.19 (23.8)	11.16 (2.8)	70.92 (17.7)	400.17	-
Mean	37.41	15.87	1.86	11.82	66.69	55.70
SD	11.34	5.52	1.96	6.92	20.32	11.88

Figures in parentheses are percent distribution of litter components

Table 3.2. Litter inputs from *Senna siamea* woodlot in Kg/ha in 2003.

Months	Leaves	Twigs & branches	Reproductive organs	Miscellaneous	Total litter	%Leaves
July	32.10	8.28	2.37	2.76	45.51	70.50
August	38.49	6.06	1.89	1.62	48.06	80.10
September	53.91	21.00	0.90	7.44	83.25	64.80
October	78.93	16.29	2.07	3.54	100.83	78.30
November	69.12	17.79	3.51	2.22	92.64	74.60
December	63.72	14.88	3.78	2.16	84.54	75.40
Total	336.27 (73.9)	84.30 (18.5)	14.52 (3.2)	19.74 (4.3)	454.83	-
Mean	56.04	14.04	2.43	3.30	75.81	73.90
SD	18.11	5.52	1.96	6.92	20.32	11.88

Figures in parentheses are percent distribution of litter components

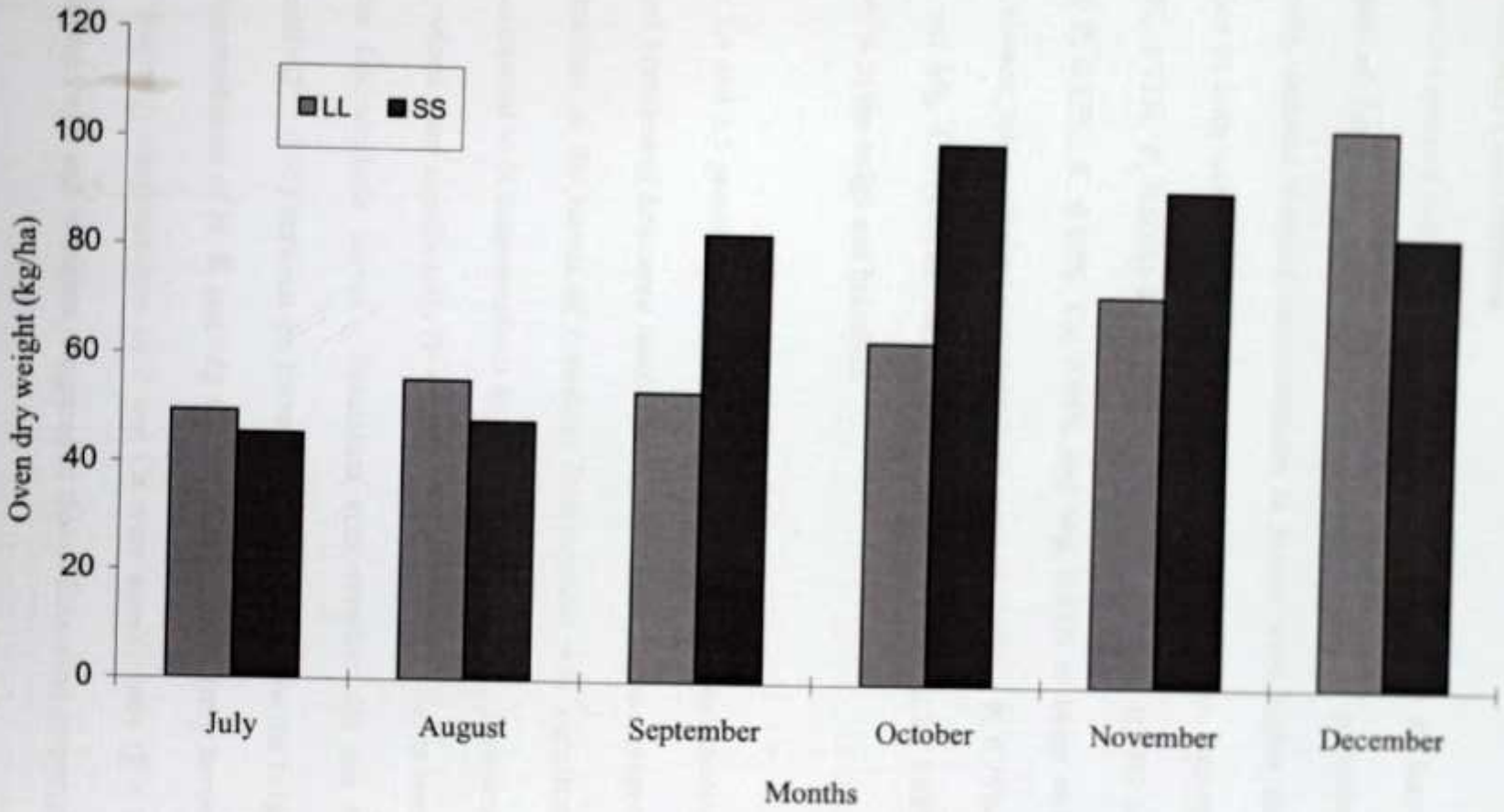

Figure 3.1 Pattern of total litter inputs in *Leucaena leucocephala* (LL) and *Senna siamea* (SS) woodlots.

3.3.3 Nutrient Concentration

The percent nutrient concentrations of N, P, K, Ca and Mg in the leaves and twigs and branches of *Leucaena leucocephala* and *Senna siamea* is presented in Table 3.3. Generally, nutrient element concentrations in leaves were higher than in twigs and branches in both woodlots. In *Leucaena leucocephala*, mean nutrient concentrations were N, 3.73%; P, 0.60%; K, 2.40%; Ca, 1.16% and Mg, 0.79% in leaves and N, 0.04%; P, 0.32%; K, 0.98%; Ca, 0.95% and Mg, 0.61% in twigs and branches. For *Senna siamea*, mean nutrient concentrations were N, 2.99%; P, 0.75%; K, 2.25%; Ca, 1.79% and Mg, 1.07% in the leaves and N, 0.06%; P, 0.51%; K, 1.08%; Ca, 1.16 and Mg, 0.67% in the twigs and branches.

Tables 3.4 and 3.5 present comparison of nutrient element concentrations in leaves and twigs and branches of *Leucaena leucocephala* and *Senna siamea*, respectively. Mean N concentrations in the leaves of *Leucaena leucocephala* was significantly ($P < 0.05$) higher compared to N concentrations in *Senna siamea* leaves. Phosphorus, Ca and Mg concentrations were significantly ($P < 0.05$) higher in *Senna siamea* leaves compared to *Leucaena leucocephala* leaves. Potassium concentration did not however, differ significantly ($P > 0.05$) between the leaves of both species. For the twigs and branches, mean concentrations of N, K and Mg did not differ significantly between species ($P > 0.05$). However, concentrations of P and Ca were significantly ($P < 0.05$) higher in *Senna siamea* twigs and branches compared to that of *Leucaena leucocephala*.

Table 3.3. Nutrient concentrations in litter components (%) from *Leucaena leucocephala* (LL) and *Senna siamea* (SS) woodlots in 2003.

Nutrient element	Species	Litter component	July	August	September	October	November	December	Mean
N	LL	Leaves	4.59	2.83	3.19	4.10	3.28	4.37	3.73
		Twigs & branches	0.04	0.03	0.16	0.01	0.01	0.01	0.04
	SS	Leaves	1.76	3.53	3.61	2.68	2.97	3.36	2.99
		Twigs & branches	0.01	0.01	0.06	0.17	0.10	0.01	0.06
P	LL	Leaves	0.77	0.63	0.58	0.48	0.69	0.46	0.60
		Twigs & branches	0.28	0.64	0.21	0.31	0.14	0.35	0.32
	SS	Leaves	0.96	0.70	0.59	0.63	0.83	0.77	0.75
		Twigs & branches	0.43	0.47	0.44	0.64	0.62	0.44	0.51
K	LL	Leaves	1.83	1.61	1.96	2.18	3.25	3.56	2.40
		Twigs & branches	1.36	1.15	0.66	0.86	1.07	0.80	0.98
	SS	Leaves	2.45	2.43	2.00	1.71	1.84	3.07	2.25
		Twigs & branches	1.46	1.39	1.11	1.20	1.18	0.14	1.08
Ca	LL	Leaves	1.07	1.67	1.02	1.15	0.93	1.09	1.16
		Twigs & branches	0.76	1.07	0.88	0.95	1.06	0.97	0.95
	SS	Leaves	1.57	1.29	1.24	1.80	2.02	2.81	1.79
		Twigs & branches	1.08	0.95	1.03	1.02	1.23	1.63	1.16
Mg	LL	Leaves	0.93	0.88	0.65	0.71	0.82	0.72	0.79
		Twigs & branches	0.56	0.82	0.40	0.71	0.73	0.45	0.61
	SS	Leaves	0.75	0.83	0.69	1.46	1.37	1.29	1.07
		Twigs & branches	0.53	0.78	0.68	0.74	0.54	0.73	0.67

Table 3.4. Comparison of nutrient concentrations (means with standard deviation in parentheses) in leaves of *Leucaena leucocephala* and *Senna siamea* in 2003[1].

Variables (%)	*Leucaena leucocephala*	*Senna siamea*	HO:$\mu_1 - \mu_2 = 0$ P-values
N	3.73 (0.72)	2.99 (0.70)	0.050*
P	0.60 (0.12)	0.75 (0.14)	0.040*
K	2.40 (0.81)	2.25 (0.50)	0.355 ns
Ca	1.16 (0.26)	1.79 (0.58)	0.018*
Mg	0.79 (0.11)	1.07 (0.34)	0.044*

[1] ns is not significant, * is significant at 0.05 probability levels, respectively.

Table 3.5. Comparison of nutrient concentrations (means with standard deviation in parentheses) in twigs and branches of *Leucaena leucocephala* and *Senna siamea* in 2003[1].

Variables (%)	*Leucaena leucocephala*	*Senna siamea*	HO:$\mu_1 - \mu_2 = 0$ P-values
N	0.04 (0.06)	0.06 (0.07)	0.326 ^{ns}
P	0.32 (0.17)	0.51 (0.10)	0.023*
K	0.98 (0.26)	1.08 (0.48)	0.336 ^{ns}
Ca	0.95 (0.12)	1.16 (0.25)	0.047*
Mg	0.61 (0.17)	0.67 (0.11)	0.257 ^{ns}

[1] ns is not significant, * is significant at 0.05 probability levels, respectively.

3.3.4 Potential Nutrient Inputs

Potential N, P, K, Ca, and Mg inputs from leaves and twigs and branches of *Leucaena leucocephala* and *Senna siamea* in kg/ha is presented in Table 3.6. The highest nutrient inputs in both woodlots could bc from leaves. Potential nutrient inputs could bc: N, 839.69 kg/ha; P, 133.03 kg/ha; K, 567.26 kg/ha; Ca, 257.92 kg/ha and Mg, 176.02 kg/ha from the leaves and N, 3.67 kg/ha; P, 30.35 kg/ha; K, 89.34 kg/ha; Ca, 89.27 kg/ha and Mg, 56.65 kg/ha from twigs and branches of *Leucaena leucocephala.* For *Senna siamea*, potential nutrient inputs could be: N, 1017.53 kg/ha; P, 247.06 kg/ha; K, 737.91 kg/ha; Ca, 620.17kg/ha and Mg 385.34 kg/ha from lcaves and N, 6.10 kg/ha; P, 42.79 kg/ha; K, 86.43 kg/ha; Ca, 99.08 kg/ha and Mg, 55.92 kg/ha from twigs and branches.

Mean litter and potential nutrient inputs in the woodlots of *Leucaena leucocephala* and *Senna siamea* during the period were compared using the Student's T- test (Table 3.7). Mean litter and potential N and K inputs did not differ significantly between species ($P > 0.05$). However, potential P, Ca and Mg inputs were significantly ($P < 0.05$) higher in *Senna siamea* litter compared to that of *Leucaena leucocephala* litter.

Table 3.6 Potential nutrient inputs in litter components (kg/ha) from *Leucaena leucocephala* (LL) and *Senna siamea* (SS) woodlots in 2003

Nutrient element	Species	Litter component	July	August	September	October	November	December	Total
N	LL	Leaves	160.83	109.69	83.93	105.04	133.50	246.70	839.69
		Twigs & branches	0.40	0.36	2.30	0.18	0.17	0.26	3.67
	SS	Leaves	56.90	135.87	193.86	211.53	205.28	214.09	1017.53
		Twigs & branches	0.08	0.06	1.26	2.77	1.78	0.15	6.10
P	LL	Leaves	26.99	24.42	15.26	12.30	28.09	25.97	133.03
		Twigs & branches	2.79	7.83	3.02	5.70	2.05	8.96	30.35
	SS	Leaves	31.04	28.48	31.68	49.73	57.07	49.06	247.06
		Twigs & branches	3.56	2.58	9.24	10.43	10.43	6.55	42.79
K	LL	Leaves	64.12	62.40	51.57	55.85	132.31	201.01	567.26
		Twigs & branches	13.55	14.08	9.48	15.79	15.70	20.74	89.34
	SS	Leaves	79.21	93.53	107.40	134.97	127.18	195.62	737.91
		Twigs & branches	12.08	8.42	23.31	19.55	20.99	2.08	86.43
Ca	LL	Leaves	37.49	64.73	26.84	29.46	37.86	61.54	257.92
		Twigs & branches	7.57	13.10	10.77	17.46	15.55	24.82	89.27
	SS	Leaves	50.76	49.56	66.59	142.59	139.62	171.05	620.17
		Twigs & branches	8.94	5.76	21.63	16.62	21.88	24.25	99.08
Mg	LL	Leaves	32.59	34.11	17.10	18.19	33.38	40.65	176.02
		Twigs & branches	5.58	10.04	5.75	13.05	10.71	11.52	56.65
	SS	Leaves	24.25	31.95	37.05	115.20	94.69	82.20	385.34
		Twigs & branches	4.39	4.73	14.28	12.05	9.61	10.86	55.92

Table 3.7. Comparison of litter and potential nutrient inputs (means with standard deviation in parentheses) in woodlots of *Leucaena leucocephala* and *Senna siamea* in 2003[1].

Variables (kg/ha)	*Leucaena leucocephala*	*Senna siamea*	HO:$\mu_1 - \mu_2 = 0$ P-values
Litter	66.70 (20.32)	75.81 (23.36)	0.244 ^{ns}
N	140.56 (58.18)	170.61 (63.01)	0.205^{ns}
P	27.23 (7.28)	48.31 (7.28)	0.005*
K	109.43 (63.19)	137.39 (38.65)	0.188^{ns}
Ca	57.87 (19.62)	119.88 (59.60)	0.018*
Mg	38.78 (10.46)	73.54 (40.20)	0.034*

[1] ns is not significant, * is significant at 0.05 probability levels, respectively

3.4 DISCUSSION

3.4.1 Litter Inputs

Total litter inputs from July to December, 2003 from *Leucaena leucocephala* and *Senna siamea* woodlots were 400.17 kg/ha and 454.83 kg/ha, respectively. Mean litter inputs were 66.69 kg/ha for *Leucaena leucocephala* woodlot and 75.81 kg/ha for *Senna siamea* woodlot. Kyerematen (2000) worked in the same woodlots between December 1999 and May 2000 and recorded total litter inputs of 464.61 kg/ha from *Leucaena leucocephala* woodlot and 719.13 kg/ha from *Senna siamea* woodlot with mean litter inputs of 77.44 kg/ha and 119.86 kg/ha, respectively. Also, Yeboah-Badu (2001) studied at the same woodlots between November 2000 and April 2001 and reported total litter inputs of 125.91 kg/ha from the *Leucaena leucocephala* woodlot and 535.50 kg/ha from the *Senna siamea* woodlot. Mean litter inputs for the six month period of 20.99 kg/ha and 89.25 kg/ha for *Leucaena leucocephala* and *Senna siamea*, respectively differed significantly ($P < 0.05$).

Total litter inputs recorded in this study are lower than values reported by Kyerematen (2000). This could be attributed to periods during which the studies were conducted. The timing of leafless period in forest trees in Ghana closely follows the rainfall pattern with the heaviest litter fall occurring at the height of dry season in December and February (Nye, 1961). Total litter inputs from *Leucaena leucocephala* (125.91 kg/ha) recorded by Yeboah-Badu (2001) was lower than the value recorded in this study (400.17 kg/ha). This could be attributed to species effect. Rainfall was erratic during November, 2002 and April, 2001 as a result *Leucaena leucocephala* had more green

leaves hence less litter fall. However, the total litter inputs recorded from *Senna siamea* (454.58 kg/ha) in this study is lower than values recorded from Yeboah-Badu (2001) and this could also be attributed to species effect. *Senna siamea* is known to produce high amount of leaves that have the tendency to fall at the least disturbance.

The total litter inputs of this study expressed on annual basis is 4,802.04 kg/ha/yr for *Leucaena leucocephala* and 5,454.96 kg/ha/yr for *Senna siamea*. These values are comparable to other reported values. For example, 3060 kg/ha/yr from *Acacia mangium* (Lim, 1985 cited by Nair, 1993); 3000 – 5000 kg/ha/yr from *Leucaena leucocephala* (Buck, 1986 cited by Nair, 1993); 2,000 – 4,000 kg/ha/yr from pure stands in tropical humid regions (Young, 1989); and for *Cordia alliodora* of 2,900 – 3,300 kg/ha/yr and *I. leptoloba* of 5,300 kg/ha/yr reported by Beer (1988). Conversely, values obtained in this study are lower than values reported by Berhnard (1970) of 12,600 kg/ha/yr from moist evergreen forest; Cornforth, (1970) of 6,800 kg/ha/yr from *Mora excelsa*; Egunjobi (1974) of 9,000 kg/ha/yr from *Tectonia grandis* and Okele and Omaliko (1991) of 9,800 kg/ha/yr from *Acioa barteri*.

3.4.2 Litter Distribution

Leaves constituted substantial portion of the total litter inputs and were 55.7% for *Leucaena leucocephala* and 73.9% for *Senna siamea* (Tables 3.1 and 3.2, respectively). These compare with the results of other authors. For instance, Bernhard (1970) reported 73.3% of total litter production as leaves; UNESCO/UNEP/FAO (1978) reported 52.2%; Songwe et al. (1988) reported 80%; Danquah-Menka (1986) reported

60.7% and Cuevas and Lugo (1998) reported 50.0%. In the same woodlots, Kyerematcng (2000) reported 62.4% and 64.6% of the total litter production as leaves for *Leucaena leucocephala* and *Senna siamea*, respectively.

The contribution of twigs and branches to total litter inputs in this study was 18.5% for *Leucaena leucocephala* and 23.8% for *Senna siamea*. These values are comparable with values reported by Bernhard (1970) of 18.6%; Lundgren (1978) of 20.4%; Boateng (1985) of 19% and Songwe et al. (1995) of 22-28%. Inputs of reproductive organs formed 2.8% and 3.2% of the total litter inputs in this study from *Leucaena leucocephala* and *Senna siamea* woodlots, respectively. These are lower than values reported by Kyerematcng (2000) of 10.5% for *Leucaena leucocephala* and 6.7% for *Senna siamea* and Yeboah-Badu (2001) of 11.4% for *Leucaena leucocephala* and 10.1% for *Senna siamea* probably due to the period during which the studies were conducted. Boateng (1985) and Danquah- Menka (1986) however, reported 3.0% of the total litter production as reproductive organs and this compares favourably with my results.

3.4.3 Pattern of Litter Inputs

From Figure 3.1, highest litter inputs were in December for *Leucaena leucocephala* and in October for *Senna siamea*. Studies conducted by Kyerematcng (2000) and Yeboah-Badu (2001) in the dry season in the same woodlot revealed highest total litter production in *Leucaena leucocephala* and *Senna siamea* woodlots in February.

The highest litter inputs in December for *Leucaena leucocephala* woodlot in this study is in agreement with Taylor (1960). In a study on the phenology of certain species in the tropical forest of Ghana, he indicated that trees that shed their leaves have highest litter production in December. Longman and Jenik (1992) also confirm the findings of this study when they reported that litter fall peaks in the first half (October-December) of the dry season as some of the trees become completely leafless in the second half (January-March) of the dry season.

The differences in highest litter inputs reported in my study for *Leucaena leucocephala* and *Senna siamea* could be attributed to species differences in tree phenology. Facelli and Pickett (1991) reported that species composition is an important variational factor in litter inputs within the same climatic condition and was corroborated by Montagnini et al. (1993). Several workers including Moughalu et al. (1993) and Montagnini et al. (1993) have reported different peak periods of litter inputs.

3.4.4 Nutrient Concentration

Mean nutrient concentrations in *Leucaena leucocephala* were N, 3.73%; P, 0.60%; K, 2.40%; Ca, 1.16% and Mg, 0.79% in leaves and N, 0.04%; P, 0.32%; K, 0.98%; Ca, 0.95% and Mg, 0.61% in twigs and branches. For *Senna siamea*, mean nutrient concentrations were N, 2.99%; P, 0.75%; K, 2.25%; Ca, 1.79% and Mg, 1.07% in the leaves and N, 0.06%; P, 0.51%; K, 1.08%; Ca, 1.16 and Mg, 0.67% in the twigs and branches (Table 3.3). These findings are inconsistent with other findings reported by Koudoro (1982) of N, 4.33%; P, 0.28%; K, 2.50%; Ca, 1.49% and Mg, 0.79% in

Leucaena leucocephala leaves and N, 4.21%; P, 0.29%; K, 3.43%; Ca, 1.40% and Mg, 0.40% in *Gliricidia sepium* leaves; Maclean et al. (1992) of N, 3.27%; P, 0.27%; K, 3.23%; Ca, 1.19% and Mg, 0.32% in *Gliricidia sepium* leaves; Sraha and Ulzen-Appiah (1997) of N, 3.85%; P, 0.32%; K, 1.56%; Ca, 1.32% and Mg, 0.36% in *Leucaena leucocephala* leaves and N, 3.58%; P, 0.34%; K, 1.40%; Ca, 1.12% and Mg, 0.29% in *Cassia spectabilis* leaves and Rainer (1999) of N, 2.69%; P, 0.23%; K, 1.41%; Ca, 1.85% and Mg, 0.36% in *Senna siamea* leaves. These could be due to specics effect and or site characteristics and management.

The ranking of mean nutrient concentrations in leaves and twigs and branches of *Leucaena leucocephala* and *Senna siamea* in this study were in the order N > K > Ca > Mg > P. These compare favourably with nutrient ranking order of N > K > Ca > Mg > P reported by Kleinjans (1984) and Budelman (1989) for *Leucaena leucocephala*; Maclean et al. (1992) for *Cassia spectabilis* and Asare (2005) for *Albizia ferruginea*. Mean nutrient concentrations ranking reported in this study however, differs from rankings reported by Singh (1982) in the order N > Ca > Mg > K > P > Na in *Pinus patula* leaves and the order N > K > Ca > P > Mg reported by Maclean et al. (1992) in *Cassia spectabilis* leaves; Sraha and Ulzen-Appiah (1997) in *Gliricidia sepium* leaves and Asare (2005) in *Albizia adianthifolia* leaves. In *Funtumia elastica* and *Nauclea diderrichii* leaves, mean nutrient concentrations were in the order Ca > N > K > Mg > P (Adu-Anning and Anglaaere, 1997).

High foliar concentrations of nutrient elements in *Leucaena leucocephala* and *Senna siamea* compares favourably with Rainer (1999) and Adu-Anning et al., (1985) who reported high N, P, K, Ca and Mg concentrations in leave litter. The patterns of nutrient concentrations in twigs and branches of both species were irregular except N which appeared to be least in both species and this agrees with the findings of Adu-Anning and Anglaaere (1997). It is acknowledged that the ranking of nutrients among components is in the order foliage > branches > stems. High nutrient concentration in the leaves of both species could be an indicator of the efficiency in nutrient cycling during decomposition and also forms a good index of nutritional status of the plants (Nwoboshi, 1985).

Mean nutrient concentration of N in the leaves of *Leucaena leucocephala* was significantly ($P < 0.05$) higher compared to that of *Senna siamea.* Phosphorus, Ca and Mg concentrations were significantly ($P < 0.05$) higher in *Senna siamea* leaves compared to *Leucaena leucocephala* leaves. Potassium concentration did not however, differ significantly ($P > 0.05$) between the two woodlots (Table 3.4). For twigs and branches there was no significant difference ($P > 0.05$) in mean nutrient concentrations of N, K and Mg between the woodlots. However, P and Ca were significantly ($P < 0.05$) higher in *Senna siamea* twigs and branches compared to *Leucaena leucocephala* twigs and branches (Table 3.5). Mean nutrient concentrations in the various components (leaves and twigs and branches) appeared to be high in *Senna siamea* than in *Leucaena leucocephala* indicating that *Senna siamea* could have higher rate of uptake and immobilization than *Leucaena leucocephala.*

3.4.5 Potential Nutrient Inputs

Potential N, P, K, Ca, and Mg inputs in leaves and twigs and branches of *Leucaena leucocephala* and *Senna siamea* increased with increasing biomass. From Table 3.6, *Senna siamea* could potentially contribute in its litter components (leaves, twigs and branches) N, 1023.63 kg/ha; P, 289.85 kg/ha; K, 824.43 kg/ha; Ca, 719.25 kg/ha and Mg, 441.2 kg/ha. *Leucaena leucocephala* could contribute N, 843.36 kg/ha; P, 163.83 kg/ha; K, 656.60 kg/ha, Ca, 347.19 kg/ha and Mg, 232.67 kg/ha. These values are higher than the nutrient inputs from *Gliricidia sepium* of N, 358 kg/ha; P, 28 kg/ha; K, 232 kg/ha; Ca, 144 kg/ha and Mg, 60 kg/ha and *Erythrina poeppigiana* of N, 278 kg/ha; P, 24 kg/ha; K, 216 kg/ha; Ca, 120 kg/ha and Mg, 52 kg/ha (Kass et al., 1989 cited by Nair, 1993) but comparable with nutrient inputs from *Nauclea diderrichii* of N, 1186 kg/ha; P, 101 kg/ha; K, 583 kg/ha; Ca, 1421 kg/ha and Mg, 376 kg/ha and *Funtumia elastica* of N, 1081 kg/ha; P, 259 kg/ha; K, 634 kg/ha; Ca, 1203 kg/ha and Mg, 367 kg/ha (Adu-Anning and Anglaaere, 1997).

Total potential nutrient inputs were in the order N > K > Ca > Mg > P for both species and this trend is similar to nutrient concentrations trend (Table 3.3). There were no significant difference ($P > 0.05$) in potential N and K inputs in *Leucaena leucocephala* and *Senna siamea* woodlots. This could be attributed the fact that *Leucaena leucocephala* is a N fixing plant which can fix about 100-500 kg of N per ha/yr (Nair, 1993) and *Senna siamea*, even though not a nitrogen fixing plant, holds large amount of N in its foliage (N.A.S, 1980; Yamoah et al., 1986).

Senna siamea has the potential to remove K from the lower depths of soil profile with the aid of mycorrhizal roots and efficiently recycled it (Pritchett, 1979) whereas *Leucaena leucocephala* has the potential to contribute as much as 264 kg of K per hectare per year (Hauser and Kang, 1993). Hence probably the lack of significant difference in potential K inputs in the woodlots.

Potential P, Ca and Mg inputs were significantly ($P < 0.05$) higher in *Senna siamea* litter compared to *Leucaena leucocephala* litter. This could be attributed to the heavy vesicular-arbuscular mycorrhizae infection of *Senna siamea* which improves uptake of P from the soil (Okon et al., 1996) and enhance uptake of secondary (Ca, Mg and S) nutrients (Blal et al., 1990; Young, 1997).

3.5 SUMMARY AND CONCLUSION

This study tested the hypothesis that litter and potential nutrients inputs in *Leucaena leucocephala* and *Senna siamea* woodlots during the period of study were similar. The results indicated that total litter and potential N and K inputs in *Leucaena leucocephala* and *Senna siamea* woodlots did not differ significantly ($P > 0.05$). However, potential P, Ca and Mg inputs in *Senna siamea* litter were significantly ($P < 0.05$) higher than in *Leucaena leucocephala* litter.

There were no significant differences ($P > 0.05$) in N, K and Mg concentrations in the twigs and branches of *Leucaena leucocephala* and *Senna siamea*. However, P and Ca concentrations were significantly higher in *Senna siamea* twigs and branches compared to *Leucaena leucocephala* twigs and branches. Potassium concentration in the leaves of both species did not differ significantly. Mean concentration of N in the leaves of *Leucaena leucocephala* was significantly ($P < 0.05$) higher compared to that of *Senna siamea* whereas P, Ca and Mg concentrations were significantly ($P < 0.05$) higher in *Senna siamea* leaves compared to *Leucaena leucocephala* leaves.

Based on the above results, it could be concluded that litter inputs in *Leucaena leucocephala* and *Senna siamea* woodlots could be similar and leaves were the major components of the total litter inputs. The pattern of litter inputs varied among the species and this could be attributed to species differences in tree phenology. Also, potential P, Ca and Mg inputs could be significantly ($P < 0.05$) higher in *Senna siamea* litter compared to *Leucaena leucocephala* litter. *Leucaena leucocephala* or *Senna*

siamea species could be used in Agroforestry practice where litter input is a management objective. However, *Senna siamea* could be a preferred species because of higher potential P, Ca and Mg inputs in its litter if nutrient inputs are part of management objective.

CHAPTER 4

4.0 'IN SITU' DECOMPOSITION AND MINERALIZATION OF *Leucaena leucocephala* AND *Senna siamea* FOLIAGE

4.1. INTRODUCTION

Plant litter contains considerable amounts of nutrients necessary for plant growth. In order to release these nutrients, litter must be broken down or decomposed. Litter decomposition and mineralization is mediated by soil and forest floor decomposer community which comprise of microflora, microfauna, mesofauna and macrofauna. The rate of decomposition is regulated by interactions between this decomposer community, the physical environment and litter residue quality (Swift et al., 1979).

Decomposition is defined as biological and chemical disintegration of dead plants and animals until a stage where the gross cell structure is no longer recognizable. Decomposition is a major component of nutrient cycling and it varies among species either directly through litter quality or indirectly through microclimate and decomposer community (Swift et al., 1979; Anderson and Swift, 1983; McClougherty et al., 1985). Mineralization is the process through which nutrients are made available to plants and microbes. Analysing decomposition at regular intervals to determine the loss in mineral content can be used to assess mineralization rates (Bocock, 1963).

The time needed to complete the process of decomposition may range from days to years depending on the prevailing physical environment and the substrate quality. These factors determine the residual time of plant detritus and the rate of nutrient

cycling (Swift et al., 1979). For example, *Leucaena leucocephala* and *Gliricidia sepium* decompose relatively fast under humid tropical conditions due to low lignin levels, low carbon/nitrogen (C/N) ratio, and low lignin/nitrogen (L/N) ratio in their foliage. Species like *Senna siamea* and *Flemingia marcrophylla* decompose slowly due to high lignin levels, high L/N ratio and high C/N ratio (Nair, 1993).

Mineralization rates normally correlate with the rate of decomposition but the correlation needs not be very close (Jensen, 1974). Mineralization varies from species to species and also among different components of the same species. For example, in the humid zone of Ghana, mineralization of decomposing leaves of *Leucaena leucocephala* was in the order K > Mg > N > P > C > Ca, *Gliricidia sepium* in the order K > Mg > P > N = Ca > C and *Cassia spectabilis* in the order K > Mg > P > N > Ca = C (Sraha and Ulzen-Appiah, 1997). Also, in a Nigerian rain forest mineralization was in the order Ca > N > K > Mg > P for leaf and wood litter and in the order N > K > Ca > Mg > P for fruit litter (Moughalu et al., 1993). In general, species with low C/N ratio, low levels of lignin and low L/N ratio release nutrients at a faster rate (Nair, 1993).

In the use of MPTs for soil fertility improvement, it will be beneficial to quantify the mineral nutrient inputs and release patterns in order to select MPTs whose nutrient release can be synchronized with plant growth demands. This can reduce leaching and other losses and increase plant uptake. *Leucaena leucocephala* and *Senna siamea* are MPTs widely used for soil fertility improvement.

The objective was to study 'in situ' decomposition and mineralization of N, P, K, Ca and Mg in *Leucaena leucocephala* and *Senna siamea* foliage. The study hypothesizes that rates of decomposition and mineralization of *Leucaena leucocephala* and *Senna siamea* foliage are similar.

4.2 MATERIALS AND METHODS

4.2.1 Study Site

The experiment was conducted in woodlots of *Leucaena leucocephala* and *Senna siamea* at the FRNR demonstration farm. The site and woodlots have been described under sections 3.2.1. and 3.2.2., respectively.

4.2.2. The Experiment

Decomposition and mineralization patterns were studied using nylon bags of mesh size 2 mm in the form of rectangular envelopes measuring 15 cm × 25 cm (Singh, 1982). Three quadrats each measuring 6 m × 8 m were laid randomly in each woodlot. Forty grams of oven-dry foliage of each species was put in nylon bags and distributed randomly on the floor of each quadrat. Litter on the floor was cleared so that the bags were in direct contact with the soil and were pinned to the floor with galvanized nails (Singh, 1982). In all 30 nylon bags were laid in each woodlot with 10 nylon bags in each quadrat. The nylon bags were randomly sampled monthly from August, 2003 to December, 2003.

On each sampling date two samples from each quadrat were collected. The samples collected were taken to the laboratory where the remains of the decomposed foliage were separated from the soil particles, oven dried at a temperature of 65°C to a constant weight and dry weights recorded. The oven dried samples were ground in a Wiley Mill and analyzed for N, P, K, Ca, and Mg. At the beginning of the experiment (day 0) sub-samples of the foliage were taken and oven-dried at a temperature of 65°C to a constant weight. The oven dried samples were ground in a Wiley Mill and analyzed for N, P, K, Ca, Mg, C and lignin.

4.2.3 Laboratory Analyses

Concentrations of N, P, K, Ca and Mg in samples were determined using the methods described under section 3.2.4. Percent lignin and organic carbon were determined using the methods described below.

Lignin

Lignin content of foliage was determined using the soxhlet extraction method (Tappi: T 222- S 88) described as follows. Ground samples were sieved using mesh sizes of 40 mm and 60 mm. Five grams of air-dried sieved sample was placed in a thimble and the weight of the thimble plus the sample (a) was recorded. The thimble with the sample was positioned in the soxhlet apparatus. The extraction was carried out in three continuous phases. First, the sample in the thimble was boiled briskly with 200 ml of alcohol-benzene in a ratio of 1:2 for four hours, allowed to cool and the extract discarded. Then the material in the thimble was boiled briskly with 200 ml of alcohol

for four hours, allowed to cool and the extract discarded. Finally, the material in the thimble was boiled briskly with 200 ml of distilled water for four hours, allowed to cool and extract discarded after which it was oven dried at a temperature of 75°C to a constant weight and dry weight (b) recorded.

One gram of the oven-dried material from the procedure above was used to determine the lignin content. To this was added 72% sulphuric acid, stirred for two hours, diluted to 3% acid concentration with 560 ml of distilled water and then boiled for four hours. The mixture was filtered through a weighed (c) Whatman No. 42 filter paper. The solute plus the filter paper were dried in an oven at 75°C to a constant weight (d). The weight of Klason lignin was expressed as percentage based on moisture-free material using the formula below.

$$\% \text{ weight of Klason lignin} = \frac{X}{Y} \times 100 \qquad \text{Eqn. 1}$$

Where $X = (d - c)$; oven dried weight of lignin

$Y = (a - b)$; weight of moisture- free sample used

Percent carbon

First, organic matter was determined by dry oxidation method described by Wilde et al. (1972) and then converted to % C. In this method, 1 g of ground sample was weighed into a preheated and weighed crucible. The weight of sample plus the crucible was recorded. The sample in the crucible was put in a cold muffle furnace and brought up to 470^0C slowly between 2 - 4 hours so as to prevent ignition of the sample material. The sample was burnt for 16 hours, allowed to cool in a desiccator for an hour and weighed.

Percent organic matter (OM) was calculated using the formula below.

$$\% \text{ OM} = \frac{(\text{Wt. B} - \text{Wt. A}) \times 100}{\text{Wt. B}} \qquad \text{Eqn. 2}$$

Where: Wt. B is weight of sample before burning

Wt. A is weight of sample after burning

The percent organic carbon (% C) was determined by dividing organic matter value by a conventional factor 1.72 (Hesse, 1975) as follows:

$$\% \text{ C} = \frac{\% \text{ organic matter}}{1.72} \qquad \text{Eqn. 3}$$

4.2.4 Other Calculations

Lignin/nitrogen (L/N) ratio

Lignin and nitrogen values obtained from section 4.2.3 were used to calculate L/N ratio as follows.

$$\text{L/N} = \frac{\% \text{ lignin}}{\% \text{ nitrogen}} \qquad \text{Eqn. 4}$$

Carbon/nitrogen (C/N) ratio

Carbon and nitrogen values obtained from section 4.2.3 were used to calculate C/N ratio as follows.

$$\text{C/N} = \frac{\% \text{ carbon}}{\% \text{ nitrogen}} \qquad \text{Eqn. 5}$$

Decomposition Rate Constants (K_d) and Nutrient Release Constants (K_n)

Decomposition rate constants (K_d) and nutrient release constants (K_n) were calculated for each species using Olson (1963) exponential relationship below.

$$\frac{X}{X_0} = e^{-kt} \qquad \text{Eqn. 6}$$

$$\ln \frac{(X)}{X_0} = -Kt \qquad \text{Eqn. 7}$$

$$\ln X - \ln X_0 = -Kt \qquad \text{Eqn. 8}$$

$$\ln X_0 - \ln X = Kt \qquad \text{Eqn. 9}$$

$$K_{(d/n)} = \frac{\ln X_0 - \ln x}{t} \qquad \text{Eqn. 10}$$

Where

X_0 = dry weights at the start of the experiment. X = dry weight after time t.

$K_{d/n}$ = Decay/ nutrient release constants. e = base of natural logarithms

4.2.5 Statistical Analysis

The experiment was analysed as a split-plot in Completely Randomized Design (CRD). *Leucaena leucocephala* and *Senna siamea* woodlots were the main plots and time was the subplot. Data on species foliage loss in weight and concentrations of N, P, K, Ca and Mg with time were subjected to analyses of variance (ANOVA) test using Statview (SAS Institute Inc., 1992). Fisher's paired least significant difference (PLSD) tests ($\alpha = 0.05$) were used to compare treatment means when ANOVA showed significant differences.

4.3 RESULTS

This section presents results on initial chemical characteristics, decomposition and mineralization of N, P, K, Ca and Mg in *Leucaena leucocephala* and *Senna siamea* foliage. Also presented are results on decomposition rate constants (K_d) and nutrient release constants (K_n) of *Leucaena leucocephala* and *Senna siamea* foliage.

4.3.1 Initial Chemical Characteristics of Foliage

The initial levels of N, P, K, Ca and Mg in *Leucaena leucocephala* and *Senna siamea* foliage are presented in Table 4.1. Phosphorus level was significantly higher ($P < 0.05$) in *Senna siamea* foliage than in *Leucaena leucocephala* foliage whereas Mg level was significantly higher ($P < 0.05$) in *Leucaena leucocephala* foliage than in *Senna siamea* foliage. Nitrogen, K and Ca levels did not differ significantly between *Leucaena leucocephala* and *Senna siamea* foliage.

Lignin and C concentrations were 6.78% and 53.49% in *Leucaena leucocephala* and 8.57% and 54.72% in *Senna siamea*, respectively. Lignin/nitrogen ratio was 1.46 for *Leucaena leucocephala* and 2.08 for *Senna siamea* and C/N ratio was 11.43 and 13.28 for *Leucaena leucocephala* and *Senna siamea*, respectively (Table 4.1).

Table 4.1 Initial chemical characteristics of *Leucaena leucocephala* and *Senna siamea* foliage[1].

Chemical characteristics	*Leucaena leucocephala*	*Senna siamea*
Nitrogen (%)	4.68a	4.12a
Phosphorus (%)	0.58a	0.99b
Potassium (%)	3.04a	3.77a
Calcium (%)	1.46a	1.63a
Magnesium (%)	1.48a	0.97b
Carbon (%)	53.49	54.72
Lignin (%)	6.78	8.57
Carbon/Nitrogen	11.43	13.28
Lignin/Nitrogen	1.46	2.08

[1]Within rows, means followed by the same letter are not significantly different at $P > 0.05$.

4.3.2 Decomposition and Rate Constants (K_d)

Decomposition

The summary of P-values of analyses of variance testing effect of species (*Leucaena leucocephala* and *Senna siamea*), time and species-time interaction on foliage decomposition (weight loss) are presented in Table 4.2. There were significant differences ($P = 0.012$) in foliage weight loss between *Leucaena leucocephala* and *Senna siamea*. Compared to the initial dry weight, *Senna siamea* foliage weights decreased significantly ($P < 0.05$) at 30 and 60 days and remained unchanged thereafter whereas in *Leucaena leucocephala,* foliage weights decreased significantly ($P < 0.05$) at 30 and 90 days and remained unchanged thereafter (Table 4.3).

Decomposition Rate Constants

Decomposition rate constants (K_d) of *Leucaena leucocephala* foliage varied between 0.013 and 0.069. That of *Senna siamea* foliage varied between 0.001 and 0.076. Negative K_d values were obtained for *Leucaena leucocephala* and *Senna siamea* foliage at 120 days. The average K_d values for *Leucaena leucocephala* and *Senna siamea* foliage were 0.024 and 0.023, respectively (Table 4.4).

4.3.3 Mineralization and Release Constants (K_n)

Mineralization

The summary of P-values of analyses of variance testing effect of species, time and species-time interaction on foliage mineralization of N, P, K, Ca and Mg are presented in Table 4.2. The release of N, P, K and Ca did not differ significantly between

Table 4.2 Summary of P-values of ANOVA testing effect of species (*Leucaena leucocephala* and *Senna siamea*) on decomposition (weight loss [Wt]) and mineralization (N, P, K, Ca and Mg release) [1].

Source of variation	Degree of freedom	P- values					
		Wt	N	P	K	Ca	Mg
Species	1	0.0123**	0.8088 ns	0.058 ns	0.3106 ns	0.3215 ns	0.0080**
Time	5	0.0001***	0.0001***	0.0037**	0.1318 ns	0.0001***	0.0001***
Species and Time	5	0.0001***	0.0009***	0.0488*	0.5652 ns	0.1298 ns	0.0280*

[1]ns is not significant; *, **, *** is significant at 0.05, 0.01, 0.001 probability levels, respectively.

Table 4.3. Comparison of mean dry weight (g) of *Leucaena leucocephala* and *Senna siamea* remaining from 0-150 days[1].

Days	*Leucaena leucocephala*	*Senna siamea*
0	40.00a (100)	40.00a (100)
30	5.02b (12.55)	23.55b (57.50)
60	2.36bc (5.90)	2.37c (5.93)
90	1.62c (4.05)	1.08c (2.70)
120	2.40bc (6.00)	1.38c (3.45)
150	1.13c (2.83)	1.33c (3.33)

[1]Figures in parentheses are percent dry weights remaining. Within species, means followed by the same letter are not significantly different at $P > 0.05$.

Table 4.4 Decomposition rate constants (K_d) of *Leucaena leucocephala* and *Senna siamea* foliage with time.

Days	*Leucaena leucocephala*	*Senna siamea*
30	0.069	0.018
60	0.025	0.076
90	0.013	0.026
120	-0.013	-0.008
150	0.025	0.001
Average	0.024	0.023

Leucaena leucocephala and *Senna siamea* foliage. However, the release of N, P, Ca and Mg differed significantly between *Leucaena leucocephala* and *Senna siamea* foliage with time. Potassium release was not significantly different (P = 0.13) between the species with time.

Within 150 days, percent nutrient release from decomposing foliage of *Leucaena leucocephala* with time varied between 19 % and 80 % for N; 21 % and 51% for P; 19% and 55% for K; 9% and 47% for Ca and 42% and 74% for Mg. In *Senna siamea,* the variations were between 33% and 90% for N; 50% and 73% for P; 29% and 61% for K; 33% and 64% for Ca and 26% and 56% for Mg (Appendix 1).

Within each species there were significant decreases in the levels of N, P, K, Ca and Mg with time. Between and within species mineralization of N, P, K, Ca and Mg in decomposing foliage with time are as follows.

Nitrogen

Changes in N levels with time in foliage of *Leucaena leucocephala* and *Senna siamea* are compared in Table 4.5. Between species, N levels were significantly higher in decomposing foliage of *Leucaena leucocephala* at 30 days (P = 0.006) and 120 days (P = 0.049) compared to *Senna siamea* foliage. However, at 150 days N levels were significantly higher (P = 0.001) in decomposing foliage of *Senna siamea* than in *Leucaena leucocephala* foliage.

Table 4.5 Comparison of N levels in decomposing foliage of *Leucaena leucocephala* and *Senna siamea* with time[1].

Days	*Leucaena leucocephala*	*Senna siamea*	P-values
0	4.676a	4.116a	0.493^{ns}
30	3.780a (0.348)	2.380b (0.369)	0.006**
60	1.814bc (0.392)	2.662b (0.568)	0.081^{ns}
90	2.147b (0.382)	2.077b (0.091)	0.881^{ns}
120	1.381bc (0.139)	0.413c (0.136)	0.049*
150	0.925c (0.092)	2.753ab (0.373)	0.0008***

[1]Figures in parentheses are standard error. Between species, ns is not significant; *, **, *** is significant at 0.05, 0.01, 0.001 probability levels, respectively. Within species, means followed by the same letter are not significantly different ($P > 0.05$).

Within species, N levels in decomposing foliage of *Leucaena leucocephala* decreased significantly ($P < 0.05$) at 60 days and 150 days compared to initial levels. Nitrogen levels in decomposing foliage of *Senna siamea* decreased significantly at 30 days and 120 days ($P < 0.05$) compared to initial levels (Table 4.5).

Phosphorus

Phosphorus levels were significantly higher in decomposing foliage of *Senna siamea* at 0 days ($P = 0.023$) and 150 days ($P = 0.049$) compared to *Leucaena leucocephala* foliage (Table 4.6). Within species, P levels decreased significantly in decomposing foliage of *Leucaena leucocephala* at 90 days ($P < 0.05$) compared to initial levels. Phosphorus levels in decomposing foliage of *Senna siamea* decreased significantly at 30 and 60 days ($P < 0.05$) and remained unchanged thereafter compared to the initial level.

Potassium

Table 4.7 presents comparison of K levels with time in decomposing foliage of *Leucaena leucocephala* and *Senna siamea*. Between species, there were no significant differences ($P > 0.05$) in levels of K in decomposing foliage of *Leucaena leucocephala* and *Senna siamea* with time. Potassium levels did not change significantly in decomposing foliage of *Leucaena leucocephala* with time. However, K levels in *Senna siamea* decreased significantly in decomposing foliage at 90 days ($P < 0.05$) compared to the initial level.

Table 4.6. Comparison of P levels in decomposing foliage of *Leucaena leucocephala* and *Senna siamea* with time[1].

Days	*Leucaena leucocephala*	*Senna siamea*	P-values
0	0.582a	0.990a	0.023*
30	0.403ab (0.035)	0.467b (0.041)	0.518^{ns}
60	0.436ab (0.034)	0.264c (0.071)	0.088^{ns}
90	0.283b (0.045)	0.377bc (0.040)	0.344^{ns}
120	0.460ab (0.020)	0.413bc(0.136)	0.633^{ns}
150	0.297b (0.030)	0.498b (0.118)	0.049*

[1]Figures in parentheses are standard error. Between species, ns is not significant; * is significant at 0.05 probability level. Within species, means followed by the same letter are not significantly different (P > 0.05).

Table 4.7. Comparison of K levels in decomposing foliage of *Leucaena leucocephala* and *Senna siamea* with time[1].

Days	*Leucaena leucocephala*	*Senna siamea*	P-values
0	3.036a	3.770a	0.517^{ns}
30	1.963a (0.292)	2.077ab (0.366)	0.861^{ns}
60	1.542a (0.316)	2.680ab (0.399)	0.091^{ns}
90	1.835a (0.430)	1.471b (0.729)	0.576^{ns}
120	1.380a (0.252)	1.937ab (0.197)	0.396^{ns}
150	2.467a (0.066)	2.181ab (0.874)	0.660^{ns}

[1]Figures in parentheses are standard error. Between species, ns is not significant at 0.05 probability level. Within species, means followed by the same letter are not significantly different (P > 0.05).

Calcium

Between species, Ca levels were significantly higher in decomposing foliage of *Leucaena leucocephala* at 120 days ($P = 0.049$) compared to *Senna siamea* foliage. Within *Leucaena leucocephala*, Ca levels in decomposing foliage decreased significantly at 60 days ($P < 0.05$) after which there was no significant decrease in Ca levels compared to the initial level. However, Ca levels in decomposing foliage of *Senna siamea* decreased significantly at 30 and 90 days ($P < 0.05$) compared to the initial level (Table 4.8).

Magnesium

Comparison of Mg levels with time in decomposing foliage of *Leucaena leucocephala* and *Senna siamea* is presented in Table 4.9. Between species Mg levels in decomposing foliage of *Leucaena leucocephala* were significantly higher than in *Senna siamea* foliage at 0 days ($P = 0.018$) and 120 days ($P = 0.002$). Within *Leucaena leucocephala*, Mg levels in decomposing foliage decreased significantly at 30 and 120 days ($P < 0.05$). In *Senna siamea*, Mg levels in decomposing foliage decreased significantly at 60 days and remained unchanged thereafter compared with initial levels.

Nutrient Release Constants (K_n)

Nutrient release constants (K_n) varied in decomposing foliage of *Leucaena leucocephala* and *Senna siamea*. In *Leucaena leucocephala*, K_n varied between 0.007 and 0.025 for N; 0.012 and 0.015 for P; 0.008 and 0.015 for K; 0.009 and 0.012 for Ca

Table 4.8. Comparison of Ca levels in decomposing foliage of *Leucaena leucocephala* and *Senna siamea* with time[1].

Days	*Leucaena leucocephala*	*Senna siamea*	P-values
0	1.457a	1.627a	0.532^{ns}
30	1.100ab (0.112)	1.093b (0.007)	0.966^{ns}
60	0.774c (0.071)	0.996b (0.049)	0.166^{ns}
90	0.870bc (0.111)	0.608c (0.033)	0.104^{ns}
120	0.907bc (0.159)	0.583c (0.144)	0.049*
150	1.323a (0.160)	1.080b (0.118)	0.130^{ns}

[1] Figures in parentheses are standard error. Between species, ns is not significant; * is significant at 0.05 probability level. Within species, means followed by the same letter are not significantly different (P > 0.05).

Table 4.9. Comparison of Mg levels in decomposing foliage of *Leucaena leucocephala* and *Senna siamea* with time[1].

Days	*Leucaena leucocephala*	*Senna siamea*	P-values
0	1.476a	0.969a	0.018*
30	0.610bc (0.076)	0.713ab (0.132)	0.377^{ns}
60	0.386b (0.014)	0.430c (0.080)	0.704^{ns}
90	0.621bc (0.064)	0.550bc (0.055)	0.542^{ns}
120	0.853c (0.049)	0.450c (0.026)	0.002**
150	0.673c (0.150)	0.554bc (0.053)	0.309^{ns}

[1]Figures in parentheses are standard error. Between species, ns is not significant; *, ** is significant at 0.05 and 0.001 probability level. Within species, means followed by the same letter are not significantly different (P > 0.05).

and 0.008 and 0.014 for Mg. In *Senna siamea*, the variations were between 0.009 and 0.054 for N; 0.015 and 0.019 for P; 0.008 and 0.020 for K; 0.001 and 0.016 for Ca and 0.007 and 0.017 for Mg. Negative K_n values were recorded for N, P, K, Ca and Mg in both species (Table 4.10).

Mean K_n values were N, 0.011; P, 0.004; K, 0.004; Ca, 0.006 and Mg, 0.005 for *Leucaena leucocephala* and N, 0.003; P, 0.003; K, 0.007; Ca, 0.003 and Mg, 0.007 for *Senna siamea*. In general, there were no significant differences in mean K_n between *Leucaena leucocephala* and *Senna siamea* (Table 4.11).

Table 4.10 Nutrient release constants (K_n) with time in *Leucaena leucocephala*(LL) and *Senna siamea* (SS) foliage.

Nutrient element	Species	Days				
		30	60	90	120	150
N	LL	0.007	0.025	-0.005	0.015	0.013
	SS	0.018	-0.004	0.009	0.054	-0.063
P	LL	0.012	-0.003	0.015	-0.017	0.014
	SS	0.015	0.019	-0.011	-0.003	-0.007
K	LL	0.015	0.008	-0.006	0.010	-0.006
	SS	0.020	0.008	0.020	-0.009	-0.004
Ca	LL	0.009	0.012	-0.004	-0.001	0.012
	SS	0.015	0.001	0.016	0.002	-0.021
Mg	LL	0.030	0.014	-0.015	-0.011	0.008
	SS	0.010	0.017	-` 0.008	0.007	-0.007

Table 4.11. Comparison of mean nutrient release constants (K_n) in decomposing foliage of *Leucaena leucocephala* and *Senna siamea* [1].

Nutrient elements	*Leucaena leucocephala*	*Senna siamea*	P-values
N	0.011 (0.005)	0.003 (0.019)	0.688^{ns}
P	0.004 (0.006)	0.003 (0.006)	0.858^{ns}
K	0.004 (0.004)	0.007 (0.006)	0.714^{ns}
Ca	0.006 (0.003)	0.003 (0.007)	0.699^{ns}
Mg	0.005 (0.008)	0.004 (0.004)	0.849^{ns}

[1]Figures in parentheses are standard error. Between species, ns is not significant at 0.05 probability level.

4.4 DISCUSSION

4.4.1 Initial Chemical Characteristics of Foliage

Initial chemical characteristics of litter have great significance in determining the rate of decomposition. The most influential among these chemical characteristics are initial lignin levels, initial N levels, L/N and C/N ratios (Swift et al., 1979). From Table 4.1, *Leucaena leucocephala* foliage had initial lignin concentration of 6.78%, initial N concentration of 4.68%, L/N ratio of 1.46 and C/N ratio of 11.43 compared to *Senna siamea* foliage with initial lignin concentration of 8.57%, initial N concentration of 4.12%, L/N ratio of 2.08 and C/N ratio 13.28. These results fall within the range of values reported by other authors. For instance, *Leucaena leucocephala* with initial N concentration of 3.85%, initial lignin concentration of 5.6%, L/N ratio of 1.45 and C/N ratio of 12.0; *Gliricidia sepium* with initial N concentration of 3.36%, initial lignin concentration of 7.6%, L/N ratio of 2.26 and C/N ratio of 12.3 and *Cassia spectabilis* with initial N concentration of 3.58%, initial lignin concentration of 8.7%, L/N ratio of 2.43 and C/N ratio of 12.2 (Sraha and Ulzen-Appiah, 1997).

Tian et al. (1992) reported of *Leucaena leucocephala* with initial N concentration of 5.87%, initial lignin concentration of 7.1%, L/N ratio of 1.23 and C/N ratio of 7.76 and *Gliricidia sepium* with initial N concentration of 5.04%, initial lignin concentration of 8.6%, L/N ratio of 1.71 and C/N ratio of 9.38 while Palm and Sanchez (1990) reported of *Leucaena leucocephala* with initial N concentration of 3.94% and initial lignin concentration of 5.2% and *Gliricidia sepium* with initial N

concentration of 3.74% and initial lignin concentration of 7.8%. *Leucaena leucocephala* and *Senna siamea* litter concentrations of mineral elements (Table 3.4) were generally lower than concentrations of mineral elements in their foliage (Table 4.1) presumably due to resorption during senescence (Rapp et al. 1999; Jamaludheen and Kumar, 1999).

4.4.2 Decomposition and Rate Constants (K_d)

Decomposition

Leucaena leucocephala and *Senna siamea* foliage differed in their rates of decomposition. At 30 days, 87.45% of *Leucaena leucocephala* foliage and 42.50% of *Senna siamea* foliage had decomposed (Table 4.3). Significant weight loss of 87.45% coincided with K_d value of 0.069 at 30 days in *Leucaena leucocephala* (Figure 4.1). However, for *Senna siamea,* significant weight loss of 94.07% coincided with K_d value of 0.076 at 60 days (Figure 4.2). Decomposition was therefore, faster in *Leucaena leucocephala* foliage compared to *Senna siamea* foliage.

Differences in species decomposition have been reported by several researchers. For example, *Lustea sp* decomposed faster than *Schizomeria sp* (Edwards, 1977); *Gliricidia sepium* decomposed faster than *Cassia siamea* (Yamoah, 1986); *Leucaena leucocephala* decomposed faster than *Gliricidia sepium* (Budelman, 1988); *Leucaena leucocephala* decomposed faster than *Senna siamea* (Van Der Meersch et al., 1993) and *Celtis zenkeri* decomposed faster than *Ceiba pentandra* (Songwe et al., 1995). Litter decomposition is influenced by lignin concentration, N concentration, and L/N

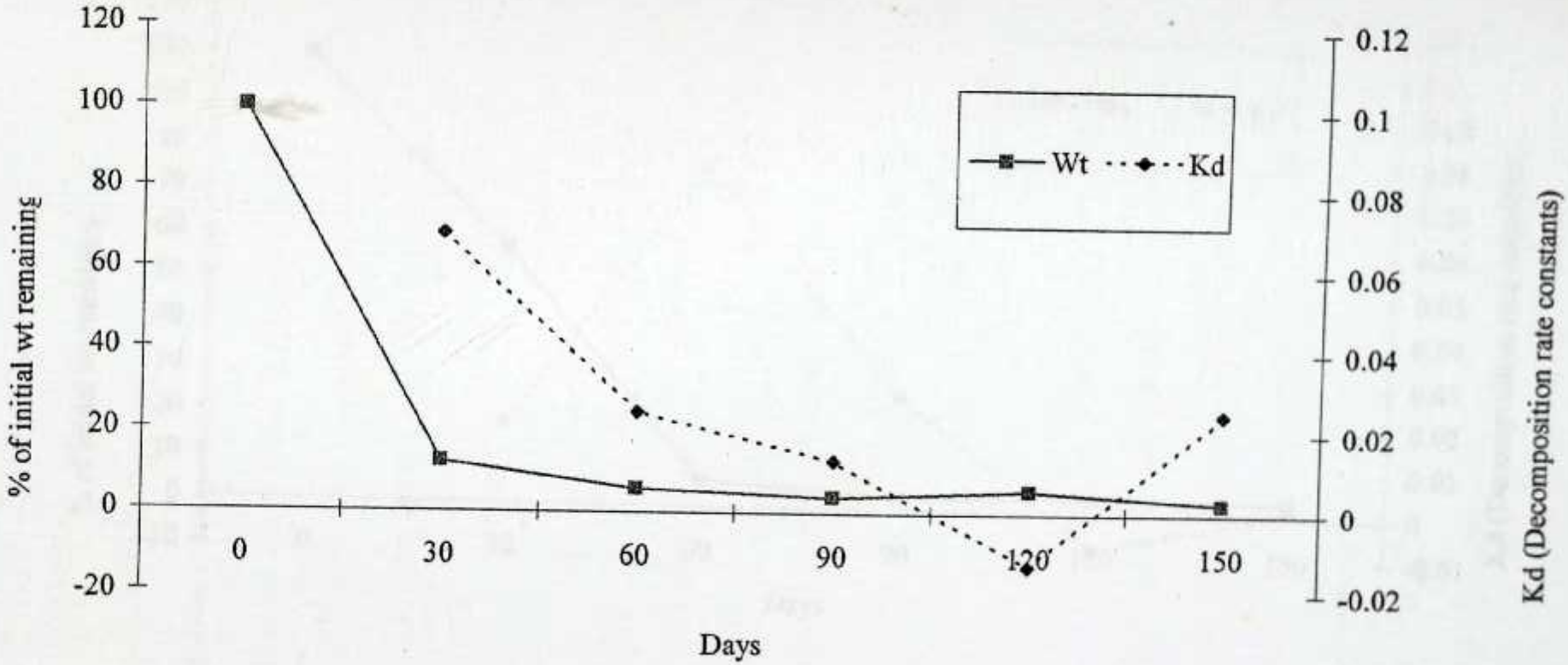

Figure 4.1 Relationship between percent of initial weight (wt) remaining in decomposing foliage of *Leucaena leucocephala* and decomposition rate constant (Kd)

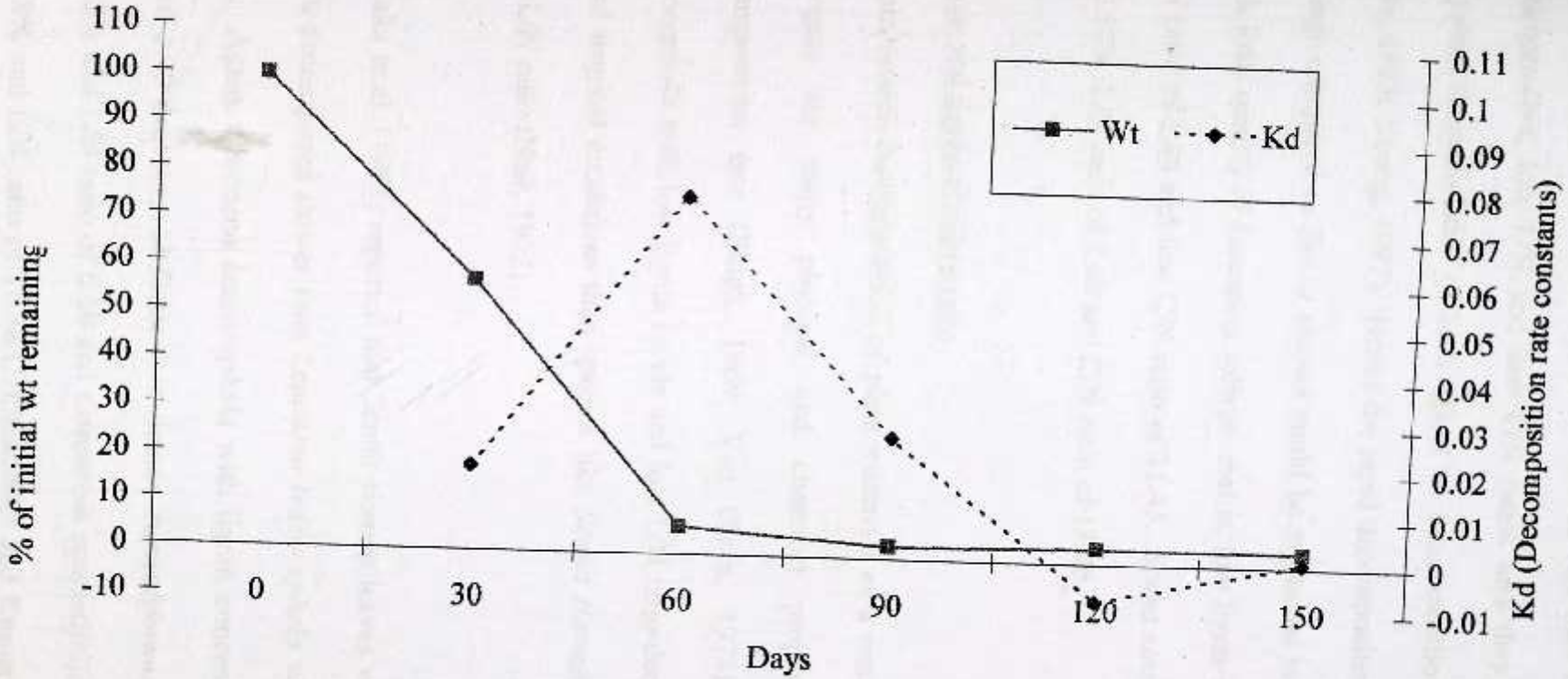

Figure 4.2. Relationship between percent of initial weight (wt) remaining in decomposing foliage of *Senna siamea* and decomposition rate constant (Kd)

and C/N ratios. High-quality litter residue has low lignin concentration, high N concentration, low L/N and low C/N ratios and they decompose rapidly. Also, physical characteristics of litter affect its decomposition rate (Melillo et al., 1982; Nair, 1993; Young, 1997). Hence the rapid decomposition of *Leucaena leucocephala* foliage compared to *Senna siamea* could be attributed to physical characteristics and high litter quality of *Leucaena* foliage: that is, low lignin concentration of 6.78%, low L/N ratio of 1.46 and low C/N ratio of 11.43. *Senna siamea* had lignin concentration of 8.57%, L/N ratio of 2.08 and C/N ratio of 13.28.

Lignin and lignin/nitrogen ratio

Lignin retards decomposition of plant materials as a result of its ability to serve as a surrogate for many physical and chemical properties which regulate litter decomposition rate (Singh, 1969; Van Cleve, 1974). Species like *Leucaena leucocephala* with low lignin levels and low L/N ratio decompose relatively fast under humid tropical conditions than species like *Senna siamea* with high lignin levels and high L/N ratio (Nair, 1993).

Kachaka et al. (1993) reported that *Senna siamea* leaves with lignin concentration of 10.4% decomposed slower than *Leucaena leucocephala* with lignin concentration of 8.1%. Again, *Leucaena leucocephala* with lignin concentration of 17.0% and L/N ratio of 5.09 decomposed faster than *Acacia auriculiformis* with lignin concentration of 16.5% and L/N ratio of 6.68 and *Casuarina equisetifolia* with lignin concentration of 26.8% and L/N ratio of 16.88 (Jamuladheen and Kumar, 1999). These values are

however, higher than values obtained in this study but corroborate the evidence that species with low lignin and low L/N ratios decompose faster.

Nitrogen and Carbon/nitrogen ratio

Several researchers have reported that species with high N levels and low C/N ratio decompose at a faster rate. For example, *Gliricidia sepium* foliage with N concentration of 3.27% and C/N ratio of 13.24 decomposed faster than *Cassia spectabilis* foliage with N concentration of 3.31% and C/N ratio of 14.35 (Maclean et al., 1992). *Leucaena leucocephala* foliage with N concentration of 3.7 % and C/N ratio of 11 decomposed faster than *Senna siamea* with N concentration of 1.8% and C/N ratio of 24 (Van Der Meersch et al., 1993) and *Leucaena leucocephala* foliage with N concentration of 5.87% and C/N ratio of 7.68 decomposed faster than *Gliricidia sepium* foliage with N concentration of 5.04% and C/N ratio of 9.38 (Tian et al., 1992).

In this study, low C/N ratio could be one of the reasons for the faster decomposition of *Leucaena leucocephala* foliage. This is because the initial N concentration of *Leucaena leucocephala* of 4.68% was not significantly different from initial N concentration of *Senna siamea* of 4.12%. However, C/N ratio of *Leucaena leucocephala* of 11.43 was lower than that of *Senna siamea* of 13.28 (Table 4.1).

Physical characteristics

Differences in decomposition of species could also be due to their physical characteristics. Thick and tough leaves with prominent midribs and veins decompose slower than species with thin and soft leaves without prominent skeletal tissues. Species with smaller leave size decompose more rapidly because they increase surface to volume area ratio (Edwards, 1977; Swift et al., 1979; Songwe et al., 1995).

It was observed that *Leucaena leucocephala* has small feathery compound leaves without prominent skeletal tissue whereas *Senna siamea* has medium sized compound leaves with prominent midribs and veins. Probably, foliage size and characteristics of *Leucaena leucocephala* also contributed to its faster decomposition compared to *Senna siamea* foliage.

Decomposition rate constant (K_d)

The mean decomposition rate constant (K_d) calculated in this study for *Leucaena leucocephala* of 0.024 and *Senna siamea* of 0.023 are within the range of values reported by Sraha and Ulzen-Appiah (1997) of 0.010 for *Cassia spectabilis;* 0.020 for *Gliricidia sepium* and 0.038 for *Leucaena leucocephala.* Songwe et al. (1995) reported higher K_d values of 1.88 for *Cola lepidota* and 1.65 for *Ceiba pentandra.* The similarities in K_d in *Leucaena leucocephala* and *Senna siamea* in this study could be attributed to initial N levels in decomposing foliage of *Senna siamea* (Table 4.1) which probably influenced K_d of *Senna siamea.* The negative values reported at 120 days in both species in this study cannot be explained (Table 4.4). Negative K_d values have however, been reported elsewhere (Songwe et al., 1995).

4.4.3 Mineralization and Release Constants (K_n)

Mineralization

The release of N, P, K, Ca and Mg from decomposing foliage of *Leucaena leucocephala* and *Senna siamea* are discussed below. Chemical characteristics of plant residue play key roles in determining nutrient mineralization and this demonstrates the importance of substrate quality in nutrient dynamics.

Nitrogen

Initial N concentrations of 4.676% in *Leucaena leucocephala* and 4.116% in *Senna siamea* did not differ significantly (Table 4.5). A significant decrease in N levels at 150 days in decomposing foliage of *Leucaena leucocephala* and *Senna siamea* ($P < 0.05$) with K_n of 0.013 and 0.054, respectively coincided with weight loss of 98.87% in *Leucaena leucocephala* and 96.55% in *Senna siamea.* From Table 4.2, the release of N did not differ significantly ($P = 0.808$) between *Leucaena leucocephala* and *Senna siamea* foliage. Also mean K_n of N in decomposing foliage of *Leucaena leucocephala* of 0.011 and *Senna siamea* of 0.003 were not significantly different. Probable explanation could be that lignin levels and C/N ratios could not influence N release between the species significantly. Probably because of lack of significant differences in initial levels of N and K_n values in the species.

Within species, 61.21% of initial N concentrations released from decomposing foliage of *Leucaena leucocephala* at 60 days (Table 4.5) coincided with K_n value of 0.025 (Table 4.10) and significant weight loss of 94.10% (Table 4.3). However, in

decomposing foliage of *Senna siamea*, 42.18% of initial N concentrations were released at 30 days (Table 4.5) with K_n value of 0.018 (Table 4.10) and this coincided with significant weight loss of 42.50% (Table 4.3). These results indicate faster release of N in *Senna siamea* foliage than in *Leucaena leucocephala* foliage. High C/N ratio and high lignin concentrations in leaf litter have been reported to decrease the rate of N mineralization (Berg and Staff, 1981; Muller et al., 1988). However, *Senna siamea* foliage with C/N ratio of 13.28; L/N ratio of 2.08 and lignin levels of 8.57 released N faster from its foliage compared to *Leucaena leucocephala* foliage with C/N ratio of 11.43; L/N ratio of 1.46 and lignin levels of 6.78 (Table 4.1). Probable explanation could be that lignin levels and C/N ratios could not influence N release in *Senna siamea* foliage. *Senna siamea* is known to hold large amount of N in its foliage (Yamoah et al., 1986) and hence probably release N readily upon decomposition.

Phosphorus

Initial P concentrations of 0.582% in *Leucaena leucocephala* and 0.990% in *Senna siamea* differed significantly (Table 4.6). However, mineralization of P did not differ significantly ($P = 0.058$) between *Leucaena leucocephala* and *Senna siamea* foliage (Table 4.2). Mean K_n of P for *Leucaena leucocephala* of 0.004 and *Senna siamea* of 0.003 were also not significantly different (Table 4.11). Probably, the similarity in mean K_n values of the species contributed to the lack of significant difference in P mineralization between them.

Within species, 51.37% of initial P concentrations released from decomposing foliage of *Leucaena leucocephala* at 90 days (Table 4.6) with K_n of 0.015 (Table 4.10) coincided with significant weight loss of 95.95% (Table 4.3). In decomposing foliage of *Senna siamea,* 52.83% of initial P concentration released at 30 days (Table 4.6) also coincided with K_n of 0.015 (Table 4.10) and significant weight loss of 42.50% (Table 4.3). The results therefore, suggest faster mineralization of P in *Senna siamea* foliage than in *Leucaena leucocephala* foliage.

Gosz et al. (1973) and Songwe et al. (1995) reported an initial build up of P in decomposing litter. To the contrary, the release of P in this study did not follow that trend. At 30 days, 30.76% and 52.83% of initial P concentrations were released from decomposing foliage *Leucaena leucocephala* and *Senna siamea,* respectively. Species with high nutrient levels release nutrients at a faster rate (Berendse et al., 1987). Therefore, rapid mineralization of P in *Senna siamea* could probably be explained by the significantly high P levels in *Senna siamea* foliage compared with *Leucaena leucocephala* foliage (Table 4.6).

Potassium

Initial K of 3.04% in *Leucaena leucocephala* and 3.77% in *Senna siamea* foliage did not differ significantly (Table 4.7). Also, mineralization of K ($P = 0.058$) (Table 4.2) and mean K_n of K for *Leucaena leucocephala* of 0.004 and *Senna siamea* of 0.007 were also not significantly different (Table 4.11). The similarities in mean K_n values of the

species could probably be attributed to lack of significant differences in initial K levels in *Leucaena leucocephala* and *Senna siamea* foliage.

Within species, 60.89% of initial K concentrations were released from decomposing foliage of *Senna siamea* at 90 days (Table 4.7). This coincided with K_n of 0.020 (Table 4.10) and significant weight loss of 97.30% (Table 4.3). However, there was no significant difference in K release in decomposing foliage of *Leucaena leucocephala* (Table 4.7). This indicates fast release of K within *Senna siamea* compared to *Leucaena leucocephala* and could be attributed to the potential of *Senna siamea* to remove K from the lower depths of soil profile with the aid of mycorrhizal roots and efficiently recycled it (Pritchett, 1979).

Generally, K mineralizes at a faster rate and leaching is reported to be the primary process influencing its release (Gosz et al., 1973; Swift et al., 1981). In this study, K mineralization within 30 days in *Leucaena leucocephala* and *Senna siamea* foliage were 35.34% and 44.91% with K_n values of 0.015 and 0.020, respectively. These values are lower than values of 72% K mineralizing in *Gliricidia sepium* and 69% in *Leucaena leucocephala* within 28 days reported by Sraha and Ulzen-Appiah (1997) and 80% of K mineralizing within 30 days in *Ceiba pentandra, Celtis zenkeri and Terminalia superba* reported by Songwe et al. (1995).

Calcium

Initial Ca concentrations of 1.457% in *Leucaena leucocephala* and 1.627% in *Senna siamea* did not differ significantly (Table 4.8). Between species, mineralization of Ca ($P = 0.322$) (Table 4.2) and mean K_n of 0.006 in *Leucaena leucocephala* and 0.003 in *Senna siamea* did not differ significantly ($P > 0.05$) (Table 4.11). Lack of significant differences in the release of Ca between the species could be due probably to lack of significant differences in initial levels of Ca and mean K_n values in both species (Table 4.8).

Within species, 46.88% of initial Ca concentrations were released from decomposing foliage of *Leucaena leucocephala* at 60 days (Table 4.8). This coincided with K_n of 0.012 (Table 4.10) and significant weight loss 94.10% (Table 4.3). In decomposing foliage of *Senna siamea,* on the other hand, 32.82% of initial Ca concentrations released at 30 days (Table 4.8) coincided with K_n values of 0.015 (Table 4.10) and significant weight loss of 42.50% (Table 4.3). These results suggest faster mineralization of Ca within *Senna siamea* foliage than in *Leucaena leucocephala* foliage.

In general, Ca mineralization in *Leucaena leucocephala* and *Senna siamea* foliage were slow. At 30 days, 24.50% of initial Ca in *Leucaena leucocephala* ($K_n = 0.009$) had mineralized whereas 32.82% of initial Ca in *Senna siamea* ($K_n = 0.015$) had mineralized (Table 4.8). Songwe et al. (1995) reported slower mineralization rate of Ca in *Celtis zenkeri, Cola lepidota* and *Terminalia superba* within 30 days. The slow mineralization of Ca could be attributed to the fact that Ca is a component part of cell wall and it is

released only after there is whole breakdown of the shielding substances such as lignin and tannins (Bernhard-Reversat, 1972).

Magnesium

From Table 4.2, there was a significant difference in the release of Mg between *Leucaena leucocephala* and *Senna siamea* (P = 0.008). The release of Mg from decomposing foliage of *Leucaena leucocephala* was faster than in *Senna siamea* foliage even though K_n did not differ significantly between the species (Tables 4.11). Sraha and Ulzen-Appiah (1997) also reported faster release of Mg in *Gliricidia sepium* than in *Leucaena leucocephala* with K_n values of both species not significantly different.

Within species, 58.78% of initial concentration of Mg released from decomposing foliage of *Leucaena leucocephala* at 30 days (Table 4.9) with K_n value of 0.030 (Table 4.10) coincided with significant weight loss of 87.47%. In *Senna siamea*, 55.62% of initial concentrations of Mg were released at 60 days (Table 4.8) with K_n value of 0.017 (Table 4.10) and this coincided with significant weight loss of 94.07% (Table 4.3). These suggest faster release of Mg within *Leucaena leucocephala* compared to *Senna siamea*. Species with high nutrient levels release nutrients at a faster rate (Berendse et al., 1987). Therefore, the probable explanation for the fast release of Mg in *Leucaena leucocephala* foliage could be due to high levels of Mg in *Leucaena leucocephala* foliage of 1.48% compared to *Senna siamea* foliage of 0.97% (Table 4.1).

4.5 SUMMARY AND CONCLUSIONS

This study tested the hypothesis that the rate of decomposition and mineralization of N, P, K, Ca and Mg in *Leucaena leucocephala* and *Senna siamea* foliage are similar. The initial levels of P in *Senna siamea* foliage were significantly higher ($P < 0.05$) than that in *Leucaena leucocephala* foliage. Alternatively, initial levels of Mg in *Leucaena leucocephala* foliage were significantly higher ($P < 0.05$) than that in *Senna siamea* foliage. Initial levels of N, K and Ca did not differ significantly ($P < 0.05$) between the species. *Senna siamea* had higher lignin concentration and higher C/N and L/N ratios in its foliage compared to *Leucaena leucocephala* foliage.

The rate of decomposition of *Leucaena leucocephala* foliage was significantly faster ($P < 0.05$) than that of *Senna siamea* foliage. At 30 days, 87.45% of *Leucaena leucocephala* foliage and 42.50% of *Senna siamea* foliage had decomposed. Rapid decomposition of *Leucaena leucocephala* foliage was probably influenced largely by lignin levels, C/N and L/N ratios and foliage size and characteristics. The decomposition rate constants (K_d) of *Leucaena leucocephala* foliage varied between 0.013 and 0.069. That of *Senna siamea* foliage varied between 0.001 and 0.076. In decomposing foliage of *Leucaena leucocephala,* a significant weight loss of 87.45% coincided with K_d of 0.069 at 30 days and in *Senna siamea*, a significant weight loss of 94.07% coincided with K_d of 0.076 at 60 days.

In general, mineralization of N, P, K and Ca between decomposing foliage of *Leucaena leucocephala* and *Senna siamea* did not differ significantly ($P > 0.05$).

Lignin levels and C/N ratios could not influence the release of nutrients in both species. Mineralization of Mg was significantly faster ($P < 0.05$) in decomposing foliage of *Leucaena leucocephala* than in decomposing foliage of *Senna siamea*. However within species, N, P, K and Ca release was faster in *Senna siamea* foliage than in *Leucaena leucocephala* foliage. This could be attributed to the heavy vesicular-arbuscular mycorrhizae infection of *Senna siamea* which improves uptake of P and enhances the uptake of Ca, Mg and K from the soil. Magnesium release, on the other hand, was faster in *Leucaena leucocephala* foliage than in *Senna siamea* foliage.

Nutrient release constants (K_n) varied in decomposing foliage of *Leucaena leucocephala* and *Senna siamea* but did not differ significantly ($P > 0.05$). In *Leucaena leucocephala*, mean K_n values were 0.011 for N; 0.004 for P; 0.004 for K; 0.006 for Ca and 0.005 for Mg. Based on K_n values, the pattern of release in *Leucaena leucocephala* was in the order N> Ca > Mg > P = K. In *Senna siamea*, mean K_n values were 0.003 for N; 0.003 for P; 0.007 for K; 0.003 for Ca and 0.004 for Mg. Based on K_n values, the pattern of release in *Senna siamea* was in the order K > Mg > N = P = Ca.

Based on the results, these conclusions can be drawn. Due to the lack of significant difference in the release of N, P, K and Ca between decomposing foliage of *Leucaena leucocephala* and *Senna siamea*, both species have the potential to improve soil fertility. However, for long term effect on soil, *Senna siamea* had better potential to improve soil fertility and also provide a good cover due to the fast release of N, P, K and Ca within its foliage and the slow rate of decomposition of its foliage compared to *Leucaena*

leucocephala foliage. Where Mg is a critical nutrient needed in the soil, *Leucaena leucocephala* foliage could however, be the preferred species to be applied as mulch.

CHAPTER 5

5.0 SOIL CHEMICAL PROPERTIES IN WOODLOTS OF *Leucaena leucocephala* AND *Senna siamea* FIFTEEN YEARS AFTER ESTABLISHMENT

5.1 INTRODUCTION

Under natural ecosystem, soils are improved through constant interactions between soil and plant communities with a high degree of internal recycling. Trees have favourable effect on soil chemical properties through addition of organic matter from plant litter and root residue. Soil organic matter refers to all organic materials that are present in the soil. Among other functions, organic matter enhances cation exchange capacity of the clay-humus complex and also improves P availability through blocking of fixation sites by organic complex (Brady and Weils, 1999; Young, 1997).

Most MPTs have proven ability to maintain and improve soil fertility. Thus in Nigeria, planted fallow of *Leucaena leucocephala* was effective in maintaining soil pH, exchangeable Ca and Mg and effective CEC three years after establishment (Juo et al., 1995). In the humid zone of Ghana, organic C, total N and exchangeable K concentrations of the top soil were improved under *Senna siamea* woodlots fifteen years after establishment (FORIG, 1995). *Acacia tortilis* was effective in improving soil N, P, K and Ca in Kenya and *Faidherbia albida* improved C, N, P, K and pH of soils in Ethiopia (Belsky et al., 1993; Kamara and Haque, 1992).

Agroforestry systems try to achieve productivity combined with the conservation of the resources on which production depends. To maintain productivity, soil fertility

conservation is the most direct and primary requirement. It will therefore be beneficial to undertake regular soil testing in Agroforestry production systems to monitor nutrient status of the soil on which production depends. *Leucaena leucocephala* and *Senna siamea* woodlots were established fifteen years ago at FRNR demonstration farm. Studies were carried out to determine soil pH, % OM, % OC, total N, available P, exchangeable K, Ca, Mg, total acidity (Al + H), effective cation exchange capacity (CEC) and % base saturation in these woodlots before establishment in 1988 (UST/AFNETA, unpublished data, 1990) and also four and nine years after establishment (Osei, 1992; Kaho, 1998).

Osei (1992) reported significantly higher soil chemical properties within 0-15 cm depth than within 15-30 cm depth in the *Leucaena leucocephala* and *Senna siamea* woodlots four years after their establishment. He noted that between *Leucaena leucocephala* and *Senna siamea* woodlots, there were no significant differences in pH, % OC, total N, available P, exchangeable K, Ca, Mg, exchangeable acidity (Al + H), effective CEC and % base saturation within 0-15 cm depth of profile. Kaho (1998) reported increases in soil pH, % OM, % OC, total N, available P, exchangeable K, Ca, Mg, exchangeable acidity (Al + H), effective CEC and % base saturation within 0-15 cm depth under the same *Leucaena leucocephala* and *Senna siamea* woodlots nine years after establishment.

The objectives of this study were to (i) compare selected soil chemical properties (soil pH, % OM, % OC, total N, available P, exchangeable K, Ca, Mg, exchangeable acidity [Al + H], effective CEC and % base saturation) between and within the woodlots and to (ii) compare changes in the selected soil chemical properties within the woodlots fifteen years after establishment. The study hypothesizes that;

(i) selected soil chemical properties within 0-30 cm depth in the *Leucaena leucocephala* and *Senna siamea* woodlots fifteen years after establishment are similar.

(ii) soil chemical properties within 0-30 cm depth in the *Leucaena leucocephala* and *Senna siamea* woodlots will increase fifteen years after establishment.

5.2 MATERIALS AND METHODS

5.2.1 Study Site

The study was conducted at the FRNR demonstration farm. The site and woodlots have been described under sections 3.2.1. and 3.2.2., respectively.

5.2.2 The Experiment

Three quadrats of size 6 m × 3 m were laid randomly in each woodlot. Using soil auger, soil samples were taken randomly from six different spots within each quadrat in July 2003. The soil samples were collected at two depths; 0-15 cm and 15-30 cm. The soil samples collected from each quadrat from the same depth were bulked, sub-sampled and bagged. The sub-samples were taken to the laboratory; air dried and sieved using a 2 mm mesh brass sieve. The sieved soil samples were analyzed for soil

pH, % OM, % OC, total N, available P, exchangeable K, Ca, Mg, exchangeable acidity (Al + H), effective CEC and % base saturation.

5.2.3 Laboratory Analyses

Soil pH, % OM, % OC, total N, available P, exchangeable K, Ca, Mg, exchangeable acidity (Al + H), effective CEC and % base saturation were determined using the methods described below.

Soil pH

Soil pH was determined using electrometric procedure described by Wilde et al. (1972). This involved the use of regular commercial pH meter with a glass electrode paired with calomel (mercury/mercurous chloride reference) electrode. Twenty five milliliters of distilled water was added to 25 g of air dried soil placed in 100 ml beaker. The suspension was allowed to sit for 30 minutes and stirred occasionally with a glass rod to permit the soil and water to come to equilibrium. The pH meter was standardized using buffer solution of pH 4 and pH 7. The electrode of the pH meter was inserted into the suspension and the pH recorded when the reading had stabilized. The electrode was rinsed with distilled water after each reading and after each 4^{th} reading the performance of the pH meter was checked with the buffer solution.

Soil organic carbon (OC) and organic matter (OM)

Soil OC was determined by Walkley Black method (Walkley and Black, 1934). In this method, 0.5 g of sieved soil was weighed into 250 ml Erlenmeyer flask. Ten milliliters

of 1N $K_2Cr_2O_7$ solution from a burette was added and swirled gently to disperse the soil. Using automatic pipette, 20 ml concentrated H_2SO_4 was added rapidly to the suspension and swirled gently until the soil and the reagent were mixed and then swirled vigorously for one minute. The flask was rotated again and allowed to stand on porcelein for about 30 minutes. Hundred milliliters of distilled water and 3-4 drops of diphenylamine indicator were added and titrated with 1 M $FeSO_4$ solution. The solution took on a greenish cast as the end point was approached and then a dark green colour. Using a burette, 0.5 ml of $K_2Cr_2O_7$ was then added. The titration was completed by adding $FeSO_4$ solution drop wise until a stable end point was attained. Percent OC was calculated using the formula below:

$$\% \text{ OC} = \frac{(\text{me}K_2Cr_2O_7 - \text{me } FeSO_4) \times 0.003 \times 100 \times (f)}{\text{mg of air-dried soil}} \qquad \text{Eqn. 1}$$

$$\% \text{ OC} = \frac{M \times V_1 - V_2 \times 0.399 \times mcf}{s} \qquad \text{Eqn. 2}$$

Where: me = normality of solution × ml of solution used

M = molarity of ferrous sulphate solution for blank titration

V_1 = ml ferrous sulphate solution required for blank

V_2 = ml ferrous sulphate solution required for sample

s = weight of air-dried sample in mg

$0.399 = 0.003 \times 100 \times 1.33$

mcf = moisture correction factor

Correction factor (f) = 1.33

Percent OM was determined after the soil % OC has been determined by multiplying % OC value by a conventional factor 1.72 (Hesse, 1975). Percent OM was calculated using the formula below:

$$\% \text{ OM} = \% \text{ OC} \times 1.72 \qquad \text{Eqn. 3}$$

Nitrogen

Nitrogen was determined using macro Kjeldahl digestion method (Cottenie, 1980). This method involved three processes; digestion, distillation and titration. In the digestion process 0.2 g of sieved soil was wrapped in a filter paper. This was digested in 5 ml of concentrated sulphric acid and 2 ml of hydrogen peroxide with one Kjeldahl tablet and 0.2 g selenium mixture as a catalyst to convert organic nitrogen to ammonia. The digests were cooled for 15 minutes when turned white after 2-3 hours of heating and were taken through the distillation process.

The distillation process involved the addition of 60 ml of distilled water, 25 ml of 40% sodium hydroxide (NaOH) and four pea size pieces of mossy zinc to the digest. The solution was then heated until about 150 ml of the distillate had been collected in 500 ml Erlenmeyer flask containing 50 ml of 4% boric acid and three drops (0.15 ml) of methyl red as an indicator. The boric acid solution changed from bluish purple to bluish green with the introduction of ammonia. The distillate was titrated with 0.02 N hydrochloric acid till the solution turned from bluish green to pink. Percent N was calculated using the formula below:

$$\% \text{ N} = \frac{\text{Titre} \times \text{N}(0.02) \times 14.007 \times 100}{\text{Sample wt.(g)} \times 1000} \times \text{recovery factor of } 0.495 \qquad \text{Eqn. 4}$$

Where N = Normality of acid

Available Phosphorus

Phosphorus was determined using Bray No. 1 method (Bray and Kurtz, 1945). Five grams of sieved soil were weighed into 50 ml extracting bottle and mixed with 35 ml of 0.03 M NH_4F and 0.025 M HCl. The mixture was shaken mechanically for 10 minutes and filtered with Whatman No. 42 filter paper into 50 ml volumetric flask. Using automatic pipette, 5 milliliters of the clear supernatant was put into a test tube. To this were added 10 ml of colour reagent and a pinch of ascorbic acid. The colour was allowed to develop for exactly 30 minutes and P concentration determined calorimetrically by measuring the absorbance with a spectrophotometer at 660 mμ wavelength. Available P was calculated using the formula below:

ppm = absorbance × eqn for the calibration curve Eqn. 5

Amount of P in ppm = ppm × extracting ratio Eqn. 6

Where;

ppm = part per million

Potassium

Potassium was determined using Leaching method. The lower side of leaching tube was closed with a wad of cotton wool by pressing the wad with glass rod. Five grams of sieved soil was weighed into the leaching tube and another cotton wad was placed on top of the soil. The leaching tube was placed in a procolation rack. Volumetric flask containing 100 ml of 1 N ammonium acetate leaching solution of pH of 7.0 was quickly placed upside down on the leaching tube containing the soil and the flow rate adjusted

to 30 drops per minute. Aliquot of leachate was used for K determination by the flame photometer. A graph relating emission to the amount of K was plotted. Potassium was calculated using the formula below.

ppm K in soil = soil dilution × ppm K graph Eqn. 7

$$\text{me K per 100g soil} = \text{soil dilution} \times \frac{1}{\text{Eq. wt}} \times \text{ppm graph} \times \frac{1}{10} \quad \text{Eqn. 8}$$

$$= \frac{100}{2} \times \frac{1}{10} \times \text{ppm graph} \times \frac{1}{39} \quad \text{Eqn. 9}$$

$$\text{me K per 100g soil} = \frac{5}{39} \times \text{ppm of graph} \quad \text{Eqn. 10}$$

Where;

ppm = part per million

me = millequivalent

Eq wt = equivalent weight determined as $\frac{\text{atomic weight}}{\text{valence number}}$

$\frac{1}{10}$ = conversion factor

Calcium and Magnesium

Calcium and Mg were determined using ethylene-diamine tetra-acetic acid (EDTA) method described by Radov et al. (1985). Five grams of sieved soil was leached with 100 ml of 1 N ammonium acetate solution of pH of 7.0 at a rate of 30 drops per minute into a volumetric flask. Aliquot of the leachate was used to determine Ca and Ca + Mg.

To determine Ca, crystals of cal-red indicator, 10 ml of 10% KOH buffer solution of pH of 12, 1 ml triethanolamine and 2 drops of 2% KCN solution were added to 25 ml

aliquot of leachate. The mixture was titrated with 0.02 N EDTA till colour changed from violet to purple to determine Ca. Calcium was calculated using the formula below.

me of EDTA used $= 0.02 \times T$ Eqn. 11

25 ml aliquot $= 0.1 \times 5$ g (weight of soil taken) Eqn. 12

me per g soil $= \frac{0.02T}{0.1 \times 5}$ Eqn. 13

me per 100 g soil $= \frac{0.02T}{0.5} \times 100 = 4T$ Eqn. 14

Exchangeable Ca $= T \times \frac{4 \text{ me}}{100 \text{ g of soil}}$ Eqn. 15

Where T = mls of EDTA used

For the determination of (Ca + Mg), 5 ml of ammonium chloride-ammonium hydroxide buffer solution of pH of 10, 1 ml of 10% hydroxylamine hydrochloride solution and 3 drops of 2% KCN solution were added to 25 ml aliquot of leachate. This was titrated with 0.02 N EDTA solution using a few drops of Eriochrome Black T as an indicator. The colour changed from pink to pure blue. Calcium + Mg were calculated using the formula below;

Exchangeable (Ca + Mg) $= T \times \frac{4 \text{ me}}{100 \text{ g of soil}}$ Eqn. 16

Where T = mls of EDTA used

Magnesium was obtained by subtracting the value of exchangeable Ca from the value of exchangeable (Ca + Mg) as follows:

Exchangeable Mg = exchangeable (Ca + Mg) - exchangeable Ca Eqn. 17

Exchangeable acidity (Al +H)

Ten grams of sieved soil was weighed into 100 ml rubber bottle (Jackson, 1958). To this was added 100 ml of 1 N KCl solution and shaken in a reciprocating shaker for 30 minutes. The solution was filtered through Whatman No. 42 filter paper into 100 ml volumetric flask. Fifty milliliters of the filtrate was pipette into 250 ml conical flask. Using 5 drops of phenolphthalein indicator the filtrate was titrated with 0.05 M NaOH to first permanent pink end point. The amount of NaOH used was recorded and Al + H calculated as follows:

$$\text{Me of acidity (Al + H) per 100 g soil} = \frac{100}{50} \times \frac{100}{10} \times (a-b) \times N \times m \qquad \text{Eqn. 18}$$

Where,

a = ml of NaOH used for titration

b = ml of NaOH used for blank titration

$\frac{100}{50}$ = ratio of volume of KCl used

$\frac{100}{10}$ = conversion factor from 10 g to 100 g of soil

N = molarity of NaOH

m = factor for moisture correction

Percent base saturation

Percent base saturation was derived by summing up the exchangeable bases, divided by CEC and multiplied by 100. The calculation is given below:

$$\text{Base saturation (\%)} = \frac{\text{Exchangeable (Ca + Mg + K + Na)}}{\text{CEC}} \times 100 \qquad \text{Eqn. 19}$$

Effective cation exchange capacity (CEC)

Effective CEC was obtained by the addition of exchangeable bases and exchangeable acidity. The calculation is presented below:

$$\text{Effective CEC} = \text{exchangeable bases} + \text{exchangeable acidity} \qquad \text{Eqn. 20}$$

5.2.4 Statistical Analysis

The experiment was analyzed as a split plot in Completely Randomized Design (CRD). *Leucaena leucocephala* and *Senna siamea* woodlots were the main plots and depths (0-15 cm and 15-30 cm) were the subplots.

Data on soil chemical properties from *Leucaena leucocephala* and *Senna siamea* woodlots were subjected to analyses of variance (ANOVA) tests using Statview (SAS Institute Inc, 1998). Fisher's paired least significant difference (PLSD) test (α=0.05) were used to compare the treatment means when ANOVA showed significant differences. Results are presented at section 5.3.

5.3 RESULTS

This section presents results on selected soil chemical properties between and within woodlots and changes in soil pH, % OM, % OC, total N, available P, exchangeable K, Ca, Mg, exchangeable acidity (Al + H), effective CEC and % base saturation fifteen years after the establishment of *Leucaena leucocephala* and *Senna siamea* woodlots.

5.3.1 Soil Chemical Properties

The summary of P-values of analysis of variance testing species, depth and species-depth interaction on soil chemical properties of *Leucaena leucocephala* and *Senna siamea* woodlots is presented in Table 5.1. Except for available P, there were no significant difference ($P > 0.05$) in soil pH, % OM, % OC, total N, exchangeable K, Ca, Mg, (Al + H), effective CEC and % base saturation between *Leucaena leucocephala* and *Senna siamea* woodlots. Also, exchangeable K, Ca, Mg, (Al + H), effective CEC and % base saturation did not differ significantly ($P > 0.05$) with depth. However, soil pH, % OM, % OC, total N and available P differed significantly ($P < 0.05$) with depth under the woodlots of *Senna siamea* and *Leucaena leucocephala*. With species-depth interaction, only exchangeable K differed significantly ($P > 0.05$).

Within woodlots

Soil chemical properties within 0-15 cm and 15-30 cm depth in the *Leucaena leucocephala* and *Senna siamea* woodlots are presented in Tables 5.2 and 5.3, respectively. Within *Leucaena leucocephala* woodlot, soil pH, total N, exchangeable

Table 5.1 Summary of P-values of ANOVA testing effect of species (*Leucaena leucocephala* and *Senna siamea*) and depth (0-15 and 15-30cm) on soil chemical properties[1]

Source of variation	Degree of freedom	P- values										
		pH	%OM	%OC	Total N	Available P	Exch. K	Exch. Ca	Exch. Mg	AL +H	CEC	% Base sat
Species	1	0.089^{ns}	0.857^{ns}	0.646^{ns}	0.646^{ns}	0.0001***	0.117^{ns}	0.85^{ns}	0.632^{ns}	0.261^{ns}	0.899^{ns}	0.927^{ns}
Depth	1	0.040*	0.001**	0.001**	0.004**	0.0003***	0.117^{ns}	0.121^{ns}	0.224^{ns}	0.321^{ns}	0.58^{ns}	0.225^{ns}
Species and Depth	1	0.984^{ns}	0.857^{ns}	0.857^{ns}	0.646^{ns}	0.507^{ns}	0.014*	0.909^{ns}	0.126^{ns}	0.355^{ns}	0.577^{ns}	0.649^{ns}

[1]ns is not significant; *, **, *** is significant at 0.05, 0.01, 0.001 probability levels, respectively.

Table 5.2. Comparison of mean soil chemical properties within 0-15 cm and 15-30 cm depth in *Leucaena leucocephala* woodlot fifteen years after establishment[1].

Soil chemical properties	0-15 cm	15-30 cm	P-value
pH (H_2O)	5.64 (0.20)	5.24 (0.21)	0.235 ns
Organic matter %	3.22 (0.37)	2.03 (0.16)	0.043*
Organic carbon %	1.87 (0.22)	1.18 (0.09)	0.043*
Total nitrogen %	0.16 (0.02)	0.10 (0.003)	0.064 ns
Available P	5.27 (0.29)	3.31 (0.08)	0.003**
Potassium (me/100 g)	0.18 (0.06)	0.27 (0.10)	0.501 ns
Calcium (mc/100 g)	7.27 (2.50)	4.64 (1.04)	0.387 ns
Magnesium (me/100 g)	3.36 (0.82)	1.49 (0.43)	0.114 ns
Al +H	0.15 (0.02)	0.24 (0.04)	0.141 ns
Effective CEC (me/100 g)	14.34 (3.49)	8.87 (1.47)	0.220 ns
Base sat. %	98.50 (0.08)	97.08 (1.39)	0.366 ns

[1]Figures in parentheses are standard error. ns is not significant; *, ** is significant at 0.05, 0.01 probability levels, respectively.

Table 5.3. Comparison of mean soil chemical properties within 0-15 cm and 15-30 cm depth in *Senna siamea* woodlot fifteen years after establishment[1].

Soil chemical properties	0-15 cm	15-30 cm	P-value
pH (H_2O)	5.33 (0.13)	4.49 (0.08)	0.061 ^{ns}
Organic matter %	3.22 (0.06)	2.12 (0.23)	0.010*
Organic carbon %	1.87 (0.04)	1.33 (0.21)	0.061*
Total nitrogen %	0.15 (0.003)	0.11 (0.006)	0.005**
Available P	7.63 (0.32)	6.07 (0.37)	0.032*
Potassium (me/100 g)	0.50 (0.05)	0.18 (0.02)	0.005**
Calcium (me/100 g)	6.83 (0.62)	4.53 (0.60)	0.056 ^{ns}
Magnesium (me/100 g)	2.00 (0.76)	2.24 (0.29)	0.784 ^{ns}
Al +H	0.25 (0.03)	0.25 (0.07)	0.966 ^{ns}
Effective CEC (me/100 g)	12.94 (1.07)	9.75 (0.23)	0.043*
Base sat. %	98.05 (0.27)	97.38 (0.72)	0.434 ^{ns}

[1]Figures in parentheses are standard error. ns is not significant; *, ** is significant at 0.05, 0.01 probability levels, respectively.

K, Ca and Mg, (Al + H), effective CEC and % base saturation did not differ significantly ($P > 0.05$) with depth of profile. However, % OM of 3.22%; % OC of 1.87% and available P of 5.27% were significantly higher ($P < 0.05$) within 0-15 cm depth compared to % OM of 2.03%; % OC of 1.18% and available P of 3.31% within 15-30 cm depth in the *Leucaena leucocephala* woodlot (Table 5.2).

In *Senna siamea* woodlot, soil pH, exchangeable Ca and Mg, (Al + H) and % base saturation did not differ significantly ($P > 0.05$) within the two depths. However, % OM of 3.22%; % OC of 1.87%; total N of 0.15%; available P of 7.63%, exchangeable K of 0.50 me/100 g and effective CEC of 12.94 mc/100 g were significantly higher ($P < 0.05$) within 0-15 cm depth compared to % OM of 2.12%; % OC of 1.33%; total N of 0.11%; available P of 6.07%, exchangeable K of 0.18 me/100 g and effective CEC of 9.75 me/100 g within 15-30 cm depth in the *Senna siamea* (Table 5.3).

Between woodlots at the same depth

Comparison of soil chemical properties within 0-15 cm depth in the *Leucaena leucocephala* and the *Senna siamea* woodlots is presented in Table 5.4. Available P of 7.63% and exchangeable K of 0.50 me/100 g were significantly higher ($P < 0.05$) within *Senna siamea* woodlot compared to available P of 5.27% and exchangeable K of 0.18 me/100 g within *Leucaena leucocephala* woodlot. Percent OM and % OC levels within 0-15 cm depth of *Leucaena leucocephala* and *Senna siamea* woodlots were similar.

Table 5.4. Comparison of mean soil chemical properties within 0-15 cm depth in *Leucaena leucocephala* and *Senna siamea* woodlots[1].

Soil chemical properties	*Leucaena leucocephala*	*Senna siamea*	P-value
pH (H_2O)	5.64 (0.20)	5.33 (0.13)	0.205^{ns}
Organic matter %	3.22 (0.37)	3.22 (0.06)	-
Organic carbon %	1.87 (0.22)	1.87 (0.04)	-
Total nitrogen %	0.16 (0.02)	0.15 (0.003)	0.364^{ns}
Available P	5.27 (0.29)	7.63 (0.32)	0.0004***
Potassium (mc/100 g)	0.18 (0.06)	0.50 (0.05)	0.009**
Calcium (mc/100 g)	7.27 (2.50)	6.83 (0.62)	0.832^{ns}
Magnesium (mc/100 g)	3.36 (0.82)	2.00 (0.76)	0.158^{ns}
Al +H	0.15 (0.02)	0.25 (0.03)	0.160^{ns}
Effective CEC (me/100 g)	14.34 (3.49)	12.94 (1.07)	0.628^{ns}
Base sat. %	98.50 (0.08)	98.05 (0.27)	0.699^{ns}

[1]Figures in parentheses are standard error. ns is not significant; **, *** is significant at 0.01, 0.001 probability levels, respectively.

Within 15-30 cm depth, available P was significantly higher ($P < 0.05$) within *Senna siamea* woodlot (6.07%) compared to *Leucaena leucocephala* woodlot (3.31%). Soil pH, % OM, % OC, total N, exchangeable K, Ca and Mg, (Al + H), effective CEC and % base saturation did not differ significantly ($P > 0.05$) within *Leucaena leucocephala* and *Senna siamea* woodlots (Table 5.5).

5.3.2 Changes in Soil Chemical Properties Fifteen Years after Establishment.

Percent changes in soil chemical properties within 0-15 cm depth in the *Leucaena leucocephala* and *Senna siamea* woodlots fifteen years after establishment is presented in Table 5.6. There were decreases in the levels of total N, available P and exchangeable K within 0-15 cm depth in both woodlots. However, soil pH increased by 8.82%; % OC by 29.59%; exchangeable Ca by 63.74% and effective CEC by 112.44% in the *Leucaena leucocephala* woodlot whereas in the *Senna siamea* woodlot, soil pH increased by 2.34%; % OC by 29.59%; exchangeable Ca by 53.82% and effective CEC by 91.70%.

Table 5.7 presents percent changes in soil chemical properties within 15-30 cm depth in the *Leucaena leucocephala* and *Senna siamea* woodlots. There were decreases in % OC, total N and available P under the *Leucaena leucocephala* woodlot. However, soil pH increased by 1.75%; exchangeable K by 92.86%; exchangeable Ca by 49.20% and effective CEC by 66.73% within 15-30 cm depth in the *Leucaena leucocephala* woodlot.

Table 5.5. Comparison of mean soil chemical properties within 15-30 cm depth of profile in *Leucaena leucocephala* and *Senna siamea* woodlots[1].

Soil chemical properties	*Leucaena leucocephala*	*Senna siamea*	P-value
pH (H_2O)	5.24 (0.21)	4.49 (0.08)	0.214 ns
Organic matter %	2.03 (0.16)	2.12 (0.23)	0.800 ns
Organic carbon %	1.18 (0.09)	1.33 (0.21)	0.519 ns
Total nitrogen %	0.10 (0.003)	0.11 (0.006)	0.710 ns
Available P	3.31 (0.08)	6.07 (0.37)	0.0001***
Potassium (me/100 g)	0.27 (0.10)	0.18 (0.02)	0.371 ns
Calcium (me/100 g)	4.64 (1.04)	4.53 (0.60)	0.958 ns
Magnesium (me/100 g)	1.49 (0.43)	2.24 (0.29)	0.417 ns
Al +H	0.24 (0.04)	0.25 (0.07)	0.876 ns
Effective CEC (me/100 g)	8.87 (1.47)	9.75 (0.23)	0.758 ns
Base sat. %	97.08 (1.39)	97.38 (0.72)	0.796 ns

[1]Figures in parentheses are standard error. ns is not significant; *** is significant at 0.001 probability levels, respectively.

Table 5.6. Percent change in soil chemical properties within 0-15cm depth in *Leucaena leucocephala* and *Senna siamea* woodlots fifteen years after establishment[1].

Soil chemical properties	Before planting (1988) †	*Leucaena leucocephala* (*LL*) (2003)	*Senna siamea* (*SS*) (2003)	% change in *LL*	% change in *SS*
pH (H_2O)	5.18	5.64	5.33	8.82	2.34
Organic matter %	nd	3.22	3.22	nd	nd
Organic carbon %	1.44	1.87	1.87	29.59	29.59
Total nitrogen %	0.85	0.16	0.15	(81.17)	(82.35)
Available P	9.89	5.27	7.63	(46.49)	(22.85)
Potassium (me/100g)	0.59	0.18	0.50	(69.49)	(15.25)
Calcium (me/100g)	4.44	7.27	6.83	63.74	53.82
Magnesium (me/100g)	nd	3.36	2.00	nd	nd
Al +H	nd	0.15	0.25	nd	nd
Effective CEC (me/100g)	6.75	14.34	12.94	112.44	91.70
Base sat. %	nd	98.50	98.05	nd	nd

[1]Figures in parentheses are negative changes, nd not determined. % change = $\frac{(a-b)}{b} \times 100$

Where; a is soil nutrient level in 2003 and b is soil nutrient level before planting (1988)
†Source: UST/AFNETA Project (Unpublished data)

Table 5.7. Percent change in soil chemical properties within 15-30cm depth in *Leucaena leucocephala* and *Senna siamea* woodlot fifteen years after establishment[1].

Soil chemical properties	Before planting (1988) †	*Leucaena leucocephala (LL)* (2003)	*Senna siamea (SS)* (2003)	% change in *LL*	% change in *SS*
pH (H_2O)	5.14	5.24	4.94	1.75	(4.08)
Organic matter %	nd	2.03	2.12	nd	nd
Organic carbon %	3.53	1.18	1.33	(66.57)	62.32
Total nitrogen %	0.06	0.10	0.11	(66.67)	83.30
Available P	5.13	3.31	6.07	(35.48)	18.32
Potassium (me/100g)	0.14	0.27	0.18	92.86	28.57
Calcium (me/100g)	3.11	4.64	4.53	49.20	45.66
Magnesium (me/100g)	nd	1.49	2.24	nd	nd
Al +H	nd	0.24	0.25	nd	nd
Effective CEC (me/100g)	5.32	8.87	9.75	66.73	83.27
Base sat. %	nd	97.08	97.38	nd	nd

[1] Figures in parentheses are negative changes, nd not determined. % change = $\frac{(a-b)}{b} \times 100$

Where; a is soil nutrient level in 2003 and b is soil nutrient level before planting (1988)
†Source: UST/AFNETA Project (Unpublished data).

With the exception soil pH which decreased by 4.08% within 15-30 cm depth in the *Senna siamea* woodlot, % OC increased by 62.32%; total N by 83.30%; available P by 18.32%; exchangeable K by 28.57%; exchangeable Ca by 45.66% and effective CEC by 83.27% in the S*enna siamea* woodlot.

5.4 DISCUSSIONS

5.4.1 Soil Chemical Properties

Within woodlots

Trees have favourable effect on soil chemical properties. Percent organic matter, % OC and available P were significantly higher ($P > 0.05$) within 0-15 cm depth compared to 15-30 cm depth in the *Leucaena leucocephala* woodlot (Table 5.2). High % OM and % OC within 0-15 cm depth could probably relate to the greater amount of above-ground litter of 400 kg/ha (Table 3.1) and its rate of decomposition with K_d of 0.024 (Table 4.4). Isichei and Moughali, (1992) reported that soil fertility is improved through increased litter and soil organic matter under trees. Soil pH, total N, exchangeable K, Ca and Mg, (Al + H), effective CEC and % base saturation were apparently not significantly different within 0-15 cm and 15-30 cm depth in the *Leucaena leucocephala* woodlot.

In *Senna siamea* woodlot, % OM, % OC, available P, total N, exchangeable K, and effective CEC were significantly higher ($P > 0.05$) within 0-15 cm depth than within 15-30 cm depth (Table 5.3). High % OM and % OC within 0-15 cm depth could probably relate to greater amount of above-ground litter of 455 kg/ha produced within the woodlot (Table 3.2) and K_d of 0.023 at which it decomposes (Table 4.4). Singh et al. (1989) reported of high nutrient concentrations within 0-15 cm horizon due to surface placement by biomass and nutrient cycling. High foliar concentration of both N of 4.12% (Table 4.5) and P of 0.99% (Table 4.6) in *Senna siamea* could contribute to the high soil N and P content beneath the woodlot at 0-15 cm depth of profile. Multipurpose tree species like *Acacia tortilis* and *Adansonia digitata* have also been reported to increase total N,

available P and exchangeable K levels in soils (Belsky et al., 1993). In the humid zone of Ghana, Osei (1992) and Kaho (1998) reported of higher % OM, % OC, available P, total N, exchangeable K, and effective CEC within 0-15 cm depth than within 15-30 cm depth in *Senna siamea* woodlot four and nine years after establishment, respectively.

Soil pH, exchangeable Ca and Mg, (Al + H) and % base saturation did not differ significantly within 0-15 cm and 15-30 cm depth in the *Senna siamea* woodlot. Recycling of bases from deep soils to surface horizon (Kaho, 1998) and Ca-pumping of trees (Drechsel et al., 1991) are known to increase soil pH. Therefore, lack of significant differences in soil pH may be attributed to high soil Ca levels under *Senna siamea* woodlot (Hasford, 1995). The effectiveness of *Senna siamea* roots in stabilizing the soil and holding nutrients against leaching out of the 0-30 cm depth profile and the heavy VAM infection (Young, 1997) could contribute to the lack of significant differences in exchangeable Ca and Mg, (Al + H) and % base saturation between the two depths.

Between woodlots

Within 0-15 cm depth, soil pH, % OM, % OC, total N, exchangeable Ca and Mg, (Al + H), effective CEC and % base saturation did not differ significantly ($P > 0.05$) between *Leucaena leucocephala* and *Senna siamea* woodlots (Table 5.4). Also, within 15-30 cm depth in the *Leucaena leucocephala* and *Senna siamea* woodlots, soil pH, % OM, % OC, total N, exchangeable K, Ca and Mg, (Al + H), effective CEC and % base saturation did not differ significantly (Table 5.5). Lack of significant differences in soil pH, % OM, % OC, total N, exchangeable Ca and Mg, (Al + H), effective CEC and % base saturation

between the two depths in both species could be attributed to the effectiveness of the tree roots in stabilizing and holding nutrients against leaching out of the 0-30 cm depth profile. Osei (1992) reported that soil pH, % OC, available P, total N, exchangeable K, Ca and Mg, (Al + H), effective CEC and % base saturation within 0-15 cm depth and 15-30 cm depth in *Leucaena leucocephala* and *Senna siamea* woodlot four years after establishment did not differ significantly.

Available P was significantly higher ($P < 0.05$) within 0-30 cm depth in the *Senna siamea* woodlot compared to *Leucaena leucocephala* woodlot (Table 5.4). This could be due to species effect. *Senna siamea* is known to have vesicular-arbuscular mycorrhiza (VAM) association which improve uptake of P from the soil (Okon et al., 1996; Young, 1997). Also, *Senna siamea* had significantly higher foliar concentration of P (0.99%) compared to 0.58% of P in *Leucaena leucocephala* foliage (Table 4.6) and recycling of this nutrient could contribute to the high soil P content beneath the woodlot. Exchangeable K was significantly higher within 0-15 cm depth in the *Senna siamea* woodlot compared to *Leucaena leucocephala* woodlot. *Senna siamea* has the potential to remove K from the lower depths of soil profile with the aid of mycorrhizal roots and efficiently recycled it (Pritchett, 1979). FORIG (1995) confirms the findings of this study when they reported of significant increase in exchangeable K levels within 0-15 cm depth in *Senna siamea* stand fifteen years after establishment.

5.3.2 Changes in Soil Chemical Properties Fifteen Years after Establishment

Table 5.6 presents changes in soil pH, % OC, total N, exchangeable K and Ca and effective CEC within 0-15 cm depth in the *Leucaena leucocephala* and *Senna siamea* woodlots fifteen years after establishment. Changes were however, not statistically tested. There was increase in soil acidity in both woodlots and this corroborates with significant increase in soil pH under *Cassia* and *Albizia* species reported by Drechsel et al. (1991). High Ca levels in the soil could be attributed to increases in soil pH (Hasford, 1995). Effective CEC was high and Nye and Greenland (1960) attributed this to the contributions of organic matter to cation build up in the surface soils. Decreases in total N, available P and exchangeable K within 0-15 cm in both woodlots could be attributed to accumulation of these elements in woody biomass and probable utilization of substantial soil N, P and K reserves. These are then recycled through decomposition of litter, prunnings and roots (Sanchez and Palm, 1996). High nutrient accumulations in some tropical trees are adaptive mechanisms of retaining potentially limiting nutrients in a closed cycle (Anderson, 1986).

At the depth of 15-30 cm (Table 5.7), Senna *siamea* woodlot recorded notable increases in % OC, total N, available P, exchangeable K and Ca and effective CEC. Even though high Ca levels are known to increase soil pH, there was a decrease in soil pH within 15-30 cm depth in the *Senna siamea* woodlot. In *Leucaena leucocephala* woodlot, % OC, total N and available P levels decreased. The decrease in % OC could probably be due to the faster decomposition rate of *Leucaena leucocephala* foliage. On the other hand,

the decrease in total N and available P could be attributed to accumulation in woody biomass and probable utilization of substantial soil N and P reserves (Anderson, 1986).

5.5 SUMMARY AND CONCLUSIONS

This study tested two hypotheses; first, that soil chemical properties between *Leucaena leucocephala* and *Senna siamea* woodlots fifteen years after establishment are similar. The results indicated that soil pH, % OM, % OC, total N, exchangeable Ca and Mg, (Al + H), effective CEC and % base saturation within 0-15 cm depth in the *Leucaena leucocephala* and *Senna siamea* woodlots were not significantly ($P > 0.05$) different. However, available P and exchangeable K were significantly higher within *Senna siamea* woodlot compared to *Leucaena leucocephala* woodlot. Within 15-30 cm depth, with the exception of available P which was significantly higher in the *Senna siamea* woodlot compared to *Leucaena leucocephala* woodlot, soil pH, % OM, % OC, total N, exchangeable K, Ca and Mg, (Al + H), effective CEC and % base saturation did not differ significantly between the woodlots.

The second hypothesis was that soil chemical properties within *Leucaena leucocephala* and *Senna siamea* woodlots will increase fifteen years after establishment. The results revealed appreciable increases in soil pH, % OC, exchangeable Ca and effective CEC in both woodlots within 0-15 cm depth profile. However, levels of total N, available P and exchangeable K decreased in both woodlots. Within 15-30 cm, soil pH decreased within *Senna siamea* woodlot whereas % OC, total N and available P decreased within *Leucaena leucocephala* woodlot.

Based on these results, it could be concluded that *Senna siamea* has the potential to improve soil P and K compared to *Leucaena leucocephala*. Both *Leucaena*

leucocephala and *Senna siamea* however, have the potential to improve soil fertility over a period of fifteen years by increasing soil pH, % OC, exchangeable Ca and effective CEC. There is also a potential to decrease soil total N, available P and exchangeable K which may be attributed to immobilization in woody biomass. Therefore, harvests that remove greater portions of woody biomass could potentially deplete N, P, and K fertility.

CHAPTER 6

6.1 GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

Introduction

Multipurpose tree species (MPTs) are major components of any Agroforestry systems which can influence both the supply and availability of nutrients in the soil. The litter produced by MPTs contributes to soil fertility improvement through the release of nutrients following decomposition and mineralization. Litter improves soil organic matter. However, the main chemical effect of organic matter in soil depends upon nutrient supply from plant litter. This is balanced across the range of primary (Nitrogen, Phosphorus and Potassium), secondary (Calcium, Magnesium, and Sulphur) and micronutrients as well as soil acidity (Brady and Weils, 1999). Organic matter also improves cation exchange capacity (CEC) and organic acids released during decomposition promote the weathering of soil minerals (Young, 1997). The results of the study of *Leucaena leucocephala* and *Senna siamea* litter and potential nutrient inputs, their rates of decomposition and mineralization could contribute to our understanding of the potential of *Leucaena leucocephala* and *Senna siamea* to substantially contribute to soil fertility improvement.

Litter and Potential Nutrient Inputs

Litter inputs

Total litter collected during the six month period from June – December, 2003 from *Leucaena leucocephala* (400.17 kg/ha) and *Senna siamea* (454.83 kg/ha) woodlots were similar. Expressed on annual basis, total litter inputs of 4,802.04 kg/ha/yr for

Leucaena leucocephala and 5,454.96 kg/ha/yr for *Senna siamea* were recorded in this study. These values compare favourably with results reported by Beer (1988) and Young (1989). Leaves constituted substantial portion of the total litter inputs and were 55.7% for *Leucaena leucocephala* and 73.9% for *Senna siamea*. These percentages compare favourably with results reported by Bernhard (1970); Songwe et al. (1988) and Cuevas and Lugo (1998). The contribution of twigs and branches to the total litter inputs in this study was 18.5% for *Leucaena leucocephala* and 23.8% for *Senna siamea* and these values are comparable with values reported by Lundgren (1978); Boateng (1985) and Songwe et al. (1995). Also in this study input of reproductive organs formed 2.8% and 3.2% of the total litter inputs from *Leucaena leucocephala* and *Senna siamea* woodlots, respectively.

Mean nutrient concentrations in *Leucaena leucocephala* were N, 3.73%; P, 0.60%; K, 2.40%; Ca, 1.16% and Mg, 0.79% in leaves and N, 0.04%; P, 0.32%; K, 0.98%; Ca, 0.95% and Mg, 0.61% in twigs and branches. For *Senna siamea*, mean nutrient concentrations were N, 2.99%; P, 0.75%; K, 2.25%; Ca, 1.79% and Mg, 1.07% in the leaves and N, 0.06%; P, 0.51%; K, 1.08%; Ca, 1.16 and Mg, 0.67% in the twigs and branches (Table 3.3). These findings are inconsistent with other findings reported by Koudoro (1982); Maclean et al. (1992) and Rainer (1999). This could be attributed to species effect and or site characteristics and management.

Potential nutrient inputs

Potential N, P, K, Ca, and Mg inputs in leaves and twigs and branches of *Leucaena leucocephala* and *Senna siamea* increased with increasing biomass. During the period of study *Senna siamea* could potentially contribute in its litter components (leaves, twigs and branches) N, 1023.63 kg/ha; P, 289.85 kg/ha; K, 824.43 kg/ha; Ca, 719.25 kg/ha and Mg, 441.2 kg/ha whereas *Leucaena leucocephala* could contribute N, 843.36 kg/ha; P, 163.83 kg/ha; K, 656.60 kg/ha, Ca, 347.19 kg/ha and Mg, 232.67 kg/ha (Table 3.6).

Potential N and K inputs in *Leucaena leucocephala* and *Senna siamea* woodlots were similar. This could be attributed the fact that *Leucaena leucocephala* is a N fixing plant (Nair, 1993; Young, 1997) and *Senna siamea,* even though not a nitrogen fixing plant, holds large amount of N in its foliage (Yamoah et al., 1986; Young, 1997). *Senna siamea* has the potential to remove K from the lower depths of soil profile with the aid of mycorrhizal roots and efficiently recycled it (Pritchett, 1979) whereas *Leucaena leucocephala* has the potential to contribute as much as 264 kg of K per hectare per year (Hauser and Kang, 1993). Hence probably the lack of significant difference in potential K inputs in the woodlots. *Senna siamea* litter had significantly higher potential P, Ca and Mg inputs compared to *Leucaena leucocephala* litter (Table 3.7). This could be attributed to the heavy vesicular-arbuscular mycorrhiza infection of *Senna siamea* which improves uptake of P from the soil (Okon et al., 1996) and enhance uptake of secondary nutrients (Young, 1997).

Decomposition and Mineralization

The rate of decomposition of *Leucaena leucocephala* foliage was faster than in *Senna siamea* foliage. At 30 days, 87.45% of *Leucaena leucocephala* foliage and 42.50% of *Senna siamea* foliage had decomposed (Table 4.3). Rapid decomposition of *Leucaena leucocephala* compared to *Senna siamea* foliage has also been reported by Van Der Meersch et al. (1993) and Wilson et al. (1986). Litter decomposition is influenced by lignin concentration, N concentration, L/N and C/N ratios and physical characteristics of litter (Nair, 1993; Young, 1997). In this study, rapid decomposition of *Leucaena leucocephala* foliage compared to *Senna siamea* could be attributed to high litter quality of *Leucaena leucocephala* foliage; that is low lignin level of 6.78%, low C/N ratio of 11.43, L/N ratio of 1.46 compared to *Senna siamea* with lignin concentration of 8.57%, C/N ratio of 13.28 and L/N ratio of 2.08 (Table 4.1). Foliage size and characteristics of *Leucaena leucocephala* probably also contributed to its faster decomposition compared to *Senna siamea* foliage. This is because *Leucaena leucocephala* has small feathery compound leaves without prominent skeletal tissue whereas *Senna siamea* has medium sized compound leaves with prominent midribs.

Between species mineralization of N, P, K and Ca were similar (Table 4.2). Lack of significant difference in N, K and Ca release between the species could probably be due to lack of significant differences in initial levels of N, K and Ca and their similar mean K_n values in both species. Even though initial level of P was significantly ($P < 0.05$) higher in *Senna siamea* foliage (Table 4.1), its release was similar between the species.

Within species the release of N, P, K and Ca were faster in decomposing foliage of *Senna siamea* whereas Mg release was faster in decomposing foliage of *Leucaena leucocephala*. High C/N ratio and high lignin concentrations in leaf litter have been reported to decrease the rate of N mineralization (Muller et al., 1988). However, *Senna siamea* foliage with C/N ratio of 13.28; L/N ratio of 2.08 and lignin levels of 8.57% released N faster from its foliage compared to *Leucaena leucocephala* foliage with C/N ratio of 11.43; L/N ratio of 1.46 and lignin levels of 6.78% (Table 4.1). Probable explanation could be that lignin levels and C/N ratios could not influence N release in *Senna siamea* foliage. *Senna siamea* holds large amount of N in its foliage (Yamoah et al., 1986) and hence probably releases N readily upon decomposition. The fast release of P within *Senna siamea* foliage could be attributed to the significantly higher levels of initial P in its foliage as a result of heavy vesicular-arbuscular mycorrhizae infection which improves uptake of P from the soil and effectively recycled it (Okon et al., 1996; Young, 1997). The heavy vesicular-arbuscular mycorrhizae infection also enhances the uptake K and Ca from the soil (Pritchett, 1979; Young, 1997) hence its fast release within *Senna siamea* foliage.

Species with high nutrient levels probably release nutrients at a faster rate (Berendse et al., 1987). Therefore, the probable explanation for the fast release of Mg in *Leucaena leucocephala* foliage could be due to high levels of Mg in *Leucaena leucocephala* foliage of 1.48% compared to *Senna siamea* foliage of 0.97% (Table 4.9).

Soil Chemical Properties

Soil chemical properties within 0-15 cm depth and 15-30 cm depth in the *Leucaena leucocephala* and *Senna siamea* woodlots fifteen years after establishment were compared in Tables 5.4 and 5.5, respectively. Soil pH, % OM, % OC, total N, exchangeable Ca and Mg, (Al + H), effective CEC and % base saturation within 0-15 cm depth were similar. Also, within 15-30 cm depth soil pH, % OM, % OC, total N, exchangeable K, Ca and Mg, (Al + H), effective CEC and % base saturation were similar. Total litter inputs between the species were similar. Although decomposition of *Leucaena leucocephala* foliage was faster compared to *Senna siamea* foliage, mineralization of N, P, K and Ca were similar between the two species. The release of these nutrients from litter following decomposition and mineralization could have improved the soil chemical properties within 0-30cm under the woodlots. Therefore lack of significant differences between the two depths could be attributed to the effectiveness of tree roots in stabilizing and holding these nutrients against leaching out of the 0-30 cm depth profile.

Comparison of soil chemical properties under the woodlots however, showed higher exchangeable K within 0-15 cm depth and higher available P within 0-30 cm depth in the *Senna siamea* woodlot (Tables 5.4 and 5.5). Young (1998) confirms high P under *Senna siamea* and attributed it to heavy vesicular-arbuscular mycorrhizae infection of *Senna siamea* which improve P uptake and enhance effective P recycling. Potential K inputs in litter and mineralization rates were similar between the species. However, exchangeable K was significantly higher within 0-15 cm depth in the *Senna siamea*

woodlot. This could probably be due to the heavy vesicular-arbuscular mycorrhizae infection of *Senna siamea* which enhanced the uptake of K from the lower depths of soil profile and efficiently recycled it within the upper soil profile (Pritchett, 1979).

Changes in Soil Chemical Properties Fifteen Years after Establishment

Comparing percent change in soil chemical properties between the woodlots fifteen years after establishment revealed appreciable increases in soil pH by 8.82%; % OC by 29.59%; exchangeable Ca by 63.74% and effective CEC by 112.44% in the *Leucaena leucocephala* woodlot (Table 5.6). In the *Senna siamea* woodlot, soil pH increased by 2.34%; % OC by 29.59%; exchangeable Ca by 53.82% and effective CEC by 91.70% (Table 5.6). These results confirmed the potential of *Leucaena leucocephala* and *Senna siamea* to improve soil fertility by effectively recycling nutrients in their litter through decomposition and mineralization. There were however, decreases in total N, available P and exchangeable K within 0-15 cm depth in both woodlots. These could be attributed to accumulation of these elements in woody biomass and probable utilization of substantially soil N, P and K reserves (Anderson, 1986). Therefore, harvests that remove greater portions of woody biomass could potentially deplete soil total N, available P, and exchangeable K fertility.

Percent change in soil chemical properties within 15-30 cm depth in the *Leucaena leucocephala* woodlot showed decreases in % OC, total N and available P. However, soil pH increased by 1.75%; exchangeable K by 92.86%; exchangeable Ca by 49.20% and effective CEC by 66.73% within 15-30 cm depth in the *Leucaena leucocephala*

woodlot. The decreases in total N and available P could be attributed to accumulation in woody biomass and probable utilization of substantial soil N and P reserves. With the exception soil pH which decreased by 4.08% within 15-30 cm depth in the *Senna siamea* woodlot, % OC increased by 62.32%; total N by 83.30%; available P by 18.32%; exchangeable K by 28.57%; exchangeable Ca by 45.66% and effective CEC by 83.27% in the *Senna siamea* woodlot. High Ca levels are known to increase soil pH however, there was a decrease in soil pH within 15-30 cm depth in the *Senna siamea* woodlot even though Ca levels were high.

Conclusion and Recommendations

From the findings of this study the following conclusions could be drawn. First, litter inputs in *Leucaena leucocephala* and *Senna siamea* woodlots could be similar. *Senna siamea* and *Leucaena leucocephala* species could have the potential to be used as litter cover to protect soils form erosion, reduce water loss from evapotranspiration and modify extremes of soil temperature. However, potential P, Ca and Mg inputs could be higher in *Senna siamea* litter compared to *Leucaena leucocephala* litter. Therefore *Senna siamea* could be a preferred species to improve soil fertility if litter and nutrient inputs are part of management objectives.

Secondly, rate of decomposition of *Leucaena leucocephala* foliage was significantly ($P < 0.05$) faster than *Senna siamea* foliage. The rate of decomposition of the species was influenced largely by the quality of the foliage (high lignin levels, low C/N ratio and low L/N ratio) and the physical characteristics. Mineralization of N, P, K and Ca between decomposing foliage of *Leucaena leucocephala* and *Senna siamea* could be similar. Both species could therefore have the potential to improve soil fertility. *Leucaena leucocephala* could release nutrients readily for plant growth. However, these nutrients could be lost by leaching if not released in synchrony with crop demand and uptake. *Senna siamea* foliage on the other hand, could contribute to the build up of nutrients in the soil slowly and provide a continual nutrient supply in the long term for the benefit of crops at later growth stages. Also for long term effect on soil, *Senna siamea* had a better potential as soil cover due to the slow decomposition rate of its foliage.

Where Mg is a critical nutrient needed in soil, *Leucaena leucocephala* could have preference over *Senna siamea* due to the significantly high Mg in decomposing foliage of *Leucaena leucocephala*

Lastly, soil pH, % OM, % OC, total N, exchangeable Ca and Mg, (Al + H), effective CEC and % base saturation within 0-30 cm depth in the woodlots were similar. However, exchangeable K and available P were significantly higher ($P < 0.05$) within 0-15 cm depth and 0-30 cm depth, respectively in the *Senna siamea* woodlot. *Senna siamea* could have the potential to improved soil available P and could therefore be used to supplement P levels in sustained crop production in Agroforestry on P-deficient soils. Also *Senna siamea* could have the potential to improved soil exchangeable K compared to *Leucaena leucocephala*. Both *Leucaena leucocephala* and *Senna siamea* have the potential to improve soil fertility over a period of fifteen years by increasing soil pH, %OC, exchangeable Ca and effective CEC within 0-15 cm depth. There is however, the potential to decrease total N, available P and exchangeable K which may be attributed to immobilization in woody biomass.

Based on these conclusions it is recommended that future studies should include;

1. Soil physical properties including infiltration rates, bulk density and water holding capacity.
2. Estimate of nutrients in tree biomass to make reports on site nutrient budget and dynamics more comprehensive.

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