DECOMPOSITION STUDIES ON FINE ROOTS OF *Gliricidia sepium, Leucaena leucocephala and Senna siamea*

BY

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DECLARATION

I hereby declare that this submission is my own work towards the MSc in Agroforestry and that, to the best of my knowledge, it contains no material previously published by another person nor materials which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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DEDICATION

This thesis is dedicated to my supervisor, Dr. Francis Ulzen- Appiah and my wife, Mrs Helena Antwi.

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ABSTRACT

Nutrient composition, rate of decomposition and nutrient release pattern of fine roots (≤ 2mm) of *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea* buried within 15cm and 30cm soil depths were studied biweekly under field conditions using litter pot method over an 84 day period. Generally, *Gliricidia sepium* had significantly higher ($P < 0.05$) initial levels of nutrients among species and could be described as high quality litter, *Leucaena Leucocephala* of moderate quality litter and *Senna siamea* of low quality litter.

Gliricidia sepium fine roots showed the most rapid root weight loss within both 15cm and 30cm soil depths, followed by *Leucaena leucocephala* and then *Senna siamea*. Mean decomposition rate constants (K_d) was significantly higher for *Gliricidia sepium* and similar for *Leucaena leucocephala* and *Senna siamea* within both 15 and 30cm soil depths. The different decomposition rate could be related to litter quality (initial nitrogen, lignin and lignin/nitrogen ratio). Depths of placement did not significantly influence decomposition of fine roots.

Nutrient release followed the order K > P > Mg > N > Ca > C for *Gliricidia sepium*, K > Ca > P > N > Mg > C for *Leucaena leucocephala* and K > P > Ca > Mg > C = N for *Senna siamea* within 15cm soil depth and K > P > Ca > Mg = N > C for *Gliricidia sepium*, K > Ca > P > N > Mg > C for *Leucaena leucocephala*, K > P >Ca > Mg > N = C for *Senna siamea* within 30cm soil depth. Nutrient release could be related to initial nutrient and lignin levels in fine roots. Depths of placement significantly influenced the release of potassium and magnesium and this could be attributed to leaching as the predominant mode for the release of potassium and magnesium.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

Agroforestry systems are designed with the intention that there is significant positive interaction either economically or ecologically between the woody and the non woody components (Lundgren and Raintree, 1982). The ecological interactions in agroforestry systems can be divided into aboveground and belowground processes. Agroforestry systems can thus be biologically more productive than either pure crop or pure tree systems if there is aboveground and belowground resource sharing between the woody and non woody components (Van Noodwijck and Purnomosidhi, 1995).

Although, the aboveground carbon and nutrient input have traditionally been viewed as the more important source, there is good evidence that the transfer of carbon and nutrients via the belowground is important to plants and in the formation of soil organic matter (Fernandes et al., 1997). Roots are important source and sink of nutrients in agroforestry systems. It is estimated that 70-80% of annual net primary production of many tree species are allocated belowground and re-translocation of nutrients out of roots is minimal compared to leaves (Wendy and Jackson, 2000).

Fine root growth and mortality represents a significant source of energy and nutrient flow in soils particularly, when trees are subjected to periodic disturbances (Baker et al., 2001). Thirty to eighty percent (30-86%) of fine roots turnover annually to add organic matter and nutrients

to soil (Fogel, 1983). Re-growth of fine roots of hardwood forest accumulated rapidly after clear cutting, reaching 71% of the matured forest within four years (Fahay and Hughes 1994). Agroforestry management practices such as shoot pruning of hedgerows in alley cropping systems temporary checks the growth of fine roots and may cause the shedding of fine roots, which decompose to add nutrients to the soil. A phenomenon that is similar to the growth of leaves and their shedding as litter (Young, 1989). However, relatively little is known about the root litter in terms of amount of organic compounds, nutrient composition, decomposition and nutrient release pattern due to the difficulties with root studies (Muñoz and Beer, 2001).

Decomposition processes are required to breakdown plant litter and make their nutrients available to the soil community for recycling. Studies on decomposition processes of plant litter have demonstrated the importance of the chemical composition of plant litter as determinants of decomposition rate and nutrient release pattern. For example, the initial concentration of nitrogen, carbon, lignin and their ratios have been used to predict decomposition rate and nutrient release pattern of leaf mulch and/or green manure (Mellilo et al., 1982). There is a lack of data on root decomposition and how it is influenced by substrate quality (Young, 1989). During decomposition, plant litter form a temporal sink of nutrients and little is known on the timing of nutrient mineralization from plant litter, particularly root litter decomposition or its role in the synchronization between net nutrient mineralization and demand by crop (Van Noodwijck and Brouwer, 1997).

Fine root biomass of most tree species are located within the upper 0 – 50cm of soil depth and sharply decrease at lower depth intervals (Muñoz and Beer, 2001). Depth of placement of plant litter in soil is known to affect the rate of decomposition and nutrient release (Fernandes et al., 1997). There is therefore the need to study the nutrient composition, decomposition and nutrient release pattern at different soil depths for fine roots of *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea,* which are commonly used in agroforestry systems to understand and use the synchronization between net nutrient mineralization and demand by crop with nutrients released by aboveground parts of the species.

1.2 OBJECTIVES

The general objective of the research was to study the decomposition and nutrient release patterns of fine roots (≤ 2mm) of *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea*.

The specific objectives of the study were to;

i. Compare the initial chemical characteristics of fine roots of the species.
ii. Compare the decomposition and nutrient release patterns of fine roots of the species.
iii. Determine the effect of soil depth on decomposition and nutrient release pattern of the species.

1.3. HYPOTHESIS

The following hypothesis were tested

i. The initial chemical characteristics of fine roots of species are not different.

ii. Decomposition and nutrient release patterns of fine roots of species are not different and not influenced by initial chemical characteristics.

iii. Fine root decomposition and nutrient release patterns of species are not influenced by soil depth.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. THE TREE ROOT SYSTEM

The tree root system can be divided into fine and coarse root based on diameter. Coarse roots are structural roots of medium to large diameter, and provide mechanical and conductive service to the tree. Fine roots are the structures primarily responsible for the acquisition of water and nutrients. The most important root features that show systematic variation and that are useful to describe root system are diameter, relative depth, colour, surface texture and the order they arise from the primary root (Fogel, 1983; Turner, 2001).

Fine roots are defined as those having a diameter of ≤ 3mm, because any root larger than 3mm has secondary xylem thickening and tend to be perennial (McClaugherty et al., 1982). However, there is no established convention defining the diameter size range of fine roots, as many researchers have used 2mm – 10mm to describe fine roots (Dawoe et al., 2000; Muñoz and Beer, 2001). The different sizes considered as fine roots affect the estimation of fine root biomass (Abate, 2004), nutrient composition (Wendy and Jackson, 2000) and the rate of decomposition (Ludovici et al., 2006).

2.1.1 Nutrient concentration in roots

Mean nitrogen concentration in dead and live roots of 56 plant species were similar suggesting that retranslocation in roots before senescence is minimal and this also suggests less variation in nitrogen in roots of plants. There is an inverse relationship of fine root nutrient concentration with root diameter. Fine roots (< 2mm) contained less carbon than coarse roots (2mm-5mm).

Mean nitrogen and phosphorus of 11.0g/kg and 0.9g/kg, respectively in fine roots (< 2mm) were higher than 6.5g/kg and 0.6g/kg in coarse roots (2mm-5mm).The average C/N ratio of 43:1 for fine roots (< 2mm) was higher than 76:1 for coarse roots (2mm-5mm) in a study of 56 plant species. However, there were no differences in potassium and calcium (Wendy and Jackson, 2000). Also, fine roots (< 2mm) had higher concentrations of nitrogen, phosphorous, and calcium and faster release rates for carbon, nitrogen, and potassium than coarse roots, 2mm-5mm (Ludovici et al., 2006).

However, Lehmann et al. (1995) reported that root diameter has little influence on the rate of decomposition compared to the initial chemical composition of roots. *Gliricidia sepium* fine roots (< 2mm) decomposed faster than the coarse root (2mm-5mm) whereas *Senna siamea* coarse roots decomposed faster than the fine roots and this inconsistency was attributed to the initial chemical characteristics of the roots of the species.

2.1.2. Fine root distribution

Root distribution is concerned with root density and root biomass as a function of soil depth and distance from the stem (Abate, 2004). For many plant species root density is greatest in the surface 15cm soil depth (Frank et al., 2004). Fine root biomass of one year old *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea* were highest within the upper 0-30cm soil depth and sharply decreased at lower depth intervals with more than 80% being observed at the 0-15cm depth of soil. Lateral root spread within 0-30 cm soil depth were 104.7cm, 98.2cm,

and 93.0cm for *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea* and these were expected to increase with time (Dawoe et al., 2000).

2.1.3. Fine root dynamics

Fine root dynamics is the mortality and re-growth of fine roots and how these vary with time (Muñoz and Beer, 2001). Fine root biomass undergoes annual turnover, analogous to the growth of leaves and their shedding as litter (McClaugherty et al., 1982). Root turnover is a specific aspect of root dynamics referring to the fraction of a root system that is restored during a certain period of time through death of some roots and their replacement by new root growth (Schroth, 2003). Fine root dynamics represent a significant source of energy and nutrient flow in soils, particularly trees that are subjected to periodic disturbances (Baker et al., 2001). Fahay and Hughes (1994) reported that re-growth of fine roots of hardwood forest after clear cutting reached 71% of the matured forest within four years.

Seasonal changes in fine root biomass suggest that fine root turnover occurs on a seasonal basis (Abate, 2004). The disappearance from view of individual roots from a series of minirhizotron images represents their transformation into litter input to the soil. New root growth is rapid at the onset of rains but is retarded as drought progresses resulting in greater root death rate at negative moisture potential (Muñoz and Beer, 2001). Many authors have reported changes in fine root biomass production and turnover. However, studies on how much nutrients are released through root turnover with time are lacking. Relatively little is known about the root litter input, which may differ significantly among species in the proportion of fine root to coarse roots, nutrient composition, decomposition rate and nutrient release pattern (Fernandes et al., 1997).

2.2. DECOMPOSITION

Decomposition is defined as the gradual disintegration of dead organic matter and is brought about by both physical and biological agencies. It results in complex energy-rich molecules being broken down by their consumers into carbon dioxide, water and inorganic nutrients. Decomposition in terrestrial ecosystem regulates the transfer of carbon and nutrient dynamics in the soil to sustain plant communities (Begon et al., 1986).

Decomposition of plant litter is usually measured by the percentage mass loss of the original mass. Several field studies indicate more than 50% mass of decomposing plant litter is lost in less than one year and about 30% remain after one year (Johnson et al., 2007). Mass loss of plant litter is best described by a two-phase model; an initial phase of rapid mass loss, resulting from decomposition of more soluble compounds and a phase of very slow loss dominated by lignocellulosic compounds. As decomposition enters the second phase the composition of the substrate becomes more recalcitrant as the microbes consume the more readily soluble materials (Mellilo et al., 1989).

2.2.1. Methods for measuring decomposition of plant litter.

The study of decomposition employs different methods to measure mass loss. These include soil respiration approach, which uses carbon dioxide emission from mixture of plant litter and soil as an index of decomposition in laboratory studies (Johnson et al., 2007). Intact-core and

minirhizotron technique, which require no *a priori* root processing, retains natural rhizosphere associations, and maintains *in situ* decay conditions of root litter (Dornbush et al., 2004). The litter bag method (Sraha and Ulzen-Appiah, 1997)) and the litter pot method (Beare, 1997).

The most commonly used method to measure mass loss and nutrient release in field studies is the litterbag method. However, preparation of roots for litterbag studies and their subsequent decay within litterbags represent major departure from *in situ* conditions. Mass loss in field studies with litter bags can be the result of material falling from the litter bag due to large pore size, rather than being decomposed (Johnson et al., 2007). Small pore size of the litter bag may exclude large soil invertebrates, which are very important in decomposition (Blair et al., 1991).

A comparison of litter bag and intact-core technique for the decomposition of fine roots of sugar maple, maize and wheat revealed that mass loss and nitrogen release were 10-23% and 21-29%, respectively greater within intact-core than buried litter bag. The difference was attributed to alteration to decomposer dynamics during preparation of fine roots for litter bag studies (Dornbush et al., 2004). However, Tierney and Fahey (2002) observed that radioactive content of fine roots harvested from minirhizotron tubes did not differ from that of fine roots collected from the soil, suggesting these two methods sampled the same population of fine roots. The litter pot method for the study of decomposition and nutrient release of plant litter described by Beare (1997) is a suitable alternative to litter bag method. This method allows full contact of plant litter with the soil and access to soil organisms to the plant litter.

2.2.2. Decomposition rate

Decomposition rate for plant litter is described by a constant percentage weight loss per unit time (Aber and Melillo, 1991). This yields a curvilinear pattern for percent of original weight remaining, which can be fixed to exponential equation of the form:

$$\% \text{ original remaining} = e^{-kt} \qquad \text{Equ. 1.}$$

Where t = time, k = litter specific constant and e = base of natural logarithm.

Positive values indicate mineralization and negative values indicate immobilization. The time required for a certain proportion of the plant material to decompose can be calculated from the relation (Kachaka et al., 1993).

Differences in k values from plant litter decomposition result from different incubation periods, different plant parts, different approaches of gathering litter and varied environmental conditions (Dubeux et al., 2006). Decomposition rate constant (k) values from 70 different studies varied from 0.006 to 4.993$gg^{-1}yr^{-1}$ (Deqiang et al., 2008). Again, k values of roots of different plant species and climatic conditions varied from 0.03 to more than 7.0 $gg^{-1}yr^{-1}$. The variability of k values of different plant litter affect the decomposability of litter with time even under the same climatic conditions. For example Sraha and Ulzen-Appiah (1997) reported the half life and k values of leaf mulches in the humid zone for *Leucaena leucocephala* –18 days, *Gliricidia sepium* – 35 days and *Cassia spectabilis* – 69 days

2.2.3. Factors affecting the rate of decomposition

The rate of decomposition of plant litter is dependent on litter quality, climate, microfaunal activity and soil factors (Parr and Papendick, 1978). Decomposition rate constant (k) values tend to decrease with latitude and lignin content of litter but increase with temperature, precipitation and nutrient concentration. On a global scale, climate is the best predictor of decomposition rate. However, within a climatic region litter quality is the best predictor of decomposition rate (Aerts, 1997). Litter quality, a combination of total nutrient and C/N ratio, accounted for 70.2% of variability of global data set for litter decomposition rate in terrestrial ecosystem and it is assumed to be the most important direct regulator of litter decomposition rate (Deqiang et al., 2008). Root chemistry is the primary controller of root decomposition whereas climatic and environmental factors played secondary role (Silver and Miya, 2001). Depth of placement of plant litter is known to affect the rate of plant litter decomposition (Kaizzi and Wortmann, 2001). The effect of litter quality, climate, soil organisms and depth of placement on the rate of plant litter decomposition is presented below.

2.2.3.1. Litter quality

Litter quality refers to the regulatory effect of the chemical composition and the physical characteristics of an organic resource on its rate of decomposition and nutrient release pattern (Mellilo et al., 1982). The resistance of a particular plant litter to decompose has been related to the quality of the plant litter as substrate for soil organisms. Plant litter inputs to the decomposer community are a diverse range of resources of varying decomposability because of intrinsic factors of chemical composition and physical structure (Anderson and Swift, 1993).

Soluble carbohydrates are leached from fresh litter and quickly metabolized by microbes while plant cell wall content such as cellulose and lignin are more resistant to decomposition (Warring and Schlesinger, 1985). The initial decomposition rate constants (K_d) values are thus higher at the beginning of the incubation period but the K_d values tend to stabilize or decrease slowly towards the end of the incubation period (Dubeux et al., 2006).

Litter quality accounts for the variation in decomposition rate of different species within the same or adjacent site (Anderson and Swift, 1993). For example, fine roots (<1.5mm) decomposition decreased in the order *Gliricidia* < *Senna* < *Caliandra*. This result was mainly attributed to chemical composition of the plant litter and termite activity (Lehmann et al., 1995). Again, Sraha and Ulzen-Appiah (1997), reported that decomposition rate of prunings decreased in the order *Leucaena leucocephala* < *Gliricidia sepium* < *Cassia spectabilis* and attributed the different rate of decomposition to the chemical characteristics of the leaf mulch. Chemical indices of litter quality include nutrient element concentration and concentration of various organic compounds. For example, initial nitrogen content, initial lignin content, and initial carbon/nitrogen ratios (Chapin, 2003). The effects of various chemical indices on plant litter decomposition are presented below.

2.2.3.2. Initial Nitrogen and Lignin/Nitrogen (L/N) ratio

The rate at which different plant litter decompose has been linked to the initial nitrogen and lignin content or lignin / nitrogen ratio of the plant litter. Litter nitrogen content has been linked to the decay rate as a function of the nutritional requirements of decomposer communities (Melillo et al., 1989). Lignin is a complex polymer of aromatic rings that is deposited in the

secondary thickening of cell wall. Lignin is one of the slowest of the common plant components to decay as it requires large amount of energy to initiate its decomposition. Lignin decomposition will not begin until the more easily decomposed materials are exhausted (Aber and Mellilo, 1991). Because lignin is the most recalcitrant component of the plant cell wall, the higher the proportion of lignin in plant litter the lower the bioavailability of the substrate and slower the decomposition rate (Haug,1993).

Nitrogen and lignin components are better predictors for partitioning plant materials into fast and slow decomposing pools (Johnson et al., 2007). Plant species with high nitrogen content are considered to be high quality litter to microbes and decompose rapidly whilst plant species low in nitrogen with high recalcitrant carbon fraction such as lignin make poor substrate for decomposers and decompose slowly (Young, 1989). Generally high levels of nutrients, particularly, nitrogen are expected to accelerate the decomposition process (Alhmad et al., 2004). Several studies have shown a positive correlation between initial nitrogen concentration and the decomposition rate constant (Melillo et al., 1982). Initial decomposition is generally higher for nitrogen rich plant litter than for species with low nitrogen. In later stages of decomposition at which lignin degradation regulate decomposition, nitrogen has a retarding effect on decomposition (Berg and Matzner, 1997)

The ratio of lignin to nitrogen (L/N) also influences the rate of decomposition. Litter decomposition is mainly controlled by the rate of lignin decomposition and that the rate in turn is decreased by high nitrogen concentration (Dubeux et al., 2006). Regression of initial L/N

ratio on mass remaining improved decomposition rate, while using N content alone decreased it, illustrating a succession of nitrogen to lignin control of decomposition rate. Nitrogen content underestimated mass loss by 10-16% of pine needle (lignin=26.2%) while lignin and L/N ratio over estimated it by less than 2% (Taylor et al., 1989). Lignin / Nitrogen ratio is inversely proportional to the rate of decomposition and it is positively correlated with immobilization of plant nutrient particularly nitrogen (Melillo et al., 1989). Yeboah-Badu (2006) reported that *Leucaena leucocephala* foliage, which had low L/N ratio of 1.46 decomposed faster than *Senna siamea* with high L/N ratio of 2.08

2.2.3.3. Carbon/Nitrogen (C/N) ratio

The carbon/nitrogen ratio has been used by many authors to predict decomposition pattern and also follow the nutrient mineralization and immobilization from plant litter. High initial C/N ratio is expected to decrease decomposition rate of plant litter whereas low initial C/N increase decomposition rate (Melillo et al, 1982). A general rule of the thumb is that a C/N ratio greater than 20 will result initially in net nitrogen immobilization (Tisdall et al., 1986). The C/N ratio favorable for decomposition to proceed faster is between 30-20:1. Therefore, when plant litter with C/N ratio 40-80:1 is added to soil, there is nitrogen immobilization due to incorporation of nitrogen into the microbe's body (Begon et al., 1986).

Nitrogen and carbon mineralization are indicators of decomposition therefore, the rate of carbon and nitrogen mineralization are related to the rate of decomposition (Johnson et al., 2007).The quality of litter is changed as a result of nitrogen and carbon utilization by microbes

(Torreta and Takeda, 1999). Carbon and nitrogen dynamics are related to the relative availability of carbon and nitrogen to microbial population. During decomposition, carbon is used as energy source while nitrogen is assimilated into protein and other compounds (Chapin, 2003). Low nitrogen availability reduces the rate at which protein is synthesized by microbes, reducing both population and level at which carbon is processed (Aber and Melillo, 1991).

Net nitrogen mineralization is triggered by carbon limitation imposed on microbial decomposition as C/N ratio drops to critical threshold (Bernendse et al., 1987). Initial high C/N ratio explains the slower decomposition rate and lesser nitrogen mineralization at the start of incubation period. The C/N ratio decreases with incubation period and this is expected because the more soluble carbon compounds decompose readily but nitrogen immobilization by the low quality residue and nitrogen bound to fiber reduce nitrogen losses (Dubeux et al., 2006). Again, declining C/N ratio at latter stages of decomposition has been attributed to cessation of the loss of soluble nitrogen together with enhancement of carbon respiration due to increase in microbial population (Zahara and Bah, 1999).

Although C/N ratio remain a critical variable in the decomposition model, several studies have demonstrated important interactions with other factors including the form of carbon in the plant cell as energy source, the concentration of other nutrients and the concentration of various secondary plant compounds (Heal et al., 1997). Ghidey and Alberts (1993) compared buried shoot and buried root residue of corn and soybean and found a faster decay rate for buried soybean materials than corn in the first year. They attempted to link their findings to higher

C/N ratios in the more slowly decomposing material; however, their measurements showed a substantially higher C/N ratio in soybean roots than corn roots.

2.2.3.4. Depth of placement

Litter in or on the soil influences the composition of decomposer communities and resulting trophic relationship is more important in determining the rate of plant litter decay and nutrient release dynamics (Beare, 1997). Incorporation of plant litter in soil results in increased rate of decomposition and short term nutrient availability (Fernandes et al., 1997).

Biomass of all microbial and faunal groups was greater on buried litter and decomposition rate was 2.5 times faster than litter applied on the surface of the soil (Ludovici et al., 2006) Ghidey and Albert (1993) examined decomposition of residue on the surface, buried shoot residue, and buried root materials of five crop species and reported 35 to 60%, 70 to 80% and 45 to 75% mass loss, respectively, in the first year. Decomposition of *Lantana camara*, *Senna hirsuta*, *Tithonia diversifolia* and *Aspilia kotschyi* trimmings were slower with surface placement than with incorporation, requiring 7 weeks for 50% decomposition with surface application and 5 to 6 weeks with incorporation. Again, more N was released for incorporated (75%) than for surface-placed (50%) materials at the end of 16 weeks, probably due to enhanced microbial activity associated with soil moisture and close contact with the soil for the incorporated samples. Decomposition of surface placement litter was delayed presumably because of variable moisture conditions (Kaizzi and Wortmann, 2001).

2.2.3.5. Climate

Temperature and moisture are the most important climatic factors that influence the rate of decomposition of plant litter. Temperature would influence decomposition where precipitation is not limiting. Temperature can indirectly influence root decomposition through decreased litter quality and increased water deficits. Where precipitation is limiting temperature would decrease decomposition. Fluctuations of temperature and moisture result in greater microbial activity and turnover resulting in increased rate of decomposition than in constant conditions (Warring and Schlesinger, 1985). Total precipitation and its distribution are the most important determinants of moisture in the decomposition process (Castanho, 2006). When precipitation is not evenly distributed throughout the year, soil moisture can limit the rate of decomposition during dry season, when temperature is high (Swift et al., 1981).

2.2.3.6. Soil Organisms

Soil organisms (macro and micro organisms) directly mediate the rate of decomposition of plant litter through their feeding and the production of metabolites. The macro organisms, for example, termites and earth worms facilitate the initial decomposition through commutation of plant litter thus increasing the surface area of the substrate and also introduce micro organisms (bacteria and fungi) attack on the substrate. Degradation of the plant litter by the macro organisms is restricted to those components they can metabolize (Lavelle et al., 1992).

The major components of plant that is cellulose and lignin are metabolized by bacteria and fungi. Bacteria are site specific and surface colonists whilst fungi are mobile and can penetrate

the cell structure of plant tissue with their hyphae (Warring and Schlesinger, 1985). Bacteria and fungi have high nutrient requirements and their activities determine the balance between mineralization and immobilization of nutrients in plant litter (Beare, 1997). Some nutrients particularly nitrogen and phosphorous from plant litter decomposition are retained by the microbes for the synthesis of body protein and growth. This results in immobilization of the nutrients. These nutrients are released (mineralized) to the soil when the microbes die (Warring and Schlesinger, 1985).

2.3 MINERALIZATION AND NUTRIENT RELEASE PATTERN

The term mineralization is used to describe the decomposition process that actually release inorganic compound from the organic matter. This takes place principally during decomposition (Molles Jr., 2002). Microbes responsible for decomposition of plant litter require nutrient elements in given concentration from decomposing litter to build cells for growth. If the nutrient present in litter is in excess of microbial requirements then the nutrient will be released as decomposition proceeds. Conversely, the nutrient may not be released when they are present in low concentration in the plant litter. A reduction in the absolute amount of nutrient in a decomposing litter is termed net mineralization. An increase in the absolute amount of nutrient in a decomposing litter is termed net immobilization (Aber and Melillo, 1991).

The pattern of mineralization varies from species to species and between different components of the same species due to different chemical composition of litter, kind of micro organisms present, site characteristics and the concentration of the nutrient element in the plant litter

(Melillo et al., 1982). In humid tropics example Ghana, nutrient release pattern of leaf mulch followed the order K>P>N>=Ca>C for *Gliricidia sepium*, K>Mg>N>P>C>Ca for *Leucaena leucocephala* and K>Mg>P>N=Ca>C for *Cassia spectabilis* (Sraha and UlzenAppiah, 1997). On the same site, mineralization of decomposing foliage followed the order

N>Ca>Mg>N=P for *Leucaena leucocephala* and K>Mg>N=P=Ca for *Senna siamea* (Yeboah-Badu, 2006).

2.3.1. Nitrogen

Nitrogen dynamics in decomposing plant litter exhibit three sequential phases: Firstly, the initial release phase which is controlled by leaching. This is followed by the net gain phase (immobilization) in which nitrogen is imported into the residual material through the activity of micro organism and thirdly, the net loss phase (mineralization), in which an absolute decrease in the nutrient mass occurs (Alhamd et al., 2004).

Net nitrogen mineralization from plant litter is predicted as a function of litter quality. High quality litter; high initial level of nitrogen, low C/N ratio and L//N ratio will result in nitrogen mineralization whereas Low quality litter; low initial level of nitrogen, high C/N ratio and L//N ratio will immobilize nitrogen (Young, 1989).

2.3.2. Carbon

Carbon is a factor of decomposition and it usually has a similar trend of decay as mass remaining, decreasing progressively with time (Alhamd et al., 2004). Carbon mineralization is

in two stages: First, an initial rapid phase consistent with a fast pool (easily decomposable carbon). This is followed by a slower pool consisting of recalcitrant fractions of carbon (Zaharah and Bah, 1999). Carbon mineralization depends on the quality of carbon (high or low) to microbes. Thus similar carbon compounds are attacked preferentially by microbes based on the energy yielding capacity. For instance lignin decomposition will not begin until the more easily decomposable materials are exhausted (Aber and Melillo, 1991).

2.3.4. Phosphorus

Phosphorus mineralization demonstrates the importance of substrate quality in nutrient dynamics. High lignin content in plant litter delays the release of phosphorus in decomposing plant litter (Kaizzi and Wortmann, 2001). Species with high nutrient content release the nutrient at a faster rate than species with low nutrient content. For instance *Gliricidia sepium* mulch, with high initial phosphorus released the nutrient at a faster rate than *Leucaena leucocephala* and *Cassia spectabilis* mulches, which were low in phophorus (Sraha and Ulzen – Appiah, 1997).

2.3.5. Calcium

Calcium forms a complex constituent of the cell wall, which is resistant to decomposition, the rate of calcium release has been related to Calcium concentration in the plant tissue. Materials with high initial calcium release more calcium than those with low initial concentration of calcium (Kaizzi and Wortmann, 2001). Calcium can be actively transported by fungi hyphae into plant litter (Cromack et al., 1975). Slow release of calcium from plant litter could be attributed to accumulation of calcium oxalate in the fungi that colonize the litter (Sraha and

Ulzen-Appiah, 1997). Faster release of calcium has been attributed to comminution and transfer by soil organisms (Zaharah and Bah, 1999).

2.3.6. Potassium

Leaching is the predominant mode of release during decomposition because of its high mobility (mobile cations in the cell fluid). Disintegration of cell membrane during decomposition results in easy leaching of potassium ions from the plant litter (Jordan, 1985). Zaharha and Bah (1999) observed that almost all the potassium from *Gliricidia* pruning were lost in the first phase of decomposition and this was ascribed to leaching as reported by other authors.

2.3.7. Magnesium

Magnesium is present in organic material as mobile cations in the cell fluid. Disintegration of cell membrane during decomposition results in easy leaching of magnesium ions from the plant litter (Zaharha and Bah 1999). Magnesium released is positively related to the initial magnesium content of the plant materials. Species with high level of magnesium are likely to release the element at a faster rate and vice versa (Kaizzi and Wortmann, 2001). High mineralization rates of magnesium from leaf mulches of *Gliricidia sepium* (k =0.030) and *Leucaena leucocephala* (k=0.029) were attributed to high initial level of magnesium and low lignin (Sraha and Ulzen-Appiah, 1997).

Slow release of magnesium on the other hand has been attributed to the occurrence of magnesium as a constituent of more complex molecules like chlorophyll and pectin (Zaharah

and Bah, 1999). Magnesium was slowly released from *Senna hirsuta* and *Aspilia kotschyi* trimmings compared with other nutrients and a net release of magnesium occurred only after 8 weeks in a 16 week study (Kaizzi and Wortmann, 2001).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study site

The study was conducted in the humid zone of Ghana at the Faculty of Renewable Natural Resources Demonstration farm, KNUST-Kumasi. The area has a bimodal rainfall with an annual average rainfall of 1250mm. The major rainfall occurs from March to July whilst the minor rainfall is between September and November. The mean temperature ranges between 22^{o}C and 34^{o}C. The soil at the study site belongs to the Asuansi series of the Bomso /Nta Association and classified as Ferric Acrisol (FAO, 1976), the soil is loamy, well drained and moderately deep.

3.2. Experimental procedure

The excavation, washing, sorting and storage of root samples were done following the method described by Schroth (2003). Roots of *Leucaena leucocephala*, *Gliricidia sepium*, and *Senna siamea* were excavated from seventeen year old woodlot up to 50cm soil depth and 5m from the bole along the course followed by the roots in the soil mass, using pick axe, spade and knife. The excavated roots were washed in a bucket with water and stirred to remove adhering soil. The roots were then poured on 1mm^2 mesh under running water.

In this study fine roots are defined as those having a diameter of ≤ 2mm. Colour and surface texture were used to distinguish the roots of the test species from the other roots. *Leucaena leucocephala* roots were pinkish and smooth. *Gliricidia sepium* roots were yellowish and rough. *Senna siamea* roots were black and rough. Fine roots ≤ 2mm of the species were sorted using hand lens, 10 x magnifications and vernier calipers. The sorted fine roots of *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea* were packaged in plastic bags and stored in deep freezer to prevent decay.

3.2.1. Experimental design and treatments

Split plot in Randomized Complete Block Design was used. Fine roots of *Leucaena leucocephala, Gliricidia sepium*, and *Senna siamea* were used as the main plot treatments. Depths of placement (15cm and 30cm) were used as Sub plot treatments and days after treatment (14, 28, 42, 56, 70, and 84 days) as blocks. Fine roots of *Leucaena leucocephala, Gliricidia sepium*, and *Senna siamea* were replicated three times for each of the 2 depths of placement (15cm and 30cm) making 6 treatments for each species and 18 treatments per block. Nine soil depths each of 15cm and 30cm making 18 soil depths were randomly allocated to each block. All the 18 treatments were applied to each of the 6 blocks making a total of 108 treatments.

3.2.2. The experiment

The experiment was conducted in an open area free of weeds. The experimental plot measured 16m x 13m. Five grammes (5.00g) each of fine roots of *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea* were weighed using electronic balance sensitive to 0.001g for initial mass determination. Each of the 5.00g of *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea* fine roots were spread in ceramic litter pots measuring 20mm in diameter and 10mm in height with 2mm holes drilled around, to give access to soil fauna to the buried fine roots. The ceramic litter pots were used in the experiment because they allowed water content in the pot to follow that of the surrounding soil. They also allowed close contact of the root litter with soil

Soil from the study site was collected and sieved to remove debris. The ceramic litter pots with their contents, fine root of *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea,* were filled with the sieved soil and tamped with a rod to firm the soil in the pot. The filled litter pots were then buried at 15cm and 30cm of soil depths. The ceramic litter pots were recovered block wise every 14 days for three months, from October, 2006 – January, 2007 as described by Beare (1997).

3.2.3. Sampling

On each sampling date, all the buried litter pots at 15cm and 30cm containing the fine roots of *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea* were removed from one block and taken to the laboratory. Intact roots were recovered, cleaned of soil and oven dried to a constant weight for dry weight determination and nutrient release pattern. (Beare, 1997).

3.3. Laboratory Analysis

Chemical analyses of samples were done at the Soil Chemistry Laboratory of the Soil Research Institute, Kwadaso, Kumasi, employing standard analytical procedures.

3.3.1. Preparation of aliquot

The fine root of *Leucaena leucocephala*, *Gliricidia sepium* and *Senna siamea* were ground with mortar and pistil and re-dried at 70^{o}C for 24 hours. A sample (0.5g) was ashed in a muffle furnace at 450^{o}C for 3.5 hours. The ash was then dissolved in 10ml of 1:2 nitric acid and distilled water. The sample solution was then placed on a hot plate until the first sign of boiling appeared. The sample solution was then filtered into a 100ml volumetric flask and topped to the 100ml mark with distilled water.

3.3.2. Calcium and Magnesium

Calcium and magnesium were determined using Ethyline-diamine tetra-acetic acid (EDTA) method (Radov et al., 1985). Twenty five millilitres of the aliquot prepared above was taken into a 100ml conical flask and 5ml buffer solution (ammonium chloride and ammonia) was added. This was followed by the addition of 1ml amide solution and 1ml of 2% potassium cyanide and then a drop of Eriochrome black 'T' was added as indicator. The solution was then titrated with 0.02 N Ethyline-diamine tetra-acetic acid (EDTA) solution to a sea blue end point, the end point value was recorded. Another 25ml of the aliquot was taken into a 100ml conical flask, 1ml of potassium hydroxide, 1ml of 2% potassium cyanide and a pinch of murixide

indicator were added and titrated with 0.02 N EDTA solution to a violet end point. The end point was recorded.

Percentage calcium was calculated from end point as follows;

$$\%Ca = \frac{0.02 \times T \times 20.04 \times 100}{\text{Sample weight} \times 100} \quad \text{Eqn. 2}$$

Where 0.02 = Normality of EDTA

T = End point value of calcium

20.04 = Equivalent weight of calcium

The percentage magnesium was calculated by subtracting titrate value of (Ca + Mg) from the titrate value of Ca and then substituted in the following formulae;

$$\%Mg = \frac{0.02 \times T \times 12.14 \times 100}{\text{Sample weight} \times 100} \quad \text{Eqn. 3}$$

Where 0.02 = Normality of EDTA

T = End point value of calcium

12.14 = Equivalent weight of magnesium

3.3.3. Phosphorus and Potassium

Phosphorus was determined using the Vanadate-Molydate yellow colour method. The remaining 50ml of the aliquot, 10ml each ammonium molybdate and ammonium vanadate solutions were added and topped to the 100ml mark with distilled water. The solution was left standing for 20 minutes for full yellow colour development. Phosphorus concentration was then determined calometrically by measuring the absorbance with a spectrophotometer at a

wave length of 470 high sensitivity. Unknown concentration is derived by extrapolating from calibration of known standards.

$$\%P = \frac{(\text{Absorbance}) - 0.01 \times 0.4}{0.0148} \qquad \text{Eqn. 4}$$

Potassium was determined by reading from a Gallenkamp flame photometer using a potassium filter.

$$\%K = \frac{\text{Emission} \times 0.4}{0.1773} \qquad \text{Eqn. 5}$$

3.3.4. Nitrogen

Nitrogen was determined with the Kjeldal digestion method. The method involves three processes of digestion, distillation, and titration. Zero point two grammes (0.2g) of root sample were weighed into a 300ml Kjeldal flask. This was digested with 1 Kjeldal tablet (potassium sulphate) and copper sulphate and 5ml of concentrated H_2SO_4 using 0.5g selenium mixture as catalyst. The mixture was digested on an Electro thermal Kjeldal apparatus for 3 hours to convert organic nitrogen to ammonia.

The distillation process involved the addition of 20ml of 10M NaOH and a few drops of mossy zinc solution. The mixture was distilled into a 300ml conical flask containing 25ml boric acid and drops of methyl red indicator and distilled under Tector Kjetech distillation apparatus. The solution changed from bluish purple to green. The distillate was titrated with 0.1N Hydrochloric acid to a pink end point. The percentage nitrogen was calculated using the formula below:

$$\%N = \frac{(T \times N \times 14.007 \times 100) \times 0.953}{1000 \times \text{Weight of sample}} \quad \text{Eqn. 6}$$

Where T = End point value of nitrogen

N = Normality of acid

14.007 = Equivalent weight of nitrogen

3.3.5. Carbon

Carbon was determined by the Dry combustion method. Zero point five grammes (0.5g) of sample was weighed into a preheated and weighed crucible. The weight of sample plus crucible was recorded. The samples were ashed in a muffle furnace at 450ºC for 4 hours. The ashed sample was cooled in a desiccator, and the weight recorded. Percentage carbon was calculated using the formulae below;

$$\%Ash = \frac{\text{Ash weight} \times 100}{\text{Oven dry weight of sample}} \quad \text{Eqn. 7}$$

$$\%\text{Organic matter} = 100 - \%Ash \quad \text{Eqn. 8}$$

$$\%Carbon = \frac{\%\text{Organic matter}}{2} \quad \text{Eqn. 9}$$

3.3.6. Lignin

Lignin content of the fine roots of *Leucaena leucocephala, Gliricidia sepium and Senna siamea* were determined at the Chemistry Laboratory of the Forestry Research Institute, Fumesua –

Kumasi, employing standard analytical procedures as described below. Lignin content was determined using the soxhlet extraction method (Tappi: T 222- S88). Fine roots of *Leucaena leucocephala, Gliricidia sepium and Senna siamea* were ground in a Wiley Mill and sieved using mesh sizes of 40mm and 60mm. Eight grams of air-dried sieved sample was placed in a thimble. 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 then boiled briskly with 200ml of 95% alcohol for four hours, allowed to cool and the extract (catehols and tannis) discarded.

Finally, the sample was then transferred into a baker and digested with 200ml of hot water at 100^{o}C for four hours in a water bath. The sample was then filtered and one gram was oven dried at a temperature of 75^{o}C to a constant weight and dry weight (Y) recorded. One gram of the oven-dried sample was then used to determine the lignin content. To this, 72% sulphuric acid was added and allowed to stand for two hours with frequent stirring. The sample was then diluted to 3% acid concentration with 560ml of distilled water and then boiled in a water bath for four hours. The mixture was filtered through a weighed Whatman No. 42 filter paper. The solute plus the filter paper were oven dried at 75^{o}C to a constant weight (X) and recorded. The weight of lignin was expressed as a percentage based on the weight remaining of one gram of oven dried sample moisture-free material (Y) using the formula below;

$$\%\text{weight of lignin} = \frac{X}{Y} \times 100 \qquad \text{Eqn. 10.}$$

Where X = Oven dry weight of lignin

Y = Weight of moisture free sample

3.4. Statistical analysis

The data collected from the experiment was analyzed using the Genstat computerized analysis of variance (ANOVA) as a Split-plot in Randomized Complete Block Design (RCBD). Differences between treatment means were compared by the least significant difference method at $p = 0.05$. Mass loss and nutrient release patterns were analyzed using a computerized exponential decay model with the Excel program.

The single exponential equation, $Y = e^{-kt}$, was used to calculate the decomposition and nutrient release rate constants, k, where Y is the percentage of the initial weight of plant material, or nutrient, remaining after time t in days (Aber and Mellilo, 1991). The decomposition rate constants were subjected to ANOVA to determine differences in the patterns and rates of decomposition due to plant materials and placement methods.

CHAPTER FOUR

4.0 RESULTS

4.1. INITIAL CHEMICAL CHARACTERISTICS OF FINE ROOTS

The initial chemical characteristics of fine roots of *Gliricidia sepium, Leucaena leucocephala and Senna siamea* are presented in Table 1. Carbon level of 48.58% in *Senna siamea* fine roots was significantly higher ($P < 0.05$) than 46.66% in *Leucaena leucocephala* and 46.67% in *Gliricidia sepium* fine roots. Nitrogen and phosphorus levels were significantly lower ($P < 0.05$) in *Senna siamea* fine roots than in *Leucaena leucocephala* and *Gliricidia sepium*. Potassium level of 1.14% in *Gliricidia sepium* was significantly higher ($P < 0.05$) than 0.79% and 0.88% in *Leucaena leucocephala and Senna siamea*, respectively.

For calcium and magnesium the comparisons are as follows. *Senna siamea* fine roots had significantly higher ($P < 0.05$) calcium (1.57%) compared to 1.04% in *Leucaena leucocephala* and 0.74% in *Gliricidia sepium*. The level of magnesium in *Leucaena leucocephala* was 0.20% and was significantly lower ($P < 0.05$) compared to 0.52% and 0.55% in *Senna siamea* and *Gliricidia sepium*, respectively.

The comparison of lignin (L), carbon/nitrogen ratio (C/N) and lignin/nitrogen (L/N) ratio are as follows. Lignin level of 23.25% in *Leucaena leucocephala* was significantly higher ($P < 0.05$) than 20.45% in *Gliricidia sepium* whereas 17.98% of lignin in *Senna siamea* was significantly lower ($P < 0.05$) than in *Gliricidia sepium*. Carbon/nitrogen ratio of 36.52 in *Senna siamea* was significantly higher ($P < 0.05$) compared to 17.41 and 17.15 in *Gliricidia*

Table 1. Initial chemical characteristic of fine roots of *Gliricidia sepium*, *Leucaena leucocephala and Senna siamea*.

Chemical characteristics		Species: *Gliricidia sepium*	*Leucaena leucocephala*	*Senna siamea*	Grand mean	P - value
Carbon	(%)	46.67b	46.66b	48.58a	47.30	0.035*
Nitrogen	(%)	2.68a	2.72a	1.33b	2.24	0.001***
Phosphrus	(%)	0.18a	0.18a	0.15b	0.17	0.003**
Potasium	(%)	1.14a	0.79b	0.88b	0.94	0.041*
Calcium	(%)	0.74b	1.04b	1.57a	1.12	0.001***
Magnesium	(%)	0.55a	0.20b	0.52a	0.42	0.002**
Lignin	(%)	20.45b	23.25a	17.98c	20.56	0.004**
Carbon/Nitrogen ratio		17.41b	17.15b	36.52a	23.76	0.001***
Lignin/Nitrogen ratio		7.63c	8.55b	13.52a	10.03	0.001***

Species means followed by the same letter are not significantly different.*, **, *** is significant at 0.05, 0.01 and 0.001 respectively.

Sepium and *Leucaena leucocephala*, respectively. Lignin/nitrogen ratio of 13.52 in *Senna siamea* was significantly higher($P < 0.05$) than 8.55 in *Leucaena leucocephala* whereas L/N ratio of 7.63 in *Gliricidia sepium* was significant lower ($P < 0.05$) than in *Leucaena leucocephala*.

4.2 FINE ROOTS DECOMPOSITION

The summary of P - values of analysis of variance results for effects of species, period of sampling and depth of placement on fine root decomposition (weight loss) of *Gliricidia sepium, Leucaena leucocephala and Senna siamea* are given in Table 2. Decomposition of fine roots differed significantly ($P < 0.05$) amongst species and was also influenced significantly ($P < 0.05$) by period of sampling. Decomposition was not influenced ($P > 0.05$) by the depth of placement. Fine roots decomposition was influenced significantly ($P < 0.05$) by the interaction effects of species x depth and species x period of sampling.

Among species comparisons

Decomposition of fine roots of *Gliricidia sepium, Leucaena leucocephala and Senna siamea* buried within 15 cm and 30 cm are compared in figures 1A and 1B, respectively. Decomposition differed significantly ($P < 0.05$) amongst species. Generally, *Gliricidia sepium* decomposed faster compared to *Leucaena leucocephala and Senna siamea* fine roots.

Within 15 cm soil depth, at 14 days fine root weight loss of 2.77g (55%) for *Gliricidia sepium* was significantly greater ($P < 0.05$) than 2.31g (46%) for *Senna siamea*, whereas 1.97g (39%) for *Leucaena leucocephala* was lower than *Senna siamea*. At 84 days, fine root

Table 2. Summary of P - values of ANOVA results for the effects of species, period of sampling and depth of placement on decomposition (weight loss) of fine roots.

Source of variation	Degrees of freedom	P - values of anova
Species	2	0.001***
Depth of placement	1	0.265^{ns}
Days after treatent	6	0.001***
Species x Depth	2	0.026*
Species x Days	12	0.001***
Depth x Days	2	0.051^{ns}
Species x Depth x Days	12	0.150$_{ns}$

^{ns} is not significant. *, *** is significant at 0.05 and 0.001 probability levels respectively.

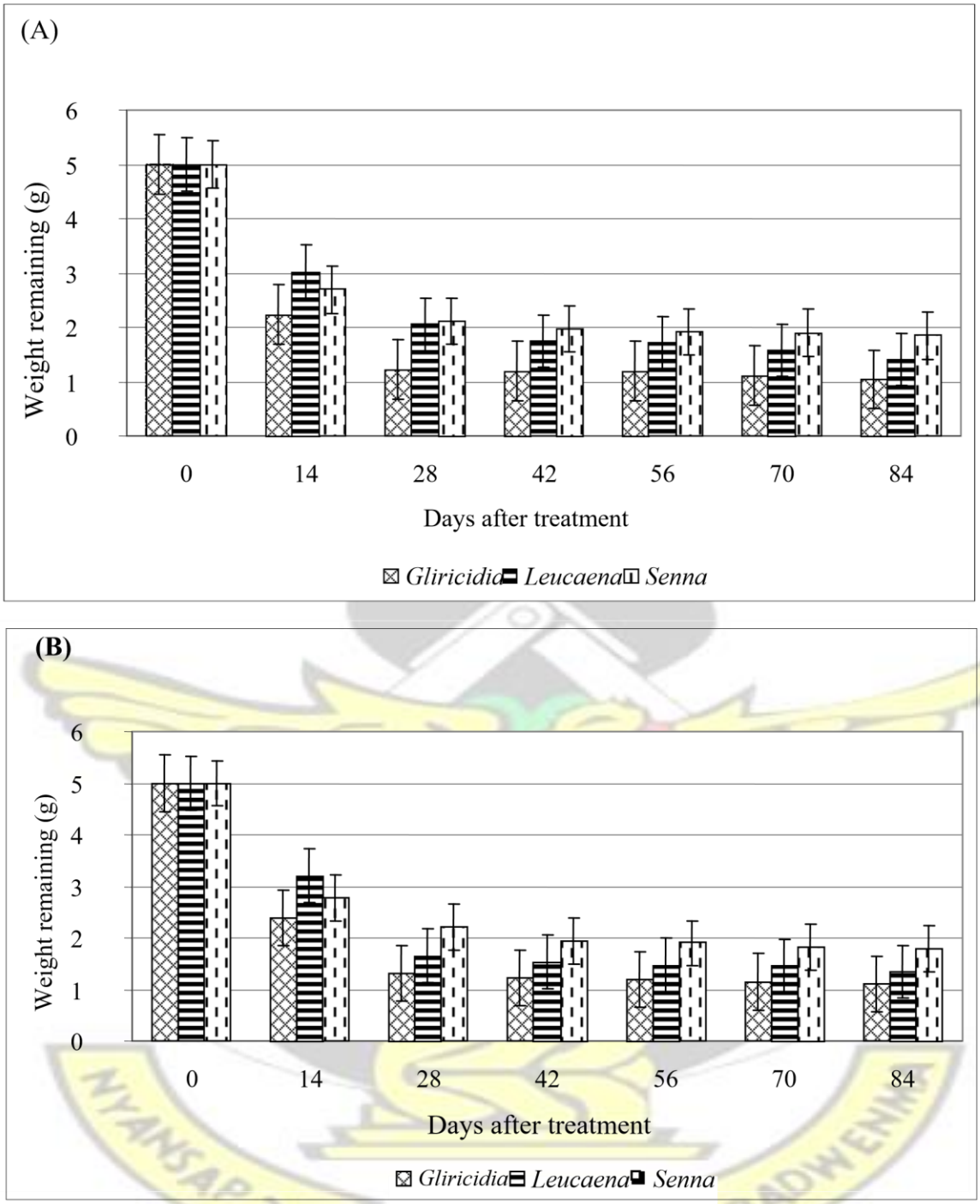

Figure 2. Comparison of mean dry weight remaining with days after treatment fine roots for *Gliricidia sepium, Leucaena leucocephala and Senna siamea* buried within (A) 15 cm and (B) 30 cm soil depth. Bars indicate standard errors.

weight loss of 3.96g (78%) for *Gliricidia sepium* was significantly higher ($P < 0.05$) than 3.59g (72%) for *Leucaena leucocephala*, whereas 3.15g (63%) for *Senna siamea* was lower than *Leucaena leucocephala* (Figure 1A).

Within 30 cm soil depth at 14 days, fine root weight loss of 2.61g (52%) for *Gliricidia sepium* was significantly higher ($P < 0.05$) than 2.22g (44%) for *Senna siamea* and 1.80g (36%) for *Leucaena leucocephala* was significantly lower ($P < 0.05$) than *Senna siamea*. At 84 days, 3.90g (78%) weight loss for *Gliricidia sepium* was significantly higher ($P < 0.05$) than 3.65g (73%) for *Leucaena leucocephala* whereas 3.21g (64 %) for *Senna siamea* was lower than *Leucaena leucocephala* (Figure 1B).

Within species comparison

Within 15 cm soil depth, fine root weight loss compared to the initial weight for *Gliricidia sepium* was significant ($P < 0.05$) at 14 and 28 days. Thereafter, weight loss did not differ significantly ($P > 0.05$). *Leucaena leucocephala* fine roots weight decreased significantly ($P < 0.05$) from the initial weight at 14, 42 and 70 days. *Senna siamea* fine roots decreased significantly ($P < 0.05$) from the initial weight at 14, 28 and 70 days (Figure 1A).

Within 30 cm soil depth, *Gliricidia sepium* and *Leucaena leucocephala* fine roots weight decreased significantly ($P < 0.05$) from the initial weight at 14 and 28 days. *Senna siamea* fine roots weight decreased significantly ($P < 0.05$) from the initial weight at 14, 28 and 42 days (Figure 1B).

4.3 DECOMPOSITION RATE CONSTANTS (K_d).

Mean decomposition rate constants (K_d) for fine roots of *Gliricidia sepium, Leucaena leucocephala and Senna siamea* buried within 15 cm and 30 cm are compared in Table 3. Within 15 cm soil depth, based on the mean decomposition rate constants (K_d), decomposition of fine roots followed the order *Gliricidia sepium* > *Leucaena leucocephala* = *Senna siamea*. Mean (K_d) of 0.042 for *Gliricidia sepium* was significantly greater ($P < 0.05$) compared to 0.024 and 0.023 for *Leucaena leucocephala* and *Senna siamea*, respectively. Half life (period taken for 50% of fine roots to decompose) were 17 days for *Gliricidia sepium* fine roots; 29 days for *Leucaena leucocephala* and 30 days for *Senna siamea*.

Within 30cm soil depth, decomposition of fine roots followed the pattern *Gliricidia sepium* > *Leucaena leucocephala* = *Senna siamea*. Mean K_d of 0.040 for *Gliricidia sepium* was significantly greater ($P < 0.05$) compared to 0.026 for *Leucaena leucocephala* and 0.023 *Senna siamea*. Half life of fine roots occurred at 17 days for *Gliricidia sepium*; 27 days for *Leucaena leucocephala* and 30 days for *Senna siamea*.

Table 3. Comparison of mean decomposition rate constants (K_d) and half life for *Gliricidia sepium, Leucaena leucocephala and Senna siamea* buried within 15 cm and 30 cm soil depth.

	Depth of placement	
Species	15 cm	30cm
Gliricidia sepium	0.042a (17)	0.040a (17)
Leucaena leucaena	0.024b (29)	0.026b (27)
Senna siamea	0.023b (30)	0.023b (30)
P - Value of K_d	0.010**	0.011**

Within columns, means followed by the same letter are not significant at $\alpha = 0.05$.

Figures in parentheses are half life (in days) of decomposing fine roots.

4.4. MINERALIZATION OF NUTRIENTS

The summary of P-values of analysis of variance results for effects of species, days after treatment, depth of placement on mineralization of nutrients from fine roots of *Gliricidia sepium, Leucaena leucocephala and Senna siamea* are given in Table 4. Mineralization of nutrients differed significantly ($P < 0.05$) amongst species and days after treatment. Also, mineralization of potassium and magnesium were significantly influenced ($P < 0.05$) by the depth of placement. Finally, mineralization of nutrients were significantly influenced ($P < 0.05$) by the species x time interaction, but were not significantly influenced ($P > 0.05$) by species x depth, depth x time as well as species x depth x time interactions. Mineralization of carbon, nitrogen, phosphorus, potassium, calcium and magnesium from decomposing fine roots of *Gliricidia sepium, Leucaena leucocephala and Senna siamea* buried within 15cm and 30cm soil depths with days after treatment are presented below.

Table 4. Summary of P - values of ANOVA results for the effects of species, days after treatment and depth of placement on mineralization of nutrients (C, N, P, K, Ca, and Mg) of fine roots of *Gliricidia sepium, Leucaena leucocephala and Senna siamea*.

		P-Values of ANOVA					
Source of variation	Degrees of freedom	C	N	P	K	Ca	Mg
Species	2	0.022*	0.003**	0.018*	0.009**	0.001***	0.001***
Depth	1	0.841^{ns}	0.482^{ns}	0.455^{ns}	0.037*	0.270^{ns}	0.013*
Days after treatment	6	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
Species x Depth	2	0.640^{ns}	0.163^{ns}	0.060^{ns}	0.405^{ns}	0.408^{ns}	0.169^{ns}
Species x Days	12	0.013*	0.001***	0.001***	0.001***	0.001***	0.001***
Depth x Days	6	0.962^{ns}	0.971^{ns}	0.433^{ns}	0.522^{ns}	0.975^{ns}	0.467^{ns}
Species x Depth x Days	12	0.240^{ns}	0.800^{ns}	0.829^{ns}	0.707^{ns}	0.920^{ns}	0.986^{ns}

[ns] is not significant. *, **, *** is significant at 0.05, 0.01, 0.001 probability level respectively.

4.4.1 Carbon

Among species comparison

Carbon released from fine roots buried within 15cm soil depth at 14 days varied between 1.00% for *Gliricidia sepium* to 3.31% for *Senna siamea* and did not differ significantly among species. At 84 days, 19.25% of carbon released for *Gliricidia sepium* was significantly higher ($P < 0.05$) compared to 3.31% for *Leucaena leucocephala* and 7.48% for *Senna siamea* (Figure 2A). Within 30cm soil depth, at 14 days carbon released from fine roots were 1.01% for *Gliricidia sepium*, 0.69% for *Leucaena leucocephala* and 3.25% for *Senna siamea* (Figure 2B). At 84 days, 13.57% and 10.36% of carbon released from *Gliricidia sepium* and *Leucaena leucocephala* were significantly higher ($P > 0.05$) compared to 4.08% for *Senna siamea* (Figure 2B)

Within species comparison

Within 15 cm soil depth, carbon level in decomposing fine roots decreased significantly ($P < 0.05$) from the initial level at 56 and 84 days for *Gliricidia* sepium; 28 and 70 days for *Leucaena leucocephala* and 42 and 84 days for *Senna siamea* (Figure 2A).Within 30 cm soil depth, level of carbon in decomposing fine roots decreased significantly ($P < 0.05$) from the initial level at 70 and 84 days for *Gliricidia sepium*; 28 and 84 days for *Leucaena leucocephala* and only 14 days for *Senna siamea* (Figure 2B).

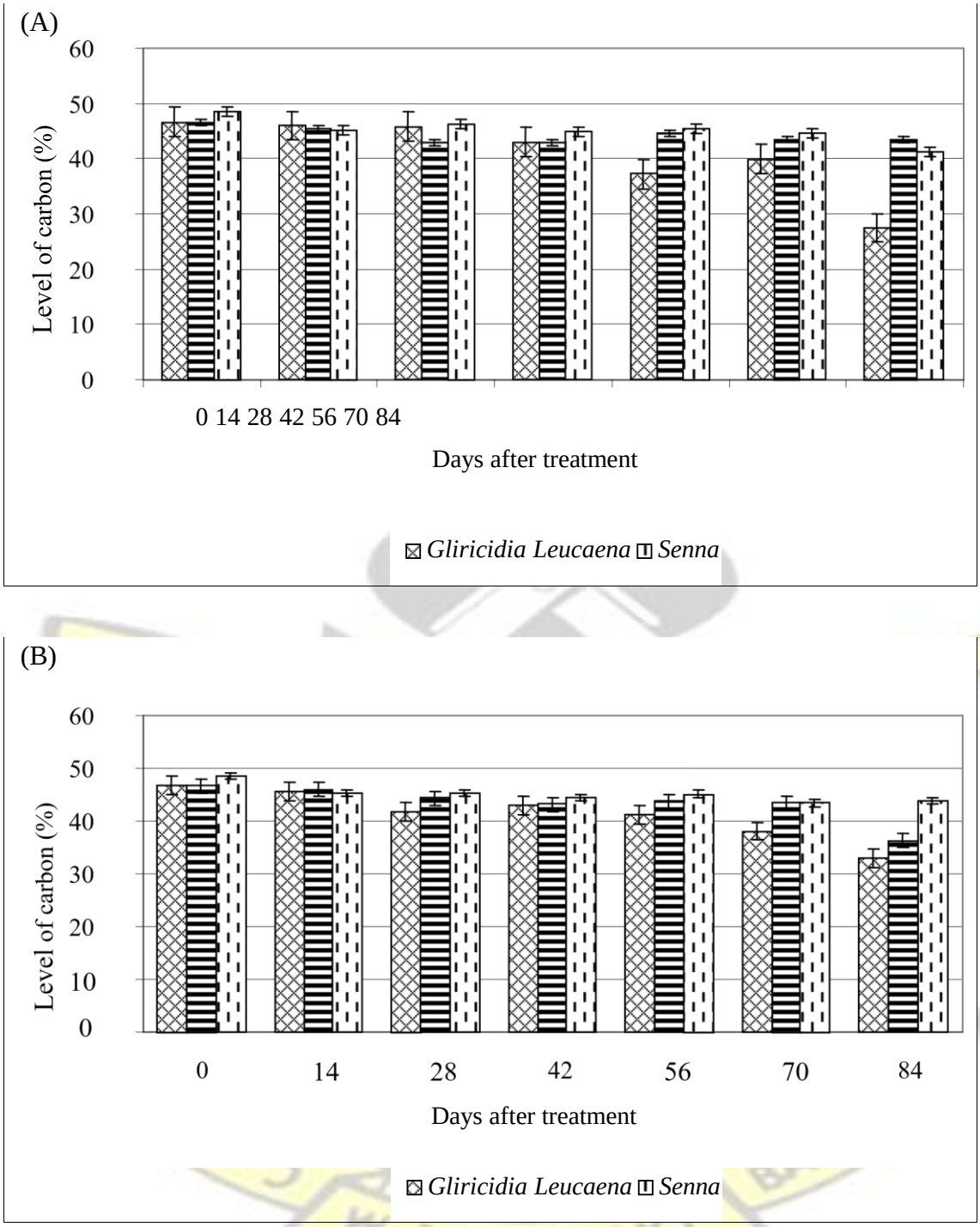

Figure 2. Comparison of carbon levels (%) with days after treatment of fine roots for *Gliricidia sepium, Leucaena leucocephala* and *Senna siamea* buried within (A) 15 cm and (B) 30 cm soil depth. Bars indicate standard errors.

4.4.2 Nitrogen

Among species comparison

Within 15cm soil depth, at 14 days 0.07% of nitrogen released for *Senna siamea* was significantly lower ($P < 0.05$) compared to 0.63% and 0.79% for *Gliricidia sepium* and *Leucaena leucocephala*, respectively. At 84 days, 0.14% of nitrogen released for *Senna siamea* was significantly lower ($P < 0.05$) compared to 0.93% and 1.19% for *Gliricidia sepium* and *Leucaena leucocephala*, respectively (Figure 3A). Within 30cm soil depth at 14 days, 0.06% of nitrogen released for *Senna siamea* was significantly lower ($P < 0.05$) than 0.70% for *Gliricidia sepium* and 0.85% for *Leucaena leucocephala*. At 84 days, 0.19% of nitrogen released for *Senna siamea* fine roots was significantly lower ($P < 0.05$) lower compared to 1.00% and 1.14% for *Gliricidia sepium* and *Leucaena leucocephala, respectively* (Figure 3B).

Within species comparison

Within 15 cm soil depth, nitrogen released from decomposing fine roots compared to the initial level was significant ($P < 0.05$) only at 14 days for *Gliricidia sepium*; 84 days *Senna siamea* and 14 and 56 days for *Leucaena leucocephala* (Figure 3A).Within 30 cm soil depth, nitrogen released from decomposing fine roots compared to the initial level were significant ($P < 0.05$) at 14 and 56 days for *Gliricidia sepium*; 14 days for Leucaena *leucocephala* and 56 days for *Senna siamea* (Figure 3B).

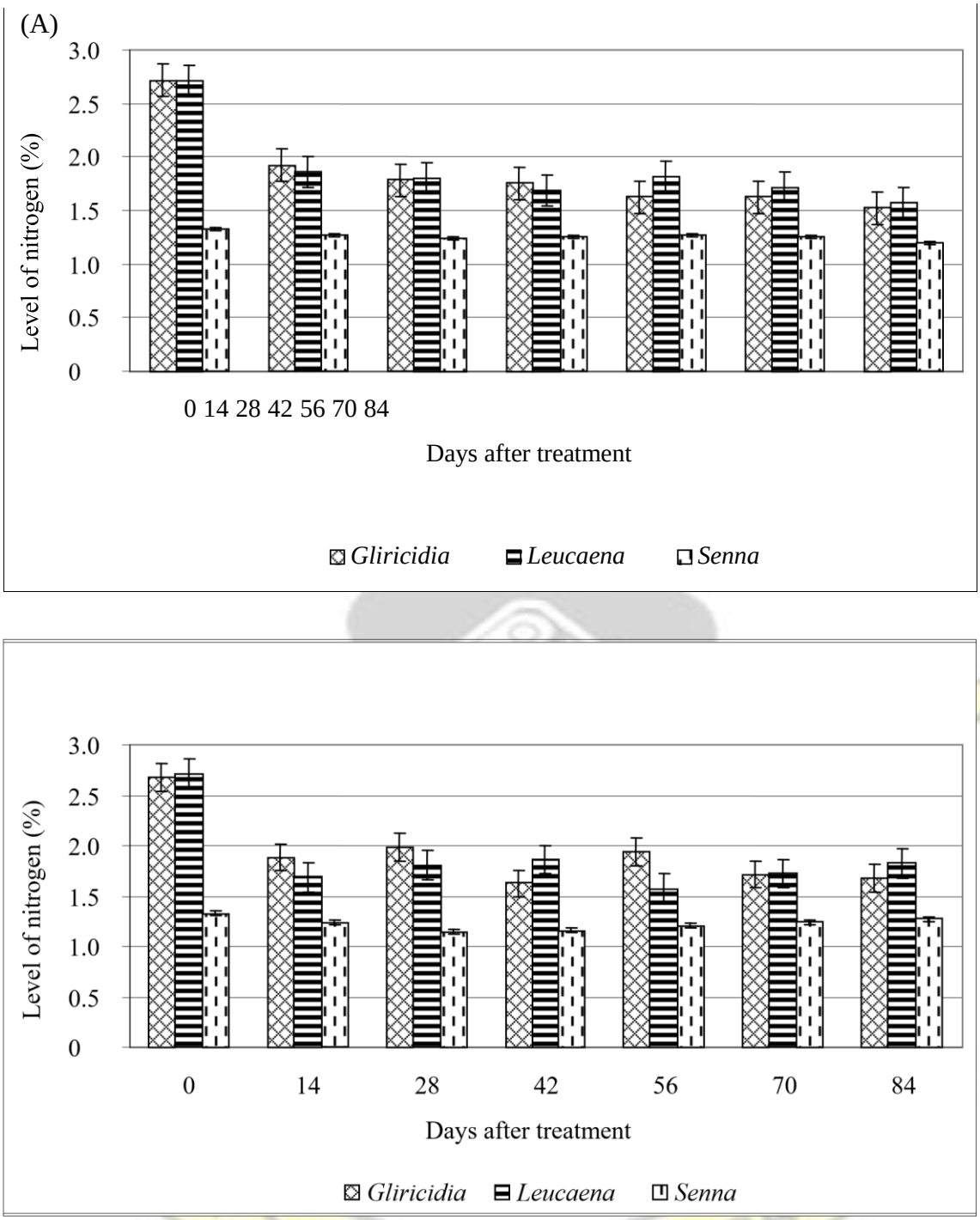

Figure 3. Comparison of nitrogen levels (%) with days after treatment of fine roots for *Gliricidia sepium*, *Leucaena leucocephala* and *Senna siamea* buried within (A) 15 cm and (B) 30 cm soil depth. Bars indicate standard errors.

4.4.3. Phosphorus

Among species comparison

Within 15cm soil depth, at 14 days, there were no significant differences ($P > 0.05$) amongst species in the level of phosphorus released which varied between 0.06% for *Gliricidia sepium* and 0.08% for *Senna siamea*. At 84 days, 0.09% of phosphorus released from *Senna siamea* was significantly lower ($P < 0.05$) compared to 0.12% and 0.11% for *Gliricidia sepium* and *Leucaena leucocephala*, respectively (Figure 4A). Within 30cm soil depth, at 14 days phosphorus released varied between 0.06% for *Gliricidia sepium* and 0.08% for *Senna siamea* and did not differ significantly ($P < 0.05$) among species (Figure 4A). At 84 days, 0.09% of phosphorus released for *Leucaena leucocephala* was significantly lower ($P < 0.05$) compared to 0.12% and 0.11% for *Gliricidia sepium* and *Senna siamea*, respectively (Figure 4B).

Within species comparison

Within 15 cm soil depth, phosphorus released compared to the initial level was significant ($P < 0.05$) at 14, 42 and 84 days for *Gliricidia sepium*; 14 and 70 days for Leucaena *leucocephala* and only at 14 days for *Senna siamea* (Figure 4A). Within 30 cm, level of phosphorus released was significantly ($P < 0.05$) lower from the initial level at 14, 42 and 84 days for *Gliricidia sepium*; 14 and 84 days for *Leucaena leucocephala* and 14 and 70 days for *Senna siamea* (Figure 4B).

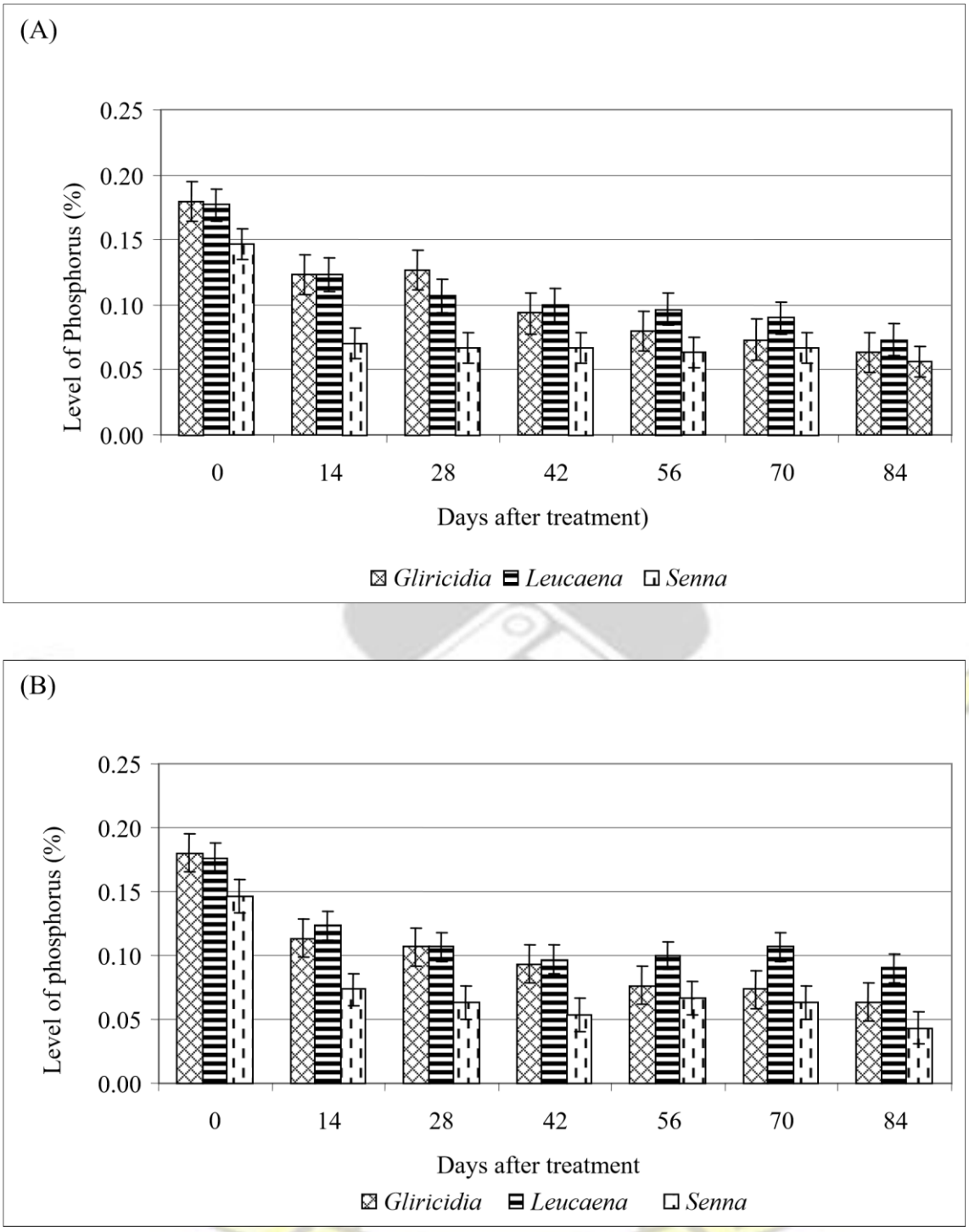

Figure 4. Comparison of phosphorus levels (%) with days after treatment of fine roots for *Gliricidia sepium*, *Leucaena leucocephala* and *Senna siamea* buried within (A) 15 cm and (B) 30 cm soil depth. Bars indicate standard errors.

4.4.4. Potassium

Among species comparison

Potassium released by *Senna siamea* was significantly higher ($P < 0.05$) than that for *Gliricidia sepium* while *Gliricidia sepium* was higher than *Leucaena leucocephala* at both 15cm and 30cm soil depths at all sampling periods (Figures 5A and B).

Within species comparison

Within 15 cm soil depth, level of potassium in decomposing fine roots compared to the initial level decreased significantly ($P < 0.05$) at 14 and 56 days for both *Gliricidia sepium* and *Leucaena leucocephala* and at 14 and 84 days for *Senna siamea* (Figure 5A). Within the 30 cm soil depth, level of potassium in decomposing fine roots decreased significantly ($P < 0.05$) from the initial level at 14, 42 and 84 days for *Gliricidia sepium*; 14, 28 and 84 days for *Leucaena leucocephala* and 14 and 28 days for *Senna siamea* (Figure 5B).

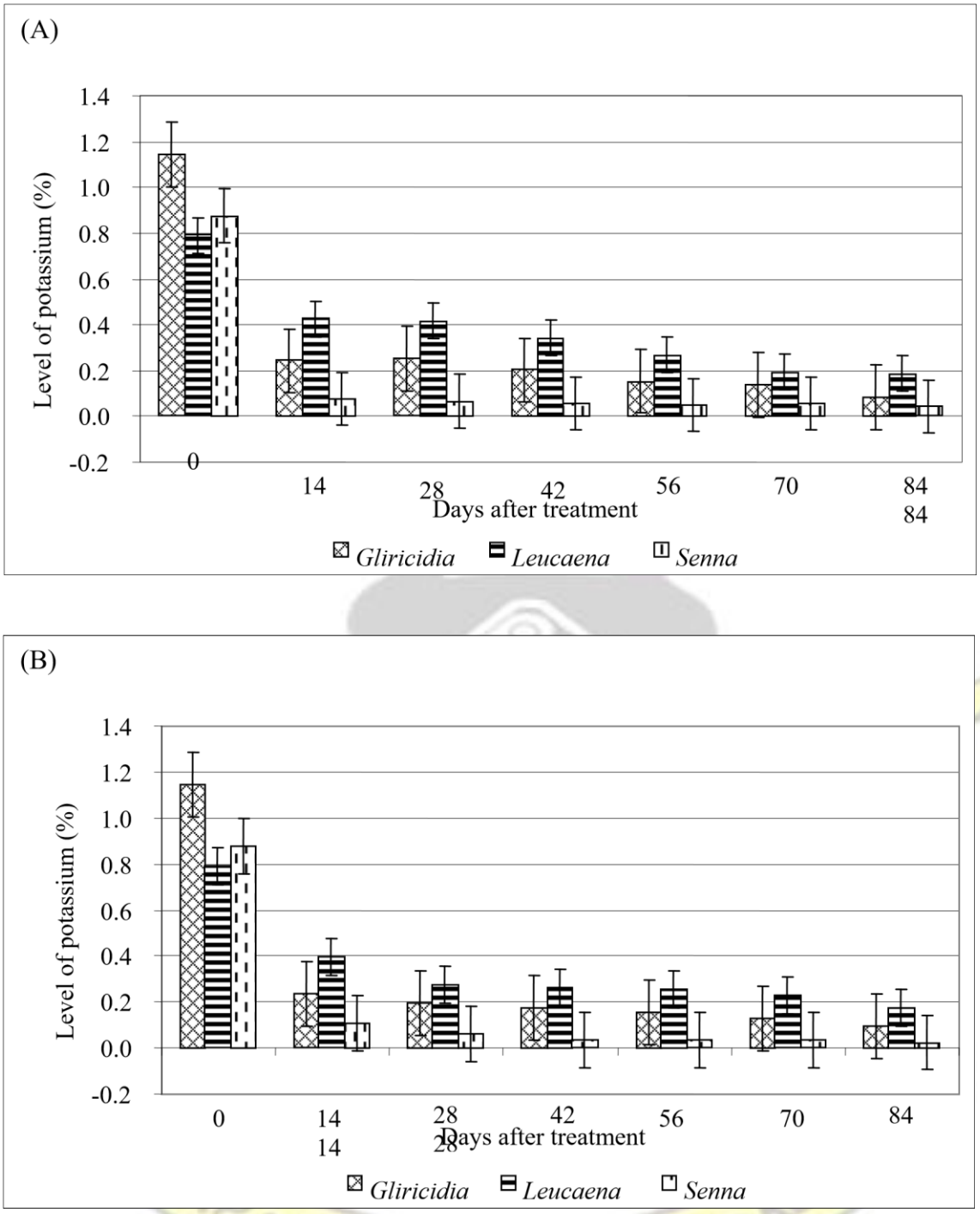

Figure 5. Comparison of potassium levels (%) with days after treatment of fine roots for *Gliricidia sepium*, *Leucaena leucocephala* and *Senna siamea* buried within (A) 15 cm and (B) 30 cm soil depth. Bars indicate standard errors.

4.4.5. Calcium

Among species comparison

Within 15 cm soil depth, calcium released in decomposing fine roots at 14 days differed significantly ($P < 0.05$) amongst species ranging from 0.12% for *Gliricidia sepium* to 0.67% for *Senna siamea*. At 84 days, calcium released for *Senna siamea* was significantly lower ($P < 0.05$) compared to *Gliricidia sepium* and *Leucaena leucocephala* (Figure 6A). Within 30m soil depth, at 14 days calcium released in decomposing fine roots differed significantly ($P < 0.05$) amongst species ranging from 0.16% for *Gliricidia sepium* to 0.65% for *Senna siamea*. Similarly, at 84 days, calcium released by *Senna siamea* was significantly lower ($P < 0.05$) compared to *Gliricidia sepium* and *Leucaena leucocephala* (Figure 6B).

Within species comparison

Within 15 cm soil depth, level of calcium in decomposing fine roots compared to the initial level decreased significantly ($P < 0.05$) at 14 and 42 days for *Gliricidia sepium*; 14, 28 and 70 days for *Leucaena leucocephala* and 14, 42 and 70 days for *Senna siamea* (Figure 6A). Within 30 cm soil depth, calcium level in decomposing fine roots of compared to the initial level decreased significantly ($P < 0.05$) at 14 and 42 days in *Gliricidia sepium*; 14, 42 and 84 days for *Leucaena leucocephala* and 14 and 42 days for *Senna siamea* (Figure 6B).

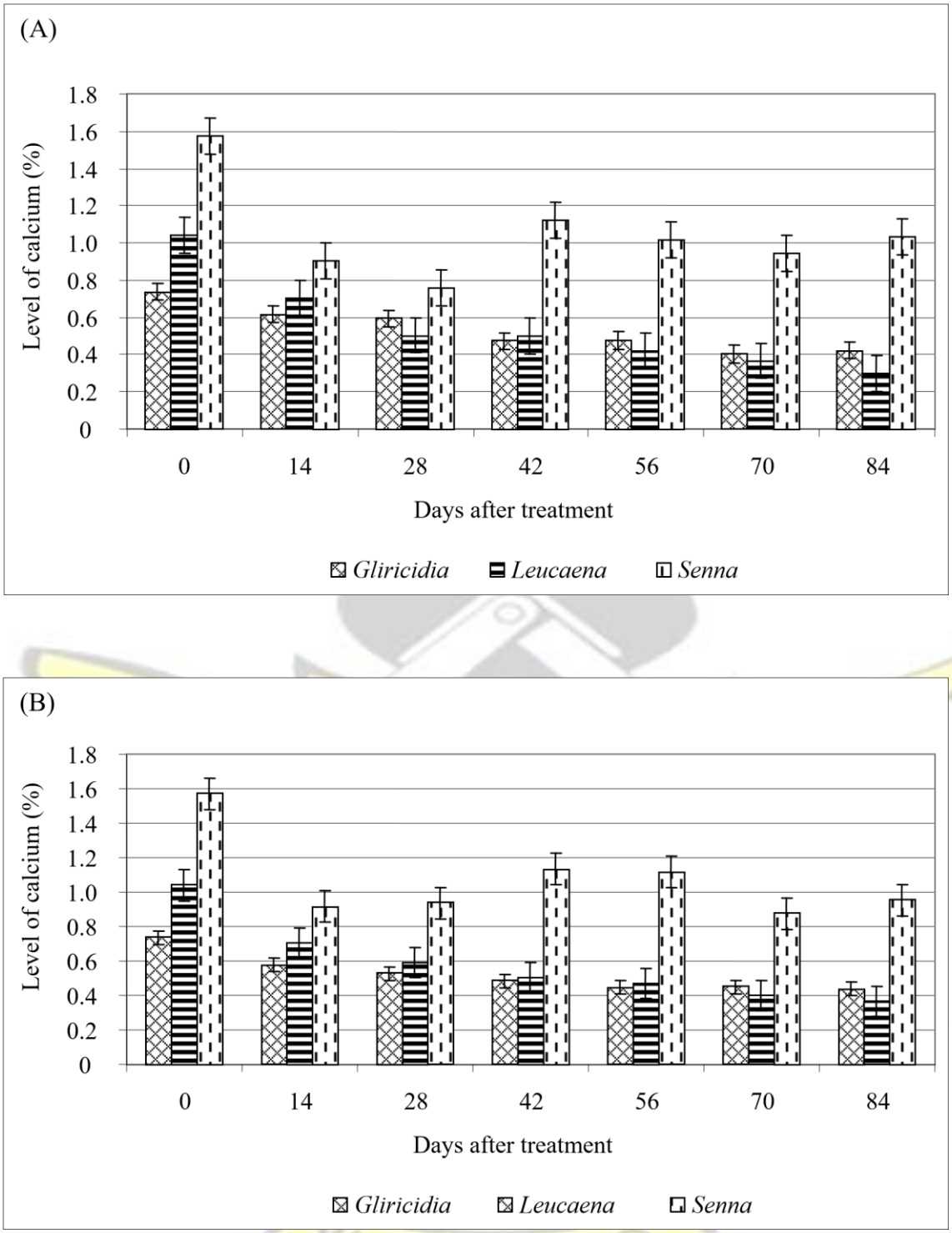

Figure 6. Comparison of calcium levels (%) with days after treatment of fine roots for *Gliricidia sepium*, *Leucaena leucocephala* and *Senna siamea* buried within (A) 15 cm and (B) 30 cm soil depth. Bars indicate standard errors.

4.4.6. Magnesium

Among species comparison

Within the 15 cm soil depth at 14 days, 0.09% of the magnesium in decomposing fine roots of *Gliricidia sepium* was released. This was significantly higher ($P < 0.05$) than that released from *Leucaena leucocephala* (0.02%). 0.01% magnesium released from *Senna siamea* was significantly lower ($P < 0.05$) than that for *Leucaena leucocephala*. At 84 days, 0.12% of magnesium released from *Leucaena leucocephala* fine roots was significantly lower ($P < 0.05$) compared to 0.38% in *Gliricidia sepium* and 0.33% in *Senna siamea* (Figure 7A). Within the 30 cm soil depth at 14 days, 0.02% of magnesium released for *Leucaena leucocephala* was significantly lower ($P < 0.05$) compared to 0.06% and 0.04% for *Gliricidia sepium* and *Senna siamea* respectively. At 84 days, magnesium released for *Leucaena leucocephala* was significantly lower ($P <0.05$) compared to that of *Gliricidia sepium* and *Senna siamea* (Figure 7B).

Within species comparison

Within the 15 cm soil depth, level of magnesium in fine roots compared to the initial decreased significantly ($P < 0.05$) at 14, 28, 42 and 56 days for *Gliricidia sepium*; 28 and 56 days for *Leucaena leucocephala* and 42 and 70 day for *Senna siamea* (Figure 7A). Within the 30 cm soil depth, level of magnesium in decomposing fine roots decreased significantly ($P < 0.05$) from the initial level at 56 and 70 days for *Gliricidia sepium*; 56 and 84 days for *Leucaena leucocephala* and 14, 28 and 42 days for *Senna siamea* (Figure 7B).

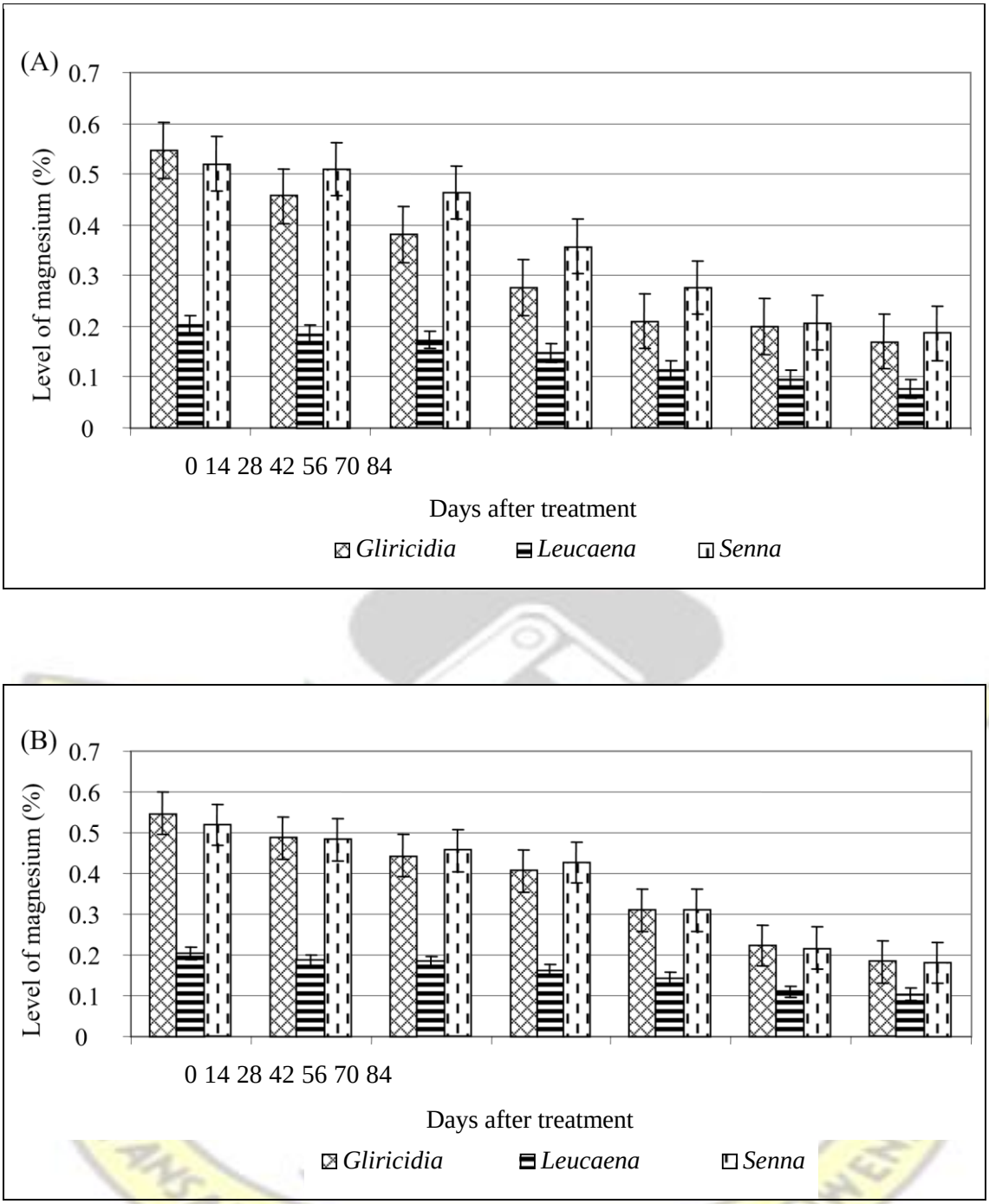

Figure 7. Comparison of magnesium levels (%) with days after treatment of fine roots for *Gliricidia sepium*, *Leucaena leucocephala* and *Senna siamea* buried within (A) 15 cm and (B) 30 cm soil depth. Bars indicate standard errors.

4.5. MINERALIZATION RATE CONSTANTS (K_n).

The summary of P-values from the analysis of variance for effects of species, period of sampling and depth of placement on mineralization rate constants (K_n) of nutrients (carbon, nitrogen, phosphorus, potassium, calcium and magnesium) for fine root of *Gliricidia sepium, Leucaena leucocephala and Senna siamea* is presented in Table 5. Mineralization rate constants (K_n) of nutrients differed significantly ($P < 0.05$) amongst species and period of sampling whereas depth of placement only influenced ($P < 0.05$) the mineralization of magnesium. Also, mineralization rate constants were significantly influenced ($P < 0.05$) by the species x Days after treatment interaction except magnesium. Again, mineralization rate constants of decomposing fine roots was not significantly influenced ($P > 0.05$) by species x depth, depth x Days as well as species x depth x Days interactions.

4.5.1. Mineralization pattern

Mean mineralization rate constants (K_n) of nutrients for decomposing fine roots of *Gliricidia sepium, Leucaena leucocephala and Senna siamea* buried within 15 cm and 30 cm are presented in Tables 6a and 6b, respectively.

Among species comparison

Within 15cm soil depth, based on mean mineralization rate constants (K_n), the order of release of nutrients in fine roots for Nitrogen; *Leucaena leucocephala = Gliricidia sepium > Senna siamea*. Potassium; *Senna siamea > Gliricidia sepium > Leucaena leucocephala*.

Calcium; *Leucaena leucocephala = Gliricidia sepium > Senna siamea*. Magnesium; *Gliricidia sepium > Leucaena leucocephala = Senna siamea*. There were no differences among species for carbon and phosphorus (Table 6a).

Table 5. Summary of P-values of ANOVA results for the effects of species, period of sampling and depth of placement on mineralization rate constants (K_n) of nutrient (C, N, P, K, Ca, Mg) of fine roots

				P-Values			
Source of variation	Degrees of freedom	C	N	P	K	Ca	Mg
Species	2	0.003**	0.001***	0.028*	0.001***	0.039*	0.004*
Depth	1	0.699^{ns}	0.278^{ns}	0.867^{ns}	0.575^{ns}	0.547^{ns}	0.020*
Days after treatment	5	0.002**	0.001***	0.001***	0.001***	0.015*	0.026*
Species x Depth	2	0.972^{ns}	0.274^{ns}	0.203^{ns}	0.661^{ns}	0.123^{ns}	0.094^{ns}
Species x Days	10	0.010*	0.001***	0.001***	0.001***	0.001***	0.672^{ns}
Depth x Days	5	0.849^{ns}	0.957^{ns}	0.948^{ns}	0.618^{ns}	0.694^{ns}	0.285^{ns}
Species x Depth x Days	10	0.289^{ns}	0.926^{ns}	0.886^{ns}	0.277^{ns}	0.677^{ns}	0.996^{ns}

^{ns} is not significant. *, **, *** is significant at 0.05, 0.01 and 0.001 probability levels respectively.

Table 6a. Comparison of mean mineralization rate constants (K_n) and half life (days) of nutrients for decomposing fine roots of *Gliricidia sepium, Leucaena leucocephala and Senna siamea* buried within 15 cm

Nutrient element	*Gliricidia sepium*	*Leucaena leucocephala*	*Senna siamea*	P- Vavlues
Carbon	0.003a (231)	0.002a (347)	0.002a (347)	0.186^{ns}
Nitrogen	0.010a (69)	0.012a (58)	0.002b (347)	0.001***
Phosphorus	0.016a (43)	0.016a (43)	0.023a (30)	0.105^{ns}
Potassium	0.052b (14)	0.024c (29)	0.080a (9)	0.001***
Calcium	0.009b (77)	0.019a (36)	0.016a (43)	0.005**
Magnesium	0.015a (46)	0.009b (77)	0.009 (77)	0.002*

Species

Table 6b. Comparison of mean mineralization rate constants (K_n) and half life (days) of nutrients for decomposing fine roots of *Gliricidia sepium, Leucaena leucocephala and Senna siamea* buried within 30 cm

Nutrient element	*Gliricidia sepium*	*Leucaena leucocephala*	*Senna siamea*	P- Vavlues
Carbon	0.003a (231)	0.002a (347)	0.002a (347)	0.090^{ns}
Nitrogen	0.010a (69)	0.012a (58)	0.002b (347)	0.001***
Phosphorus	0.017ab (41)	0.014b (50)	0.023a (30)	0.025*
Potassium	0.053b (13)	0.028c (25)	0.078a (9)	0.001***
Calcium	0.011a (63)	0.018a (39)	0.014a (50)	0.061ns
Magnesium	0.010a (69)	0.006a (116)	0.008a (87)	0.208ns

Species

Within rows, means followed by different letters are significant at $\alpha = 0.05$. Figures in parentheses are half life (days) of nutrients mineralized from fine roots.
Within the 30cm soil depth the order of release in fine roots followed the order, Nitrogen;

Leucaena leucocephala = *Gliricidia sepium* > *Senna siamea*. Phosphorus; *Senna siamea* ≥ *Gliricidia sepium* = *Leucaena leucocephala*. Potassium; *Senna siamea* > *Gliricidia sepium* > *Leucaena leucocephala*. There were no differences among species for carbon, calcium and magnesium (Table 6b).

4.5.2. Half life for nutrient mineralization

Among species comparison

Within the 15 cm soil depth, days taken for 50% (half life) of nutrient to be mineralized in *Gliricidia sepium* ranged from 14 days for potassium to 231 days carbon. Within *Leucaena leucocephala* half life ranged from 29 days for potassium to 347 days for carbon. Half life mineralization within *Senna siamea* varied between 9 days for potassium and 347 days for carbon (Table 6a).

Within 30 cm soil depth, half life mineralization of nutrients in *Gliricidia sepium* varied between 13 days for potassium to 231 days for carbon. Within *Leucaena leucocephala* half life ranged from 25 days for potassium to 347 days for carbon. Within *Senna siamea* half life varied between 9 days for potassium to 347 days for carbon (Table 6b).

Within species comparison

Based on the mean K_n values and half life (days), mineralization of nutrients in decomposing fine roots buried within 15 cm soil depth followed the order; K > P > Mg > N > Ca > C for *Gliricidia sepium*, K > Ca > P > N > Mg > C for *Leucaena leucocephala* and K > P > Ca > Mg > C = N for *Senna siamea*.Within 30 cm of soil depth, nutrient mineralization pattern in decomposing fine roots followed the order; K > P > Ca > Mg = N > C for *Gliricidia sepium*, K > Ca > P > N > Mg > C for *Leucaena leucocephala*, K > P >Ca > Mg > N = C for *Senna siamea*.

CHAPTER FIVE

DISCUSSION

5.1 Variation in fine roots chemical characteristics.

The chemical characteristics of fine roots differed significantly ($P < 0.05$) among species. Fine roots of *Gliricidia sepium* and *Leucaena leucocephala* had significantly higher initial levels of nitrogen and phosphorus, than those of *Senna siamea*. Generally, *Gliricidia sepium* had significantly higher ($P < 0.05$) initial levels of nutrients amongst the species, apart from carbon and calcium, which were significantly higher ($P < 0.05$) in *Senna siamea*. *Leucaena leucocephala* had significantly lower ($P < 0.05$) initial level of magnesium (Table 1).

Initial Lignin level in fine roots was significantly higher ($P < 0.05$) in *Leucaena leucocephala* compared to *Gliricidia sepium* and *Senna siamea*. The initial levels of nitrogen significantly influenced the level L/N and C/N ratios of fine roots. When litter nitrogen is low the lignin/nitrogen (L/N) and carbon/nitrogen (C/N) ratios are generally high and when litter nitrogen is high, L/N and C/N ratios are low (Young, 1989).

Fine roots of *Gliricidia sepium* and *Leucaena leucocephala*, had significantly higher initial levels of nitrogen of 2.68% and 2.72%, respectively and recorded significantly lower ($P < 0.05$) initial L/N ratio of 7.63 for *Gliricidia sepium* and 8.55 for *Leucaena leucocephala* compared to 13.52 for *Senna siamea* fine roots, even though, *Senna siamea* had significantly lower ($P < 0.05$) level of lignin, 17.98% compared to 20.45% and 23.25% for *Gliricidia sepium* and

Leucaena leucocephala respectively. The probable explanation for higher L/N ratio for *Senna siamea* fine roots could be the lower level of nitrogen (1.33%) for *Senna siamea* compared to 2.68% and 2.72% for *Gliricidia sepium* and *Leucaena leucocephala* fine roots, respectively. Similarly, the C/N ratio for *Senna siamea* fine roots was significantly higher ($P < 0.05$) due to the lower level of nitrogen (Table 1).

Litter quality is often characterized on the basis of its carbon, nitrogen, phosphorus, lignin, polyphenol and their ratios. (Kaizzi and Wortmann, 2001). The relative levels of chemical nutrients in decomposing plant litter are used to describe it as high or low quality plant litter. High quality plant litter has high level of nitrogen and low levels of lignin, carbon, lignin/nitrogen and carbon/nitrogen ratios. High quality plant litter is a high quality resource to microbes and decomposes and releases nutrients rapidly. On the other hand, low quality plant litter has low level of nitrogen and high levels of lignin, carbon, lignin/nitrogen (L/N) and carbon/nitrogen (C/N) ratios. Low quality plant litter makes poor substrate to decomposers and decomposes and releases nutrients slowly (Young, 1989).

5.2 Pattern of weight loss and decomposition rate.

Fine roots weight loss differed significantly among species, period of sampling, species x period of sampling and species x depth interactions (Table 2). Generally, decomposition of fine roots was fastest within 28 days and stabilized thereafter within both 15cm and 30cm soil depths (Figures 1A and1B).This could be attributed to decomposition of more soluble compounds in the early stages of decomposition leaving the more recalcitrant compounds, which decompose slowly (Johnson et al., 2007).

The decomposition pattern of fine roots incorporated within 15cm and 30cm soil depths followed the order *Gliricidia sepium* > *Leucaena leucocephala* > *Senna siamea* (Figures 1A and 1B). Decomposition rate of plant material is controlled by litter quality (Sraha and Ulzen –Appiah 1997; Silver and Miya, 2001), climate (Aerts, 1997), decomposer community (Lavelle et al., 1992) and placement (Beare, 1997). The quality of plant litter is known to control decomposition in the tropics more than climate, which does not change so much within a year (Meentemyer, 1978). The difference in decomposition pattern of fine roots of *Gliricidia sepium, Leucaena leucocephala, Senna siamea* could be attributed to the initial chemical characteristics, nitrogen, lignin, C/N and L/N ratios, of the fine roots, which differed significantly ($P < 0.05$) among the species (Table 1).

Many authors have reported that litter of different quality decomposes at different rate. The initial nitrogen concentration, lignin concentration, lignin/nitrogen and C/N ratios have been shown to be the most reliable predictors of decomposition (Mellilo et al., 1989; Silver and Miya, 2001). The initial level of nitrogen, lignin and lignin/nitrogen ratios probably influenced the decomposition of fine roots of *Gliricidia sepium, Leucaena leucocephala, Senna siamea*.

Senna siamea fine roots had the lowest initial nitrogen of 1.33% and highest lignin/nitrogen ratio of 13.53 compared to 2.68% and 2.72% of nitrogen and 7.63 and 8.58 L/N ratio respectively for *Gliricidia sepium* and *Leucaena leucocephala* and thus decomposed slowest amongst the species within both 15cm and 30cm soil depths. At 84 days, 63% and 64% of fine root weight lost for *Senna siamea* within 15cm and 30cm soil depths, respectively were significantly lower ($P < 0.05$) compared to *Gliricidia sepium* and *Leucaena leucocephala*. This

could be attributed to the significantly higher ($P < 0.05$) initial level of higher lignin/nitrogen ratio in *Senna siamea* compared to *Gliricidia sepium* and *Leucaena leucocephala*. *Gliricidia sepium* with the lowest L/N ratio decomposed fastest, whereas *Leucaena leucocephala* with intermediate L/N ratio decomposed moderately.

Gliricidia sepium fine roots had a significantly lower lignin/nitrogen ratio (7.63) and the highest mean decomposition rate amongst the species with K_d of 0.042 and 0.040, respectively within 15cm and 30cm soil depths compared to significantly higher lignin/nitrogen ratios of 8.58 and 13.53 for *Leucaena leucocephala* and *Senna siamea* with low mean decomposition rates of 0.024 - 0.026 for *Leucaena leucocephala* and 0.023 for *Senna siamea* respectively within 15cm and 30cm soil depths. Again, *Gliricidia sepium* fine roots lost 50% of its dry weight in 17 days compared to 30 days for *Senna siamea* and 29 days and 27 days for *Leucaena leucocephala*, respectively within 15cm and 30cm soil depths (Table 3).

5.3. Mineralization of nutrients

The summary of P-values from the analysis of variance indicate that mineralization of nutrients differed significantly ($P < 0.05$) amongst species and period of sampling and was not influenced by depth of placement except for potassium and magnesium. Within 15 cm soil depth, mineralization of nutrients followed the order; K > P > Mg > N > Ca > C for *Gliricidia sepium*, K > Ca > P > N > Mg > C for *Leucaena leucocephala* and K > P > Ca > Mg > N = C for *Senna siamea*. Within 30 cm soil K > P > Ca > Mg = N > C for *Gliricidia sepium*, K > Ca > P > N > Mg > C for *Leucaena leucocephala*, K > P >Ca > Mg > N = C for *Senna siamea*

within 30cm soil depth. Mineralization pattern of carbon, nitrogen, phosphorus, potassium, calcium and magnesium of fine roots *Gliricidia sepium*, *Leucaena leucocephala* and *Senna siamea* buried within 15cm and 30cm soil depths are presented below.

5.3.1. Carbon

Carbon mineralization among species within 15cm and 30cm was the slowest compared to the other nutrients. Carbon mineralization depends on its substrate quality to microbes and is attacked preferentially by microbes (Aber and Melillo, 1991). Carbon released from *Gliricidia sepium* fine roots was significantly ($P < 0.05$) higher at 70 and 84 days compared to *Leucaena leucocephala* and *Senna siamea* (Figure 2A and 2B). This could be due to significantly lower initial L/N ratio (7.63) in *Gliricidia sepium* compared to 8.55 and 13.52 in *Leucaena leucocephala* and *Senna siamea*, respectively (Table 1).

Mean mineralization rate constant K_n followed the order *Gliricidia sepium* = *Leucaena leucocephala* = *Senna siamea* and varied between 0.002 for *Gliricidia sepium* and 0.003 for *Leucaena leucocephala* and *Senna siamea*. (Tables 6a and 6b).The probable explanation for low K_n values compared to other nutrients could be that fine roots have more recalcitrant carbon fractions which decompose very slowly (Aber and Melillo, 1991).

5.3.2. Nitrogen

Nitrogen released from fine roots was significantly lower ($P < 0.05$) for *Senna siamea* and than for *Gliricidia sepium* and *Leucaena leucocephala* within both 15cm and 30cm soil depths

(Figures 3A and 3B). Nitrogen mineralization pattern followed the order *Leucaena leucocephala = Gliricidia sepium < Senna siamea*.

The initial chemical composition of fine roots influenced the release of nitrogen. Species with high initial level of nitrogen and low C/N and L/N ratios decompose and release nitrogen at a faster rate than species with low initial level of nitrogen and high C/N and L/N ratios (Young, 1989; Sraha and Ulzen –Appiah, 1997). *Senna siamea* fine roots, which had the lowest initial level of nitrogen (1.33%), higher C/N (36.62) and L/N (13.53) ratios released nitrogen at a slower rate within both 15cm and 30 cm soil depths compared to *Gliricidia sepium* and *Leucaena leucocephala*, which had significantly higher initial nitrogen content of 2.68% and *2.72*% and lower initial L/N ratios of 7.63 and 8.58 and C/N ratios of 17.42 and 17.29, respectively.

5.3.3Phosphorus

Phosphorus mineralization pattern of fine roots followed the order *Senna siamea* >*Gliricidia sepium = Leucaena leucocephala* within 15 cm soil depth and *Senna siamea* > *Gliricidia sepium = Leucaena leucocephala* within 30 cm soil depth (Table 6a and 6b). The initial level of phosphorus for *Senna siamea* (0.15%) was significantly lower ($P < 0.05$) than that 0.18% respectively for *Gliricidia sepium* and *Leucaena leucocephala* fine roots (Table 1). *Senna siamea* was thus expected to release phosphorus more slowly than *Gliricidia sepium* and *Leucaena leucocephala* since plant material with high nutrient content release the nutrient at a faster rate than plant material with low nutrient content (Aber and Melillo, 1991).

Phosphorus release was influenced by the initial level of lignin in fine roots (Sraha and Ulzen - Appiah, 1997). The faster mineralization rate for *Senna siamea* could be attributed to significantly lower initial level of lignin in *Senna siamea* (17.98) compared to 20.45 in *Gliricidia sepium* and 23.25 in *Leucaena leucocephala*. *Gliricidia sepium* and *Leucaena leucocephala* had similar initial phosphorus levels. However, phosphorus mineralization rate was significantly higher ($P < 0.05$) for *Gliricidia sepium*, Kn = 0.017 than *Leucaena leucocephala* Kn = 0.014. The slow mineralization rate for *Leucaena leucocephala* than *Gliricidia sepium* could be due to higher initial level of lignin in *Leucaena leucocephala*.

5.3.4. Potassium

Nearly 80% of potassium in *Leucaena leucocephala* to 100% in *Senna siamea* fine roots was mineralized within the period of experiment (Figure5A and 5B). Half life for the release of potassium ranged from only 9 days for *Senna siamea* to 29 days for *Leucaena leucocephala* fine roots. The significantly higher rate of mineralization for potassium compared to the other nutrients could be attributed to the fact that potassium has a faster release rate because of its high mobility in plant cell and it is released from plant litter predominantly through leaching (Jordan, 1985).

Potassium mineralization amongst species followed the order *Senna siamea* >*Gliricidia sepium* > *Leucaena leucocephala* within both 15cm and 30cm soil depths (Tables 6a and 6b). The significantly faster ($P < 0.05$) release of potassium for *Senna siamea* compared to *Gliricidia sepium* and *Leucaena leucocephala* could be that *Senna siamea* fine roots were more susceptible to leaching than *Gliricidia sepium* and *Leucaena leucocephala* fine roots.

5.3.5. Calcium

Calcium released from fine roots was rapid initially within the15cm and 30cm soil depths (Figures 6A and 6B). The initial faster release of calcium could be attributed to commutation and transfer by soil organisms (Zaharah and Bah, 1999). Calcium released was faster initially for *Senna siamea* compared to *Gliricidia sepium* and *Leucaena leucocephala*. The initial faster release for *Senna siamea* could be attributed to the significantly higher ($P < 0.05$) initial level of calcium for *Senna siamea*. This confirms Kaizzi and Wortmann's 2001 observation that the rate of calcium release is related to initial calcium concentration in the plant tissue. Materials with high initial calcium release more calcium than those with low initial concentration of calcium.

After 28 days there was immobilization of calcium for *Senna siamea* and a slower release for *Gliricidia sepium* and *Leucaena leucocephala* (Figures 6A and 6B). This could probably be due to calcium being actively transported by fungi hyphae into the plant litter and accumulation of calcium oxalate in the fungi that colonize the litter. (Cromack et al., 1975).

5.3.6. Magnesium

Magnesium released is positively related to the initial magnesium content of the plant materials (Kaizzi and Wortmann, 2001). The slower release of magnesium at 14 days and at 84 days for *Leucaena leucocephala* fine roots within both 15 cm and 30 cm soil depths (Figures 7A and 7B) could be due to the significantly lower ($P < 0.05$) initial level of magnesium for *Leucaena leucocephala* compared to *Gliricidia sepium* and *Senna siamea* fine roots (Table 1).

Magnesium mineralization of fine roots followed the order *Gliricidia sepium* > *Senna siamea* = *Leucaena leucocephala* within 15 cm soil depth and *Gliricidia sepium* = *Senna siamea* = *Leucaena leucocephala* within 30 cm soil depth. The slower initial release of magnesium for *Senna siamea* fine roots (Figures 7A and 7B) could be attributed to the significantly higher ($P < 0.05$) initial level of C/N and L/N ratios for *Senna siamea* compared to *Gliricidia sepium* and *Leucaena leucocephala* (Table 1). The higher initial C/N and L/N ratios for *Senna siamea* might have delayed decomposition and disintegration of cell membrane resulting in delayed leaching of magnesium for *Senna siamea* at the initial stages (Zahara and Bah, 1999).

Mean K_n of 0.015 and 0.010, obtained for the15cm and 30cm depths, respectively for *Gliricidia sepium* fine roots were significantly higher ($P < 0.05$) compared to 0.009 and 0.006 for *Leucaena leucocephala* and 0.009 and 0.008 for *Senna siamea* (Table 6a and 6b). The significantly lower ($P < 0.05$) K_n for *Leucaena leucocephala* could be attributed to the significantly lower ($P < 0.05$) initial level of magnesium for *Leucaena leucocephala*, whereas the significantly higher ($P < 0.05$) initial level of C/N and L/N ratios for *Senna siamea* could be responsible for the lower K_n for *Senna siamea*.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusions

Root litter is an important nutrient pool in agroforestry system. An understanding of how plant root litter decompose and release nutrients would help to provide an insight into how to complement this with the use of aboveground litter to synchronize with crop demand in agroforestry systems. The hypotheses of this study were that decomposition and nutrient release pattern of *Leucaena leucocephala, Gliricidia sepium* and *Senna siamea* fine roots are influenced by the initial chemical characteristics and depth of placement in the soil.

Based on the results of the study, these conclusions could be drawn. First, the initial chemical characteristics of fine roots differed significantly ($P < 0.05$) among species. Initial nitrogen was significantly lower ($P < 0.05$) for *Senna siamea* fine roots resulting in a significantly higher ($P < 0.05$) L/N and C/N ratios. Initial lignin was significantly higher ($P < 0.05$) for *Leucaena leucocephala* fine roots. However, significantly higher ($P < 0.05$) initial nitrogen for *Leucaena leucocephala* resulted in a lower L/N and C/N ratios compared to *Senna siamea*. *Gliricidia sepium* fine roots had significant higher initial nitrogen and lower L/N and C/N ratios among species and could be described as high quality litter, *Leucaena Leucocephala* of moderate quality litter and *Senna siamea* of low quality litter.

Secondly, the rate of decomposition was fastest for *Gliricidia sepium* fine roots within both 15cm and 30cm soil depths, but quite slow for *Leucaena Leucocephala* and *Senna siamea* fine roots. Mean half life within 15cm and 30cm soil depths were 17 days for *Gliricidia sepium* fine roots, 28 days for *Leucaena Leucocephala* fine roots and 30 days for *Senna siamea* fine roots. The different rates of decomposition were influenced by the initial chemical

characteristics of fine roots. The fastest rate of decomposition for *Gliricidia sepium* fine roots was due to significant higher initial nitrogen and lower L/N and C/N ratios. Higher initial lignin could be the reason for the slow decomposition rate for *Leucaena Leucocephala* fine roots, whereas significant lower nitrogen and higher C/N and L/N ratios could be the probable explanation for the slow decomposition rate for *Senna siamea* fine roots.

Lastly, nutrient mineralizations in fine roots were influenced by their initial nutrient and lignin levels. Species with high nutrient level but low lignin released the nutrient at a faster rate than species with low nutrient level and high lignin. Fifteen centimetres and thirty centimetres depths of placement significantly influenced the release of potassium and magnesium and this could be attributed to leaching, which is the predominant mode for the release of potassium and magnesium.

6.2 Recommendations

It is recommended that in future fine root decomposition studies on the three species should;

1. be conducted *insitu* in order to minimize altering the decomposer dynamics, disturbances to roots, soil and rhizosphere associations prior to root decomposition.

2. combine the study on belowground and aboveground parts of the three species in order to get the timing of their nutrient release to synchronize with crop demand.

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