THE AGRONOMIC QUALITIES OF THE MEXICAN SUNFLOWER (*Tithonia diversifolia*) FOR SOIL FERTILITY IMPROVEMENT IN GHANA: AN EXPLORATORY STUDY

by

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DECLARATION

I hereby declare that except references to other people's publications which have been duly cited, the contents of this research presented as a thesis for the award of the degree of Doctor of Philosophy in Agroforestry, are the findings of my own investigations.

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DEDICATION

I dedicate this thesis to:

The Lord Almighty for being the stronghold of my life and the source of my academic excellence.

My fidus achate Rachel Djam Mawusi.

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"A thankful heart is not only the greatest virtue, but the parent of all the other virtues": Cicero

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GENERAL ABSTRACT

Soil fertility depletion remains a major biophysical constraint to increased food production in Ghana even when improved germplasm has been made available. With the growing concern of the potential of low input agriculture in mitigating soil fertility challenges, exploratory researches are imperative in selecting best quality organic materials that meet this expectation. This study was conducted to assess the suitability of *Tithonia diversifolia* green biomass as a nutrient source for smallholder agriculture in Ghana using both on-station and on-farm trials. The on-station research comprised an evaluation of the decomposition and nutrient release patterns of *T. diversifolia* in comparison with well-known leguminous species of agroforestry importance: *Senna spectabilis*, *Gliricidia sepium*, *Leucaena leucocephala* and *Acacia auriculiformis*. Concurrently, field trials were conducted to appraise the quality of *T. diversifolia* green biomass in relation to its biophysical effects on soil properties and the agronomic characteristics of crops. This was a comparative study with *S. spectabilis*, *G. sepium* and mineral fertilizer on a ferric acrisol. Field trials were also conducted to determine best practices for optimum biomass production of *T. diversifolia* using different pruning regimes and cutting heights as factors. The on-farm research was conducted at Dumasua in the Brong Ahafo Region of Ghana to appraise 200 farmers' preliminary knowledge of *T. diversifolia* and evaluate the effect of *T. diversifolia* green biomass on soil fertility indicators and crop yields. The results of the decomposition study confirmed significantly high N, P, K concentrations in *T. diversifolia* comparable to levels recorded for the four leguminous species. In addition, *T. diversifolia* recorded the highest decomposition and nutrient release rates which differed significantly ($p < 0.05$)

from rates of the four leguminous species. Although decomposition and nutrient release rates of species were related to quality of leaf material, P and Mg concentrations in particular were most influential in decomposition and nutrient release based on significant results. The on-station trials showed significant effect of the green manures (particularly *T. diversifolia*) on soil properties and the biomass and fruit yield of okro (*Abelmoschus esculentus*). These results were comparable and in some cases greater than fertilizer treatments. Total yield response in *T. diversifolia* treatment was 61% and 20% greater than the control and fertilizer treatments respectively. From the pruning experiment, it was evident that height of cutting, pruning frequency and their interaction significantly affected dry matter production of *T. diversifolia*. Dry matter production was highest (7.2 t $ha^{-1}yr^{-1}$) when *T. diversifolia* was pruned bi-monthly at 50 cm height. Results from the sociological survey confirmed farmers' general knowledge on *T. diversifolia* at Dumasua was poor. Although majority of respondents had seen the plant growing, none could give a common name. Only the ornamental importance of *T. diversifolia* was identified. Meanwhile, the on-farm trials revealed a significant synergistic effect of combining *T. diversifolia* and fertilizer on soil nutrient availability and harvest index of maize. The results showed that the application of *Tithonia* either alone or in combination with fertilizer can increase yield by 24% and 54% respectively compared to plots which received no inputs.

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CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Project Background

Subsistence agriculture which is a way of life for many people in Ghana, today engages a wider percentage of the 60% of Ghanaians thought to be indulged in agriculture and its related activities. Although this system of agriculture is practiced on small landholdings, farmers markedly make the best out of it for their livelihoods. For this reason, improving subsistent agriculture has been highlighted in Ghana's Growth and Poverty Reduction Strategy as the mainstream opportunity to alleviate rural poverty and ensure food security. In Ghana, land productivity and food production particularly in subsistence agriculture have depended for several decades probably centuries on a system of shifting cultivation characterized by a long period of fallow followed by a relatively short cropping period. This traditional practice of shifting cultivation and related bush fallow systems have for generations provided resource-poor farmers with an efficient and stable food production system with no purchased inputs (Sanchez and Salinas, 1981). Nair (1984) attributed the effectiveness of this system to the constant cycle and transfer of nutrients from one compartment of the system to another which operates through the physical and biological processes of canopy-wash, litter-fall, root decomposition and plant uptake. Although, traditional shifting cultivation with adequately long fallow period is accepted as a sound soil management system well adapted to the local ecological and social environment (Nair, 1984), Getahun *et al.,* (1982) reported that with the

increased pressure on cropping land, and the concomitant shortening of fallow periods, soil fertility regeneration under this system would be less effective.

Over a long period of time, agricultural research and extension had hoped to halt the decrease in soil fertility by regular application of mineral fertilizer. It was assumed that the nutrients applied not only replaced those extracted through cropping but also increased biomass production to provide the urgently needed organic matter. However, long-term field trials could not verify this hypothesis. With regular application of mineral fertilizer, organic matter content and with it, soil fertility continued to decrease (Kotschi *et al*., 1988). This notwithstanding, it is also becoming increasingly difficult for resource poor farmers who earn less than US$1 per day to meet the fertilizer requirements in many developing countries. Limited accessibility of fertilizers will mean that farmers will continuously cultivate marginal and low productive lands with high probability of crop failure, posing threats to food security. Under these circumstances, the agronomic potential of organic materials such as plant biomass needs to be explored.

1.2 Problem Statement and Rationale

By the middle of the 21st century, world food production will need to be at least twice what it is now if we are to meet both economic demand and human needs as a result of the rising population. Failure to achieve this increase will slow economic growth and add to the presently unacceptable levels of poverty, hunger, diseases and malnutrition (Uphoff, 2002). This is particularly critical in sub-Saharan Africa where populations are rapidly growing but food production is not keeping pace with it, thus leading to millions left hungry and malnourished. In these regions, the quality of the environment is also deteriorating as areas under forests and wetlands or areas

preserved for wildlife conservation are continuously threatened by the expansion of land under agriculture. This is not sustainable. To reduce and reverse this phenomenon, increasing food production will require agriculture practices that increase the productivity of land under production without compromising the integrity of natural resources (van Straaten, 2007).

In the humid and sub-humid tropics of sub-Saharan Africa, soil fertility depletion is invariably identified as the fundamental reason and the major biophysical root cause for declining per capita food availability (from 50 to 130 kg per person over the past 35 years in production) on smallholder farms (Sanchez *et al*., 1997). The emerging cause is attributed to the extensive crop production systems in the region, which contribute to deterioration in soil structure through diminishing soil biomass and organic matter, with consequently reduced water retention capacity and accelerated erosion (Uphoff, 2002). Scientists therefore concur that no matter how effectively other constraints are remedied, per capita food production on smallholder farms will continue to decrease unless soil fertility depletion is effectively addressed (Sanchez and Leakey, 1997). According to Fernandes and Matos (1995), agroforestry practices generally contribute to intensified production that is agro-ecologically sound and maintains soil fertility. This is because plant residues applied on soils via agroforestry soil management practices (such as biomass transfer, alley cropping etc.) play critical roles by contributing to recycling of plant nutrients, improvements in soil temperature, enhancement of soil structure, erosion control, high microbial activity and maintenance of high soil nutrient status (Wu *et al*., 2000; Vanlauwe *et al*., 2001). These notwithstanding, the selection and use of appropriate plant materials to maintain a sufficiently high nutrient supply to meet crop needs remains a

major challenge of nutrient management under agroforestry soil management systems (Kwabiah *et al*., 2001). It is expected that plant species used in these systems accumulate large amounts of nutrients in their biomass, which can be readily released in plant-available forms when the biomass is applied to crop-growing areas.

Previous field trials have confirmed species such as *Leucaena leucocephala, Gliricidia sepium, Tephrosia candida, Cajanus cajan, Flemingia macrophylla* and many other leguminous species as suitable for biomass transfer systems including alley cropping (Kang, 1991). It is however envisaged that the huge competitive uses of some of these recommended species make exploratory and definitive research in agroforestry imperative for identifying and screening rarely used traditional and non-traditional species that have equal attributes of high coppiceability, ease of establishment, high biomass yield, relatively nutrient rich biomass, deep rooting systems and multipurpose functions that can be incorporated into agroforestry technologies. One of such rarely used non-traditional species in Ghana that has recently gained tremendous research interest in the tropics is the wild or Mexican Sunflower, *Tithonia diversifolia*. A member of the asteraceae family, *T. diversifolia* is a succulent and soft shrub that grows to a height of 1 – 3 metres; and bears alternately positioned leaves along most of the stem (ICRAF, 1997). It originates from Mexico and its now wildly distributed in Africa, Asia and South America (Jama *et al*., 2000). Research confirmed *T. diversifolia* green manure as an effective organic amendment for soil fertility improvement and crop yield increment in Kenya (Jama *et al*., 2000), Tanzania (Ikerra *et al*., 2006), Nigeria (Olabode *et al*., 2007), Vietnam (Cong and Merckx, 2005) and many parts of the humid and sub-humid tropics. As a multipurpose species, *T. diversifolia* has been used as fodder (Anette, 1996), poultry

feed (Odunsi *et al*., 1996), fuelwood (Ng'inja *et al*., 1998), compost (Drechsel and Reck, 1998), land demarcation (Ng'inja *et al*., 1998), termite control (Adoyo *et al.*, 1997) and building materials and shelter for poultry (Otuma *et al*., 1998).

In Ghana, *T. diversifolia* is seen growing as a pure stand or among vegetation along roadsides and on smallholder farms. Although the potential of *T. diversifolia* for soil fertility improvement has long been confirmed in certain parts of Africa, it is not so in Ghana. The result of this may stem from limited research on the potential of *T. diversifolia* for agroforestry in Ghana. The promising nature of *T. diversifolia* for agroforestry and its underutilization, owing to limited research reports, makes *T. diversifolia* an interesting plant for research as a contributory factor to the overall scientific and traditional efforts to mitigate soil fertility challenges for enhanced crop productivity and food security in Ghana. It was therefore the overall objective of this research to evaluate the agronomic qualities of *T. diversifolia* for soil fertility improvement in Ghana. Specifically, this research sought to:

i. determine the decomposition and nutrient release patterns of *T. diversifolia*,
ii. evaluate the effect of adding *T. diversifolia* green manure either alone or in combination with mineral fertilizer on soil fertility indicators and crop yields; and
iii. determine best practices for optimum biomass production of *T. diversifolia*.

1.3 Research Hypotheses

This research was based on the hypotheses that:

i. *T. diversifolia* green biomass quality is comparable to commonly used agroforestry species

ii. the application of *T. diversifolia* green manure will improve soil chemical properties and crop yields;

iii. biomass production of *T. diversifolia* will decline with increasing pruning frequency regardless of differences in pruning height;

1.4 Scope of Research

The overall research consisted of on-station and on-farm trials. The on-station research comprised a decomposition study that evaluated the decomposition and nutrient release patterns of *T. diversifolia* in comparison with well-known leguminous species of agroforestry importance: *Senna spectabilis*, *Gliricidia sepium*, *Leucaena leucocephala* and *Acacia auriculiformis*. Concurrently, field trials were conducted to appraise the quality of *T. diversifolia* green biomass in relation to its biophysical effects on soil properties and the agronomic characteristics of crops. This was a comparative study with *S. spectabilis*, *G. sepium* and mineral fertilizer on a ferric acrisol. Furthermore, field trials were conducted to evaluate the influence of different pruning regimes and cutting heights on the vegetative growth and biomass production of *T. diversifolia* using existing niches.

The on-farm research comprised a sociological survey to appraise farmers' preliminary knowledge of *T. diversifolia* using semi-structured questionnaire interviews. Thereafter, field trials were conducted with participation of farmers to evaluate the effect of *T. diversifolia* green biomass on soil fertility indicators and crop yields.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 *Tithonia diversifolia* (Hemsl.) A. Gray

2.1.1 Scientific Classification

The United States Department of Agriculture (2010) classifies *T. diversifolia* under the following taxonomic ranks:

Kingdom: Plantae

Division: Magnoliophyta

Class: Magnoliopsida

Order: Asterales

Family: Asteraceae

Genus: *Tithonia*

Species: *diversifolia*

2.1.2 Physiognomy

Tithonia diversifolia, commonly known as the wild sunflower, is a succulent and soft shrub that grows to a height of 1 – 3 metres; and bears alternately positioned leaves along most of the stem. Each leaf has 3 – 5 lobes with toothed margins, a pointed apex and a long petiole (ICRAF, 1997). The leaves have many hairs on the lower

side, giving them a grey appearance. The leaf veins are parallel. The flowers are similar to the well-known sunflower plant, *Helianthus* but are smaller. The flower disc of *T. diversifolia* is about 3 cm in diameter and has yellow petals, 4 – 6 cm long. The plant flowers and produces seeds throughout the year. Each mature stem may bear several flowers at the top of the branches. The lightweight seeds can easily be dispersed by wind, water and animals (ICRAF, 1997).

2.1.3 Origin and Distribution

Tithonia diversifolia originated from Mexico, and it is now widely distributed throughout the humid and sub-humid tropics in Central and South America, Asia and Africa (Sonke, 1997). *Tithonia diversifolia* was probably introduced into Africa as an ornamental. It has been reported in Kenya (Niang *et al*., 1996), Malawi (Ganunga *et al*., 1998), Nigeria (Ayeni *et al*., 1997), Rwanda (Drechsel and Reck, 1998) and Zimbabwe (Jiri and Waddington, 1998). In addition, it is also known to occur in Cameroon, Uganda and Zambia (Jama *et al*., 2000). In Ghana, *T. diversifolia* has been found at Bechem, Sunyani, Berekum, Dormaa Ahenkro, Kumasi, Wenchi, and some other parts of the forest and transition agroecological zones.

2.1.4 Uses of *T. diversifolia*

The reported uses of *T. diversifolia* include fodder (Anette, 1996; Roothaert and Patterson, 1997), poultry feed (Odunsi *et al*., 1996), fuelwood (Ng'inja *et al*., 1998), compost (Drechsel and Reck, 1998; Ng'inja *et al*., 1998), land demarcation (Ng'inja *et al*., 1998), soil erosion control (Ng'inja *et al*., 1998), building materials and shelter for poultry (Otuma *et al*., 1998). In addition, extracts from *T. diversifolia* plant parts reportedly protect crops from termites (Adoyo *et al*., 1997) and contain chemicals

that inhibit plant growth (Tongma *et al*., 1997) and control insects (Dutta *et al*., 1993). Extracts of *T. diversifolia* also have medicinal value for treatment of hepatitis (Kuo and Chen, 1997) and control of amoebic dysentery (Tona *et al*., 1998). The green manure of *T. diversifolia* is confirmed to be high in essential nutrients and effective for the improvement of soil fertility and crop yields (Palm *et al*., 1997; Gachengo *et al*., 1999; Jama *et al*., 2000; Olabode *et al*., 2007).

2.1.5 Propagation and Biomass Production of *T. diversifolia*

T. diversifolia can be propagated from seeds and cuttings (ICRAF, 1997). Seeds frequently germinate naturally under the *T. diversifolia* canopy, and the seedlings can be dug up and transplanted elsewhere. When established from seeds in the field, germination can be poor if the seeds are sown deep or covered with clayey soil. Covering the seeds with a thin layer of sandy soil and grass mulch can enhance germination (King'ara, 1998).

T. diversifolia is more easily propagated from stem cuttings than from seeds (King'ara, 1998). Stem cuttings of 20- to 40-cm length establish readily, regardless of the angle at which they are inserted into the soil. Cuttings buried horizontally in the soil will sprout, but they are less effective than cuttings inserted either upright or at an angle into soil. The cuttings should be planted into moist soil immediately after collection and not allowed to sun dry. Termites can damage stem cuttings, particularly during dry periods. Under such conditions, it might be necessary to establish *T. diversifolia* with seedlings rather than cuttings (Jama *et al*., 2000). The biomass production of *T. diversifolia* is influenced by establishment methods, frequency of cutting, stand density and site conditions. The reported values for *T.*

diversifolia biomass production are generally higher for planted pure stands than for existing hedges. Comparison of production values among studies, however, is confounded by differences in the plant part measured (total above-ground biomass, green tender stems + green leaves or leaves only), the time period since last cutting, water content (dry or fresh weight basis) and units of expression (surface area or linear length of hedge) (Jama *et al*., 2000). King'ara (1998) reported production of green biomass (green tender stems + green leaves) of 2.0 to 3.9 t dry matter ha^{-1} for eight-month-old pure stands of *T. diversifolia* established from 40-cm-long cuttings by either upright or angled placement in soil at 10 cm by 10 cm spacing. Green biomass was higher for stands established from woody than from soft stem cuttings – 4.2 compared to 2.6 t dry matter ha^{-1} per cutting averaged for three cutting times. Field observations suggest that while woody cuttings can be superior to soft cuttings, woody cuttings are more prone than soft cuttings to damage by termites. Soft cuttings might then be superior to woody cuttings when termite activity is high (King'ara, 1998). The biomass production of *T. diversifolia* can be influenced by soil fertility. For example, *T. diversifolia* established from stem cuttings produced more biomass on soil fertilized with 50 kg P ha^{-1} than on severely P-deficient soil receiving no P application. Phosphorus fertilization increased stem biomass (green + woody material) more than leaf + litter biomass (Jama *et al*., 2000).

2.1.6 *T. diversifolia* Biomass Quality

The concept of 'quality' of plant residues refers to their relative content of nutrients (especially nitrogen), lignin and polyphenols; the C/N ratio and the content of sugars, cellulose and hemicellulose (Young, 1997). The green biomass of *T. diversifolia*, as compared to the green biomass of other shrubs and trees, is relatively high in

nutrients (Jama *et al*., 2000). Average nutrient concentrations of green leaves of *T. diversifolia* collected in East Africa were 3.5% N, 0.37% P and 4.1% K on a dry weight basis (Table 2.1).

Table 2.1 N, P, K concentration of leaves (dry weight basis) of *Tithonia diversifolia* as compared to other shrubs and trees

Species	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	Mean	Range	Mean	Range	Mean	Range
Tithonia diversifolia	3.5	3.1 - 4.0	0.37	0.24 - 0.56	4.1	2.7 - 4.8
Calliandra calothyrsus	3.4	1.1 - 4.5	0.15	0.04 - 0.23	1.1	0.6 - 1.9
Crotalaria grahamiana	3.2	3.0 - 3.6	0.13	0.13 - 0.14	1.3	0.9 - 1.6
Lantana camara	2.8	2.3 - 4.0	0.25	0.18 - 0.30	2.1	1.8 - 2.4
Leucaena leucocephala	3.8	2.8 - 6.1	0.2	0.12 - 0.33	1.9	1.3 - 3.4
Sesbania sesban	3.7	1.4 - 4.8	0.23	0.11 - 0.43	1.7	1.1 - 2.5
Tephrosia vogelii	3.0	2.2 - 3.6	0.19	0.11 - 0.27	1.0	0.5 - 1.3

Source: adapted from Jama *et al*. (2000)

As shown in Table 2.1, the variability associated with these nutrient concentrations can be high. The N concentrations are comparable to those found in N_2-fixing leguminous shrubs and trees, whereas the P and K concentrations are higher than those typically found in shrubs and trees. The averages and corresponding range in concentrations reported in Table 2.1 for *T. diversifolia* are generally within the ranges of 3.2 to 5.5% N, 0.2 to 0.5% P and 2.3 to 5.5% K reported by Nagarajah and

Nizar (1982) for the analysis of 100 samples of *T. diversifolia* leaves plus tender stems in Sri Lanka.

The concentration of nutrients in *T. diversifolia* can conceivably be influenced by plant part, age of *T. diversifolia*, position of the leaf within the plant canopy, soil fertility and provenance (Jama *et al*., 2000). The nutrient concentration tends to be lower in senesced than green leaves. For example, a comparison of senesced and green leaves collected from plants at ten locations in western Kenya revealed a mean N concentration of 1.1% for senesced leaves as compared to 3.2% for green leaves (Jama *et al*., 2000). Nutrient concentrations in litterfall and wood are relatively low compared to fresh leaves of *T. diversifolia*. Nutrient concentrations of only 1.3% N, 0.08% P and 0.5% K, for example, were observed for undercomposed *T. diversifolia* litter on the soil surface under a *T. diversifolia* canopy in western Kenya. Stems (woody + green) harvested eight months after establishment of *T. diversifolia* averaged 0.8% N, 0.07% P and 1.1% K (Jama *et al*., 2000).

In addition, Olabode *et al* (2007) reported comparable N concentration in *T. diversifolia* to that of animal manure (Table 2.2). The study also confirmed significantly highest K composition than all other considered organic matter sources. Furthermore, Gachengo *et al* (1999), found 1.8% Ca and 0.4% Mg in green *T. diversifolia* biomass. From the same study, it was reported that the lignin and polyphenols concentrations of 10% and 2% respectively were below levels that would significantly reduce decomposition rates.

Table 2.2 Comparison of manurial properties of *Tithonia diversifolia* and other organic matter sources

Organic source	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
T. diversifolia	1.76	0.82	3.92	3.00	0.005
Poultry manure	1.78	2.00	1.80	9.70	0.44
Cattle manure	1.06	0.52	0.95	1.06	0.86
Swine manure	1.69	1.32	0.76	3.81	0.54

Source: adapted from Olabode *et al*. (2007)

2.1.7 *T. diversifolia* Green Biomass Effect on Soil and Crops

The biomass of *T. diversifolia* used for soil fertility improvement generally includes both green tender stems and leaves but not the woody stem. A wide range of experiments have shown that *T. diversifolia* can increase crop yields from depleted soils. These evidences are comparable to the effects of mineral fertilizers and other sources of soil nutrients on crop yields and soil fertility. For instance, when the effects of organic residues and inorganic fertilizers were compared on P availability and maize yield on a Nitisol of western Kenya, Nziguheba *et al* (2000) reported that the addition of *T. diversifolia* increased soil resin-extractable P over that of fertilizer amended soil throughout the first crop. In addition, the total maize yields after six seasons were tripled by the application of *T. diversifolia* compared to the control, and were higher than those of *Calliandra*, *Senna*, *Sesbania* and *Lantana* treatments. Furthermore, P recovered in the aboveground biomass and resin P, immediately after

the implementation of the treatments, was higher in *T. diversifolia* treatments than in the inorganic fertilizer treatments. The study inferred that *T. diversifolia* green manure can replace inorganic fertilizers for the enhancement of P availability and maize production (Nziguheba *et al*., 2000).

Similarly, a field experiment on a Kandiudalf in western Kenya on the effect of organic and inorganic sources of phosphorus (P) on soil P fractions and P adsorption, showed that the application of *T. diversifolia* either alone or with triple superphosphate fertilizer increased resin P, bicarbonate P, microbial P, and sodium hydroxide inorganic P (Nziguheba *et al*., 1998). In Vietnam, Cong and Merckx, (2005) reported that green manure additions of *T. diversifolia* caused an immediate and sustained increase in soil pH and an immediate and sustained decrease in extractable Al in two upland soils (cambisol and ferralsol). The study showed that Labile P (resin P + soluble molybdate reactive + unreactive P) was increased more by P added as *T. diversifolia* green manure than when added in inorganic form (KH_2PO_4) on a ferralsol. In both ferralsol and cambisol, the study reported that the concentrations of soluble unreactive P were frequently higher where *T. diversifolia* had been added. Cong and Merckx (2005) therefore concluded that at a large addition rate – and in addition to the well-known effect derived from the extra supply in P, *T. diversifolia* green manure amendment may improve the chemical availability and diffusive supply of P through the following mechanisms: an increase in soil pH increasing the solubility of phosphate sources; a decrease in extractable Al reducing the fixation of added P; increased macro-aggregation and reduced specific surface area and porosity leading to fewer sorption sites for P and hence enhanced diffusion

rates; and increased negative charges and reduced positive charges at the soil surface resulting in a net increase in repulsive force for P.

In Morogoro, Tanzania, a 2-year field experiment conducted on a chromic acrisol showed that the application of *T. diversifolia* green manure enhances P availability and improve maize yields through modification of soil properties associated with P transformation and availability (Ikerra *et al*., 2006). At Ogbomoso in Nigeria, a laboratory and pot experiments carried out in Ladoke Akintola University of Technology, confirmed high nutrient values of *T. diversifolia* compared with those of other forms of organic manure namely: poultry, swine, cattle manure and *Sesbania sesban* (Olabode *et al*., 2007). Further, the study confirmed a significant improvement in the yield of Okra when applied with crushed *T. diversifolia* green biomass. Again, research by Sharrock *et al* (2004) confirmed *T. diversifolia* to have a high degree of mycorrhizal colonization therefore making it an effective accumulator of phosphorus and other nutrients.

2.2 Soil Fertility Management

Soil is a fundamental resource base for agricultural production systems. Besides being the main medium for crop growth, soil functions to sustain crop productivity, maintain environmental quality, and provide for plant, animal, and human health (Mitchell *et al*., 2000). The term soil fertility describes the soil's ability to perform these critical functions. According to Young (1997), soil fertility is the capacity of soil to support plant growth, under the given climatic and other environmental conditions. These climatic and environmental conditions have been broadly classified by Charman (2007a) under three headings: physical, chemical, and biological. Soil fertility is not a static feature. On the contrary, it changes and its

direction (accumulation or depletion) is determined by the interplay between physical, chemical, biological, and anthropogenic processes. This dynamism is also reflected in terminology such as nutrient cycles, budgets, or balances, referring to inputs and outputs in natural ecosystems and managed agroecosystems, to which nutrients are added and from which nutrients are removed (Smaling *et al*.,1997).

According to Hillel (2008), the capacity of a soil to serve as a favourable medium for plant growth depends on several interrelated attributes: the soil must be porous and permeable enough to permit the free entry, retention, and transmission of water and air; it must also contain a supply of nutrients in forms that are available to plants but that do not leach too rapidly; the soil should be deep and loose enough to allow roots to penetrate and proliferate. In addition, the soil must have an optimal range of temperature and pH, and be free of excess salts or toxic factors. The most productive soils are on level or slightly sloping terrain in the mid-latitudes, with an adequate but not excessive supply of water, good drainage and aeration, a sufficient supply of nutrients and effective protection against erosion. However, some plant communities and some crops, most notably rice and sugarcane, can grow well in flooded soils that are poorly aerated (Hillel, 2008). Baldwin (2006) proposed a minimum data set of physical, chemical and biological indicators for screening soil quality (Table 2.3).

Table 2.3 Proposed minimum data set of physical, chemical and biological indicators of screening soil quality

Indicator	Function and Rationale for Measurement a. Relationship to soil condition and function b. Rationale for measurement
	Biological
Microbial biomass C and N	a. Describes microbial catalytic potential and repository for carbon and nitrogen. b. Provides an early warning of management effects on organic matter.
Potentially mineralizable N	a. Describes soil productivity and nitrogen supplying potential. b. Provides an estimate of biomass.
Soil respiration	a. Defines a level of microbial activity. b. Provides an estimate of biomass activity.
	Chemical
Soil organic matter (OM)	a. Defines soil fertility and stability.
pH	a. Defines biological and chemical activity thresholds.
Electrical Conductivity	a. Defines plant and microbial activity thresholds.
Extractable N, P, and K	a. Describes plant-available nutrients and potential for N loss. b. Indicates productivity and environmental quality.
	Physical
Soil texture	a. Indicates how well water and chemicals are retained and transported. b. Provides an estimate of soil erosion and variability.
Soil depth and rooting	a. Indicates productivity potential. b. Evens out landscape and geographic variability.
Infiltration and soil Bulk density (SBD)	a. Describes the potential for leaching, productivity, and erosion. b. SBD needed to adjust soil analyses to volumetric basis.
Water holding capacity	a. Describes water retention, transport, and erosion. b. Available water is used to calculate soil bulk density and organic matter.

(Source: adapted from Baldwin, 2006)

2.2.1 Historical Review of Soil Fertility Management

Traditional farming systems have generally included a fallow period in the cropping sequence to help restore soil fertility. The biblical injunction, for example, required land to be left fallow every seventh year to let the land rejuvenate (Deuteronomy 15). From at least the time of Cato the Censor (234 - 139 B.C.E), the Romans were also aware of the need to boost soil fertility by fallowing, as well as by crop rotation, liming acid soils, and adding manure. In medieval Europe, between one-third and one-half of the arable land was left fallow (Hillel, 2008).

However, increases in population density gradually led to a reduction in the fractional area left fallow, until the custom of fallowing nearly disappeared. Spreading animal manures in the field, as well as the inclusion of leguminous crops, helped to add nitrogen, a principal nutrient, to the soil. Legumes such as clover, beans, and peas can improve soil fertility because of their symbiotic association with specialized bacteria that attach themselves to plant roots and that can absorb elemental nitrogen from the atmosphere and fix it as inorganic nitrogen that is then available to the plant (Hillel, 2008). As agricultural production was further intensified, with multiple cropping per year and with more nutrients removed from the fields as crops were harvested, extensive areas began to experience a progressive loss of soil fertility resulting from the depletion of essential nutrients. Consequently, yields began to decline. Some farmers were desperate enough to glean animal and human bones from the great battlegrounds of Europe (Waterloo, Austerlitz, etc.) in order to crush and spread them on their gardens and field plots. In 1840, Justus von Liebig of Germany proved that treatment with strong acid increased the availability of bone nutrients to plants. The advent of chemical fertilizers marked a revolutionary change in modern agriculture. Along with improvement of crop varieties and of

methods to control diseases, pests and soil erosion, the development of fertilizers, brought about dramatic increases in crop yields (Hillel, 2008).

2.3 Biomass Transfer

Agroforestry is one of the most promising land-use systems with respect to enhanced productivity and soil nutrient accumulation in many geographical regions around the world. The adoption of agroforestry technologies such as biomass transfer of tree and shrub prunings is associated with increased nutrient inputs, reduction in nutrient losses, and improved soil physical properties as compared to sole cropping systems (Young, 1989). According to Young (1997) biomass transfer is an agroforestry technology where trees are grown as a block planting and prunings from them applied to cropped soils on another site. The trees are grown as a separate block, possibly on less fertile parts of the farm. Leaf matter is cut from the trees, transported and added to soil of the cropland. Alternative names are tree green manuring and tree-mulch transfer. It is also called cut-and-carry mulching or tree-litter mulching.

Biomass transfer technology has also been traditionally used by tropical farmers to relocate nutrients from forests to agricultural land (Nyathi and Campbell, 1993). In most cases, this has involved the use of naturally occurring biomass (i.e. tree and shrub prunings), and rarely biomass that has been specifically planted for that purpose. Recently, however, the attention of researchers has focused on transfer of biomass from purposely planted 'biomass banks' of several species including *T. diversifolia* (Jama *et al*., 2000), *G. sepium* (Rao and Mathuva, 2000), and *L. leucocephala* (Mugendi *et al*., 1999); as a means of providing nutrients for crop growth, and organic matter for soil physical improvement. While similar in principle to alley-cropping, in that plant biomass is cut and incorporated into soil to release

nutrients for crops and to help improve soil organic matter levels, one of the advantages of biomass banks is that direct competition between the main crop and the trees used to supply the biomass is minimised, if not eliminated altogether. Often, this can result in substantially increased crop yields for biomass transfer technologies (Mugendi *et al*., 1999). Research suggests that transferring biomass of plants to soil can help to increase soil fertility and sustain or increase crop yields (Mugendi *et al.,* 1999). In Zimbabwe, studies have shown that the application of five tons dry matter (DM) per hectare of high quality residues from three perennial legumes *(L. leucocephala, C. cajan and A. angustissima)* gave a mean maize yield of about 5 t DM ha^{-1}, compared to the yield of 1.1 t DM ha^{-1} obtained for maize when no organic inputs from the three legume species were used (Mafongoya *et al*., 1997).

In biomass transfers, considerable quantities of plant material are required to maintain suitable levels of soil organic matter in agricultural soils. The exact amount will differ greatly under differing conditions, but on the whole, large amounts of plant biomass are required, to maintain the physical condition of soil at a level that would support continuous and sustained crop production (Snapp *et al.,* 1998). However, for the technology to be sustainable the quality of plant biomass needs to be high. Also, very large amounts of plant biomass are required to supply 'ideal' quantities of nutrients to crops (Snapp *et al*., 1998).

2.3.1 Constraints Associated with the Use of Plant Biomass

The need for large quantities of biomass is one of the major requirements for effective functioning of nutrient management with the use of plant biomass for soil physical improvement. The use of plant biomass may require several tons of biomass per hectare, in order to supply adequate quantities of nitrogen. This implies that large

areas of land are needed to grow the biomass, and that considerable labour is required to shift it to its new location (Jama *et al.,* 2000). The transfer and supply of N through large quantities of plant biomass at levels required to sustain most crops at an attractive level may be problematic. In the context of continuous agriculture, the labour requirements for the harvesting, preparation, transfer, and incorporation of the biomass at adequate levels may be beyond the means of many resource-poor farmers, especially where the full N requirements of the crops are to be supplied entirely through plant biomass (Jama *et al.*, 2000).

In addition, the production of high quality biomass that mineralises in time to supply N to crops, is one of the major requirements for effective use of low-input techniques in crop production. Where such high quality biomass cannot be supplied for direct use as a green manure, further requirements may be to supplement nutrients in the organic matter with mineral fertilisers, or to start the decomposition process by producing compost (Snapp *et al.,* 1998).

2.4 Plant Residue Decomposition

Decomposition is the breakdown of organic residues by microorganism into simple inorganic forms. The products of complete decomposition of organic materials (e.g. plant biomass) are carbon dioxide, water, and inorganic ions (ammonium, nitrate, phosphate, and sulphate) (Koukoura *et al*., 2003). The decomposition of tree litter and prunings can substantially contribute to maintenance of soil fertility. These residues may be in the form of litter – natural leaf fall – or prunings – fresh material cut from the tree (Young, 1997).

Litter decomposition is a critical process that removes wastes, recycles nutrients, renews soil fertility and sequesters carbon among different ecosystems services such as natural forests or agroecosystems. Litter decomposition is however affected by soil micro- and macro faunal activities, climatic factors, substrate type and its quality. In agroforestry systems, prunings of different tree species and shrubs that are incorporated into soils or applied as mulch have to undergo decomposition to release nutrients. Since soil physical and chemical properties may be different in different agroforestry systems, litter decay rate and nutrient release pattern of different mulch species may also be different (Moretto *et al*., 2001; Koukoura *et al*., 2003).

2.4.1 Factors that Control Decomposition of Plant Biomass

The rate and patterns of litter decomposition are dependent on the interaction of climate, soil biota and quality and quantity of organic matter. One can predict gross estimates of decomposition based on the climate and the C/N and lignin/N ratios of organic matter (litter). The primary factors that affect litter decomposition are grouped as climate, substrate and its quality and soil biota (Swift *et al*., 1979).

2.4.1.1 Climate

Climate modifies the nature and rapidity of litter decomposition. Climatic factors such as moisture and temperature are among the most crucial variables because they affect the activities of microorganisms (which are highly critical factors involved in litter breakdown). Effects of soil moisture on litter decomposition are little complicated. Decomposition is inhibited in very dry soils because bacteria and fungi dry out. It is also slow in very wet soils due to anaerobic conditions that develop in such soils (Anderson, 1991). The process of decomposition is also slow at low

temperatures, but tends to rise with higher temperatures till the optimal level is reached. Increase or decrease of temperature beyond the optimal level (about 30 ^{o}C) brings about a decline in the rate of organic matter decomposition (Brady, 1990).

2.4.1.2 Soil Biota

Soil biota is known to regulate ecosystem processes such as decomposition and nutrient cycling. Soil biological organisms play a significant role in decomposition by affecting the type and availability of nutrients. It is also reported that seasonal variations in rate of decomposition could be due to variation in the abundance of soil fauna (Paustian *et al*., 2000). In addition, the actual rate and degree of decomposition are moderated by the local activity of decomposer organisms, among other factors (Heal *et al*., 1997). The addition of decomposable plant residues to soil triggers an increase in the rate of microbial activity. This microbial activity can either mineralize or immobilize nitrogen (Troeh and Thompson, 2005). However, the mineralization of N depends on the quality of the decomposable material.

2.4.1.3 Substrate Quality

Substrate quality has been defined as the relative content of nutrients (especially nitrogen), lignin and polyphenols, the C/N ratio; and the content of sugars, cellulose and hemicelluloses. Substrates of high quality (high in N, low in lignin and polyphenols) decompose faster whiles those of low quality (low in N, high in lignin or polyphenols) decompose more slowly (Swift *et al*., 1979). Wolf and Snyder (2003) reported that C: N ratio of organic materials markedly influences the decomposition rate and the mineralization of N because N determines the growth and turnover of the microorganisms that mineralize organic carbon. Schroth (2003) also confirmed that as a rule, the decomposition of organic materials in soil leads to an

initial net immobilization of nitrogen through incorporation of nitrogen from the surrounding soil into the decomposer biomass if the C: N ratio is less than 30. According to Troeh and Thompson (2005), microbes use carbon both for building body tissue and as an energy source. Nitrogen is required in a rather fixed ratio to the amount of carbon going into body tissue. The break-even point for decomposing organic materials in a few weeks time is a C: N ratio of about 32:1. A C: N ratio narrower than 32:1 in decomposing residues indicates that net mineralization is probably taking place. Wider ratios cause some soil nitrogen to be immobilized, and narrow ratios permit mineralization to occur as the organic matter decomposes. Nitrogen will eventually be mineralized even though the organic material added has a wide C: N ratio, but a lengthy waiting period is required so the decomposition process can go through additional cycles (Troeh and Thompson, 2005). Dead microbial tissue is decomposed in the later cycles along with any plant tissue that remains. The wider the C: N ratio, the longer the period of net immobilization. The narrower the C: N ratio of freshly added decomposable materials, the sooner nitrogen will be mineralized (Troeh and Thompson, 2005). The relationship between time and the C: N ratio is illustrated in Figure 2.1.

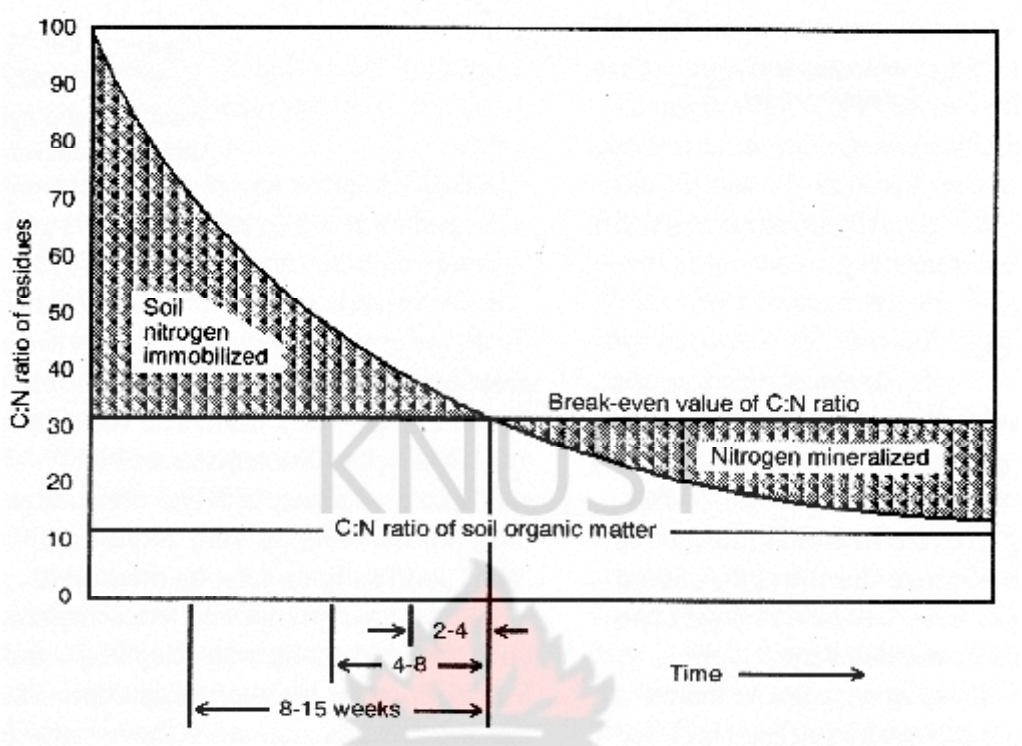

Figure 2.1 A schematic diagram showing the effect of C: N ratio on immobilization or mineralization of nitrogen.[1]

For phosphorus and sulphur, Schroth (2003) reported corresponding threshold values of C: P < 200 and C: S < 200 for initial net mineralization, and C: P < 300 and C: S < 400 for initial net immobilization. In addition to the C: N ratio, lignin and phenol contents also influence the decomposition and release of nitrogen from green manures – plant residues used to enrich agricultural soils (Figure 2.2). The lignin contents of plant litter range from less than 2% to more than 50%. Those materials with high lignin content decompose very slowly (Brady and Weil, 2004). Report by

[1] *The time scale at the bottom indicates how much warm weather is needed for residue decomposition to begin releasing nitrogen and thus indicates how much times should be allowed before the next crop is planted if nitrogen fertilizer is not used. (Source: Adapted from Troeh and Thompson, 2005).*

Schroth (2003) states that a threshold level of 150 g lignin kg^{-1} of plant material has been suggested above which decomposition is impaired.

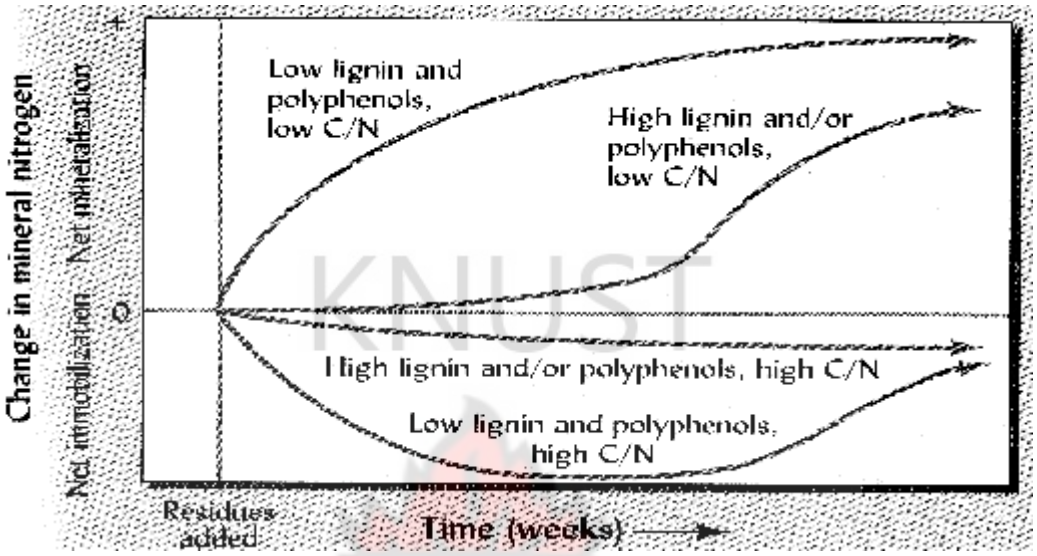

Figure 2.2 Temporal patterns of nitrogen mineralization or immobilization with organic residues differing in C/N ratios and contents of lignin and polyphenols.[2]

The phenolics are often water soluble and may be present in concentrations as high as 5 to 10% of the dry weight. By forming highly resistant complexes with proteins during residue decomposition, these phenolics can dramatically slow the rates of both nitrogen mineralization and carbon oxidation (Brady and Weil, 2004). Because they support only low levels of microbial activity and biomass, residues high in phenols and/or lignin are considered to be poor quality resources for the soil organisms that cycle carbon and nutrients. For example in the leaves of certain

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[2] *Lignin contents greater than 20%, polyphenol contents greater than 3%, and C/N ratios greater than 30 would all be considered high in the context of this diagram, the combination of these properties characterizing green manure of poor quality – that is, green manure that has limited potential for microbial decomposition and mineralization of plant nutrients. (Source: Adapted from Brady and Weil, 2004).*

legume trees, the C/N ratio is quite narrow, but the phenol content is quite high. When these leaves are added to soil in agroforestry systems, nitrogen is released only slowly – often too slowly to keep up with the needs of a growing crop (Brady and Weil, 2004). Report by Schroth (2003) stated a critical soluble polyphenol content of 40 g kg^{-1} above which nitrogen release patterns are affected.

2.4.2 Litterbag technique for Studying Litter Decomposition

Leaf litter decomposition is most commonly measured using the litter bag technique. A known quantity of leaf litter is placed into a litterbag which is then buried into the litter layer of a forest floor or an agricultural land. Litterbags are sampled at periodic intervals, dried and reweighed to determine the amount of mass lost (Weider and Lang, 1982). By incubating the leaves in situ, they are exposed to the normal fluctuations in temperature and moisture (Woods and Raison, 1982). The advantage of this technique is that it allows registering the litter weight loss in field and the subsequent chemical and biological examination of the materials involved (Weber, 1987).

2.4.3 Patterns of Litter Decomposition

Generally there are two stages in the litter decomposition process, each one with different decomposition rates. During the initial stages (i.e. 0 to 3 months) of leaf breakdown, small soluble carbon molecules like starches and amino acids are lost first leaving behind the more recalcitrant molecules like lignin. Decomposition during this first phase is rapid because these molecules are energy rich and easy to breakdown. The second stage of decomposition (i.e. the beak down of lignin) is much slower because lignin consists of very large and complex molecules. This rapid initial breakdown followed by a longer period of slow decomposition results in a

mass loss curve that resembles an exponential decay curve (McClaugherty and Berg, 1987).

2.5 Chemical Indicators of a Fertile Soil

2.5.1 Soil pH

The pH scale serves as a measure of acidity and alkalinity. It uses as a reference, or "neutral", point the concentration of H^+ ions in pure water at 24 ^oC. Most soils have pH values between 4 and 8. Nearly all soils with pH values above 8 have a high percentage of Na^+ on their cation-exchange sites. Most soils with pH values below 4 contain sulphuric acid (Troeh and Thompson, 2005). Soil pH depends on a variety of factors including all five soil-forming factors (climate, parent material, topography, time and living organisms) plus the season of the year, cropping practices, the soil horizon sampled, the water content at sampling time, and the way the pH is determined (Troeh and Thompson, 2005).

There is evidence that pH has little or no direct effect on plant growth. Varying the concentrations of H^+ and OH^- ions over a wide range seems to make no difference to plants so long as other factors remain favourable. However, pH does have a number of indirect effects. A soil at pH 4 probably has enough soluble Al^{3+} to be very detrimental to most plants, whereas nutrient solutions at higher pH show no such effects. Similar effects are experienced with manganese at low pH (Troeh and Thompson, 2005). The most universal effect of pH on plant growth is nutritional. The soil pH influences the rate of plant nutrient released by weathering, the solubility of all materials in the soil, and the amounts of nutrient ions stored on the cation-exchange sites. Therefore pH is a good guide for predicting which plant nutrients are

likely to be deficient (Troeh and Thompson, 2005). In strongly acidic soils, the availability of the macronutrients (Ca, Mg, K, P, N and S) as well as Molybdenum and Boron is restricted. In contrast, availability of most micronutrients cations (Fe, Mn, Zn, Cu, and Co) is increased by low soil pH, even to the extent of toxicity to higher plants and microorganisms (Brady and Weil, 2004). In slight to moderately alkaline soils, molybdenum and all of the macronutrients (except phosphorus) are readily available, but levels of available Fe, Mn, Zn, Cu, and Co are low and plant growth is constrained. Phosphorus and boron availability is likewise reduced in alkaline soils, often to a deficiency level (Brady and Weil, 2004). Figure 2.3 shows the relative probabilities of plant nutrient deficiencies at various soil pH values. Nutrient requirements vary with plant species and so does the optimum pH. Usually the optimum pH is somewhere between 6.0 and 7.5 because all plant nutrients are reasonably available in that range (Troeh and Thompson, 2005).

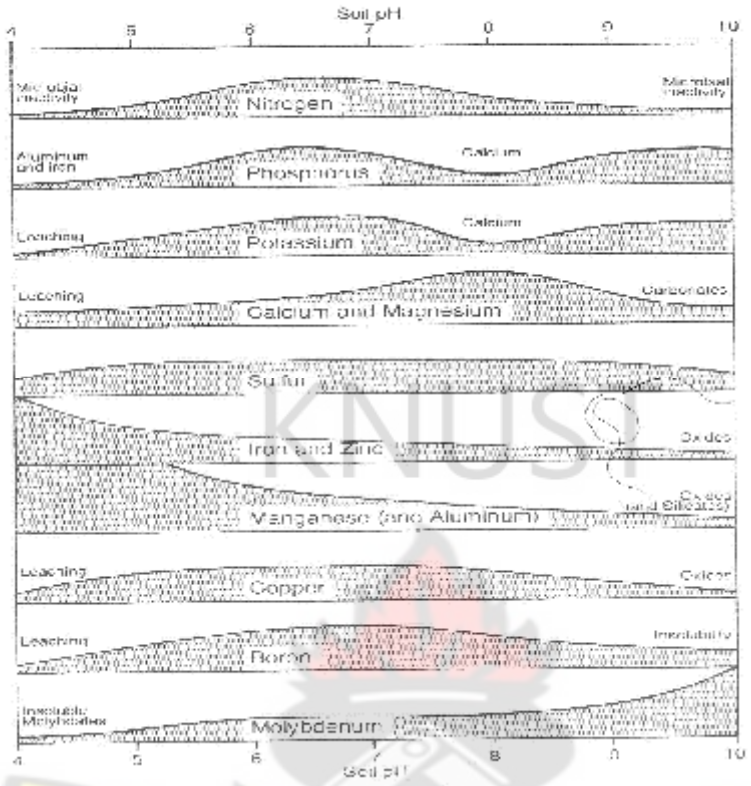

Figure 2.3 A schematic illustration of the relationship between plant nutrient availability and soil reaction.[3]

2.5.2 Cation Exchange Capacity

Cation Exchange Capacity (CEC) refers to the potential capacity of the soil to interact with and bind to, elements and compounds in the soil. As such, it is a measure of the capability of the soil to store and filter chemicals or other reagents, and buffer the soil chemical properties against changes (Charman, 2007b). The CEC is expressed as the number of moles of positive charge adsorbed per unit mass (Brady and Weil, 2004). The cation exchange capacity of the soil is largely based on

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[3] *The thicker parts of the bars represent the highest availability. Possible toxicity is indicated where a bar touches the bar above it. Aluminium is shown only because of its toxicity at low pH – it is not considered a plant nutrient. (Source: Adapted from Troeh and Thompson, 2005).*

clay particles that are the smallest mineral component of soils, and those generally less than 1µm in size display colloidal properties (Charman, 2007b). Because of their extremely small size, their specific surface area is large in relation to their mass. The clay particles are mainly layered silicates that have a net negative charge because of an excess of oxygen atoms within the crystal structure of the clay particles. There may also be some negatively charged sites on the broken edges of some clay particles (Charman, 2007b).

Soil organic matter can also contribute to the CEC of the soil, although it does this in a complex way (Charman, 2007b). The CEC of the organic matter depends on the type of organic matter and the inherent soil chemical environment within the soil. If the clay colloid is dispersed in soil water these charges are available to attract oppositively charged ions from the soil solution. The layered silicates forming the clay particles are negatively charged owing to these surface ions, so in soils the attraction for positive ions such as sodium, potassium, calcium, magnesium, aluminium, and hydrogen tend to predominate. CEC has an important bearing on many soil properties, particularly fertility, salinity, acidity, and structure (Charman, 2007b). The CEC of a given soil horizon is determined by the relative amounts of different colloids in that soil and by the CEC of each of these colloids (Brady and Weil, 2004). Figure 2.4 illustrates the common range in CEC among different soils and other organic and inorganic exchange materials.

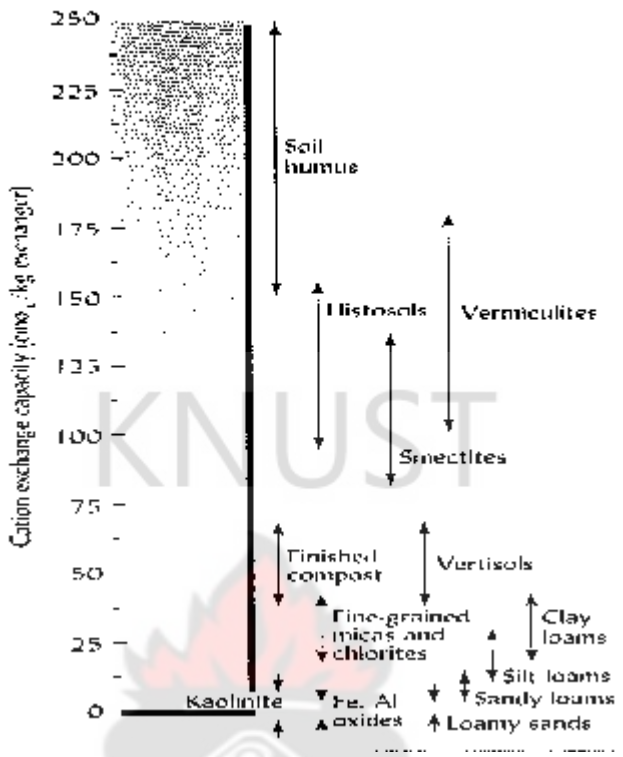

Figure 2.4 Ranges in the cation exchange capacities (at pH 7) that are typical of a variety of soils and soil materials.[4]

2.5.3 Essential Plant Nutrients

Plant growth is the result of a complex process whereby the plant utilizes solar energy, carbon dioxide, water, and nutrients from the soil. In all, 16 elements are necessary for plant growth (Gruhn *et al*, 2000). The primary nutrients for plant growth are nitrogen, phosphorus, and potassium (known collectively as NPK). When insufficient, these primary nutrients are most often responsible for limiting crop growth. Nitrogen, the most intensively used element, is available in virtually

[4] *The high CEC of humus shows why this colloid plays such a prominent role in most soils, and especially those high in kaolinite and Fe. (Source: Brady and Weil, 2004)*

unlimited quantities in the atmosphere and is continually recycled among plants, soil, water, and air (Gruhn *et al*, 2000). However, it is often unavailable in the correct form for absorption and synthesis by the plant. In addition to the primary nutrients, less intensively used secondary nutrients (sulphur, calcium, and magnesium) are necessary as well. A number of micronutrients such as chlorine, iron, manganese, zinc, copper, boron, and molybdenum also influence plant growth. These micronutrients are required in small amounts (ranging from a few grams to a few hundred grams per hectare) for the optimum functioning of plant metabolism. The absolute or relative absence of any of these nutrients can hamper plant growth; alternatively, too high a concentration can be toxic to the plant (Gruhn *et al.*, 2000).

2.5.3.1 Nitrogen

Nitrogen is an integral component of many essential plant compounds. It is a major part of all amino acids which are the building blocks of all proteins including the enzymes which control virtually all biological processes. Other critical nitrogenous plant components include the nucleic acids and chlorophyll (Brady and Weil, 2004). Plants require nitrogen for growth of roots, shoots, fruits and seeds (van Straaten, 2007). The pale green colour of nitrogen-deficient plants is the most common deficiency symptom exhibited by growing plants (Troeh and Thompson, 2005). Soils rarely contain enough nitrogen for maximum plant growth (Troeh and Thompson, 2005). The nitrogen concentration of soils varies considerably. Most soils contain 0.2 – 0.3% nitrogen with a global average of 0.2% N kg^{-1} (Ure and Berrow, 1982). The total nitrogen content in soils varies from approximately 2 – 20 t N ha^{-1}, and is primarily related to the quantities of organic compounds in the soil. While the nitrogen concentration in soil is generally very low in desert soils, it can reach 2% in highly organic soils (van Straaten, 2007).

The addition of nitrogen to soils promotes the formation of chlorophyll. Nitrogen is essential in the process of photosynthesis and for protein biosynthesis and promotes vigorous vegetative growth (van Straaten, 2007). Although nitrogen plays a crucial role for the growth of all plants, the absolute nitrogen requirement of individual crops varies widely. Cereal crops such as maize/corn and rice commonly have a relatively high demand for nitrogen; maize/corn commonly requires 100 kg N ha^{-1}. Leguminous crops on the other hand obtain most of their nitrogen needs through the symbiotic relationship with nitrogen-fixing bacteria (van Straaten, 2007). The potential rate of nitrogen use by growing plants generally exceeds the rate at which nitrogen becomes available. Consequently, the amount of available nitrogen in the soil is usually very small (Troeh and Thompson, 2005). Occasionally, a soil may contain 110 kg ha^{-1} or more of available nitrogen, but the average amount is generally less than 33 kg ha^{-1}. The amount of organic nitrogen is much larger, somewhere near 3,300 kg ha^{-1} in an average furrow slice. The organic nitrogen can be considered as a reservoir of which between 1 and 5% is likely to become available each year in temperate climates and up to 50% under tropical conditions (Troeh and Thompson, 2005).

2.5.3.2 Phosphorus

Phosphorus has been called "the key to life" because it is directly involved in most life processes (Troeh and Thompson, 2005) and is a key component of DNA and ATP. It tends to be concentrated in seeds and in the growing points of plants. A phosphorus-deficient plant is usually stunted, thin stemmed, and spindly, but its foliage is often dark, almost bluish green. In severe cases, phosphorus deficiency can cause yellowing and senescence of leaves (Brady and Weil, 2004).

Phosphorus is naturally available only in very small quantities in soil solutions. Not surprisingly, the amount of phosphorus available to plants is often the predominant limiting factor for agricultural production in large parts of the world (van Straaten, 2007). The total phosphorus content in soils varies considerably. The global average is 0.08% P (800 mg P kg^{-1}) (Ure and Berrow, 1982). The concentration of phosphorus in soil solution necessary for optimum growth of plants varies, but is commonly in the order of 0.2 mg P kg^{-1}. Of this amount, only a small fraction is available to plants. This means that only 0.1% or less of the total phosphorus in soils is available to plants (van Straaten, 2007). Even so, it is believed that plants obtain all or most of their phosphorus from solution (Troeh and Thompson, 2005). The five main forms of phosphorus in soils are: phosphorus in solution, inorganic phosphorus mineral grains (mainly apatite), phosphorus adsorbed on Fe-Al hydrous oxides and clay edges, precipitated phosphorus, (mainly Fe-, Al-, and Ca-phosphates), and organic phosphorus (van Straaten, 2007). Figure 2.5 shows the general inputs (gains) and outputs (losses) in a rock-soil-plant continuum.

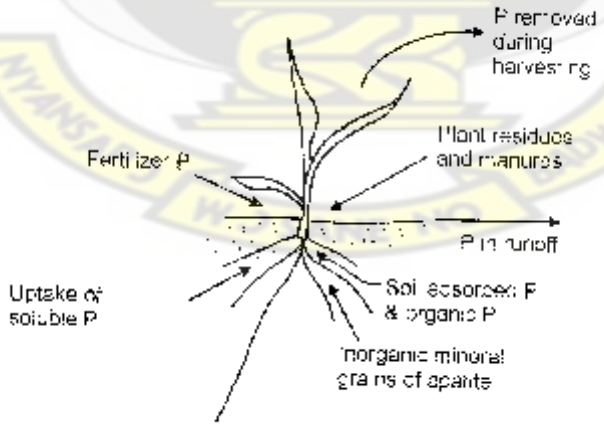

Figure 2.5 Generalized phosphorus gains and losses in the rock-soil plant system (Source: Adapted from van Straaten, 2007).

There are several organic and inorganic phases of phosphorus in soils as well as substances that bind and release phosphorus forms. The soil is a dynamic system and phosphate substances are transformed from one form to another, adsorbed, and desorbed, incorporated into microorganisms, released and finally taken up by plant roots (van Straaten, 2007). The principal pathways by which phosphorus is lost from the soil system are by plant removal (5 to 50 kg/ha annually on organic and mineral particles), dissolved in surface runoff water (0.01 to 3.0 kg/ha annually) and leaching to groundwater (0.0001 to 0.4 kg/ha annually) (Brady and Weil, 2004). A simplified model diagram, portraying the different forms of Phosphorus species, their transformation and pathways in the root zone (rhizosphere) and their uptake by roots is shown in Figure 2.6.

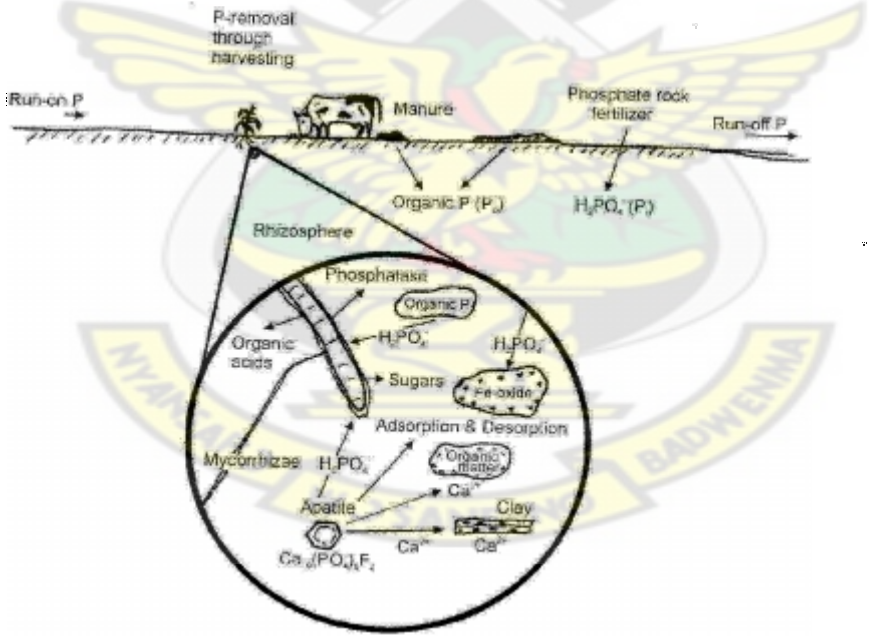

Figure 2.6 Forms and transformations of P in the near root environment (Source: van Straaten, 2007)

2.5.3.3 Potassium

Potassium is a macronutrient that is essential for the growth of plants. It is required in quantities similar to that of nitrogen. It promotes and regulates enzyme activation, supports the translocation of carbohydrates, increases water use efficiencies and resistance to the effects of drought and diseases. More potassium is required by plants in the early stages of growth than in maturity stages. Potassium is commonly more concentrated in stems and leaves than in seeds. However, potassium is not part of any plant tissue but rather a constituent of the fluids that fill internal tissues as soluble potassium ions (K^+). It is highly mobile and moves widely within plants (van Straaten, 2007). When potassium is deficient, the tips and edges of the oldest leaves begin to yellow (chlorosis) and then die (necrosis), so that the leaves appear to have been burned on the edges (Brady and Weil, 2004). Potassium in the soil occurs as potassium ions in mineral structure and as hydrated potassium ions either in solution or adsorbed on cation-exchange sites. Organic materials do have effect as a source of cation-exchange sites that attract readily available potassium ions (Troeh and Thompson, 2005). Most soils contain between 1 and 5 kg ha^{-1} of potassium dissolved in the soil solution of the plow layer (Troeh and Thompson, 2005).

2.5.3.4 Calcium

Calcium is a structural component of cell walls and is therefore vital in the formation of new cells (Troeh and Thompson, 2005). Calcium activates or inhibits certain enzymes and controls root activity and selectivity of uptake. It is also needed for good seed germination and growth of seedlings (van Straaten, 2007). Calcium deficiencies cause the deformation and eventual death (necrosis) of apical growing points (van Straaten, 2007).

The mean calcium concentration of the earth's crust is 3.5% and the mean calcium concentration in soils is 1.96% (Ure and Berrow, 1982). Calcium in soils occurs in various forms, the major form being primary minerals. This fraction contains predominantly calcium-bearing silicates, Ca-Mg carbonates and gypsum (van Straaten, 2007). Calcium may constitute more than 5% of the weight of a saline soil in an arid region or as little as 0.01% of the weight of a soil in the humid tropics. Most soils of humid temperate regions contain about 1 – 2% calcium. Very low calcium contents occur in highly leached soils with low cation-exchange capacities, especially in strongly weathered tropical soils that contain mostly oxide clays (Troeh and Thompson, 2005). Calcium has a great effect on soil properties, especially on soil structure. Soils with high calcium saturation on clay and organic complexes show a high degree of aggregation. They have a good porosity and a good tilth, meaning a good workability (van Straaten, 2007). The critical exchangeable soil calcium concentrations at which deficiencies occur in soils vary from crop to crop. Munson (1982) reported the critical exchangeable calcium concentrations in tropical soils as below the range 400 – 800 mg kg^{-1}.

2.5.3.5 Magnesium

Magnesium occupies the centre of the chlorophyll molecule and is thus required for photosynthesis. Magnesium is more concentrated in the seeds and grain than in leaves and stems (van Straaten, 2007). Magnesium deficiencies result in the accumulation of carbohydrates in leaves and an undersupply to the roots, thus impeding root development (Scott and Robson, 1990). The mean total magnesium concentration of the earth's crust is 2.33% and the mean magnesium concentration in soils is 0.83% (Ure and Berrow, 1982). Magnesium occurs in the soils in various forms. The main form is the non-exchangeable form, either as primary minerals (Mg-

silicates or Mg-rich carbonates) or associated with secondary clay minerals (van Straaten, 2007). Exchangeable magnesium is the largest source of available magnesium in soils. From 12 to 18% of the exchangeable bases are normally Mg^{2+} ions, an amount that is second only to the 75 – 85% represented by Ca^{2+} ions (van Straaten, 2007). Magnesium deficiency is indicated by less than 3 – 8% exchangeable Mg^{2+} (van Straaten, 2007). Munson (1982) put the critical exchangeable Mg concentrations in tropical soils in the range between 24 – 121 mg kg^{-1}. Soils with lower concentrations of exchangeable magnesium are considered to be magnesium (Munson, 1982).

2.6 Soil Organic Matter and Microbial Biomass

2.6.1 Soil organic matter

The general term soil organic matter (SOM) encompasses all the organic components of a soil: living biomass (intact plant and animal tissues and microorganisms), dead roots and other recognizable plant residues, and a largely amorphous and colloidal mixture of complex organic substances no longer identifiable as tissues (Brady and Weil, 2004). Depending on the turnover time in soil, SOM can be either active (fast recycling, corresponding mainly to carbohydrate, amino acid, and lipid fractions), remaining in the soil for months or even decades (10-40%), or passive or refractory (humic fraction), remaining in the soil for centuries to millennia (40-60%) (Balesdent and Mariotti, 1996; Arias *et al*., 2005). The amount of organic matter present in a soil is normally expressed as a percentage of the oven-dry weight of the soil (Troeh and Thompson, 2005). This percentage may be determined by burning out the organic matter in a furnace or by the use of a chemical oxidizing agent such as hydrogen peroxide. Most A horizons contain between 1 and 6% organic matter. This represents

between 20,000 to 120,000 kg of organic matter per hectare furrow slice (Troeh and Thompson, 2005). The organic matter in the total solum (surface and subsoil layers) is commonly about two to three times as much as that in the furrow slice. Fresh residues usually represent less than one-tenth of the weight of soil organic matter, and the rest is humus (Troeh and Thompson, 2005). The particular significance of soil organic matter for soil fertility is that it influences so many different soil properties (Swift and Woomer, 1993). Figure 2.7 illustrated some aspects of the central role that soil organic matter plays in soil fertility.

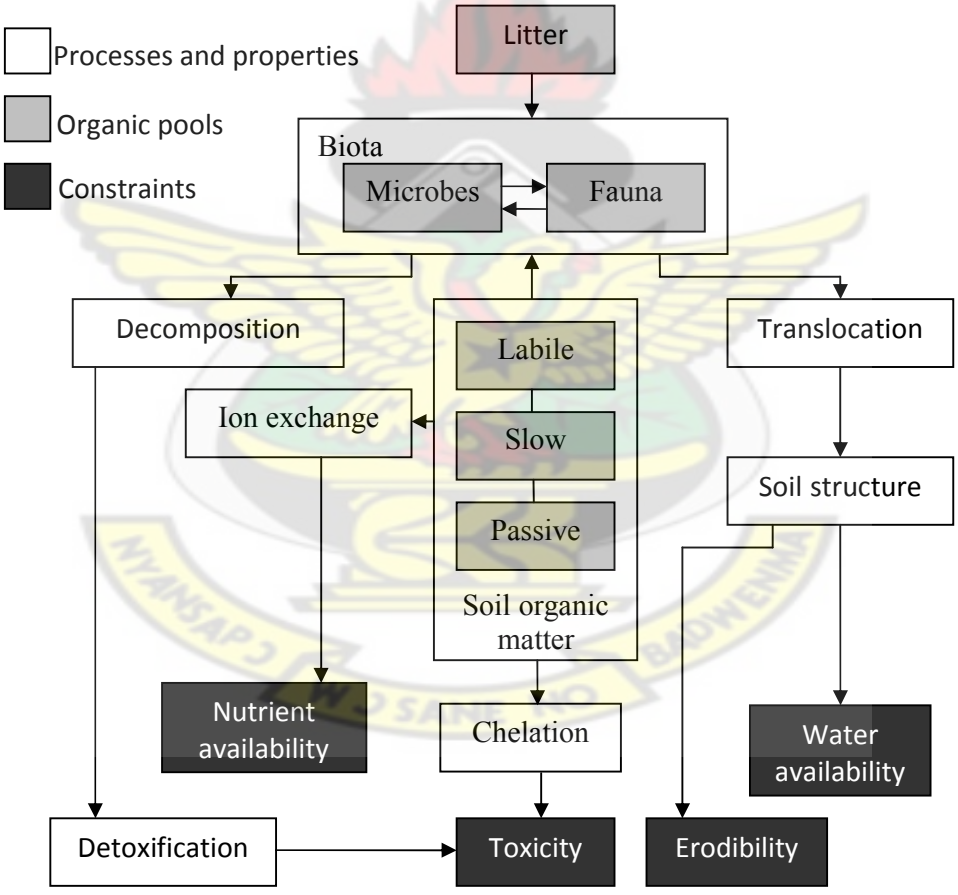

Figure 2.7 The role of soil organic matter in soil fertility. (Source: Swift and Woomer, 1993).

Soil organic matter is simultaneously a source and sink for nutrient elements which can form organic moieties (for example, with nitrogen, phosphorus and sulphur); it has charge properties which make it a site of ion exchange (often the most important one in the low-activity clay soils of the tropics); it has physical and chemical properties which facilitate aggregation with mineral particles, particularly clays, and in turn modify soil physical structure and influence soil water regimes; and it is a source of energy for the soil biota and thus influences many of the biologically mediated processes of soil. Thus, soil organic matter itself represents a set of attributes rather than an entity (Swift and Woomer, 1993).

2.6.2 Soil microbial biomass

The microbial biomass of soil is defined as the part of the organic matter in the soil that constitutes living microorganisms smaller than 5-10 μm^3. It is generally expressed in the milligrams of carbon per kilogram of soil or micrograms of carbon per gram of dry weight of soil. Typical biomass carbon ranges from 1 to 5% of total soil organic matter. The degradation of organic compounds, such as industrial chemicals and pesticides, can be monitored by following changes in the soil microbial biomass (AGVISE, 2009). Soil microbial biomass describes microbial catalytic potential and repository for carbon and nitrogen. It also provides an early warning of management effects on organic matter (Baldwin, 2006). Table 2.4 and Table 2.5 show the differences in soil microbial biomass as related to texture and organic matter contents respectively. Microbial biomass is an important source of plant nutrients and is more labile than the bulk of soil organic matter (Jenkinson, 1988). The organic matter content of soils changes at low rates and is sometimes difficult to detect in the short term. Soil microbial biomass however, responds much more rapidly than soil organic matter to changes in management, climate etc. The

soil microbial biomass is a constant state of turnover and dead microbial cells are readily mineralized by the remaining microflora. Recognition of the importance of soil microorganisms has led to increased interest in measuring the nutrients held in their biomass (Martikainen and Palojarvi, 1990).

Table 2.4 Microbial biomass of samples as related to texture

Soil Texture (USDA)	% OM (mean)	Microbial Biomass (µg/g)
Sand	2.0	55
Loamy Sand	1.5	137
Sandy Loam	1.6	106
Silt Loam	3.2	292
Loam	4.5	358

(Source: AGVISE, 2009).

Table 2.5 Microbial biomass of soil samples as related to organic matter

Organic Matter Range (%)	Average Microbial Biomass (µg/g)	Microbial Biomass range (µg/g)
0 to 1.0	76	10 to 165
1.0 to 2.0	130	17 to 379
2.0 to 3.0	169	24 to 418
3.0 to 4.0	219	119 to 300
4.0 to 5.0	345	127 to 454
5.0 to 6.0	427	369 to 506
6.0+	613	421 to 805

(Source: AGVISE, 2009).

Strong positive correlations have been found between the amount of nutrients held in the microbial biomass, and amounts of mineralizable nutrients in the soil (Smith, 1993), indicating that nutrient cycling is closely linked to the turnover of microbial biomass. Both direct and indirect methods have been used for the estimation of microbial biomass in the soil. Direct counting includes the use of staining techniques

in conjunction with epifluorescence microscopy or automated image analysis (Bloem and Breure, 2003). The most common indirect methods are chloroform fumigation and substrate-induced respiration (SIR) (Arias *et al*., 2005).

CHAPTER THREE

3.0 ON-STATION RESEARCH

3.1 Experiment I: Decomposition and nutrient release patterns of *Tithonia* leaf biomass

3.1.1 Materials and Methods

3.1.1.1 Study Site

The study was conducted at the Agroforestry Research Station of the Faculty of Renewable Natural Resources (FRNR), Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana, located at Lat 06 43^0 N and Long 01 36^0 W. The research area had lied fallow for one and half years after two years of maize cultivation with no external inputs. The area falls within the moist semi-deciduous forest zone of Ghana. It is characterized by a bimodal rainfall pattern, with the major wet season between May and July. This area also experiences a short dry season in August and a long one between December and March. The annual rainfall of the area ranges between 1250 mm – 1500 mm. The area is characterized by a mean annual temperature of 26.6 ^oC and a mean annual humidity of 67.6 %. Climatic data collected during the research period is shown in Figure 3.1. Soil type at study site is a Ferric Acrisol with extreme acidic condition according to the soil reaction rating by Motsara and Roy (2008). In addition, the soil recorded moderate levels of N and organic matter (Table 3.1).

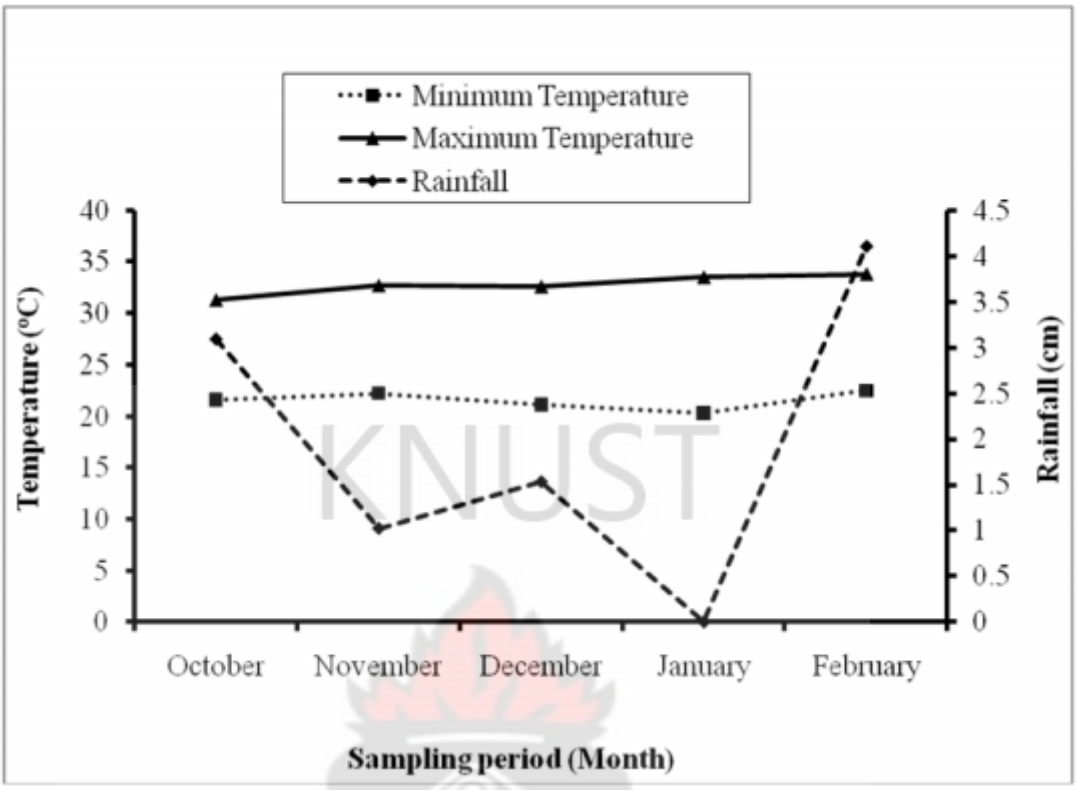

Figure 3.1 Mean monthly rainfall and temperature recordings during the sampling period at the Agroforestry Research Station.[5]

[5] Minimum and maximum temperatures represent monthly means

Table 3.1 Physicochemical properties of the top-soil (0-15cm) of the experimental site at the Agroforestry Research Station

Parameter	Value
pH (H_20) (1:1)	4.1
Organic C (g/kg)	22.9
Organic matter (g/kg)	39.5
Total N (g/kg)	2.2
Available Bray-1 P (mg/dm^3)	5.6
Available Bray-1 K (mg/dm^3)	251.0
Exchangeable cations ($cmol_c$/kg)	
Ca	3.7
Mg	2.4
K	0.4
Na	0.1
Exchangeable Acidity (Al + H) ($cmol_c$/kg)	0.6
Effective cation exchange capacity ($cmol_c$/kg)	7.2
Base saturation (%)	92.0
Texture (g/kg)	
Sand	604.0
Silt	355.0
Clay	41.0
Textural Class	Sandy-loam

3.1.1.2 Plant sampling and characterization

Plant species used in the study were: *T diversifolia*, *G. sepium*, *L. leucocephala*, *S. spectabilis* and *A. auriculiformis*. The selection of these species was based on their relative abundance at the study area and their use as organic amendments for soil fertility improvement. Fresh leaves of these species including petioles (in the case of *T. diversifolia*, *G. sepium* and *A. auriculiformis*) and rachis in the case of *L.*

leucocephala and *S. spectabilis* (since they have compound leaves) were collected from already established fields at study site and characterized for quality parameters. The quality of the plant materials were expressed in terms of their nutrient (N, P, K, Ca, Mg) content, carbon/nitrogen ratio, lignin and polyphenolic composition. Samples of the plant materials collected were oven-dried at 65^{o}C till constant weight and ground to pass through a 0.5mm sieve and analyzed for total N, P, K, Ca, Mg, C, lignin and polyphenols.

3.1.1.3 Laboratory analytical procedures

(a) Nitrogen

Total N was determined by the Kjeldahl digestion and distillation method as described by Motsara and Roy (2008). One gram (1 g) of grounded oven-dried plant sample was placed in a Kjeldahl flask and added with 0.7 g of copper sulphate, 1.5 g of K_2SO_4 and 30 ml of H_2SO_4. The solution was heated gently until frothing ceases. After being boiled briskly until the solution was clear, the solution was digested for 30 minutes. After cooling, 50 ml of water was added and transferred to a distilling flask. Twenty millilitres of standard acid (0.05M H_2SO_4) was placed in the receiving conical flask with 2 drops of methyl red indicator and water added. Thirty millilitres of 35% NaOH was added in the distilling flask in such a way not to mix the contents. Contents were for 30 minutes heated to distil ammonia. Thereafter, excess acid in the distillate was titrated with 0.1M NaOH.

The N content of the plant sample was calculated using the relation:

$$\text{Percent nitrogen} = \frac{1.401\,[(V_1M_1 - V_2M_2) - (V_3M_1 - V_4M_2)}{W} \times df \qquad 3.1$$

Where:

V_1 = millilitres of standard acid put in receiving flask for samples;

V_2 = millilitres of standard NaOH used in titration;

V_3 = millilitres of standard acid put in receiving flask for blank;

V_4 = millilitres of standard NaOH used in titrating blank;

M_1 = molarity of standard acid;

M_2 = molarity of standard NaOH;

W = weight of sample taken (1 g);

df = dilution factor of sample

(b) Phosphorus

Phosphorus was determined by the spectrophotometric vanadium phosphomolybdate method as described by Motsara and Roy (2008). One gram of plant material was dry ashed in a muffle furnace, after which the ash was dissolved in 1.0M HCl solution and filtered. The filtrate was diluted to 100 ml with distilled water. A 5 ml aliquot of the filtrate was put in a 50ml volumetric flask and 10ml vanadomolybdate reagent added. The volume was made up to the mark with distilled water and shaken thoroughly. After 30 minutes, the yellow colour developed was read on a spectrophotometer at a 420 nm wavelength. A standard curve was also developed concurrently with P concentrations: 0, 1, 2, 3, 4, 5 and 10 µg P/ml. For the observed absorbance, the P content was determined from the standard curve. The calculation was:

P content (µg) in 1g of sample = C x df (3.2)

C = concentration of P (μg/ml) as read from the standard curve;

df = dilution factor

(c) Potassium

Potassium in the ash solution (as described for P above) was determined using Gallenkamp flame analyzer. Potassium standard solutions were prepared with the following concentrations: 0, 10, 20, 40, 60 and 100 mg K per litre of solution. The emission values were read on the flame analyzer. A standard curve was obtained by plotting emission values against their respective concentrations.

(d) Calcium and Magnesium

For Ca and Mg, a 10.0 ml aliquot of ash solution (as prepared for p above) was put in erlenmeyer flask. Potassium cyanide and potassium ferrocyanide solutions were added to complex to remove interfering cations such as Cu and Fe. In Ca + Mg determination, the solution was titrated with 0.01 EDTA solution in the presence of murexide indicator. To determine Ca content, potassium hydroxide was added to raise the pH to about 12. At this pH, Mg is precipitated leaving Ca in solution. The solution was titrated again with EDTA using Eriochrome Black T as the indicator. The difference between the first and second titres represents magnesium concentration in solution.

(e) Polyphenols

Dried milled and sieved plant materials (1.0 g) were put in 50 ml flask. Ethanol (20 ml) was added to the organic material and heated to 60 ^{o}C to extract the polyphenol. The alcohol extract was decanted into another flask and the extraction repeated. After the third extraction, the total volume of the extract was made to 50 ml by adding

ethanol. Standard solutions of tannic acid (0, 10, 20, 50 and 100 mg tannic acid per litre) were prepared. The samples and tannic acid standards were subjected to colour development. Values of absorbance of the standard and sample solutions were read on the spectrophotometer at 760 nm wavelength. A curve was obtained by plotting absorbance values against concentrations of the standard solutions and used to determine the concentration of the sample solutions.

Calculation:

mg/kg polyphenol = graph reading x sample dilution x aliquot dilution

= graph reading x 4

Where

Sample dilution = final volume / weight of sample = 50/1

Aliquot dilution – 50/1 (i.e.1.0 ml of initial 50 ml extract was put in a 50 ml flask and made to the 50 ml mark with ethanol)

(f) Lignin

To determine lignin, one gram of the organic material was extracted for 1 hour with 20 ml of ethanol: benzene (1:1 v/v) in a sealed pyrex tube at 60 ^{o}C, cooled and centrifuged. The clear supernatant solution was saved in a separate flask. This was repeated twice and the combined extract was evaporated slightly and made to 50ml in a flask. Ten millilitres aliquot was taken for dry weight determination. The dry weight was taken as lipid fraction (Kachaka *et al.*, 1993). The residue was hydrolyzed with 25 ml 1.0N H_2SO_4 in a sealed pyrex tube at 100 ^{o}C for 1 hour cooled and centrifuged. After the alcohol and dilute sulphuric extraction, 2 ml of 72% H_2SO_4 was added to the residue and shaken for 4 hours. The solution was transferred into a 100 ml erlenmeyer flask with 40 ml distilled water, boiled for 3 hours and filtered. The residue was washed with water, dried at 65 ^{o}C for 48 hours,

weighed and ashed in a muffle furnace. The loss in weight on ignition was taken as the lignin content of the residue.

(g) Carbon

Organic carbon content of the plant residues was determined using the dichromate oxidation method. To 0.05 g of the organic material in an erlenmeyer flask was added 10 ml concentrated H_2SO_4, 10 ml 0.5N $K_2Cr_2O_7$ and 10 ml concentrated orthophosphoric acid. After the addition of distilled water, the solution was allowed to stand for 30 minutes and back titrated with 0.5N $FeSO_4$ solutions with diphenylamine indicator. The organic content was calculated from the following equation:

$$\text{Percent carbon} = \frac{N \times (a-b) \times 10^{-3} \times 1.3}{S} \times df \quad (3.3)$$

Where

N = normality of ferrous sulphate

a = ml ferrous sulphate solution required for sample titration

b = ml ferrous sulphate solution required for blank titration

S = weight of oven dried sample in grams

3 = equivalent weight of carbon

1.3 = compensation factor allowing for incomplete combustion

3.1.1.4 Experimental design and sampling procedure

Decomposition and nutrient release patterns of the selected species were studied using the littler bag technique. Fresh leaves of *T. diversifolia*, *G. sepium*, *L. leucocephala*, *S. spectabilis* and *A. auriculiformis* equivalent to forty grams on a dry

weight basis were placed in a 22 cm x 50 cm rigid nylon litterbag of 1.5mm mesh size and buried horizontally in the soil surface (0 – 15cm) with 0.5 m spacing between litter bags in a replicate. Using plant species as treatments, litter bags were arranged in a randomized complete block design with five replications and 25 litter bags per replicate. Replicates were 1 m apart. At one, two, four, eight and 12 weeks of decomposition, five litter bags representing five replicates per treatment were randomly selected to follow dry matter and nutrient losses. Plant materials remaining in the litterbags at each sampling time were separated from soil and organic debris by hand and oven dried at 65 ^{o}C to constant weight. In order to correct for contamination by the mineral soil, samples were ashed at 450 ^{o}C for four hours. The difference between the dry weight of the decomposition leaves and its ash content were taken as the ash-free dry weight. Sub-samples of the initial plant materials (at time 0) and plant materials remaining at each sampling time were analyzed for N, P, K, Ca and Mg concentrations using the analytical procedures described above. The amount of nutrients remaining in the litterbags at each sampling time was determined by multiplying the ash-free dry weight of the mass of leaves remaining by their nutrient concentrations. The percent dry weight and nutrient remaining at each sampling time was calculated using the relation:

$$A_R = \frac{At}{Ao} \times 100\% \qquad (3.4)$$

Where A_R is the percent nutrient or quantity of plant material remaining, At is the amount of plant material or nutrient remaining at each sampling time and Ao is the initial weight of plant material or nutrient concentration.

3.1.1.5 Statistical analysis

Data collected on the dry weight and nutrient remaining (on ash-free basis) in decomposing leaves at each sampling time were analyzed using Analysis of Variance (ANOVA). Least significant difference (LSD) at α = 0.05 was used to make treatment comparisons. Percent dry weight and nutrient remaining (on ash-free basis) were regressed on time using nonlinear regression models. Nonlinear regression models were produced using standard curve procedures in GENSTAT 11 (VSN International, 2008). The single three parameter exponential model (Wieder and Lang, 1982) was used to determine the decomposition and nutrient release rate constant (*k*). The half-life was estimated from the graph. Root mean square error values were used to assess fit of the models. The best fit model was determined based on lowest root mean square error values. The general form of the model was:

$$Y = \beta_o + \beta_i e^{-kt} + error \quad (3.5)$$

Where Y is the percent of initial material or nutrient remaining at sampling time t, β_o is the recalcitrant pool fraction and β_i *is* the difference 100 - β_o. Correlation and regression analysis were also carried out between chemical parameters of the plant materials used in the litterbags and their decomposition and nutrient release rates.

3.1.2 Results

3.1.2.1 Quality of plant materials

Analysis of variance test (Appendix 1) revealed significant effect of species type on the chemical composition of the leaf materials. The initial foliar analysis showed significant ($p < 0.05$) differences in N, P, K, Ca, Mg, C, lignin and polyphenol

concentrations between some of the leaf materials. Meanwhile, all plant materials had C: N ratios narrower than 32:1 beyond which soil N immobilization can be expected (Troeh and Thompson, 2005). Carbon to nitrogen ratios varied from 13.6 in *T. diversifolia* to 22.3 in *A. auriculiformis*. Among the different plant materials analyzed, *A. auriculiformis* and *L. leucocephala* recorded C: P ratios greater than 200:1 which represent threshold value for initial net mineralization of P (Schroth, 2003). Nitrogen concentration in *T. diversifolia* was highest and significantly ($p < 0.05$) different from levels recorded for the other four species. However, recorded N concentrations for all tested species were above the critical level of 20 to 25 g/kg, below which net immobilization of N would be expected (Palm *et al*., 1997). Nitrogen levels ranged from 21.5 g/kg in *A. auriculiformis* to 33.6 g/kg in *T. diversifolia*. Phosphorus concentration in *A. auriculiformis*, and *L. leucocephala* were below the critical level of 25 g/kg, below which net P immobilization would occur (Palm *et al*., 1997). However, P levels in all species were high compared to levels in other tropical species (Vitousek, 1984). Potassium level was highest in *G. sepium* and the same for *T. diversifolia* and *L. leucocephala*. Calcium and magnesium levels recorded for the five species, followed the increasing order of *S. spectabilis* < *G. sepium* < *L. leucocephala* < *T. diversifolia* < *A. auriculiformis* and *A. auriculiformis* < *S. spectabilis* < *L. leucocephala* < *G. sepium* < *T. diversifolia*, respectively. Lignin levels in the plant materials followed the order: *T. diversifolia* < *S. spectabilis* < *G. sepium* < *L. leucocephala* < *A. auriculiformis*. Similarly, polyphenol concentrations in *A. auriculiformis*, *G. sepium* and *L. leucocephala* were beyond the 3% critical level that reduces microbial decomposition and mineralization (Brady and Weil, 2004). Polyphenol levels were in the increasing order of *S.*

spectabilis < *T. diversifolia* < *G. sepium* < *L. leucocephala* < *A. auriculiformis* (Table 3.2).

3.1.2.2 Decomposition patterns

The highest dry weight loss occurred in *T. diversifolia* during the first week (7 days) of the experiment and lowest in *A. auriculiformis* (Figure 3.2). Percent dry weight remaining after the first week of decomposition ranged from 20% in *T. diversifolia* to 82% in *A. auriculiformis*. During the same period, 49% of *G. sepium* leaves had decomposed which increased rapidly to 77% after the second week. After 8 weeks, the amount of *T. diversifolia* leaf material remaining was insignificant (and inseparable from mineral soil) compared with all species, especially with *A. auriculiformis* recording about 31% of decomposing leaf material remaining on the 12th week of the experiment.

Table 3.2 Chemical characteristics of species used in decomposition experiment

Treatment	N	P	K	Ca	Mg	C	Lig	Poly (TAE)	C: N	C:P	Lig: N	Poly: N	(Lig + Poly): N
	g/kg												
Aa	21.5	1.5	5.0	14.7	3.4	479.2	458.0	84.3	22.3	319.5	21.30	3.92	25.22
Ss	29.9	2.6	5.4	6.5	5.1	466.2	87.0	15.6	15.6	179.3	2.91	0.52	3.43
Ll	25.6	2.0	6.2	12.8	6.1	478.7	244.0	41.3	18.7	239.4	9.53	1.61	11.14
Td	33.6	4.2	6.2	13.6	9.2	457.3	58.0	18.4	13.6	108.9	1.73	0.55	2.27
Gs	28.7	3.0	6.4	8.0	6.7	471.0	230.5	31.0	16.4	157.0	8.03	1.08	9.11
$LSD_{0.05}$	0.6	0.2	0.5	0.6	0.2	20.0	20.4	3.7	0.29	4.21	0.91	0.17	1.02
CV (%)	1.5	4.1	5.9	4.2	1.9	1.6	7.1	7.3	2.2	2.8	7.8	8.2	7.4

Aa = *Acacia auriculiformis*, Ss = *Senna spectabilis*, Ll = *Leucaena leucocephala*, Td = *Tithonia diversifolia*, Gs = *Gliricidia sepium;* LSD = Least Significant Difference, CV = Coefficient of variation, Lig = lignin, Poly = polyphenol, TAE = Tannic Acid Equivalent. Values represent means of five replicated samples.

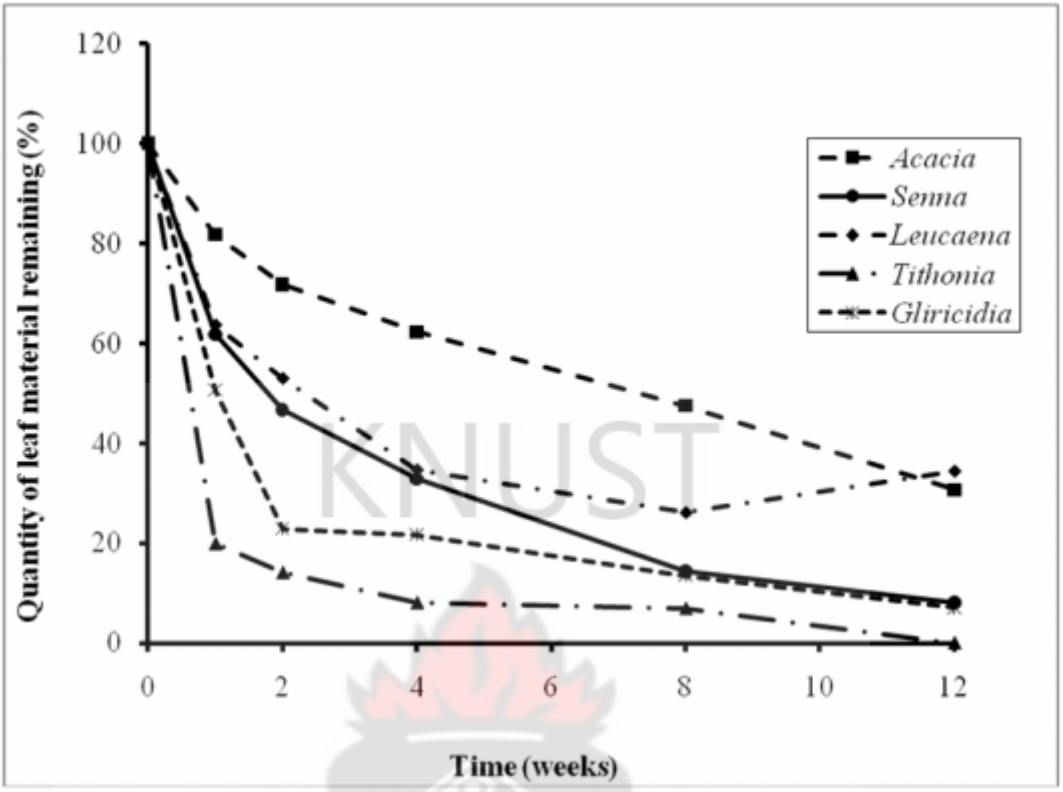

Figure 3.2 Quantity of initial leaf material remaining from decomposing leaves over 12 weeks. Data points are the means of five replicates.

Analysis of variance test (Appendix 2) confirmed significant ($p < 0.05$) effect of species type on decomposition rates at all sampling periods (Table 3.3). Generally, percent decomposition rate was highest in *T. diversifolia* and lowest in *A. auriculiformis*. Decomposition rate of *T. diversifolia* differed significantly from all species. Nonlinear relationship between percent decomposing leaf material remaining and time was significant ($p < 0.01$) (Appendix 3) with *L. leucocephala* having the best fit (Table 3.4).

Table 3.3 Decomposition rates of different leaf materials as influenced by species type under field conditions

Species	Sampling period (days)				
	7	14	28	56	84
	% decomposition rate (k_D day^{-1})				
A. auriculiformis	0.029	0.024	0.017	0.013	0.014
S. spectabilis	0.069	0.055	0.040	0.035	0.030
L. leucocephala	0.065	0.045	0.038	0.024	0.013
T. diversifolia	0.231	0.136	0.088	0.048	0*
G. sepium	0.097	0.109	0.055	0.036	0.032
$LSD_{0.05}$	0.005	0.016	0.016	0.002	0.002

**zero because leaf materials remaining could not be quantified. Leaf material was inseparable from soil mineral particles*

Table 3.4 Nonlinear regression models for weight loss of leaf material

Species	Equation	R^2	S_{yx}†	*P* value‡
Acacia auriculiformis	$Y = 24.8 + 71.5\ e^{-0.025t}$	0.98	4.90	0.004
Senna spectabilis	$Y = 10.82 + 86.29\ e^{-0.061t}$	0.98	5.46	0.002
Leucaena leucocephala	$Y = 30.24 + 69.13\ e^{-0.092t}$	0.98	4.48	0.002
Tithonia diversifolia	$Y = 6.21 + 93.64\ e^{-0.258t}$	0.99	4.97	0.001
Gliricidia sepium	$Y = 12.16 + 88.0\ e^{-0.125t}$	0.98	5.74	0.002

† Standard error of estimate, ‡ Significance of fit , R^2 = coefficient of determination

3.1.2.3 Nutrient release patterns

Data collected showed observable differences in the nutrient (N, P, K, Ca and Mg) release patterns of the decomposing leaf materials of *A. auriculiformis*, *S. spectabilis*, *L. leucocephala*, *T. diversifolia* and *G. sepium*. The highest percent N, P, K, Ca and

Mg released was recorded for *T. diversifolia* during the first week and even afterwards. Between 4 and 8 weeks of decomposition, N immobilization apparently occurred in *A. auriculiformis*, *S. spectabilis*, *L. leucocephala* and *G. sepium* whilst *T. diversifolia* mineralized its leaf N at a relatively faster rate. Nitrogen retention in decomposing leaves at the end of the study period was less than 32% and followed the increasing order: *T. diversifolia* (undeterminable level) < *S. spectabilis* < *G. sepium* < *A. auriculiformis* < *L. leucocephala* (Figure 3.3). Even though N release pattern differed from patterns observed for decomposition, percent N release rate (k_N day^{-1}) was also highest in *T. diversifolia* (0.328 day^{-1}) and lowest in *A. auriculiformis* (0.056 day^{-1}). Percent N release rate followed the increasing order of *A. auriculiformis* < *S. spectabilis* < *L. leucocephala* < *G. sepium* < *T. diversifolia* (Table 3.5).

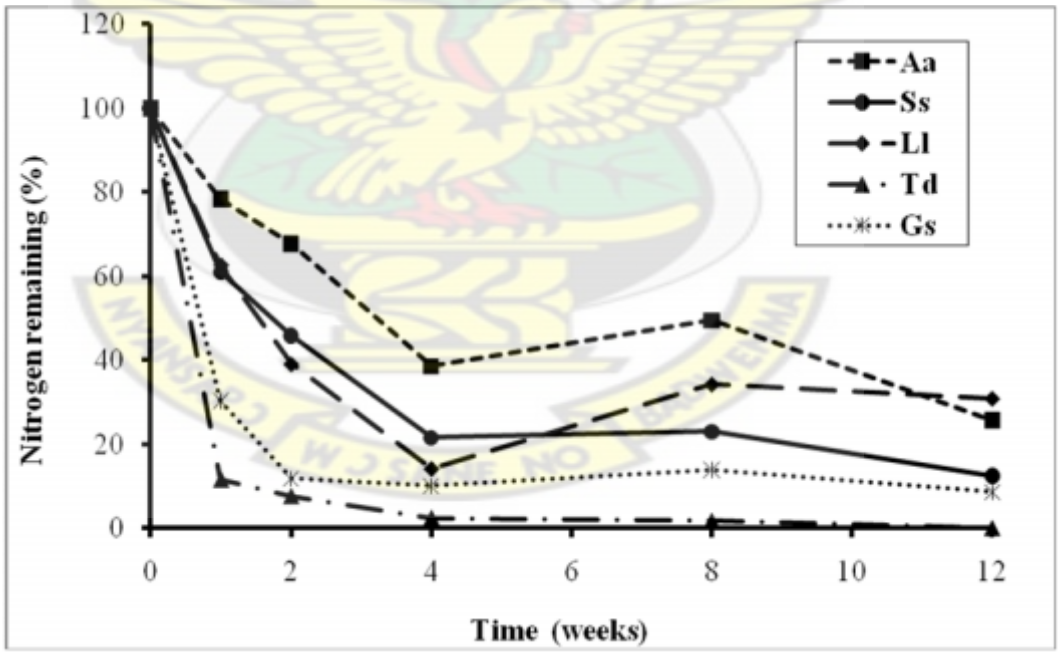

Figure 3.3 Nitrogen release patterns of decomposing leaf materials of *Tithonia diversifolia* (Td), *Acacia auriculiformis* (Aa), *Senna spectabilis* (Ss), *Leucaena leucocephala* (Ll) and *Gliricidia sepium* (Gs) over 12 weeks of placement in soil.

Analysis of variance test confirmed significant ($p < 0.05$) effect of species type on k_N day^{-1} (Appendix 4). Significant differences in k_N day^{-1} among species was observed during the second, fourth and eighth weeks of decomposition. At weeks one and 12, there were no significant ($p > 0.05$) differences in k_N day^{-1} among the following pairs: *S. spectabilis* and *L. leucocephala;* and *A. auriculiformis* and *L. leucocephala* respectively. Meanwhile, k_N day^{-1} in *T. diversifolia* differed significantly ($p < 0.05$) from all species (Table 3.5).

Table 3.5 Nutrient release rates of different leaf materials as influenced by species type under field conditions

Species	Sampling period (days)				
	7	14	28	56	84
	% N release rate (k_N day^{-1})				
A. auriculiformis	0.035	0.028	0.034	0.013	0.016
S. spectabilis	0.071	0.056	0.055	0.026	0.025
L. leucocephala	0.067	0.067	0.070	0.019	0.014
T. diversifolia	0.309	0.184	0.132	0.072	0*
G. sepium	0.170	0.153	0.082	0.035	0.029
$LSD_{0.05}$	0.008	0.006	0.003	0.005	0.003
	% P release rate (k_P day^{-1})				
A. auriculiformis	0.039	0.040	0.025	0.021	0.020
S. spectabilis	0.069	0.063	0.047	0.044	0.033
L. leucocephala	0.065	0.061	0.053	0.027	0.015
T. diversifolia	0.300	0.180	0.129	0.072	0*
G. sepium	0.142	0.110	0.060	0.044	0.038
$LSD_{0.05}$	0.019	0.019	0.010	0.002	0.002

Table 3.5 *(continued)*

Species	Sampling period (days)				
	7	14	28	56	84
	% K release rate (k_K day^{-1})				
A. auriculiformis	0.093	0.070	0.050	0.051	0.039
S. spectabilis	0.086	0.097	0.091	0.071	0.054
L. leucocephala	0.101	0.067	0.111	0.063	0.034
T. diversifolia	0.265	0.158	0.173	0.093	0*
G. sepium	0.141	0.118	0.173	0.075	0.051
$LSD_{0.05}$	0.004	0.011	0.079	0.005	0.003
	% Ca release rate (k_{Ca} day^{-1})				
A. auriculiformis	0.072	0.045	0.031	0.014	0.014
S. spectabilis	0.071	0.059	0.004	0.025	0.021
L. leucocephala	0.094	0.071	0.057	0.017	0.007
T. diversifolia	0.247	0.154	0.107	0.053	0*
G. sepium	0.143	0.072	0.072	0.018	0.02
$LSD_{0.05}$	0.003	0.002	0.006	0.002	0.002
	% Mg release rate (k_{Mg} day^{-1})				
A. auriculiformis	0.098	0.024	0.038	0.009	0.021
S. spectabilis	0.097	0.068	0.089	0.044	0.033
L. leucocephala	0.082	0.056	0.051	0.018	0.014
T. diversifolia	0.241	0.148	0.146	0.076	0*
G. sepium	0.136	0.088	0.123	0.047	0.033
$LSD_{0.05}$	0.017	0.004	0.004	0.003	0.002

**zero because leaf materials remaining could not be quantified. Leaf material was inseparable from soil mineral particles*

Phosphorus released increased steadily among species through time. However, P immobilization occurred in *L. leucocephala* between the 8th and 12th week of decomposition (Figure 3.4). As observed for N, phosphorus release rates (k_P day^{-1}) were highest in *T. diversifolia* and lowest in *A. auriculiformis*. Phosphorus release rate had a significant positive correlation with P ($p < 0.05$) and Mg ($p < 0.01$)

concentrations. In addition, ANOVA test (Appendix 5) confirmed significant ($p < 0.05$) effect of species type on k_P day^{-1} with no observable significant difference ($p < 0.05$) in k_P day^{-1} between *S. spectabilis* and *L. leucocephala* at weeks 1, 2 and 4 of decomposition. In addition, differences in k_P day^{-1} at weeks 4 and 8 were not significant ($p > 0.05$) between *L. leucocephala* and *G. sepium;* and *S. spectabilis* and *G. sepium* respectively (Table 3.3).

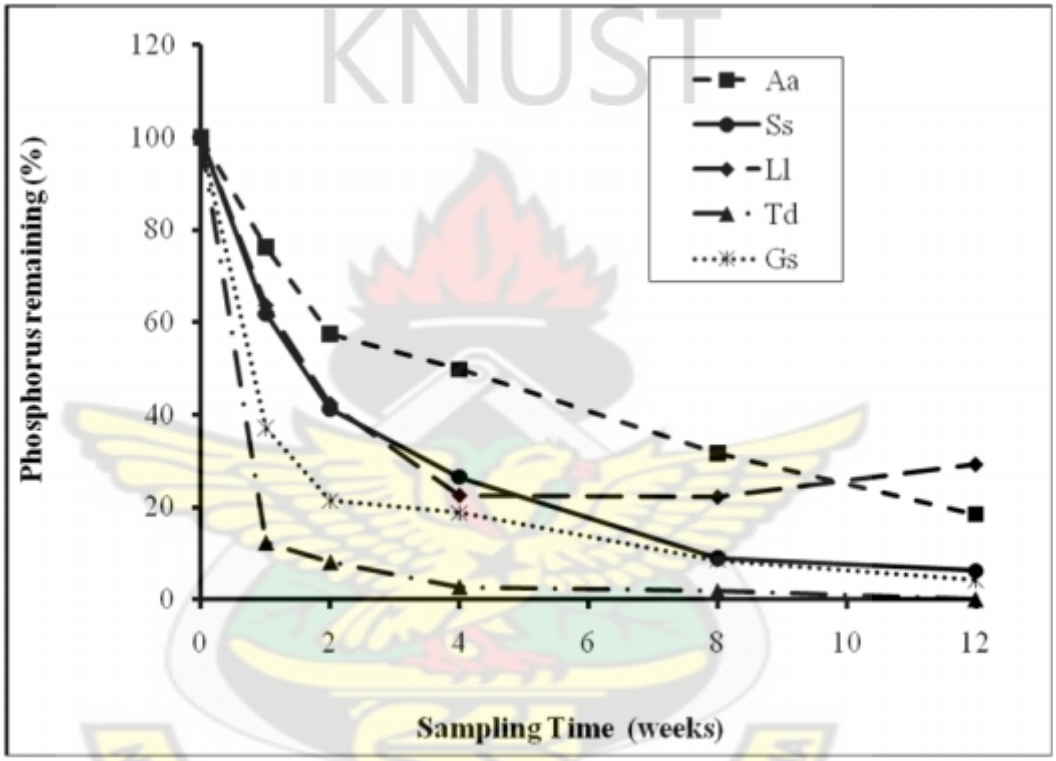

Figure 3.4 Phosphorus release patterns of decomposing leaf materials of *Tithonia diversifolia (*Td*), Acacia auriculiformis* (Aa), *Senna spectabilis (*Ss*), Leucaena leucocephala (*Ll*)* and *Gliricidia sepium (*Gs*)* over 12 weeks of placement in soil. Data points are the means of five replicates.

Potassium happened to be the element with the fastest release rate among species with its dynamic patterns differing among species. Data showed immobilization of K in *L. leucocephala* between 8 to 12 weeks of decomposition (Figure 3.5).With the

exception of weeks two and four, potassium release rate (k_K day^{-1}) differed significantly ($p < 0.05$) (Appendix 6) among all species. At week two, k_K day^{-1} did not differ significantly ($p > 0.05$) between *A. auriculiformis* and *L. leucocephala.* This observation also occurred at week four together with the following pairs: *A. auriculiformis* and *S. spectabilis; S. spectabilis and L. leucocephala; L. leucocephala* and *T. diversifolia; L. leucocephala* and *G. sepium; and T. diversifolia and G. sepium.* Potassium release rate followed the order: *T. diversifolia* > *G. sepium* > *S. spectabilis* > *L. leucocephala* > *A. auriculiformis*.

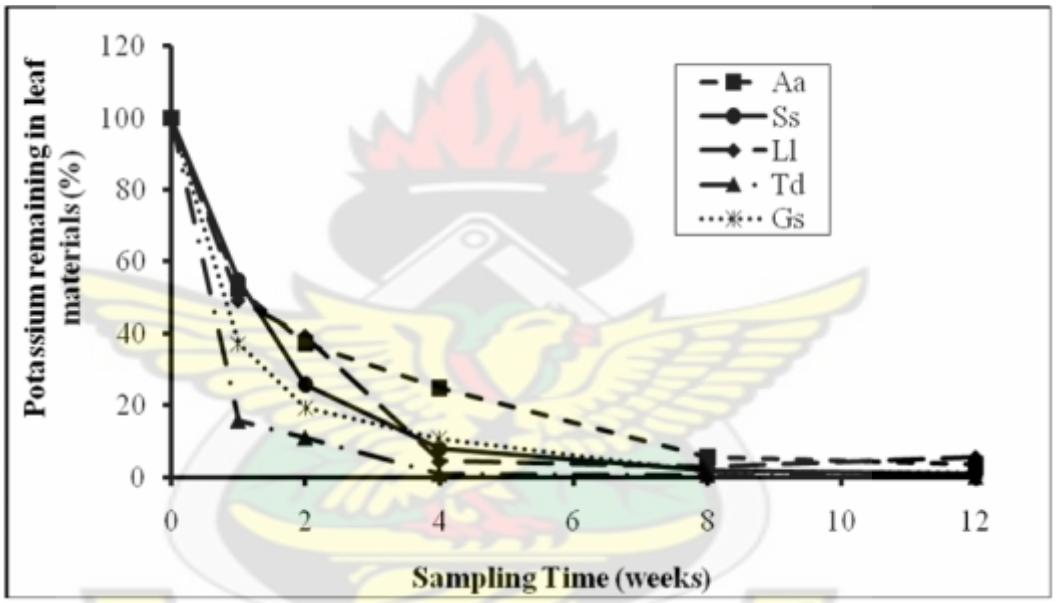

Figure 3.5 Potassium release patterns of decomposing leaf materials of *Tithonia diversifolia* (Td), *Acacia auriculiformis* (Aa), *Senna spectabilis* (Ss), *Leucaena leucocephala* (Ll) and *Gliricidia sepium* (Gs) over 12 weeks of placement in soil. Data points are the means of five replicates.

Magnesium and phosphorus recorded the same percent release rate of 0.14 day^{-1} representing the grand mean of all species used. Between 4 to 8 weeks of decomposition, Mg immobilization was recorded for *A. auriculiformis*, *L.*

leucocephala, and *G. sepium* which were later mineralized at a relatively faster rate especially in *A. auriculiformis* (Figure 3.6). ANOVA test confirmed significant effect of species type on k_{Mg} day^{-1} (Appendix 7).

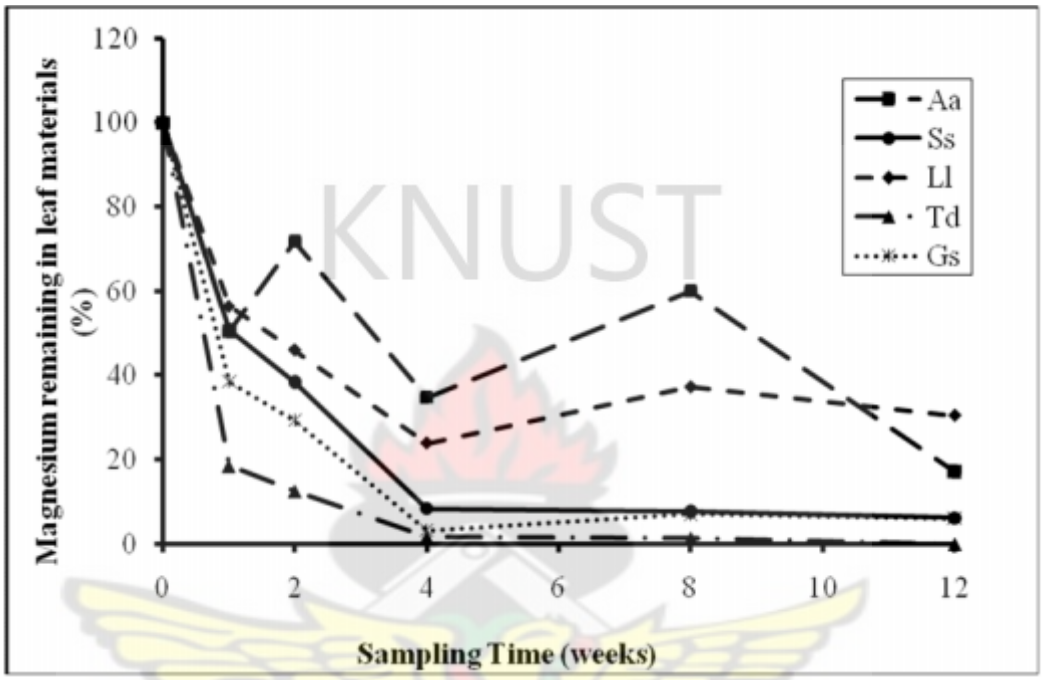

Figure 3.6 Magnesium release patterns of decomposing leaf materials of *Tithonia diversifolia* (Td), *Acacia auriculiformis* (Aa), *Senna spectabilis* (Ss), *Leucaena leucocephala* (Ll) and *Gliricidia sepium* (Gs) over 12 weeks of placement in soil. Data points are the means of five replicates.

ANOVA test (Appendix 8) showed significant effect of species type on k_{Ca} day^{-1}. Ca release rate was highest in *T. diversifolia* and lowest in *S. spectabilis* during the first week of decomposition. Percent Ca release rate (representing the grand mean of k_{Ca} day^{-1} recorded for all species studied) was the lowest among all nutrients considered. In addition, immobilization of Ca occurred in *A, auriculiformis*, *L. leucocephala* and *G. sepium* between the 4th and 8th week of decomposition (Figure 3.7).

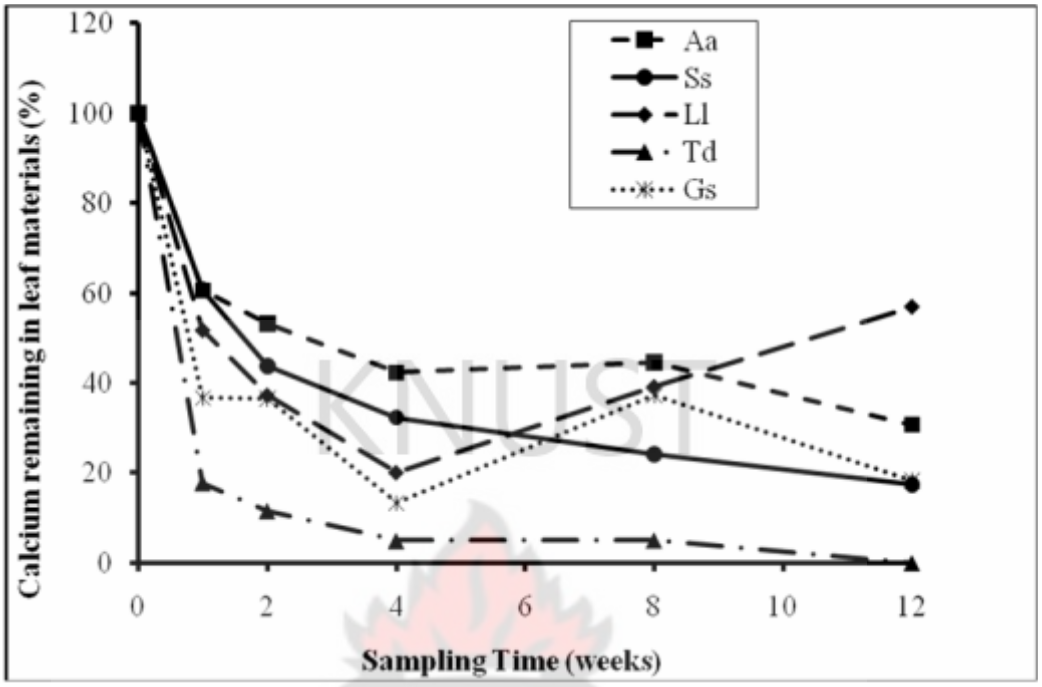

Figure 3.7 Calcium release patterns of decomposing leaf materials of *Tithonia diversifolia* (Td), *Acacia auriculiformis* (Aa), *Senna spectabilis* (Ss), *Leucaena leucocephala* (Ll) and *Gliricidia sepium* (Gs) over 12 weeks of placement in soil. Data points are the means of five replicates.

Regression analysis and fitted exponential models for nutrient release

Correlation and regression analysis confirmed a significant positive correlation between k_N day^{-1} and P ($p < 0.05$, r = 0.93); and Mg concentrations ($p < 0.01$, r = 0.96). Similarly, P release rate also had a significant positive correlation with P ($p < 0.05$) and Mg ($p < 0.01$, r = 0.96) concentrations (Table 3.6). Potassium and magnesium release rates had a significant correlation with P and Mg concentrations respectively. Furthermore, lignin and polyphenol concentrations were inversely correlated to the release rates of all the nutrients. Inverse correlation with lignin concentration was strongest with P release rate and weakest in Ca release rate. This

observation was comparable to the correlation observed with lignin: N ratio, polyphenol concentration, polyphenol: N ratio and (lignin + polyphenol): N ratio and the biochemical characteristics of the leaf materials studied. Nonlinear models derived from the nutrient release curves and their significance of fit are presented in Table 3.7. All models were tested significant by ANOVA (Appendix 9 to 13).

Table 3.6 Pearson correlation coefficient (r) of the linear relationship between nutrient release rate and initial chemical characteristics of leaf materials

Nutrient release rate / Nutrient	k_N	k_P	k_K	k_{Ca}	k_{Mg}
C	-0.74	-0.79	-0.85	-0.26	-0.69
N	0.78	0.80	0.79	0.41	0.68
P	0.93*	0.93*	0.94*	0.57	0.83
K	0.75	0.66	0.53	0.89*	0.60
Ca	0.09	0.19	0.19	0.33	0.40
Mg	0.96**	0.96**	0.91*	0.81	0.92*
C:N	-0.75	-0.75	-0.74	-0.40	-0.62
C:P	-0.83	-0.81	-0.79	-0.50	-0.66
Lignin	-0.59	-0.62	-0.61	-0.27	-0.53
Polyphenol	-0.56	-0.55	-0.51	-0.28	-0.42
Lignin: N	-0.61	-0.62	-0.59	-0.32	-0.51
Polyphenol: N	-0.58	-0.56	-0.52	-0.34	-0.44
(Lignin + Polyphenol): N	-0.60	-0.61	-0.58	-0.32	-0.50

* and ** means significant at 5% and 1% probability levels respectively

Based on the root mean square error values of the species studied, it can be inferred from Table 3.7 that K release pattern represented the best fitted model for *A. auriculiformis* and *S. spectabilis* whilst N release pattern presented the best fitted model for *T. diversifolia* and *G. sepium.* However, for *L. leucocephala,* the best fitted model was determined by its P release patterns.

Table 3.7 Nonlinear regression models for nutrient loss in leaf materials

Nutrient/Species	Equation	S_{yx}	R^2	*p* value
Nitrogen				
Acacia auriculiformis	$Y = 33.16 + 67.2\ e^{-0.056t}$	10.6	0.91	0.027
Senna spectabilis	$Y = 16.43 + 83.14\ e^{-0.083t}$	5.0	0.99	0.002
Leucaena leucocephala	$Y = 26.54 + 74.9\ e^{-0.124t}$	10.3	0.93	0.018
Tithonia diversifolia	$Y = 2.51 + 97.45\ e^{-0.328t}$	2.87	1.0	< 0.001
Gliricidia sepium	$Y = 10.21 + 89.90\ e^{-0.222t}$	2.79	1.0	< 0.001
Phosphorus				
Acacia auriculiformis	$Y = 19.96 + 77.22\ e^{-0.041t}$	5.97	0.98	0.004
Senna spectabilis	$Y = 7.53 + 90.98\ e^{-0.067t}$	3.72	0.99	< 0.001
Leucaena leucocephala	$Y = 23.68 + 77.21\ e^{-0.103t}$	4.85	0.98	0.002
Tithonia diversifolia	$Y = 2.63 + 97.32\ e^{-0.317t}$	2.98	1.0	<0.001
Gliricidia sepium	$Y = 10.16 + 89.41\ e^{-0.160t}$	5.88	0.98	0.002
Potassium				
Acacia auriculiformis	$Y = 6.56 + 90.71\ e^{-0.079t}$	4.81	0.98	0.003
Senna spectabilis	$Y = 0.84 + 99.73\ e^{-0.093t}$	1.75	1.0	< 0.001
Leucaena leucocephala	$Y = 2.80 + 96.31\ e^{-0.089t}$	7.11	0.98	0.003
Tithonia diversifolia	$Y = 1.94 + 97.90\ e^{-0.2610t}$	4.19	0.99	<0.001
Gliricidia sepium	$Y = 3.95 + 95.48\ e^{-0.141t}$	4.01	0.99	<0.001

Table 3.7 *(continued)*

Nutrient/Species	Equation	S_{yx}	R^2	*p* value
Calcium				
Acacia auriculiformis	$Y = 38.8 + 60.36\ e^{-0.123t}$	6.54	0.96	0.009
Senna spectabilis	$Y = 21.77 + 77.21\ e^{-0.089t}$	3.93	0.99	0.001
Leucaena leucocephala	$Y = 38.13 + 62.1\ e^{-0.237t}$	15.3	0.81	0.081
Tithonia diversifolia	$Y = 4.45 + 95.43\ e^{-0.266t}$	3.92	0.99	<0.001
Gliricidia sepium	$Y = 24.83 + 74.9\ e^{-0.230t}$	11.8	0.91	0.026
Magnesium				
Acacia auriculiformis	$Y = 38.0 + 58.0\ e^{-0.097t}$	23.2	0.61	0.240
Senna spectabilis	$Y = 5.78 + 93.44\ e^{-0.091t}$	5.34	0.99	0.001
Leucaena leucocephala	$Y = 30.99 + 68.91\ e^{-0.135t}$	6.77	0.96	0.007
Tithonia diversifolia	$Y = 2.43 + 97.33\ e^{-0.236t}$	4.37	0.99	<0.001
Gliricidia sepium	$Y = 5.83 + 93.24\ e^{-0.129t}$	6.36	0.98	0.002

3.1.3 Discussions and Conclusion

As expected, differences in biochemical composition were apparent among the species. Although *T. diversifolia* is non-leguminous, its N concentration was comparable and significantly higher than levels recorded for the four leguminous species. The N, P and K levels of *T. diversifolia* recorded in this study were comparable to the observations of Jama *et al*. (2000) who confirmed high nutrient composition values of *T. diversifolia* green manure in comparison with six different agroforestry species used in soil fertility improvement practices (see Table 2.1) Although the mechanism by which *T. diversifolia* is able to build nutrients in its biomass is unclear, it is evident to have a tremendous scavenging ability in pumping these nutrients from large volumes of soil and accumulating them in the leaves: an

attribute of the Asteraceae family of *T. diversifolia* (Garrity and Mercado, 1994). This scavenging characteristic of *T. diversifolia* might restrict its establishment in association with annual crops. In addition, *T. diversifolia* roots are confirmed to be associated with arbuscular mycorrhizal fungi particularly of the *Glomaceae* family (Sharrock *et al*., 2004) which might have tremendous influence on its nutrient uptake abilities even on nutrient depleted soils. Besides differences in intrinsic characteristics of the various leaf materials studied, the concentrations of nutrients (particularly N, P and K) confirm their suitability for soil fertility improvement practices in smallholder agriculture. Most of the nutrients were above critical and optimal levels reported in leaf materials by Motsara and Roy (2008). Like the other organic materials, the application of *T. diversifolia* biomass to the soil can be very advantageous and serve a better alternative in affecting many chemical and microbiological indicators associated with nutrient cycling (Nziguheba *et al*., 2000) and soil fertility especially in places where mineral fertilizer applications are limited.

The applicability of using rates constants obtained from the single exponential model in describing best fitted decomposition and nutrient release patterns of plant materials have been contested (Weider and Lang, 1982, Ezcura and Becerra, 1987). However, the high R^2 values obtained from this study makes the single exponential model seem applicable. Statistical comparison of the decomposition constant of the species confirmed the fastest decomposition and nutrient release in *T. diversifolia*. This rapid decomposition and nutrient release rates of *T. diversifolia* leaf biomass is in agreement with the findings of Gachengo *et al.* (1999) who reported a half-life of about one week for the disappearance of *T. diversifolia* dry matter in the rainy season in western Kenya. From the results, it was evident that substrate quality influences

decomposition and nutrient release patterns of plant materials. The control of substrate quality in decomposition is highly documented and has been shown to be more influential than climatic factors in the tropics (Meentemeyer, 1978; Palm and Sanchez, 1990). In this study, neither N concentration nor C/N ratio was useful in predicting decomposition and nutrient release rates. The assertion by Melillo and Aber (1983) that initial N concentration and C: N ratio influences the degradability of organic residues added to the soil was not confirmed by the results of this experiment. Results may be related to different decomposer communities which may have developed on plant materials based on their intrinsic qualities (Cobo *et al*., 2002). Among the plant chemical characteristics studied, only P and Mg concentrations served as useful indicators of degradability of plant materials based on significant results (Tables 3.6 and 3.8). The nutrient release patterns followed by the species studied demonstrate the importance of substrate quality in nutrient dynamics. Potassium happened to be the fastest release cation. The order of release of the cations (Ca < Mg < K) are similarly reported by Palm and Sanchez (1990). The fastest release rate of potassium is in support of the hypothesis that leaching is the primary process influencing K losses (Swift *et al*., 1981). Net N immobilization occurred in all leguminous species (*A. auriculiformis*, *S. spectabilis*, *L. leucocephala* and *G. sepium*) which agrees with results from temperate regions (Berg and Staaf, 1982; Melillo and Aber, 1983). The lack of net N immobilization in non-leguminous species such as *T. diversifolia* is also reported (Swift *et al*., 1981; Anderson *et al*., 1983) in the tropics which is consistent with the observation made here. Phosphorus immobilization occurred only in *L. leucocephala*. Phosphorus immobilization during decomposition is reported at both tropical and temperate regions (Anderson *et al*., 1983; Melillo and Aber, 1983; Palm and Sanchez, 1990). This observation is said to

occur when P is limiting to microbial activities (Melillo and Aber, 1983; Schlesinger and Hasey, 1985).

Table 3.8 Relationship between percent rate of decomposition (k_D day^{-1}) and chemical composition of leaf materials of the various species used in the experiment

Element	Equation	R^2	SE*	*P* value‡
N	k_D = 0.016 (N) – 0.34	0.68	0.06	0.088
P	k_D = 0.081 (P) – 0.1	0.88	0.04	0.019
K	k_D = 0.1007 (K) – 0.48	0.47	0.08	0.205
Ca	k_D = 0.004 (Ca) + 0.07	0.03	0.10	0.793
Mg	k_D = 0.041 (Mg) – 0.14	0.95	0.02	0.005
C	k_D = -0.008 (C) + 3.79	0.64	0.06	0.105
C:N	k_D = -0.021(C: N) – 0.48	0.61	0.06	0.121
C:P	k_D = -0.001 (C: P) – 0.29	0.68	0.06	0.086
Lignin	k_D = -0.0004 (Lig) – 0.19	0.44	0.08	0.220
Polyphenol	k_D = -0.0019 (Poly) – 0.19	0.35	0.08	0.292
Lignin: N	k_D = -0.008 (Lig: N) – 0.18	0.44	0.08	0.220
Poly: N	k_D = -0.039 (Poly: N) – 0.17	0.37	0.08	0.275
(Lig + Poly): N	k_D = -0.0064 [(Lig + Poly): N] – 0.18	0.43	0.08	0.23

*R^2 = coefficient of determination, * = standard error, ‡ = significance of fit, Lig = Lignin, Poly = Polyphenol*

It was evident from the study that N dynamics influenced P dynamics. All plant materials generally had a moderate to high P concentration in their tissues before decomposition but showed an increased P concentration at week 4 (Fig 3.8) resulting in N/P ratios near ten, the ideal ratio for decomposer organisms (Vogt *et al*., 1986). N/P ratios generally increased to 23, 30 and 19 at week 8 in *A. auriculiformis, S. spectabilis*, *L. leucocephala* and *G. sepium* respectively but dropped drastically

thereafter. Lack of available N (toward the end of the experiment) should be more influential in this circumstance than phosphorus limitation (Palm and Sanchez, 1990). This is evident in the independent P mineralization at week 12. Further explanation is supported by the trend followed by *T. diversifolia* which maintained a N/P ratio near ten throughout the course of the study suggestion that N was controlling P dynamics.

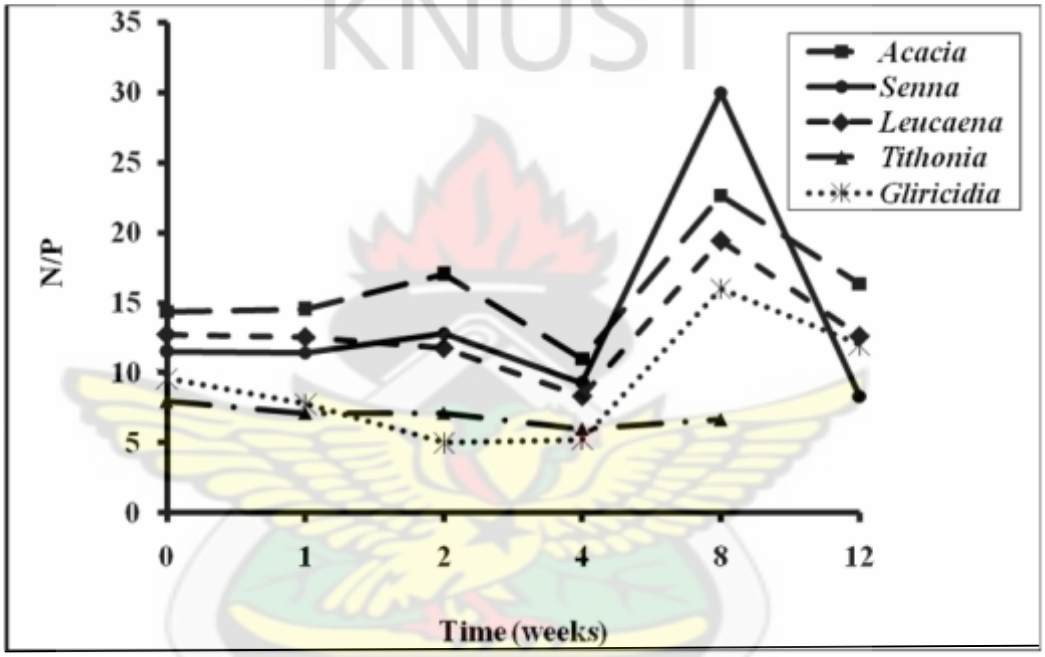

Figure 3.8 Nitrogen-to-phosphorus ratios with time in the decomposing leaves of *Tithonia diversifolia*, *Acacia auriculiformis, Senna spectabilis, Leucaena leucocephala and Gliricidia sepium.*

From the results obtained, there are clear indications that biomass quality affects the decomposition and nutrient release patterns of the selected plant leaf biomass. Based on the above results, the fresh leaves of *T. diversifolia, S. spectabilis* and *G. sepium* were rated as high quality litter and may be applied as green manure to short duration crops such as vegetables as well as most annual crops, due to their high N (> 2.5%)

and P (> 0.25%) concentrations (Palm *et al*., 2001). Meanwhile, the accelerated decomposition and nutrient release of *T. diversifolia* may limit its potential for long term build-up of soil fertility. *L. leucocephala* leaves were rated as intermediate high quality litter due to the relatively low P concentration (< 0.25%) which might lead to immobilization of P or reduce the rate of mineralization despite the high levels of N in the leaves. Therefore, such materials may be composted to start the breakdown before application to crops (Palm *et al*., 2001). On the other hand, the fresh leaves of *A. auriculiformis* were rated as low quality litter due to the low levels of N (< 2.5%) and P (< 0.25%). The leaves may be unsuitable for use as a fertilizer technology. Meanwhile, *A. auriculiformis* fresh leaves may be used as surface mulch to protect soil against evaporative losses or to control surface water flow. Alternatively, the fresh leaves of *A. auriculiformis* may be mixed with very high grade organic matter or N and P fertilizers to compensate for the low N, P or both N and P levels (Palm *et al*., 2001). Furthermore, organic residues such as *L. leucocephala and A. auriculiformis*, which decompose and release nutrients slowly, can be considered for long-term build up of soil fertility.

3.2 Experiment II: On-station trials of *T. diversifolia* for soil improvement and crop production

3.2.1 Materials and Methods

3.2.1.1 Study Site

As described in section 3.1.1.1

3.2.1.2 Plant sampling and analysis

Fresh leaves of *Tithonia*, used in the experiment were collected from natural hedges at Sunyani in the Brong Ahafo Region whilst *Senna spectabilis* and *Gliricidia sepium* were collected from the research site. The plant materials collected were characterized for quality parameters. Samples of fresh leaves including soft stems collected were oven-dried at 65 ^{o}C till contant weight and ground to pass through a 0.5 mm sieve and analyzed for total lignin, polyphenol, N, P, K, Ca, Mg, and organic C using the analytical procedures described in section 3.1.1.3.

3.2.1.3 Soil sampling and analysis

Prior to setting up the experiment, soil samples were randomly collected at the surface 0 – 15 cm from 16 locations in a grid format at the experimental site for site characterization. The samples were composited and homogenized. They were then air-dried and passed through a 2 mm sieve and analyzed for site characterization using five replicated sub-samples. In addition, soil samples were randomly collected per plot at flowering (5 weeks after planting) and at last harvest (16 weeks after planting) and analyzed for soil pH, organic carbon, cation exchange capacity

available P and available K. Furthermore, soil samples were analyzed for soil microbial activities by determining soil microbial biomass (C, N and P). All soil analyses were conducted at the Soil Research Institute of Ghana, Kwadaso, Kumasi.

3.2.1.4 Laboratory analytical procedures for soil chemical parameters

(a) Total N

Total N was determined by the Kjeldahl digestion and distillation method following the same procedures as described in section 3.1.1.3

(b) Available P

Available P was determined by the Bray's Method No. 1 (Bray and Kurtz, 1945). The readily acid – soluble forms of P were extracted with an HCl: NH_4F mixture. Phosphorus in the extract was determined on a spectrophotometer by the blue ammonium molybdate method with ascorbic acid as reducing agent. A 2.0 g soil sample was weighed into a shaking bottle (50 ml) and 20 ml of extraction solution of bray-1 (0.03 M NH_4F and 0.025 M HCl) was added. The sample was shaken for one minute by hand and then immediately filtered through a fine filter (Whatman No. 42). One ml of the standard series, the blank and the extract, 2 ml boric acid and 3 ml of the colouring reagent (ammonium molybdate and antimony tartarate solution) were pipetted into a test tube and homogenized. The solution was allowed to stand for 15 minutes for the blue colour to develop to its maximum. The absorbance was measured on a spectronic 21 D spectrophotometer at 660 nm wavelength.

A standard series of 0, 1.2, 2.4, 3.63, 4.8, and 6 mg P/l was prepared from a 12 mg/l stock solution by diluting to 0, 10, 20, 30, 40, and 50 ml of 12 mg P/l in 100 ml

volumetric flask and made to volume with distilled water. Aliquots of 0, 1, 2, 4, 5 and 6 ml of the 100 mg P/l of the standard solution were put in 100 ml volumetric flasks and made to the 100 ml mark with distilled water.

Calculations:

$$P\,(mg/kg) = \frac{(a-b)\,x\,20\,x\,6\,x\,mcf}{s} \qquad (3.5)$$

Where:

a = mg/l P in sample extract

b = mg/l P in blank

s = sample weight in gram

mcf = moisture correcting factor

20 = ml extracting solution

6 = ml final sample solution

(c) Exchangeable Calcium and Magnesium

Exchangeable Ca and Mg were determined by the Ethylene diamine tetraacetic acid (EDTA) titration method described by Motsara and Roy (2008).

For Ca only, 5 g of air-dried soil sample was put in a 150 ml conical flask and added with 25 ml of neutral normal ammonium acetate. The mixture was shaken on a mechanical shaker for 5 minutes and filtered through No.1 filter paper. A 5ml suitable aliquot was added on with two crystals of carbamate and 5 ml of 16% NaOH solution. Thereafter, 40 mg of an indicator powder was added and titrated with 0.01N EDTA solution until the colour changed gradually from orange-red to reddish-violet

(purple). A drop of EDTA solution was also added at intervals of 5 – 10 seconds, as the change of colour was not instantaneous.

Calculations:

If N_1 is normality of Ca^{2+} and V_1 is volume of aliquot taken and N_2V_2 are the normality and volume of EDTA used respectively, then:

$N_1V_1 = N_2V_2$

$$N_1 = \frac{N_2V_2}{V_1} = \frac{\text{Normality of EDTA x Vol. of EDTA}}{\text{ml of aliquot taken}} \quad (3.6)$$

Here, N_1 (normality) = equivalent of Ca^{2+} present in 1 litre of aliquot. Hence, Ca^{2+} me/litre is:

$$\frac{\text{Normality of EDTA x Vol.of EDTA x 1000}}{\text{ml of aliquot taken}} \quad (3.7)$$

When expressed on soil weight basis, Ca^{2+} me/100g soil is:

$$\frac{100}{\text{wt.of soil}} \text{ X } \frac{\text{extract volume}}{1000} \text{ x Ca as me/litre} \quad (3.8)$$

(d) Exchangeable Potassium and Sodium

Potassium and Sodium were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1000 mg/l potassium and sodium solutions to 100 mg/l. This was done by taking a 25 ml portion of each into one 250 ml volumetric flask and made to volume with water. Portions of 0, 5, 10, 15

and 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks respectively. One hundred millilitres of 1.0 M NH_4Ac solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5, 10.0 mg/l for potassium and sodium. Potassium and sodium were measured directly in the percolate by flame photometry at wavelengths of 766.5 and 589.0 nm respectively.

Calculations:

$$\text{Exchangeable K(cmol/kg soil)} = \frac{(a-b) \times 250 \times mcf}{10 \times 39.1 \times s} \quad (3.9)$$

$$\text{Exchangeable Na(cmol/kg soil)} = \frac{(a-b) \times 250 \times mcf}{10 \times 23 \times s} \quad (3.10)$$

Where:

a = mg/l K or Na in the diluted sample percolate

b = mg/l K or Na in the diluted blank percolate

s = air-dried sample weight of soil in gram

mcf = moisture correcting factor

(f) Exchangeable Acidity and Effective cation exchange capacity (CEC_e)

Exchangeable acidity is defined as the sum of Al and H (i.e. Al + H). The soil sample was extracted with unbuffered 1.0 M KCl, and the sum of Al + H was determined by titration. Fifty grams of soil sample was put in a 200 ml plastic bottle and 100 ml of 1.0 M KCl solution added. The bottle was capped and shaken for 2.0 hours and then filtered. Fifty millilitres portion of the filtrate was taken with a pipette into a 250 ml

erlenmeyer flask and 2 – 3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.1 M NaOH until the colour just turned permanently pink. A blank was included in the titration.

Calculation:

$$\text{Exchangeable acidity (cmol/kg soil)} = \frac{(a-b) \times M \times 2 \times 100 \times mcf}{s} \quad (3.11)$$

Where:

a = ml NaOH used to titrate with sample

b = ml NaOH used to titrate with blank

M = molarity of NaOH

S = air-dried soil sample weight in gram

2 = 100/50 (filtrate/pipetted volume)

mcf = moisture correction factor ((100 + % moisture)/100)

The effective cation exchange capacity was calculated as the sum of the exchangeable cations and exchangeable acidity

(g) Soil microbial biomass (C, N and P)

Soil microbial carbon, nitrogen and phosphorus were monitored under the different amendments. The method of chloroform fumigation and extraction (FE) as described by Ladd and Amato (1989) was used to determine the microbial biomass. Ten grams field - moist soil sample, after passing through a 4 mm mesh, was put in a crucible and placed in a desiccator. A shallow dish containing 30 ml of alcohol -free chloroform was placed by it. A crucible containing a control sample (10 g) was placed in a separate desiccator without chloroform. The desiccators were covered

and allowed to stand at room temperature for 5 days (Anderson and Ingram, 1998). Immediately after fumigation, 50 ml of 0.5 *M* K_2SO_4 solution was added to the soil samples to extract microbial carbon and nitrogen from the lysed microorganisms. Total nitrogen in the extract was then determined by the Kjeldahl method. The amount of microbial carbon in the extract was determined using the colorimetric method. An aliquot (5 ml) of the extract was pipetted into 250 ml Erlenmeyer flask. To this were added 5 ml of 1.0 *N* (0.1667 *M*) potassium dichromate and 10 ml concentrated sulphuric acid. The resulting solution was allowed to cool for 30 minutes after which 10 ml of distilled water was added. A standard series was developed concurrently with carbon concentrations ranging from 0, 2.5, 5.0, 7.5, 10.0 mg/ml C. These concentrations were obtained when volumes of 0, 5, 10, 15 and 20 ml of a 50 mg/ml C stock were pipetted into labelled 100 ml volumetric flasks and made up to the mark with distilled water. The absorbances of the standard and sample solutions were read on a spectronic 21D spectrophotometer at a wavelength of 600 nm. A standard curve was obtained by plotting absorbance values of the standard solutions against their corresponding concentrations. Extracted carbon concentration of the samples was determined from the standard curve. For biomass C and N calculations, k -factors of 0.35 (Sparling *et al.,* 1990) and 0.45 (Jenkinson, 1988; Ross and Tate, 1993) were used, respectively. The following equations according to Sparling and West (1998) were used to estimate the microbial C and N from the extracted C and N respectively:

Microbial C (mg) = Ec/k

Microbial N (mg) = E_N/k

Where

E_N = the extracted nitrogen produced following fumigation

Ec = the extracted carbon produced following fumigation

k = the fraction of the killed biomass extracted as carbon or nitrogen under standardized conditions

For microbial biomass P analysis, 5 g of field-moist soil was weighed into a crucible and fumigated in a dessicator with 30 ml of alcohol-free chloroform for 5 days. Both fumigated and unfumigated soil samples were shaken with 35 ml Bray's No.1 extracting solution (0.03 *M* NH_4F + 0.025 *M* HCl) for 10 minutes and filtered. Correction for adsorption of P during fumigation was made by simultaneously equilibrating unfumigated soil with a series of P containing standard solutions followed by extraction with the Bray-1 solution. The amount of chloroform released P was determined according to the relationship between P added (from standard solutions or microbial lysis) and P extracted by the Bray-1 solution (Oberson *et al.,* 1997). Phosphorus adsorption during equilibrium is described by the following equation according to Barrow and Shaw (1975) and adapted by Morel *et al*. (1997):

$$Ext_p = Ext_0 + b_1 Pad^{b2}$$

Where

Ext_p = Pi concentration (mg/l) extracted after equilibration with different amounts of P added;

Ext_0 = Pi concentration extracted without P addition,

b_1, b_2 = coefficients estimated by non- linear regression of mean values of Ext_p against Pad

Pad = amount of P added (0 - 20 mg/kg)

Chloroform released P corresponds to a P addition and is calculated from the Equation:

$$P_{chl.} = [(Ext_{chl} - Ext_0)/b1]^{1/b2}$$

Where

$P_{chl.}$ = chloroform released P (mg/kg).

Ext_{chl} = Pi concentration in extracts of fumigated samples.

The amount of microbial P is estimated by assuming a kp factor of 0.4 (Brookes *et al.,* 1982; McLaughlin and Alston, 1986).

3.2.1.5 Experimental design and treatment applications

The experiment was conducted during the minor rainy season of 2008 (August – December, 2008) and major rainy season of 2009 (March – July 2009) using okro (*Abelmoschus esculentus*) as a test crop. Five treatments were arranged in a randomized complete block design with a plot dimension of 3 m x 3 m, replicated four times. The treatments included: a control (no input); green biomass of *Senna spectabilis, Gliricidia sepium* and *Tithonia* (all applied at 4.5 t dry matter ha^{-1}); and mineral fertilizer applied at 150 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1}, and 100 kg K_2O ha^{-1}. Treatments were applied in both cropping seasons. The green biomass of *Tithonia*, *S. spectabilis* and *G. sepium* including soft stems were surface applied on the soil by hand and hoe a week before planting. At planting, mineral fertilizer in the form of NPK (15:15:15) was basally applied at 250 kg ha^{-1}. After 30 days of planting, plants were side-dressed with 150 kg $ha^{-1}$of NPK (15:15:15) and subsequently top-dressed with 90 kg N ha^{-1} (in an equivalent amount of urea), 89 kg of triple superphosphate and 67 kg of muriate of potash equally split-applied at 50 and 70 days after planting. During planting, okro seeds were sowed four seeds per hill at 0.6 x 0.6 m spacing and thinned to 2 plants per hill two weeks after planting. Crop residues from the minor rainy season cropping were totally removed from the field to reduce the

confounding effects of organic residues of the okro plants for the subsequent major rainy season cropping.

3.2.1.6 Data collection and Statistical Analysis

For all cropping seasons, data was collected on stem diameter, height, belowground (BG) and aboveground (ABG) biomass, leaf area index, nutrient recovery and fruit yields of okro. Leaf area index was determined at flowering using the dry weight approach as described by Williams and Joseph (1973). BG and ABG were determined at flowering using 20 plants per treatment. To determine BG and ABG, plants were uprooted from soil after watering the surface soil to minimize root destruction during sampling. Roots were thoroughly washed in distilled water and separated from shoots. Thereafter, the roots and shoots were enveloped and oven-dried in the laboratory at 65^{o} C till constant weight. Fruit yields were measured at each harvest using the fresh weight of fruits collected from 28 plants per plot. Fruit harvesting was done every four days after the first harvest until 16 weeks after planting. In order to compare the treatment effects of the different seasons, yields were converted to relative increase compared to the control using the relation by Gachengo *et al*. (1999):

$$\text{Yield increase (\%)} = \frac{(\text{Yield}_{\text{treatment}} - \text{Yield}_{\text{control}})}{\text{Yield}_{\text{control}}} \text{ X } 100 \qquad (3.12)$$

Nutrient uptake in the aboveground biomass of the okro plants was determined at last harvest (16 weeks after planting) for each cropping season. To determine nutrient uptake, leaf samples were collected from a sample of fifteen plants per plot and oven dried at 65 ^{o}C to constant weight. Dried material was ground to pass through a 0.5 mm sieve and analyzed for N, P and K concentrations using the analytical methods

described under section 3.2.1.4. Nutrient uptake was determined by multiplying the dry matter yields by the various nutrient concentrations. Nutrient uptake was used to determine amount of nutrient recovered using the relation by Gachengo *et al.,* (1999):

Nutrient recovery (%) =

$$\frac{(\text{Nutrient uptake}_{treatment} - \text{Nutrient uptake}_{control})}{\text{Amount of nutrient applied to minor crop}_{control}} \text{ X } 100 \qquad (3.13)$$

For the minor cropping season, all parameters measured were statistically analyzed using Analysis of Variance (ANOVA) test. However, in order to determine whether treatments applied in the major season significantly affected the agronomic characteristics of okro and soil properties, the residual effects of previous treatments in the minor season were removed by taking all measurements in the minor season as covariates. For this reason, variables measured in the major cropping season were analyzed using Analysis of Covariance (ANCOVA) test. Treatment means were compared using Duncan's multiple range test (DMRT) at a 0.05 probability level. All statistical analyses were conducted using GENSTAT 11 (VSN International, 2008).

3.2.2 Results

3.2.2.1 Initial soil physicochemical properties

The soil was very acidic with low effective cation exchange capacity and available P. Total N was moderate with relatively high organic matter and available K levels (Table 3.9).

Table 3.9 Physicochemical properties of the top-soil (0-15 cm) of the experimental site at the Agroforestry Research Station

Parameter	Value
pH (H_20) (1:1)	4.1
Organic C (g/kg)	22.9
Organic matter (g/kg)	39.5
Total N (g/kg)	2.2
Available Bray-1 P (mg/dm^3)	5.6
Available Bray-1 K (mg/dm^3)	251.0
Exchangeable cations ($cmol_c$/kg)	
Ca	3.7
Mg	2.4
K	0.4
Na	0.1
Exchangeable Acidity (Al + H) ($cmol_c$/kg)	0.6
Effective cation exchange capacity ($cmol_c$/kg)	7.2
Base saturation (%)	92.0
Texture (g/kg)	
Sand	604.0
Silt	355.0
Clay	41.0
Textural Class	Sandy-loam

3.2.2.2 Biochemical properties of green manures used

Chemical analysis showed distinct differences in the biochemical parameters measured for the different leaf materials. *Tithonia* leaves were of highest quality than the other organic materials based on its biochemical characteristics (Table 3.10). Meanwhile, nitrogen concentration of all species was above the critical level of 2.0 to 2.5%, below which net immobilization of N would be expected (Palm *et al*., 1997).

In addition, P concentration in all species was above the critical level of 0.25%, below which net P immobilization would occur (Palm *et al*., 1997). C: N ratios were narrower than 32:1 beyond which soil N immobilization can be expected (Troeh and Thompson, 2005). C: P ratios were also less than 200 and 300 which represent threshold values for initial net mineralization and net immobilization of P, respectively (Schroth, 2003) (Table 3.10).

With the exception of *G. sepium*, lignin concentrations in *Tithonia* and *S spectabilis* leaf materials were below the 20% critical levels that impedes microbial decomposition and nutrient release. Lignin levels in the plant materials followed the order: *Tithonia* < *S. spectabilis* < *G. sepium.* Similarly, polyphenol concentration in *G. sepium* was beyond the 3% critical level that reduces microbial decomposition and mineralization (Brady and Weil, 2004).

Table 3.10 Chemical characteristics of organic plant materials used in the experiment

Species	N	P	K	Ca	Mg	C	Lig	Poly (TAE)	C: N	C:P
	g/kg						%			
Ss	30.0	2.6	5.4	6.5	5.1	476.2	8.7	1.56	15.9	183.2
Td	33.3	4.2	6.2	14.0	9.2	453.7	5.8	1.84	13.6	108.0
Gs	29.0	3.0	6.4	8.0	7.0	443.6	23.1	3.10	15.3	147.9

Ss = S. spectabilis, Td = Tithonia, Gs = G. sepium, Lig = lignin, Poly = polyphenol, TAE = Tannic Acid Equivalent

3.2.2.3 Effects of treatments on soil properties

(a) Soil pH

Figures 3.9 (a) and 3.9 (b) show the changes in soil pH measured during the short and major rainy seasons of 2008 and 2009. Pattern of changes in soil pH during the minor season period was similar for all treatments with no observable significant differences on the 5th week. However, at week 16 of the same season, treatments had significant effect on soil pH ($p < 0.05$) with the highest pH (5.0) recorded for plots treated with *G. sepium* green manure. All treatments including the control differed significantly ($p < 0.05$) from the fertilizer treated plots on the 16th week (Table 3.11) of the minor season.

During the major rainy season, soil pH levels were virtually at a steady state throughout the experimental period (Figure 3.9b). Analysis of covariance (ANCOVA) test did not show significant effect of treatments on soil pH at both weeks 5 and 16 ($p > 0.05$), although there were observable differences in soil pH measurements among treatments at both sampling periods.

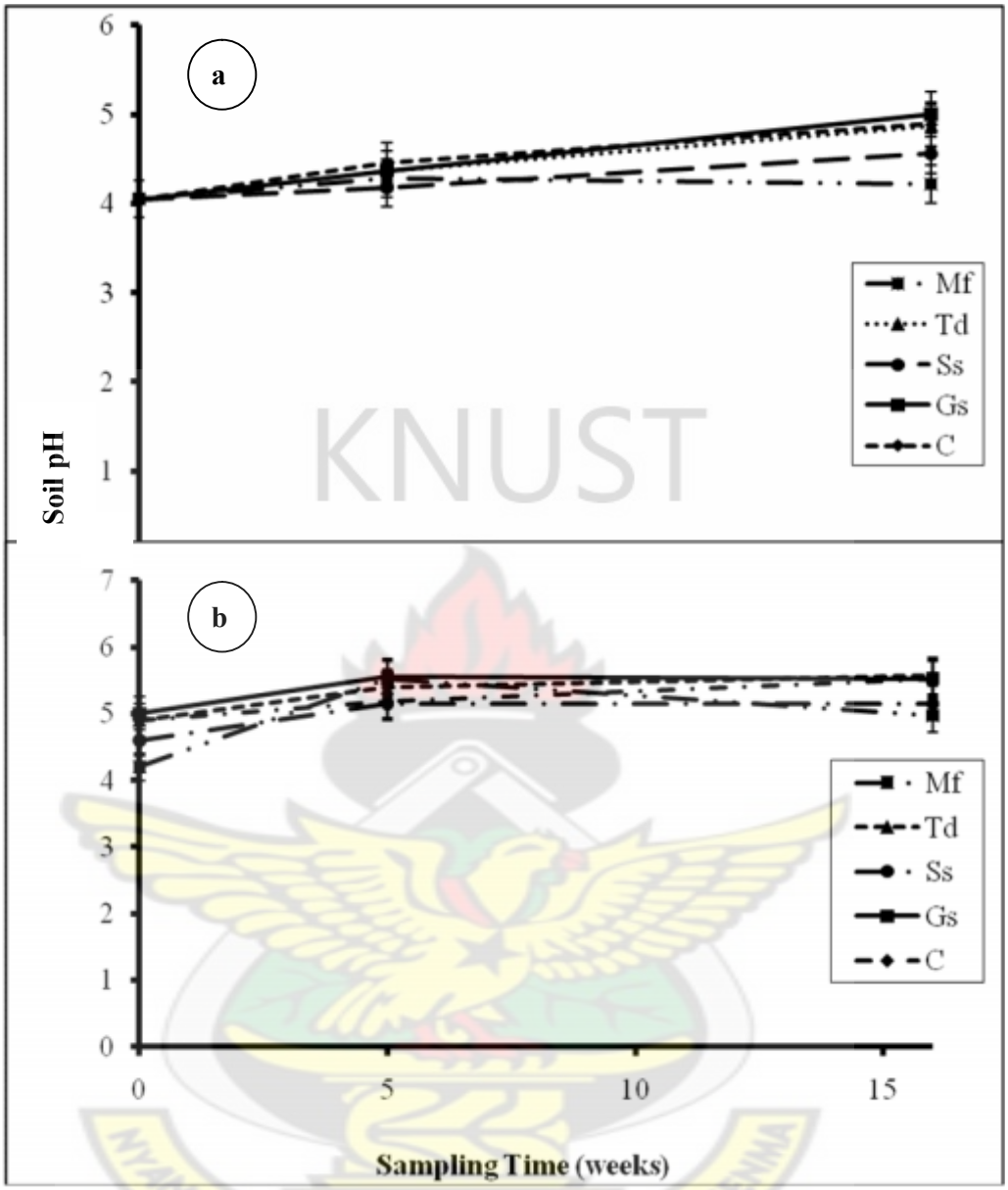

Figure 3.9 Changes in soil pH over 16 weeks as affected by the application of the different soil nutrient amendments during the minor (a) and major (b) rainy seasons of 2008 and 2009 respectively. (Gs = *G. sepium*, Ss = *S. spectabilis*, Td = *Tithonia*, mf = mineral fertilizer

Table 3.11 Some chemical properties of the soil at the surface (0 -15cm) as affected by the different treatments during the minor season of 2008

Treatments	pH H_2O (1:1)		Total N		Organic C		Available K		Available P		CEC_e ($cmol_c/kg$)	
			g kg^{-1}				mg g^{-1}					
	W_5	W_{16}	W_5	W_{16}	W_5	W_{16}	W_5	W_{16}	W_5	W_{16}	W_5	W_{16}
Control	4.46^{a}	4.89^{b}	1.4^{ab}	1.5^{a}	Nd	13.5^{a}	122.19^{a}	137.3^{a}	6.94^{a}	5.94^{a}	6.11^{a}	6.89^{ab}
Tithonia	4.37^{a}	4.87^{b}	1.5^{ab}	1.7^{ab}	Nd	17.3^{bc}	180.78^{c}	187.5^{d}	9.93^{c}	11.05^{b}	7.07^{ab}	8.08^{b}
S. spectabilis	4.18^{a}	4.56^{ab}	1.6^{b}	2.1^{b}	Nd	19.3^{c}	174.09^{bc}	164.0^{bc}	9.05^{b}	11.46^{bc}	7.03^{ab}	7.20^{ab}
G. sepium	4.37^{a}	5.00^{b}	1.5^{ab}	1.8^{ab}	Nd	15.1^{ab}	187.48^{c}	177.4^{cd}	9.35^{bc}	7.93^{a}	7.60^{b}	7.99^{b}
Mineral fertilizer	4.28^{a}	4.22^{a}	1.3^{a}	1.7^{ab}	Nd	16.8^{abc}	160.70^{b}	150.7^{ab}	15.34^{d}	13.75^{c}	5.97^{a}	6.46^{a}
C.V. (%)	4.9	6.6	11.3	17.0	Nd	12.9	5.9	7.5	4.0	16.2	10.9	11.2

Means with the same superscript in a column do not differ significantly according to DMRT ($p = 0.05$). CEC_e = effective cation exchange capacity, nd = not determined. N = 4.

(b) Total N

Pattern of changes in total N was dissimilar for both cropping seasons. During the minor season, all treatments showed decline in total N concentration at the 5th week which increased at the 16th week of the experiment (Figure 10a). Conversely, total N concentration increased on the 5th week and declined drastically at week 16 during the major season (Figure 3.10b). Statistically, all treatments including the control differed significantly ($p < 0.05$) from mineral fertilizer treatments at week 5 of the minor season, whilst all treatments differed significantly ($p < 0.05$) from the control at week 16 of the same cropping season (Table 3.12). During the major season, treatments did not differ significantly ($p > 0.05$) from the control by ANCOVA test at both weeks 5 and 16 of the experimental period (Table 3.12).

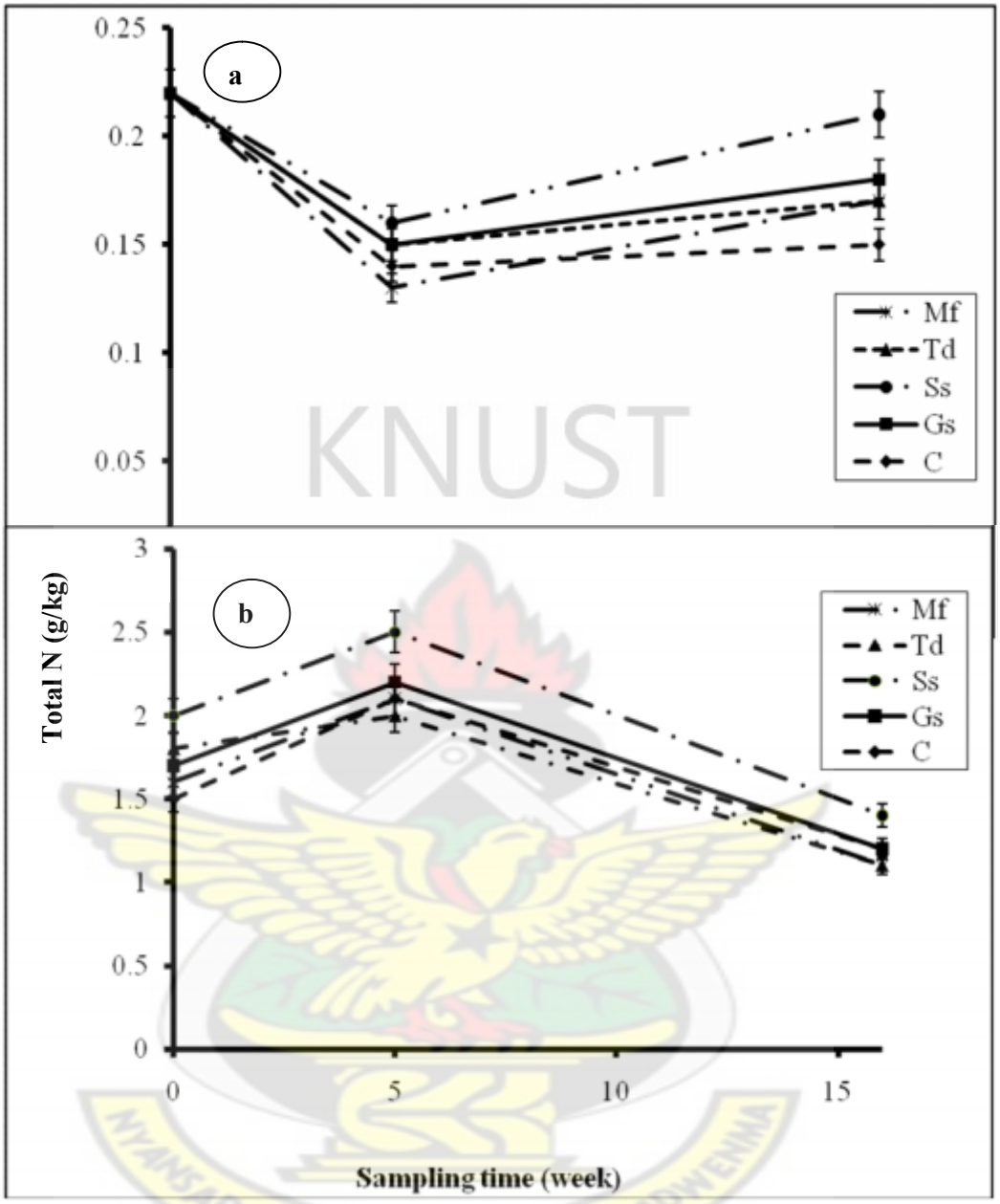

Figure 3.10 Changes in soil total N over 16 weeks as affected by the application of the different soil nutrient amendments during the minor (a) and major (b) rainy seasons of 2008 and 2009 respectively. (Gs = *G. sepium*, Ss = *S. spectabilis*, Td = *Tithonia*, mf = mineral fertilizer, C = control). Data points are the means of four replicates. Error bars are standard error of means.

Table 3.12 Some chemical properties of soil sampled at the surface (0 -15cm) as affected by the different treatments during major seasons of 2009

Treatments	pH H_2O (1:1)*		Total N*		Organic C*		Available K*		Available P*		CEC_e ($cmol_c/kg$)*	
			g kg^{-1}				mg g^{-1}					
	w_5	w_{16}	w_5	w_{16}	w_5	w_{16}	w_5	w_{16}	w_5	w_{16}	w_5	w_{16}
Control	5.18[a]	5.44[a]	2.1[a]	1.2[a]	Nd	12.6[ab]	77.8[a]	73.76[c]	35.22[b]	14.82[a]	7.58[a]	6.21[ab]
Tithonia	5.39[a]	5.50[a]	2.0[a]	1.1[a]	Nd	13.4[ab]	159.1[bc]	46.77[a]	20.99[b]	11.88[a]	3.92[a]	6.24[ab]
S. spectabilis	5.16[a]	5.22[a]	2.5[a]	1.4[a]	Nd	15.4[c]	100.6[a]	73.65[c]	21.23[b]	12.09[a]	3.96[a]	6.28[ab]
G. sepium	5.55[a]	5.40[a]	2.2[a]	1.2[a]	Nd	11.9[a]	188.3[c]	63.55[b]	25.71[b]	10.29[a]	3.15[a]	7.81[b]
Mineral fertilizer	5.52[a]	5.19[a]	2.1[a]	1.1[a]	Nd	11.9[a]	119.7[ab]	60.32[b]	1.61[a]	12.72[a]	7.50[a]	5.13[a]
C.V. (%)	8.9	8.1	10.5	15.9	Nd	12.4	13.4	5.6	11.6	17.9	14.5	20.6

*Means with the same superscript in a column do not differ significantly according to DMRT (p = 0.05). *= data was analyzed using corresponding 2008 data as covariates. CEC_e = effective cation exchange capacity, Nd = not determined. N = 4.*

(c) Soil organic C

Soil organic C (SOC) was determined at the end of each cropping season. At the end of the minor season, ANOVA test showed significant effect of treatments on SOC levels. Generally, SOC increased significantly ($p < 0.05$) with the application of treatments as all treatments generally differed significantly ($p < 0.05$) from the control during this season. In addition, treatments generally differed among each other during the minor season. SOC increased in the order: control < *G. sepium* < fertilizer < *Tithonia* < *S. spectabilis* respectively.

Statistically, ANCOVA test showed significant effect of treatments on SOC levels at the end of he major season trials. Meanwhile, fertilizer and *G. sepium* treated plots did not differ significantly ($p > 0.05$) from the control. With the exception of fertilizer and *G. sepium* amended plots, all treatments generally differed significantly among each other. As observed during the minor season experiment, SOC was highest in *S. spectabilis* treated plots.

(d) Effective cation exchange capacity

Figures 3.11a and 3.11b show the changes in the effective cation exchange capacity (CEC_e) of soils as affected by the different treatments during the minor and major rainy seasons. All figures depicted observable differences in CEC_e among treatments. During the minor season *G. sepium* treatments exhibited a steady increase in CEC_e whilst all treatments fluctuated through time (Figure 3.11a). At week 5 of the minor season, CEC_e values for the amended plots differed significantly ($p < 0.05$) from the control except for fertilizer treatments. At week 16 of the same season, all treatments

including the control differed significantly from mineral fertilizer treatments (Table 3.12). CEC_e recorded for weeks 5 and 16 of the minor season followed the increasing order of fertilizer < control < *S. spectabilis* < *Tithonia* < *G. sepium* and fertilizer < control < *S. spectabilis* < *G. sepium* < *Tithonia* respectively. CEC_e patterns observed during the major season looks comparatively opposite to observations made for total N during the major rainy season (see Figures 3.10a and 3.10b). ANCOVA test did not show significant effect of treatments on CEC_e on the 5^{th} week of the major season. However, all treatments including the control differed significantly from fertilizer treatments at week 16 of the major season. Furthermore, CEC_e was determined to be significantly ($p < 0.05$) correlated to pH during the major season (Figure 3.12).

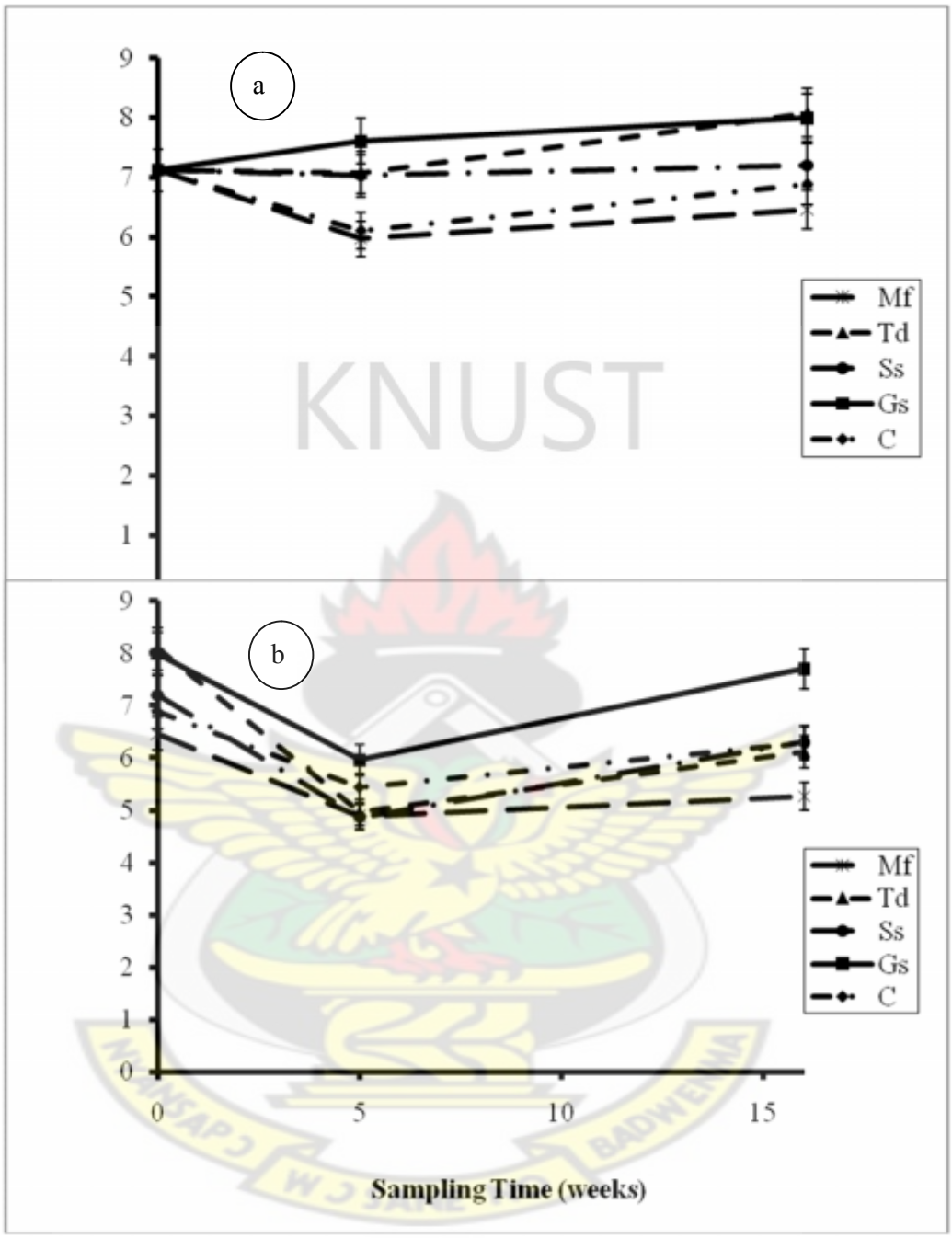

Figure 3.11 Changes in CEC_e as affected by different soil amendments during the minor (a) and major (b) rainy seasons of 2008 and 2009 respectively. (Gs = *G. sepium*, Ss = *S. spectabilis*, Td = *T. diversifolia*, mf = mineral fertilizer, C = control). Data points are the means of four replicates. Error bars are standard error of means.

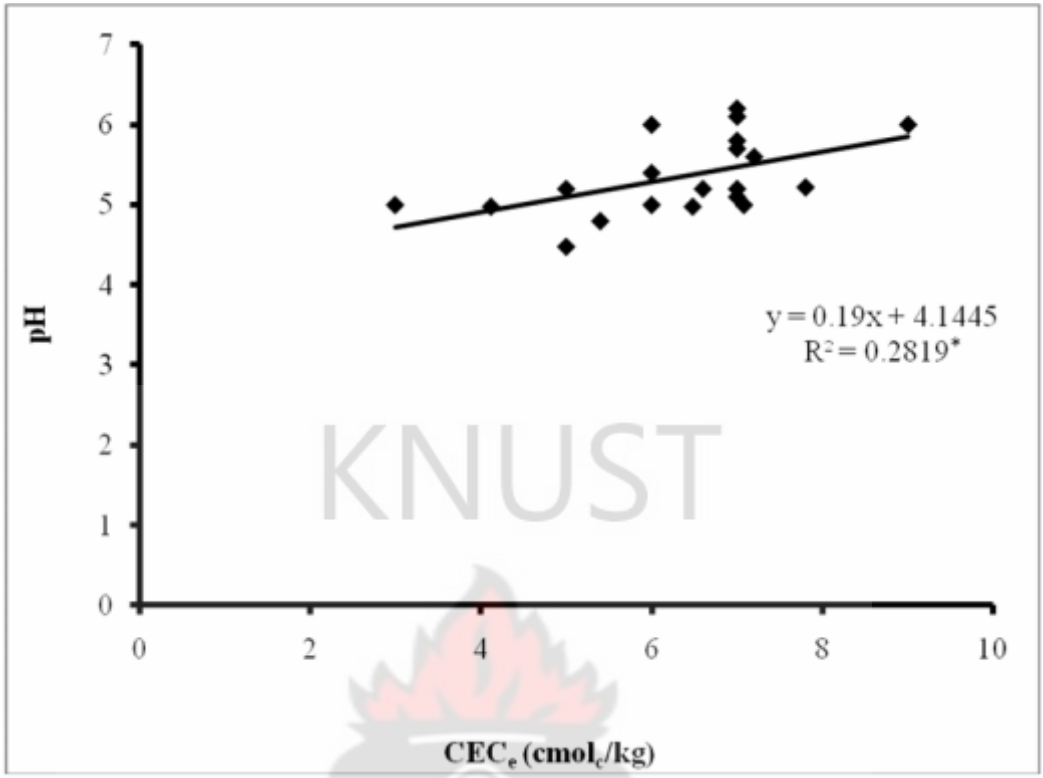

Figure 3.12 Relationship between pH and CEC_e during the major season of 2009

(e) Available K

The dynamic pattern of available K levels during the minor season was similar to that of total N during the same season. Available K levels during this season declined in all treatments at week 5 of the experiment which increased slightly in virtually all treatments at week 16 (Figure 3.13a). At both sampling periods, treatment effect on available K status was significant with treatments differing significantly ($p < 0.05$) from the control. Available K levels were highest in *G. sepium* at week 5 but highest in *Tithonia* amended plots at week 16 during the minor season (Figure 3.13a). During the major season of 2009, all treatments recorded gradual decline in available K through time. Declination was very drastic in *G. sepium*, *Tithonia* and fertilizer treatments (Figure 3.13b). Effect of treatments on available K level was significant ($p < 0.05$) at both weeks 5 and 16 of the experiment. All treatments rather than *S.*

spectabilis differed significantly ($p < 0.05$) from the control at week 5. At week 16, all treatments including the control differed significantly from *Tithonia* treatments. There was a significant ($p = 0.05$) positive correlation between available K and total N during the major season (Figure 3.14).

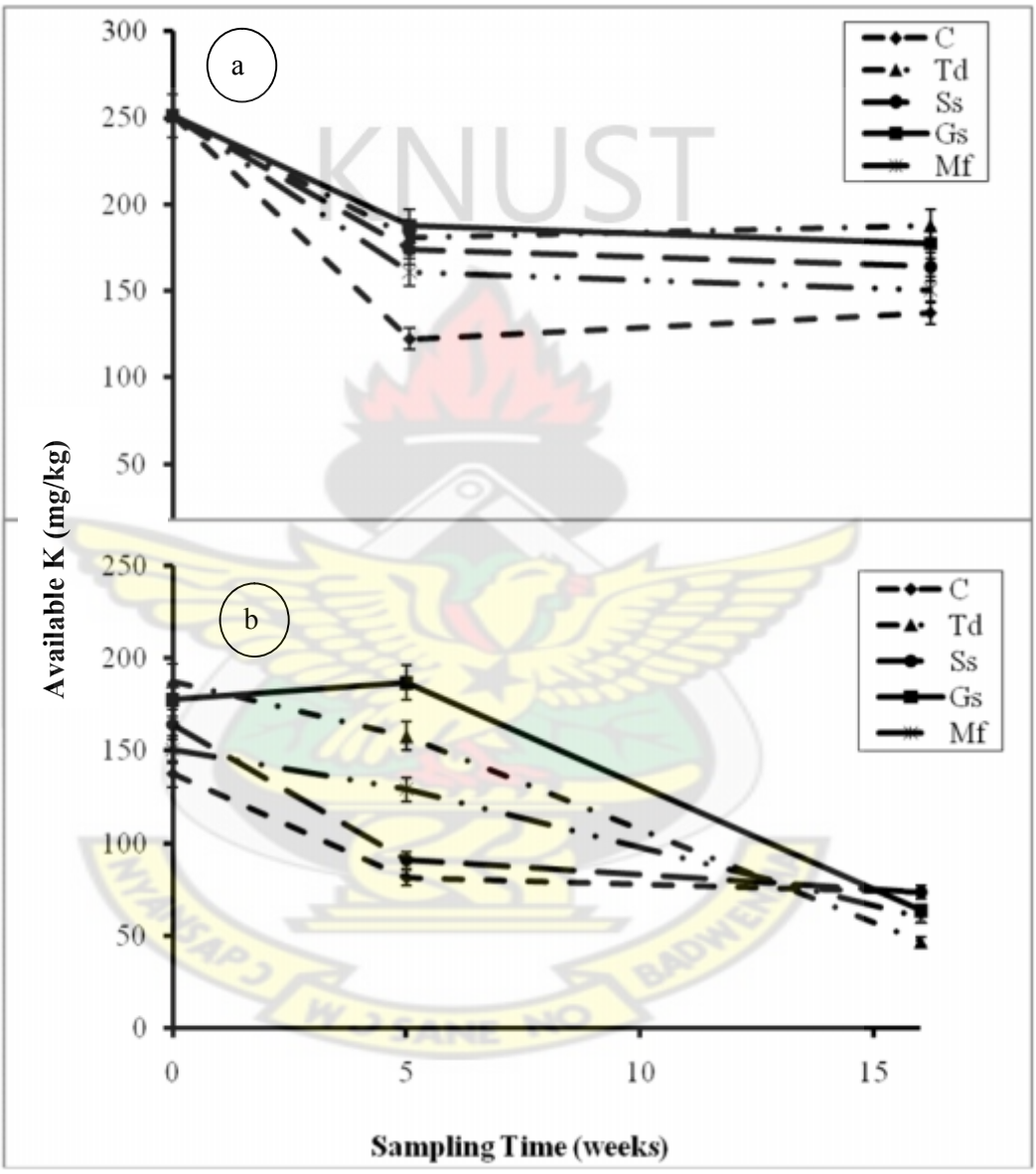

Figure 3.13 Changes in available K as affected by different soil amendments during the minor (a) major (b) rainy seasons of 2008 and 2009 respectively (Gs = *G. sepium*, Ss = *S. spectabilis*, Td = *Tithonia*, mf = mineral fertilizer, C = control).

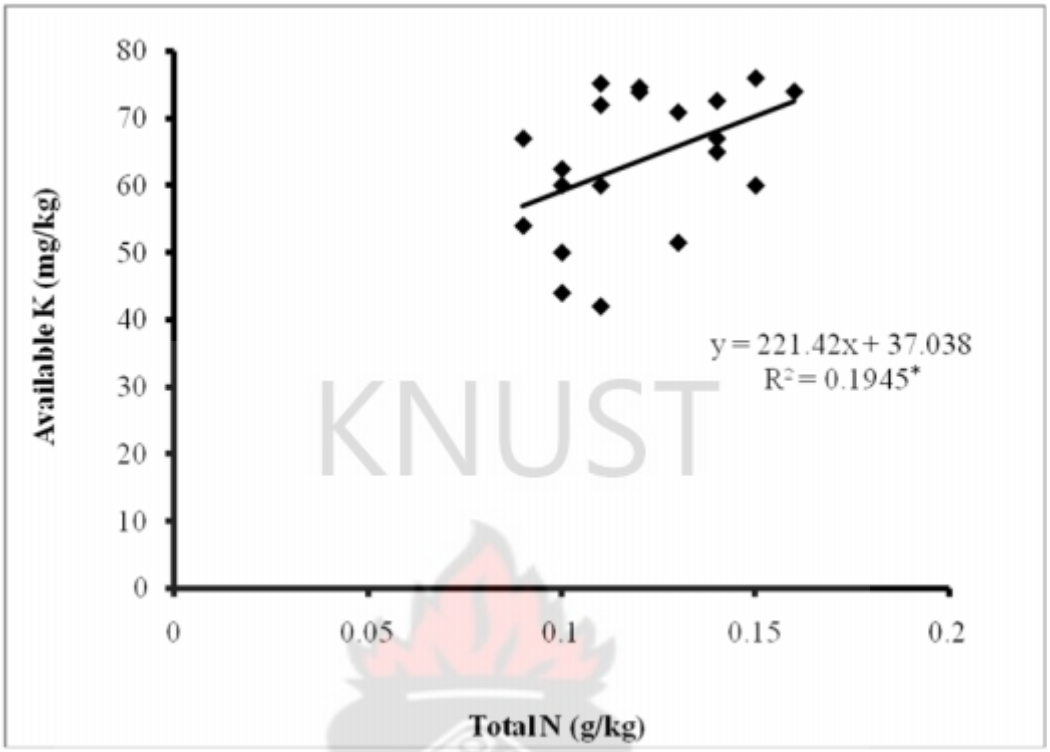

Figure 3.14 Relationship between available K and total N during the major season

(f) Available P

The application of treatments, increased phosphorus availability at the 5th week of both the minor and major seasons of 2008 and 2009 respectively. All treatments with the exception of *S. spectabilis* and *Tithonia* recorded a slight decline in available P between the 5th and 16th weeks during the minor season experiment (Figure 3.15a). Phosphorus availability in the amended plots differed significantly ($p < 0.05$) from the control at both weeks 5 and 16 in the minor season experiment (except for *G. sepium* which did not differ significantly from the control at week 16). During the major season of 2009, there was a drastic rise and fall in available P in most of the treatments (Figure 3.15b). Meanwhile, all treatments including the control differed significantly from fertilizer treatments at week 5 of the experiment. In addition,

ANCOVA test did not show significant effect of treatments on available P levels on the 16th week (Table 3.12). Available P was recorded to have a significant correlation with SOC ($p < 0.05$) (Figure 3.16) and pH ($p < 0.01$) (Figure 3.17).

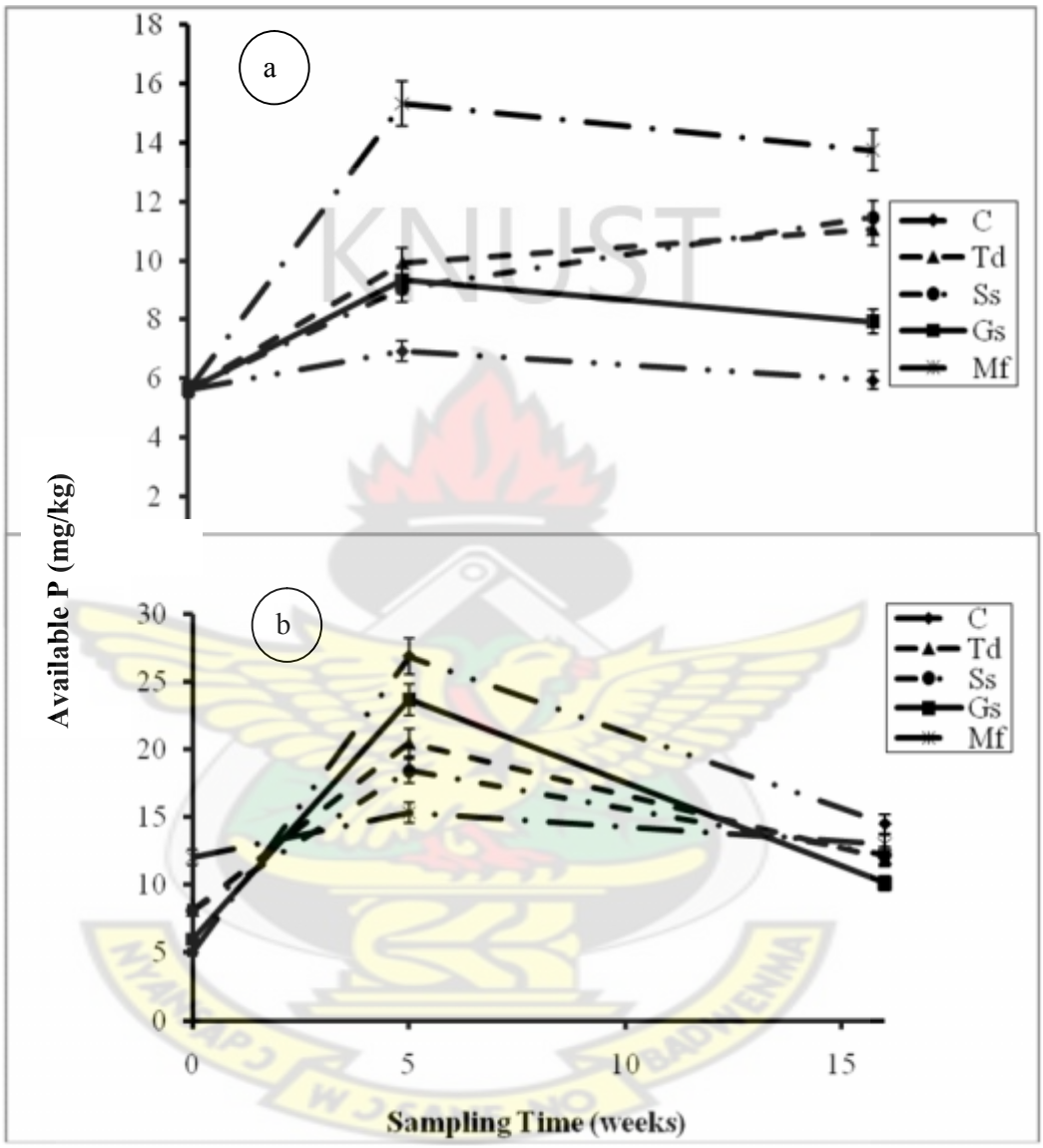

Figure 3.15 Changes in available P as affected by different soil amendments during the minor season (a) of 2008 and major rainy season (b) of 2009 (Gs = *G. sepium*, Ss = *S. spectabilis*, Td = *Tithonia*, mf = mineral fertilizer, C = control). Data points are the means of four replicates. Error bars are standard error of means.

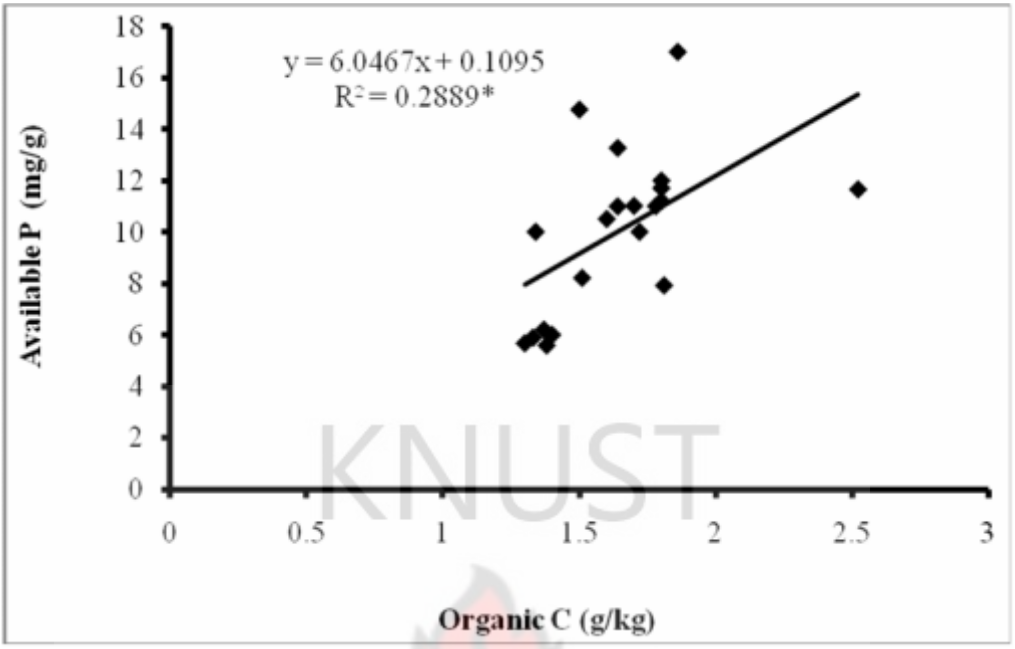

Figure 3.16 Relationship between organic C and available P during the minor season of 2008. * = significant at 5% probability level

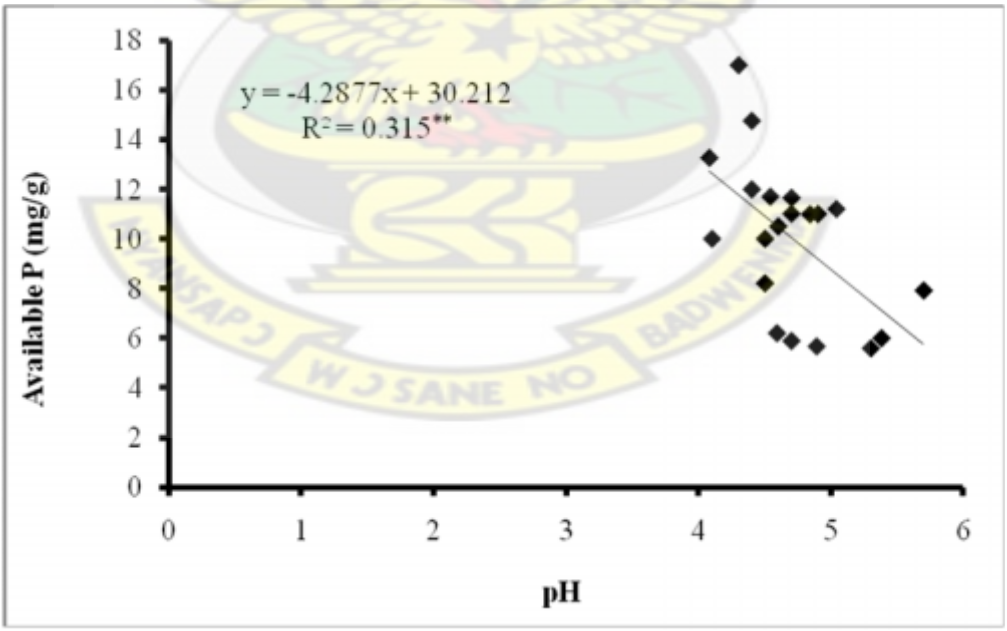

Figure 3.17 Relationship between pH and available P during the minor season of 2008. ** = significant at 1% probability level.

Available P was determined to be significantly ($p < 0.05$) correlated to CEC_e during the major rainy season (Figure 3.18).

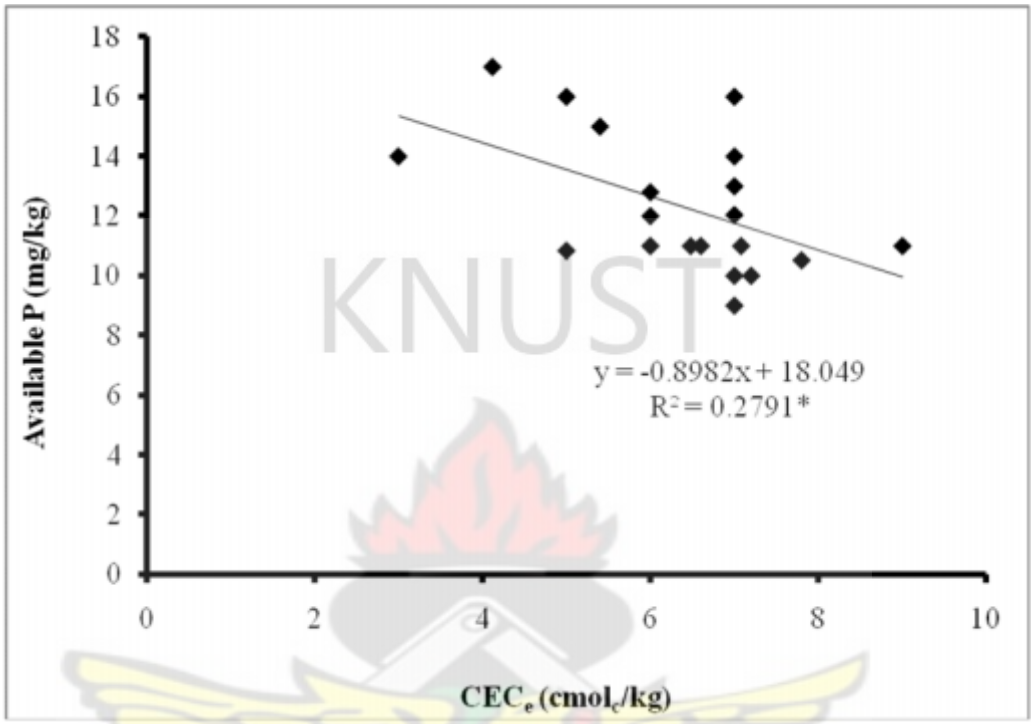

Figure 3.18 Relationship between CEC_e and available P during the major season of 2009. * = significant at 5% probability level.

(g) Soil Microbial Biomass C, N and P

During the minor season, microbial biomass C on amended plots (MBC) significantly differed ($p < 0.001$) from the control and among treatments (Table 3.13). The greatest MBC (1160 mg/kg) was recorded in plots treated with *Tithonia* green manure. In the major season, all treatments including the control differed significantly ($p < 0.001$) from mineral fertilizer treatments. The highest MBC (1410 mg/kg) during this period was recorded in plots treated with *S. spectabilis* green manure.

Effect of treatments on soil microbial biomass N (MBN) was tested significant (p = 0.001) during the minor season with the highest MBN (140 mg/kg) recorded in plots treated with *G. sepium* green manure. Plots treated with *Tithonia, S. spectabilis* and *G. sepium* differed significantly (p = 0.001) from the control and fertilizer treated plots during this period. In the major season, only *G. sepium* treated plots differed significantly from the control. All other treatments including the control recorded the same level (100 mg/kg) of MBN. During the two cropping seasons, the effect of treatments on the ratio of MBC to MBN (MBC: MBN) was also recorded. Treatments had significant ($p < 0.01$) effect on MBC: MBN ratio in both seasons. In both seasons, *G. sepium* recorded the lowest MBC: MBN ratio. MBC: MBN ratio decreased in the order fertilizer > control > *S. spectabilis* > *Tithonia* > *G. sepium;* and *S. spectabilis* > *Tithonia* > *control* > *fertilizer* > *G. sepium* in the minor and major seasons respectively.

As shown in Table 3.13, microbial biomass P (MBP) recorded in treated plots was not significantly ($p > 0.05$) different from the control during the minor season. However, during the major rainy season, all treatments differed significantly ($p < 0.05$) from the control. The decreasing order of MBP recorded during this period was: *Tithonia* > *G. sepium* > *S. spectabilis* > *mineral fertilizer* > *control.*

In both seasons, microbial biomass (C, N, and P) were significantly correlated either among themselves or with other soil properties (Table 3.14).

Table 3.13 Soil microbial biomass (C, N and P) and the microbial biomass C and N ratio in soils as affected by different nutrient sources during the minor and major rainy seasons of 2008 and 2009 respectively

Treatments	Minor season				Major season			
	MBC	MBN	MBP	MBC: MBN	MBC	MBN	MBP	MBC: MBN
	(mg kg^{-1} of soil)				(mg kg^{-1} of soil)			
Control	850^{a}	79^{a}	9.57^{a}	10.76^{bc}	1100^{ab}	100^{a}	9.0^{a}	11.0^{b}
Tithonia	1160^{c}	130^{b}	9.17^{a}	8.92^{ab}	1260^{bc}	100^{a}	19.7^{c}	12.60^{bc}
S. spectabilis	1090^{b}	120^{b}	8.85^{a}	9.08^{abc}	1410^{c}	100^{a}	14.6^{b}	14.10^{c}
G. sepium	1130^{bc}	140^{b}	9.89^{a}	8.07^{a}	1100^{ab}	200^{b}	16.2^{b}	5.50^{a}
Mineral fertilizer	910^{a}	80^{a}	8.85^{a}	11.38^{c}	1000^{a}	100^{a}	14.0^{b}	10.0^{b}
C.V. (%)	4.1	16.2	13.7	16.7	8.5	17.7	13.4	17.6

Means with the same superscript in a column do not differ significantly according to DMRT (p = 0.05). MBC = microbial biomass carbon, MBN = microbial biomass N, MBP = microbial biomass phosphorus. N = 4.

Table 3.14 Pearson correlation coefficient (r) for the relationship between soil microbial and chemical properties during the minor and major rainy seasons

	MBC	MBN	MBC: MBN	MBP
Minor season				
MBC	1			
MBN	0.828***	1		
MBC: MBN	-0.60**	-0.915***	1	
MBP	0.062	0.449*	-0.537*	1
Organic C	0.462*	0.272	-0.162	-0.034
CEC_e	0.437*	0.455*	-0.381	0.154
Total N	0.209	0.013	0.141	-0.558**
Available K	0.746***	0.778***	-0.667***	0.131
Major season				
MBC	1			
MBN	-0.190	1		
MBC: MBN	0.574**	-0.852***	1	
MBP	0.347	0.138	0.104	1
Organic C	0.781***	-0.177	0.472*	0.083
Available P	-0.293	-0.387	0.099	-0.509*
CEC_e	0.208	0.650**	-0.389	0.109
Total N	0.326	-0.30	0.445*	-0.046
Available K	0.073	-0.005	0.069	-0.680***

*MBC = microbial biomass carbon, MBN = microbial biomass N, MBP = microbial biomass phosphorus, CEC_e = effective cation exchange capacity. * = $p \leq 0.05$, ** $p \leq 0.01$, *** = $p \leq 0.001$*

3.2.2.4 Effects of treatments on agronomic characteristics of okro plants

(a) Height and stem diameter

The effect of treatments on the height and stem diameter of okro plants were investigated during the minor and major seasons of 2008 and 2009 respectively. For all two cropping seasons, amended plots differed significantly ($p < 0.05$) from the control in height and diameter recordings. The highest height measurement was observed in *Tithonia* treated plots in both seasons. The increasing order of mean height recorded for the two cropping seasons were the same: control < *G. sepium* < mineral fertilizer < *S. spectabilis* < *Tithonia* (Table 3.15). Meanwhile, stem diameter in the minor season was highest in *S. spectabilis* and followed the order: Control < mineral fertilizer < *G. sepium* < *Tithonia* < *S. spectabilis*. This order was different from observations made in the major season: C < mineral fertilizer < *G. sepium* < *S. spectabilis* < *Tithonia*.

Table 3.15 Height and stem diameter measurements of okro plants as influenced by treatments during the minor and major cropping seasons of 2008 and 2009 respectively

Treatments	Minor season		Major season	
	Height (cm)	Stem diameter (mm)	Height† (cm)	Stem diameter† (mm)
Control	24.22[a]	7.77[a]	21.03[a]	6.21[a]
Tithonia	37.80[b]	11.51[bc]	63.60[c]	15.46[b]
S. spectabilis	36.62[b]	12.25[c]	56.16[bc]	13.57[b]
G. sepium	33.84[b]	10.88[bc]	49.10[b]	13.38[b]
Mineral fertilizer	36.55[b]	10.54[b]	50.71[bc]	12.76[b]
C.V. (%)	17.4	8.1	15.0	9.6

†analyzed using height and stem diameter data of minor season as covariates.

Means with the same superscript in a column do no differ significantly according to DMRT ($p = 0.05$). C.V. = coefficient of variation. N = 4.

(b) Leaf area index

Table 3.16 shows the effect of treatments on the leaf area index (LAI) of the okro plants at flowering for the two cropping seasons. LAI recorded for all treatments was significantly different from the control ($p < 0.05$). LAI was fairly constant among some treatments (Table 3.16).

Table 3.16 Leaf area index of okro plants as influenced by treatments during the minor and major cropping seasons of 2008 and 2009 respectively

Treatments	Minor season	Major season
	LAI	LAI†
Control	0.11[a]	0.15[a]
Tithonia	0.19[b]	0.24[c]
S. spectabilis	0.25[c]	0.22[bc]
G. sepium	0.14[ab]	0.19[b]
Mineral fertilizer	0.18[b]	0.18[ab]
C.V. (%)	18.9	10.2

†analyzed using LAI data of minor cropping season as covariates. N =4.

Means with the same superscripts do no differ significantly according to DMRT (p = 0.05). C.V. = coefficient of variation, LAI = specific leaf area index.

(c) Dry matter production

The effect of treatments on the above-and below-ground biomass of the okro plants were recorded at flowering during both cropping seasons. Treatments had significant ($p < 0.001$) effect on both above- and below-ground biomass in both seasons. In both seasons, treatments differed significantly from the control (Table 3.17). During the minor season, above and below-ground biomass increased in the order: control < *S. spectabilis* < mineral fertilizer < *Tithonia* < *G. sepium* and control < *S. spectabilis* < mineral fertilizer < *G. sepium* and *Tithonia* respectively. In the major season, the highest above-and below-ground biomass was recorded in *Tithonia* treated plots.

Table 3.17 Aboveground (ABG) and belowground (BG) dry matter production of okro plants as influenced by treatments during the minor and major cropping seasons of 2008 and 2009 respectively

Treatments	Minor season		Major season	
	ABG	BG	ABG†	BG†
	kg dry matter ha^{-1}			
Control	192.6^{a}	41.1^{a}	46.8^{a}	54.2^{a}
Tithonia	465.4^{c}	95.5^{c}	1240.6^{c}	171.3^{d}
S. spectabilis	326.4^{b}	71.8^{b}	770.2^{b}	142.0^{cd}
G. sepium	474.7^{c}	88.4^{bc}	1106.7^{bc}	132.7^{bc}
Mineral fertilizer	400.8^{bc}	81.6^{bc}	901.4^{bc}	107.6^{b}
C.V. (%)	13.9	14.9	16.1	10.7

†analyzed using aboveground and belowground data of minor cropping season as covariates. Means with the same superscripts do not differ significantly according to DMRT ($p \leq 0.05$). C.V. = coefficient of variation. N = 4.

(d) Nutrient uptake and recovery

Nutrient (N, P and K) uptake in the above-ground biomass of okro plants increased with increasing nutrient addition. Nitrogen, P and K recovery were highest in *G. sepium* treated plots among all treatments. The percentage of N, P and K recovered ranged from 28 to 88; 12 to 65 and 1 to 23 respectively. In addition, Phosphorus and K recovered in the above-ground biomass of the okro plants were lowest in mineral fertilizer treated plots among treatments (Table 3.18).

Table 3.18 Nutrient taken up and recovered in total aboveground biomass of okro plants at flowering as affected by the different treatments during the minor season

Treatments	Nutrients added (kg ha^{-1})			Nutrient uptake (kg ha^{-1})			Nutrient recovery (%)		
	N	P	K	N	P	K	N	P	K
Control	0	0	0	60.7	6.4	4.8	NA	NA	NA
Tithonia	150	18.9	27.9	144.6	15.4	10.7	56	47	21
S. spectabilis	135	11.7	24.3	98.8	9.1	6.9	28	23	8
G. sepium	131	13.5	28.8	176.5	15.2	11.5	88	65	23
Mineral fertilizer	150	100	100	154.1	18.2	5.6	62	12	1
SED				17.5	1.8	1.1	12	4.9	4.28

NA = not applicable, SED = standard error of difference. N = 4.

(e) Yield

In all cropping seasons, yield of okro increased with the application of the soil amendments as yields recorded for treatments differed significantly ($p < 0.001$) from the control. In most treatments, yields were as much as twice that of the control. The sum of the yields recorded in both seasons increased in the order: control < *S. spectabilis* = mineral fertilizer < *G. sepium* < *Tithonia* (Table 3.19). The highest (200%) and lowest (150%) relative yield increment was recorded in *S. spectabilis* and mineral fertilizer during the minor season. During the major season the trend was different: the highest (130%) and lowest (50%) relative yield increment was recorded in *Tithonia* and *S. spectabilis* respectively (Figure 3.19).

Table 3.19 Effects of different soil amendments on yield of okro

Treatments	Minor season	Major season†	Total†
	Yield (t ha^{-1})		
Control	0.6^{a}	1.0^{a}	1.6^{a}
Tithonia	1.7^{c}	2.3^{b}	4.1^{c}
S. spectabilis	1.8^{c}	1.5^{ab}	3.3^{b}
G. sepium	1.6^{bc}	2.1^{b}	3.7^{c}
Mineral fertilizer	1.5^{b}	1.8^{ab}	3.3^{b}
C.V	10.4	12.9	8.6

†analyzed using yield in minor season as covariate. Means with the same superscripts do no differ significantly according to DMRT ($p \leq 0.05$). C.V. = coefficient of variation. N = 4.

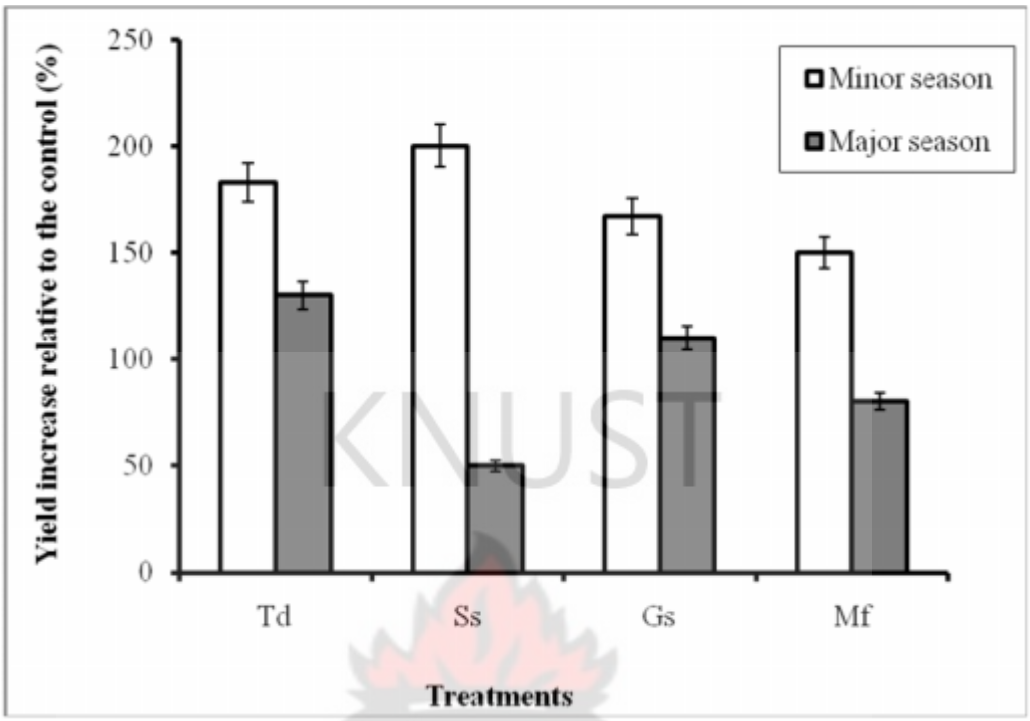

Figure 3.19 Okro yields expressed as percent yield increase relative to the control for the minor and major rainy seasons of 2008 and 2009 respectively. Error bars represent mean differences at 5% probability level.

3.2.3 Discussion and conclusion

As expected, differences in the effect of the various treatments on soil properties, nutrient recovery and agronomic characteristics of okro plants in the experiment reflected the apparent differences in the biochemical characteristics of the soil amendments applied. In all cases, the study confirmed the beneficial effects of soil amendments in cropping systems; particularly *Tithonia* which is rarely used in soil fertility improvement practices in Ghana. As observed, higher inputs of C, N, P, and K generally resulted in increased soil organic C and N, available P and K, CEC_e and soil microbial biomass in all cropping seasons. For instance at the end of the minor season experiment, all treatments differed significantly from the control in total N,

organic C, available P and K contents of the soil (Table 3.11). This result was similar to observations made during the major season trials. As can be observed in Tables 3.11 and 3.12, fertilizer treated plots generally had low CEC_e at the end of each cropping season compared to the other amendments. This indicates potential condition for nutrient unavailability for subsequent cropping as fertilizers are easily leached from the surface soil compared to organic materials. Most of the soil properties investigated were significantly correlated indicating the dependency of one property over the other.

Plots treated with organic materials generally showed increase in pH compared to the control and fertilizer treated plots. However, pH increment was quite dominant in *Tithonia* plots. Reading from Tables 3.11 and 3.12, unit increment in soil pH from the 5^{th} to the 16^{th} week of the minor season, and pH levels at the end of the major season experiment were highest in *Tithonia.* High pH units associated with the application of *Tithonia* biomass has been previously observed by Phan Thi Cong (2000) and George *et al*. (2002) in Vietnam and Kenya respectively. Increased pH levels with *Tithonia* biomass application have been attributed to the high concentration of Ca in its biomass (Ikerra *et al*., 2006). In addition, Parffit (1978) attributed such observations to the displacement of hydroxyls from sesquioxide surfaces by organic anions. Ikerra (2004) confirms from Parffit's assertion that *Tithonia* contained relatively high concentrations of organic acids like oxalic and tartaric, and these could have participated in such displacement reactions.

Results from the experiment demonstrated that difference in C inputs (including quantity and quality) can significantly impact microbial biomass. Over the

experimental period, organic amendments generally increased soil microbial biomass C, N and P as compared to the control and mineral fertilizer treated plots. Increased microbial biomass by organic C inputs has been well documented in various organic substrates such as green manures, cattle manure compost, saw-dust compost and rice husk compost (Goyal *et al*., 1999; Chowdhury *et al*., 2000), wheat straw and farmyard manure (Goyal *et al*., 1999), dairy shed effluent (Zaman *et al*., 1999), and municipal solid waste compost and cow manure (Garcı´a-Gil *et al*., 2000; Peacock *et al*., 2001). However, various qualities of organic substrates may differentially impact soil microbes since substrate composition has profound influences on microbial utilization of C and nutrients in the substrate (Tu *et al*., 2006; Cheshire and Chapman, 1996; Martens, 2000). This may account for the differential effects of the various treatments on soil microbial biomass. Meanwhile, the significance of C inputs for increased soil microbial biomass was confirmed in the results of this study as per the significant correlation observed between MBC and organic C during both cropping seasons (Table 3.14). This significant interaction explains why the effects of mineral fertilizer on microbial biomass (C, N and P) were less significant, obviously because extractable C inputs were nil although N, P and K inputs were high in the fertilizer applied. Further, since the application of easily decomposable organic materials with a significantly low total C/N ratio is associated with enhanced soil microbial biomass in cropping systems (Smith and Paul, 1990), it was undoubted to observe the highest MBC and a comparable MBN and MBP in *Tithonia* treated plots. According to several authors (Zaman *et al*., 1999; Tu *et al*., 2006; Wang *et al*., 2004), differences in soil microbial biomass under different organic amendments may have implications for nutrient availability to crops. This is because high microbial biomass often leads to high nutrient availability to crops through

enhancing both the microbial biomass turnover and the degradation of non-microbial organic materials. The authors' assertions are confirmed by the significant interaction obtained between soil microbial biomass parameters and CEC_e, available K, available P and Total N (Table 3.14).

The highest and comparable growth parameters (height, stem diameter, LAI and dry matter production) and yield observed in *Tithonia* treatments during the experimental trials are due to a faster nutrient release patterns of *Tithonia* green manure compared with the other organic amendments; especially *S. spectabilis* characterized as a low quality material due to its relatively slow decomposition and nutrient release patterns (Gachengo *et al*., 1999). Nitrogen availability seemed to play a major part in determining the yield of okro plants as per the results of this study. This is seen in the significant positive correlation obtained when yield was regressed on the amount of N added from the treatments (Figure 3.20). Although nutrients in fertilizers could be more readily available, the fate of these nutrients is generally low especially during heavy rains compared to organic materials. It is no doubt total yields from both seasons tended to be significantly low in fertilizer and *S. spectabilis* treatments compared to *Tithonia* and *G. sepium* (Table 3.19). The okro plants recovered a higher percentage of the N, P and K added from *G. sepium* green manure compared to the other treatments. Nutrient recovered from *Tithonia* followed closely to *G. sepium* and was higher than fertilizer treated plots which received the highest N, P and K inputs. This observation supports the idea that the quality of the organic input, not just the amount of nutrients added, affects nutrient availability patterns and crop growth (Gachengo *et al*., 1999). The lower recovery of nutrients particularly P and K

from fertilizer treatments may be a result of leaching losses that resulted in a lack of synchrony between crop nutrient demand and supply by the soil.

It can be concluded from the results of this study that nutrient availability in the right quantity, ratio and also in synchrony with crop nutrient demands is a requirement for higher yields which in most cases depend directly on the quality and quantity of the amendment applied. The application of the soil amendments particularly the organic materials markedly increased crop yields compared to the control. The study confirms that the application or adoption of *Tithonia* in agroforestry practices particularly for soil fertility improvement will be one viable option for diversifying crop productivity especially for smallholder agriculture. As observed, the application of *Tithonia* green manure increased crop yields twice the control in both cropping seasons. Yields recorded for *Tithonia* treated plots were also comparatively higher than fertilizer treatments. Smallholder farmers who are compelled to cultivate poor soils due to limited affordability and availability of inorganic fertilizers can therefore count on *Tithonia* as a potential source of nutrients for improved resilience of soil productivity and crop yields.

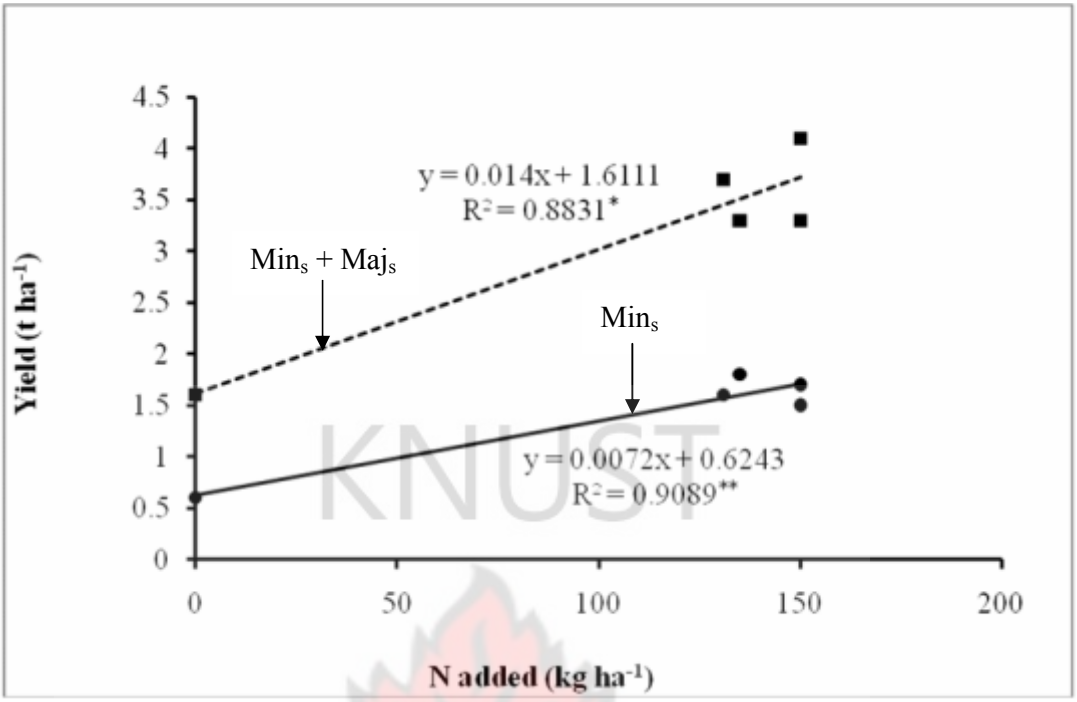

Figure 3.20 Okro yields in relation to N added from soil amendments for the minor season and the sum of the minor and minor season. Min_s = minor season, Maj_s = major season

3.3 Experiment III: Effect of pruning frequency and cutting height on the biomass production of *T. diversifolia*

3.3.1 Materials and Methods

3.3.1.1 Study site

The study was conducted at the Department of Horticulture of the Kwame Nkrumah University of Science and Technology, Kumasi (KNUST), Ghana. The area falls within the moist semi-deciduous forest zone of Ghana and receives a bimodal rainfall, with the major wet season between May and July. This area experiences two dry periods: in August and in December to March. The annual rainfall ranges between 1200 mm to 1500 mm with a mean annual temperature of 26.6 ^{o}C and a mean annual humidity of 67.6%. The soils are classified as ferric acrisol (FAO, 1988) with a sandy-loam textural class. Climatic data and some chemical and physical properties of the soil at the study site are reported in Figure 3.21 and Table 3.20 respectively.

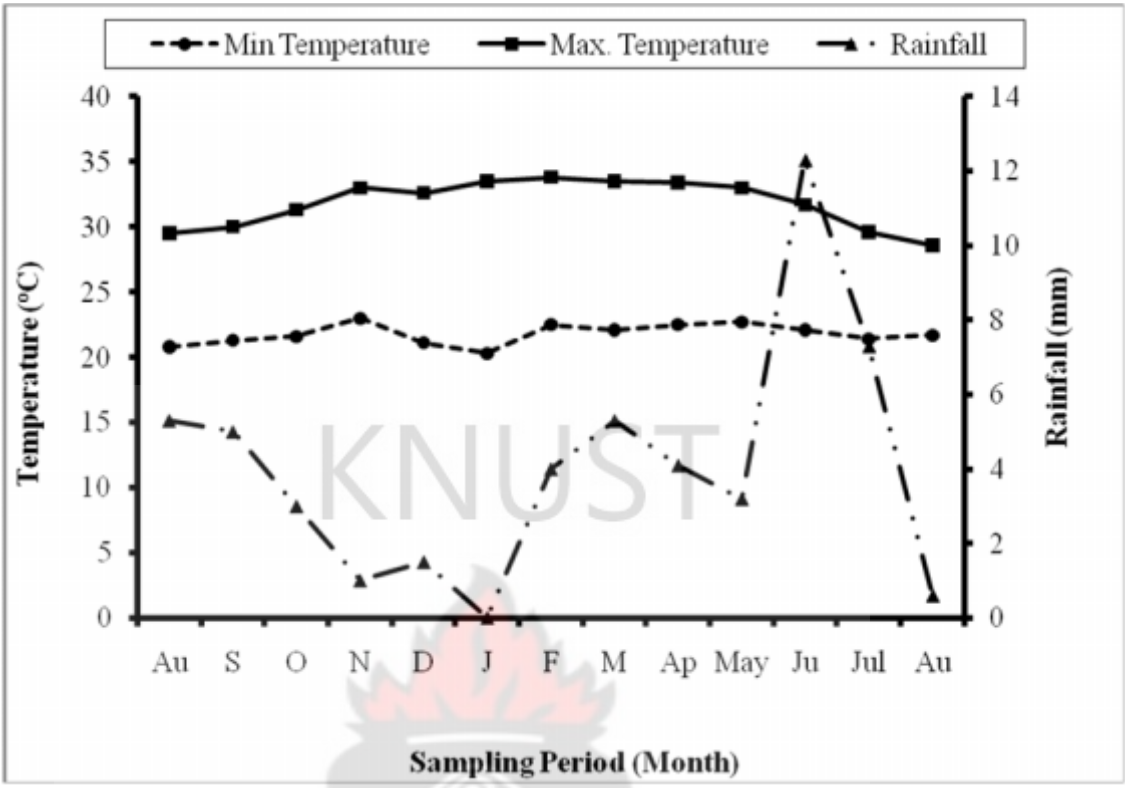

Figure 3.21 Climatic data at study site during the experimental period. Au = August, S = September, O = October, N = November, D = December, J = January, F = February, M = March, Ap = April, Ju = June, Jul = July

Table 3.20 Some chemical and physical properties of the soil (at the surface 0 - 20cm) at the experimental site

Parameter	Value
pH (H_20) (1:1)	6.1
Organic C (g/kg)	22.8
Organic matter (g/kg)	39.3
Total N (g/kg)	2.0
Available Bray-1 P (mg/kg)	2.2
Available Bray-1 K (mg/kg)	113.8
Exchangeable cations ($cmol_c$/kg)	
Ca	8.5
Mg	0.8
K	0.4
Na	0.2
Exchangeable Acidity (Al + H) ($cmol_c$/kg)	
CEC_e ($cmol_c$/kg)	10.1
Base saturation (%)	98.5
Texture (%)	
Sand	60.4
Silt	35.5
Clay	4.1
Textural class	Sandy-loam

3.3.1.2 Experimental design and sampling procedure

Established stands of *T. diversifolia* at the Department of Horticulture, KNUST were used for this experiment. *Tithonia* plants used in the experiment were five years old before biomass harvests began in 2008. *Tithonia* plants were planted at a 1 m x 1 m spacing with ten (10) plants per treatment. Treatments were separated by a row of five *Tithonia* plants as buffers. The experiment was arranged in a split-plot design

with treatments randomly arranged in four blocks. Treatments consisted of three cutting heights (which were 25 cm, 50 cm and 100 cm above the ground and coded as H1, H2, and H3 respectively) and three cutting frequencies (2-, 4-, and 8-week interval as F1, F2, and F3 respectively). Cutting height (CH) represented whole-plot treatments whilst pruning frequency (PF) was designated as sub-plot treatment.

When the study began, mean shrub height was 2.3 m. All *Tithonia* plants were initially cut back to the designated cutting height treatment and the pruning frequency treatments were subsequently imposed. At each subsequent cutting, all coppice sprouts on the stumps were cut back to within 1cm of the stump. Number of shoots and fresh weight of the coppice production (green stems and leaves) were recorded after each cutting. Subsamples from each plot were taken to the laboratory and oven-dried at 65 ^{o}C to constant weight. Percentage dry weight of the original fresh weight was used to determine total plot dry matter. Yield (production) assumed a plant density of 5000/ha (which is derived from a typical alley cropping spacing of 0.5 m x 4 m) (Erdmann *et al*., 1993).

3.3.1.3 Statistical Analysis

Data on shoot number and dry matter production were analyzed using general analysis of variance procedures in GENSTAT 11.1 (VSN International, 2008). Treatment means were compared using least significant difference ($p = 0.05$). Multiple linear regression models were fitted to determine if cutting frequency and cutting height were significantly ($p = 0.05$) correlated to shoot development and dry matter production.

3.3.2 Results

3.3.2.1 Shoot number

Pruning frequency and its interaction with cutting height significantly ($p < 0.001$) influenced mean shoot number. Shoot production tended to be highest (19.7) at H2 and lowest (17.3) at H3. With respect to pruning frequency, mean number of shoots decreased with decreasing pruning frequency: F3 (14.7) < F2 (18) < F1 (22.3). The cutting height by pruning frequency interaction, indicated that pruning frequencies F1, F2, and F3 favoured shoot production in H2, H1, and H3 respectively (Fig. 3.22). Multiple regression analysis showed there was a significant correlation ($p < 0.001$, $r^2 = 0.64$) between pruning frequency and shoot production.

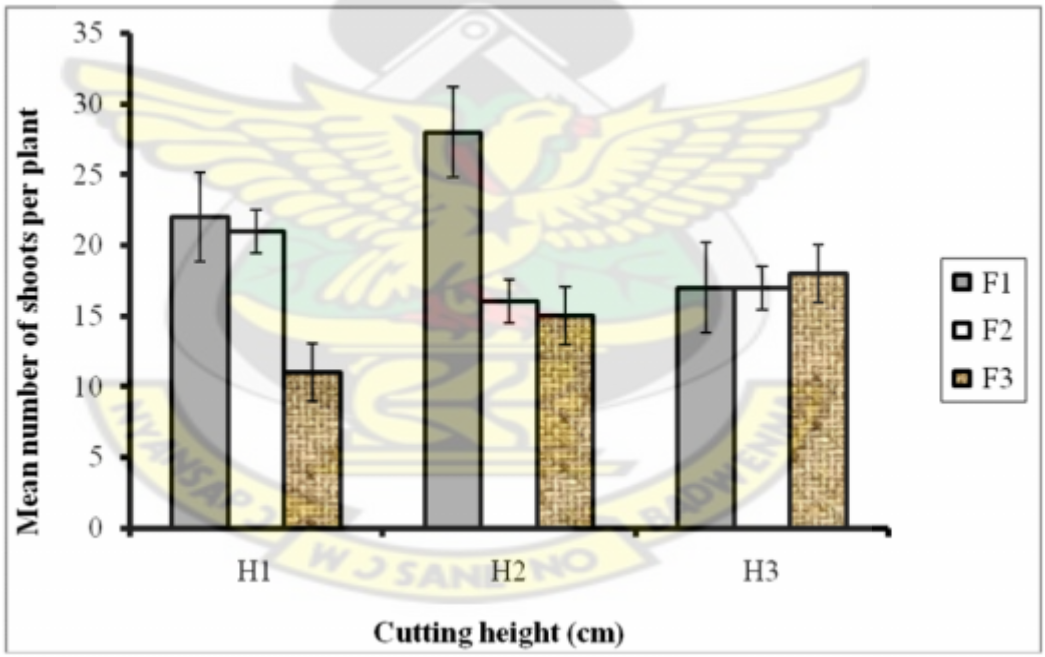

Figure 3.22 Mean number of shoots as affected by different pruning frequencies at different cutting heights.. H1 = 25 cm, H2 = 50 cm, H3 = 100 cm, F1 = 2-week interval, F2 = 4-week interval, F3 = 8-week interval. Data points are the means of four replicates. Error bars represent standard error of means.

3.3.2.2 Biomass production

Analysis of variance test showed significant ($p < 0.001$) effect of pruning frequency, cutting height, and their interaction on the dry matter production of *T. diversifolia.* Regardless of cutting heights and pruning frequencies, dry matter content (in leaves + stems) ranged between 10 – 20% of fresh weight. All pruning height treatments markedly decreased biomass production from the 2nd to the 8th week of the experiment at F1 (Fig. 3.23). Although there was a rise in biomass production (particularly at H3) after 8 weeks, signs of mortality were prevalent among treatments after 12 weeks.

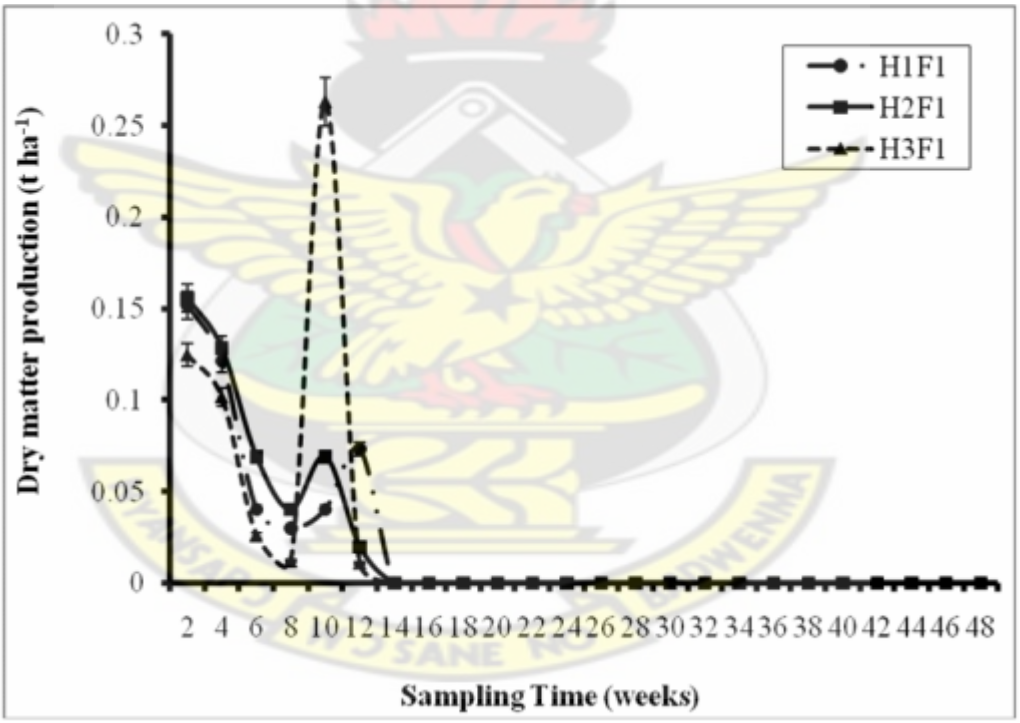

Figure 3.23 Dry matter production of *T. diversifolia* as influenced by different cutting heights at two-week (F1) pruning frequency over 48 weeks. H1 = 25 cm, H2 = 50 cm and H3 = 100 cm. Data points are the means of four replicates. Error bars are the standard error of means.

Patterns of dry matter production at F2 were quite consistent with F1 during the first 16 weeks of the experiment (Fig. 3.24). Biomass production fell to nearly zero following three times of pruning. Conversely, 'stump-life' or survival tended to be longer (approximately 40 weeks) in stumps pruned at F2.

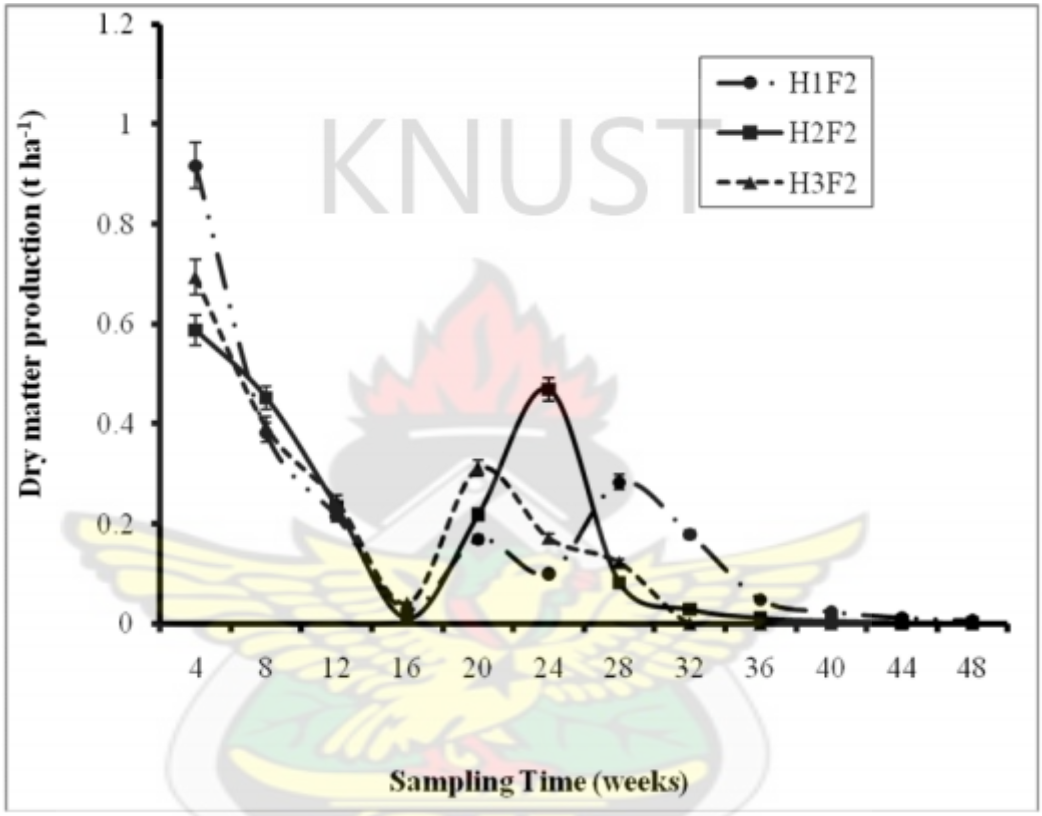

Figure 3.24 Dry matter production of *T. diversifolia* as influenced by different cutting heights at four-week (F2) pruning frequency over 48 weeks. H1 = 25 cm, H2 = 50 cm and H3 = 100 cm. Data points are the means of four replicates. Error bars are standard error of means.

The pattern of dry matter production at F3 was similar among all pruning heights (Fig. 3.25). There was a drastic decline in dry matter production from 8 to 16 weeks, which then increased sharply to 24 weeks and then decreased gradually till the 48th

week. Polynomial models describing the cumulative dry matter production of *T. diversifolia* as influenced by the interactive effect of pruning frequency and cutting height (Figs 3.23 to 3.25) are shown in Table 3.21.

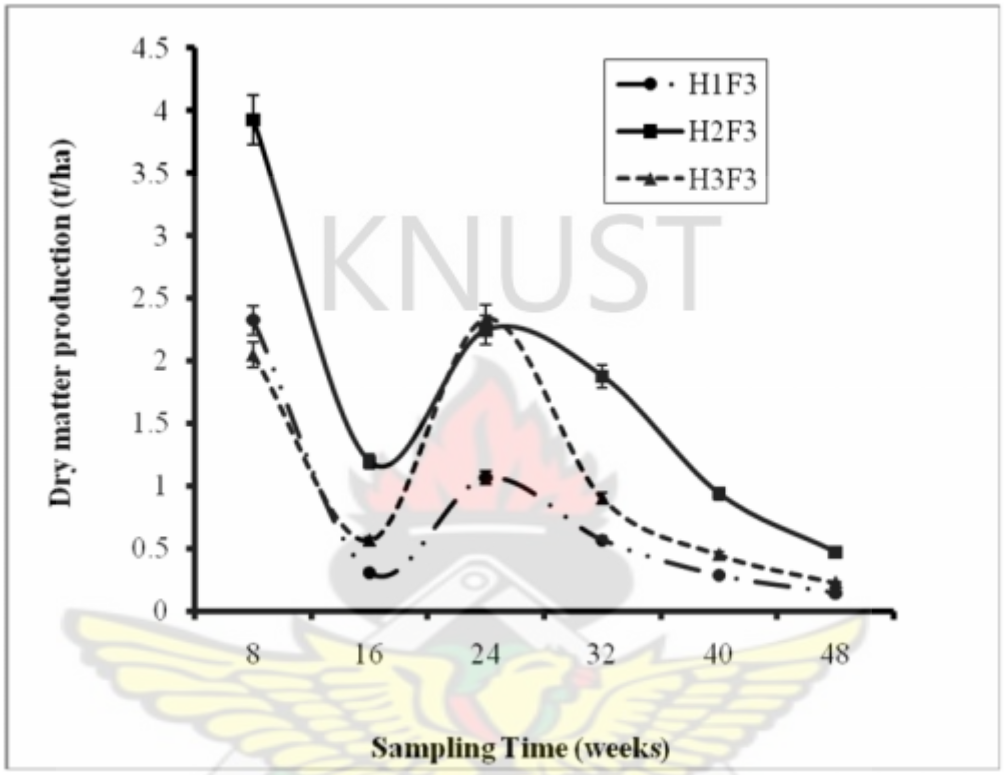

Figure 3.25 Dry matter production of *T. diversifolia* as influenced by different cutting heights at eight-week (F3) pruning frequency over 48 weeks. H1 = 25 cm, H2 = 50 cm and H3 = 100 cm. Data points are the means of four replicates. Error bars are standard error of means.

Dry matter production rate as shown by the slope of the curves described in Table 3.21 was highest in H3, H2, and again H2 for pruning frequencies, F1, F2, and F3 respectively. Among cutting heights, mean dry matter production was highest (4.3 t ha^{-1}) in H2 and lowest (2.3 t ha^{-1}) in H1 (Fig. 3.25a). Regardless of cutting height, dry matter production generally decreased with increasing pruning frequency (Fig. 3.25b). Among cutting height and pruning frequency interaction, biomass production

was highest in H2F3 and lowest in H1F1. Biomass production for F1 was low compared to F2 and F3. In addition, dry matter production in plants pruned at F3 was approximately 3 times that of plants pruned at F2 (Table 3.22). Regardless of cutting height, mean dry matter production was 7.2 t ha^{-1} when *T. diversifolia* was pruned at F3. Multiple regression analysis showed there was a significant ($p < 0.001$, $r^2 = 0.19$) correlation between pruning frequency and dry matter production.

Table 3.21 Polynomial models for cumulative dry matter production of *T. diversifolia* as influenced by different pruning frequencies and cutting heights

Treatment	Polynomial model	R^2
H1F1	$Y = -0.0003x^2 + 0.017x + 0.22$	0.80
H2F1	$Y = -0.0003x^2 + 0.017x + 0.25$	0.73
H3F1	$Y = -0.0004x^2 + 0.027x + 0.16$	0.77
H1F2	$Y = -0.011x^2 + 0.267x + 0.72$	0.98
H2F2	$Y = -0.018x^2 + 0.367x + 0.27$	0.97
H3F2	$Y = -0.018x^2 + 0.336x + 0.43$	0.98
H1F3	$Y = -0.07x^2 + 1.007x + 1.22$	0.97
H2F3	$Y = -0.158x^2 + 2.552x + 1.21$	0.98
H3F3	$Y = -0.165x^2 + 2.135x - 0.26$	0.96

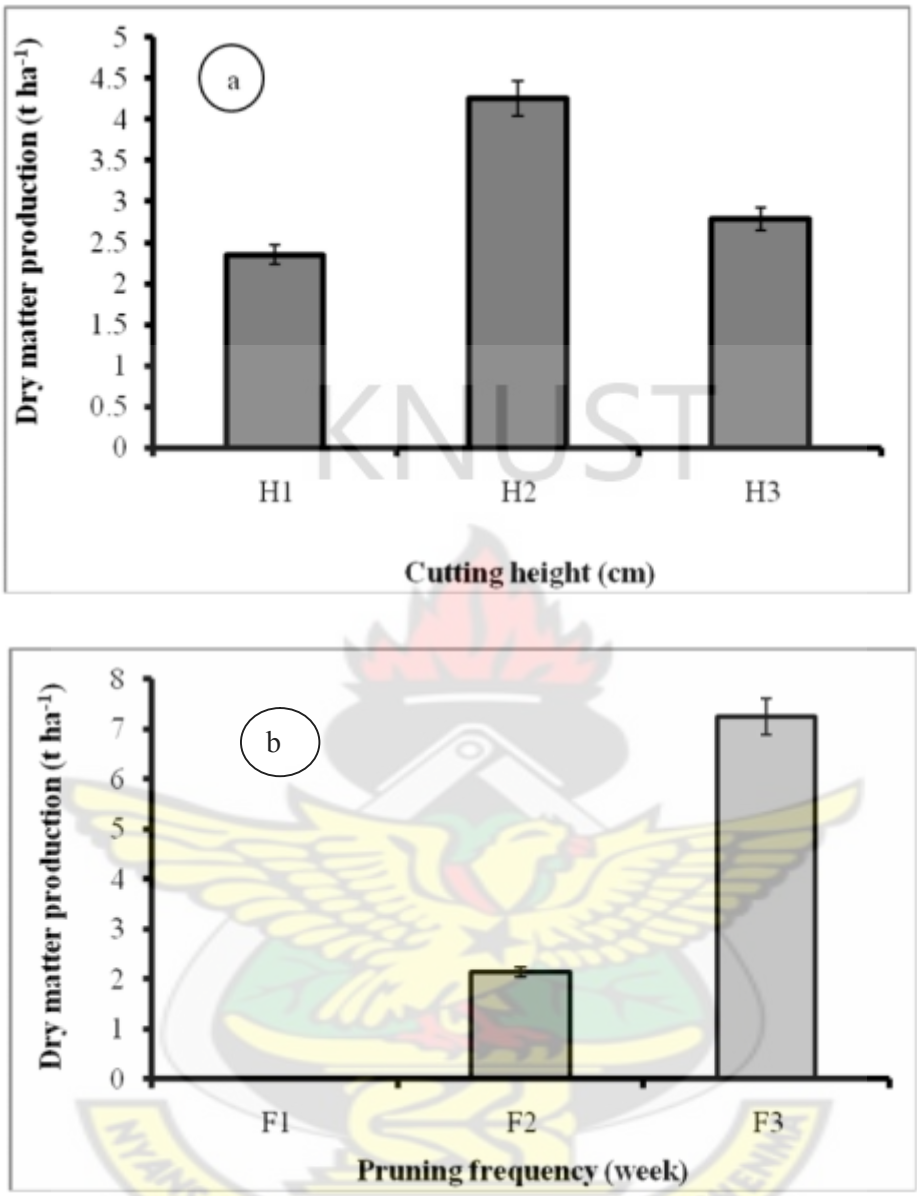

Figure 3.25 Dry matter production of *T. diversifolia* as affected by cutting height (H1 = 25 cm, H2 = 50 cm and H3 = 100 cm of cuttings) (a) and pruning frequency (F1 = 2-week interval, F2 = 4-week interval, F3 = 8-week interval) (b). Data points are the means of four replicates. Error bars represent standard error of means.

Table 3.22 Total dry matter production of *T. diversifolia* as affected by different pruning frequencies and cutting heights over 48 weeks

Treatment	Total dry matter production (t $ha^{-1}yr^{-1}$)
H1F1	0.005
H2F1	0.005
H3F1	0.005
H1F2	2.360
H2F2	2.100
H3F2	1.980
H1F3	4.680
H2F3	10.640
H3F3	6.520
$LSD_{0.05}$	0.343
C.V. (%)	6.8

Values are the means of four replicates

3.3.3 Discussion and Conclusion

Cutting height, pruning frequency, and their interaction significantly influenced dry matter production of *T. diversifolia*. Similar studies with *T. diversifolia* are rare. While similar studies have been conducted with *G. sepium* and *L. leucocephala*, it is often difficult to compare biomass production of agroforestry shrubs in one study to another as plant age, cutting height, plant density, percent dry matter of fresh weight, and plant part weighed (i.e. leaves, green stems, or woody stems) may differ. Dry matter production of *G. sepium* and *L. leucocephala* increased with increasing pruning height and decreasing pruning frequency (Duguma *et al*., 1988). A follow-up experiment (Erdmann *et al.,* 1993) did not confirm the effect of cutting height on

biomass production. Discrepancies between tests were attributed to sampling errors and did not dispute the assertion that increasing cutting height increased biomass production (Duguma *et al*., 1988). Even though dry matter production in this study did not strictly increase from H1 to H3, it was evident that dry matter production at H2 and H3 were significantly higher than at H1 (the lowest cutting height), which might support a hypothesis that increasing cutting height increased dry matter production.

The hypothesis that frequent cutting decreases biomass production in agroforestry trees (Latt *et al*., 2000) was confirmed by this study. Several studies have demonstrated that increased frequency of cutting decreases subsequent biomass production in woody species used in tropical alley cropping systems (Duguma *et al*., 1988; Ella *et al*., 1989; Guevarra *et al*., 1978). Although this experiment did not investigate the dynamism in reserve carbohydrates and soluble sugar with increasing pruning frequency, biomass production in many agroforestry species has been related to reserve carbohydrates which are major influential factors of biomass production in plants. According to Harrington (1989), repeated defoliation of plants at short intervals depleted reserve carbohydrates. Harrington's assertion was in support of observations made by Latt *et al* (2000) when they studied the interactions among cutting frequency, reserve carbohydrates, and post-cutting biomass production in *G. sepium* and *L. leucocephala* in Ibadan, Nigeria. They observed from their study that frequent cutting progressively decreased concentrations of starch and total reserve carbohydrates in *G. sepium* and *L. leucocephala* which was also linearly correlated to dry matter production. The evidence strongly supports the idea that plants mobilize reserve carbohydrates to rebuild photosynthetic tissue after cutting, defoliation, or

seasonal loss of foliage. It is therefore reasonable to assume that if trees are cut too frequently; carbohydrate reserves will be progressively depleted unless sufficient time for replenishment is allowed between cuts (Latt, 1996). This intermittent interruption of temporal cycles of carbohydrate reserves owing to increased pruning frequency may therefore account for the decreased dry matter production in *T. diversifolia*.

The ability of trees in early-successional agroforestry systems to coppice after being cut or pruned is important since many of the soil-fertility and nutrient-cycling benefits of agroforestry systems are derived from the decomposition and release of plant nutrients from tree biomass (Latt *et al*., 2000; Nair *et al*., 1999). As observed in this study, frequent prunings negatively affected the survival of *T. diversifolia* stands. With bi-weekly pruning frequency, about 90% mortality was recorded within three weeks for all pruning heights. The strong negative effect of frequent pruning on the survival of *T. diversifolia* stands may in part be due to the age of the plants used in this trial. Chadhokar (1982) and Duguma *et al* (1988) observed that frequent cuttings in the year of establishment had a negative effect on *Gliricidia* yield in later years. Further studies are needed to determine if the effect of pruning height is the same for older and more established stands than those used in this experiment. Following the above observations, the management of *T. diversifolia* would require prudent decisions on when to harvest the biomass. The results showed that more biomass was produced when *T. diversifolia* was pruned at long pruning intervals. Pruning height was also of importance in the harvesting of the biomass as shoot and dry matter production were greatest when *T. diversifolia* was pruned at 50 cm height. This height would be comfortable to farmers as they would not have to bend so

much. With a bi-monthly pruning frequency (F2), dry matter production could be as high as 7.2 t $ha^{-1}yr^{-1}$. While data obtained from the study have provided a general relationship between pruning frequency, pruning height, and biomass production, conclusions may be specific to the age of plants and the geographical region. Caution must be taken in making yield predictions for different ages and climatic regions.

CHAPTER FOUR

4.0 ON-FARM TRIALS AND ETHNOBOTANICAL KNOWLEDGE OF *T. diversifolia* BIOMASS FOR SOIL FERTILITY IMPROVEMENT

4.1 Materials and Methods

4.1.1 Study site

4.1.1.1 Demographic characteristics

The study was conducted at 'Dumasua' a farming community and suburb of Sunyani, the capital of the Brong Ahafo Region of Ghana. 'Dumasua' falls within the transitional agroecological zone of Ghana. It is located 9 km from the Tain II Forest Reserve. In 2007, the population size of the community was 2175 (1080 males and 1095 females) locally governed by two Assemblymen at the Sunyani Municipal Assembly. A small number (5%) of people in the community work in the civil service in the village or in Sunyani (teachers, local government) whilst 95% of the community are subsistence food crop farmers. The principal crops are okra (*Abelmoschus esculentus*), garden-eggs (eggplant) (*Solanum melongina*), pepper (*Capsicum sp.*), tomatoes (*Lycopersicon esculentus*), maize (*Zea mays*), cassava (*Manihot esculentus*) and plantain (*Musa* sp.) Most of the food crops are for household use. There is a Primary and Junior Secondary School in Dumasua with intermittent electricity and pipe-borne water supply. There are youth groups in the community who undertake self-help projects and clean-up activities in the village, thus providing enhanced self-esteem to these youths.

4.1.1.2 Biophysical characteristics

'Dumasua' is located at Lat 07 55^{o} N and Long 02 00^{o}W. The area falls within the dry semi-deciduous forest zone of Ghana. It is characterized by a bimodal rainfall pattern, with the major wet season between May and July. This area also experiences a short dry season in August and a long one between December and March. The annual rainfall of the area ranges between 1000 mm – 1500 mm. The area is characterized by a mean annual temperature of 23.9 ^{o}C and a mean annual humidity of 67.6%. Soil type is a ferric acrisol (FAO/UNESCO) or Oxic Haplustult (USDA – Soil Taxonomy).

4.1.2 Experimental procedure

4.1.2.1 Reconnaissance survey

The study began with a reconnaissance survey at study site to acquaint and establish contacts with key informants, farmers, District Assembly and opinion leaders. In addition, the survey included an evaluation of smallholder farmers' ethnobotanical knowledge of *Tithonia diversifolia* through the administration of semi-structured questionnaire (Appendix 14). This social survey was essential as a baseline study to appraise the social implications and the adoption potential of the integration of *T. diversifolia* into indigenous cropping systems. To confirm farmers' knowledge about *T. diversifolia*, sample of the plant parts including leaves, flowers (Appendix 15) and seeds were shown to all respondents. Interview was purposeful to farmers. Heads of two hundred (200) households (people who eat from the same pot) were interviewed. Where there were multiple households in the same house, each was interviewed separately. Data obtained were analyzed using SPSS and MS Excel softwares.

4.1.2.2 Field work

(a) Plant sampling and analysis

Fresh leaves of *Tithonia*, used in the experiment were collected from hedges at Sunyani in the Brong Ahafo region. The plant materials collected were characterized for quality parameters. Samples of fresh leaves including soft stems collected were oven-dried at 65^{o}C and ground to pass through a 0.5 mm sieve and analyzed for total lignin, polyphenol, N, P, K, Ca, Mg, and C using the analytical procedures described in section 3.1.1.3

(b) Soil sampling and analysis

Prior to setting up the experiment, soil samples were randomly collected at the surface 0 – 15 cm from 16 locations in a grid format at the experimental site for site characterization. The samples were composited and homogenized. They were then air-dried and passed through a 2 mm sieve and analyzed for site characterization using five replicated sub-samples. In addition, soil samples were randomly collected per plot at flowering (5 weeks after planting) and analyzed for soil pH, total N, organic C, CEC_e, available P and K, NH_4 – N, NO_3 – N, and soil microbial biomass (C, N and P) using the analytical procedures described in section 3.2.1.4.

(c) Experimental design and treatment applications

The experiment was conducted during the major season (April – September) of 2009. Four treatments arranged in a randomized complete block design with five replications were randomly allocated to 3 m x 3 m plots. The treatments included a control (no inputs), *Tithonia* green biomass applied at a rate of 2.7 t ha^{-1}, mineral fertilizer applied at 90 kg N ha^{-1}: 60 kg P ha^{-1}: 60 kg K ha^{-1} and a combination of

Tithonia and mineral fertilizer at the same rates. The green biomass of *Tithonia* including soft and tender stems was surface applied on the soil by hand and hoed a week before planting. At planting, mineral fertilizer in the form of NPK (15:15:15) was basally applied at 250 kg ha^{-1}. After 2 weeks of planting, plants were side-dressed with 150 kg ha^{-1}(of NPK, 15:15:15) and subsequently top-dressed with 30 kg N ha^{-1} (as urea) equally split-applied at 5 and 7 weeks after planting. During planting, maize seeds were sowed three seeds per hill at 0.4 m x 0.8 m spacing and thinned to 1 plant per hill two weeks after planting.

(d) Data collection and statistical analysis

Data was collected on growth characteristics (below- and above-ground dry matter production) at flowering; and maize grain yield. A total of 20 plants were sampled per plot for this purpose. Yields were expressed on a per hectare basis assuming a 31, 250 plant population. The relative agronomic effectiveness (RAE) of the combined *T. diversifolia* and fertilizer treatments compared to sole fertilizer and sole *Tithonia* was compared using the relation by Ikerra *et al*., (2006):

$$\text{RAE} = \frac{Y_{Tf} - Y_{control}}{Y_{F\ or\ T} - Y_{control}} X\ 100\%$$

Where Y_{Tf} = maize grain yield of combined *T. diversifolia* and fertilizer, $Y_{F\ or\ T}$ = maize grain yield of either sole fertilizer or sole *Tithonia* and $Y_{control}$ = maize grain yield of the control treatment.

All parameters measured were statistically analyzed using Analysis of Variance (ANOVA) test. Treatment means were compared using Duncan's multiple range test

(DMRT) at a 0.05 probability level. All statistical analyses were conducted using GENSTAT 11 ((VSN International, 2008).

4.2 Results

4.2.1 Sociological survey

4.2.1.1 Demographic characteristics of respondents

Table 4.1 shows the demographic characteristics of respondents at the Dumasua farming community. Age class of respondents ranged from 18 to above 60. Among the age categories considered, thirty-two percent (32%) of the 200 farmers interviewed was recorded for both respondents between 31– 45 and above 60 years. Only 9% were between 18 – 30 years. The results showed how probably participation in agriculture at the community might be skewed towards the aged. Although agricultural activities are patronized by all gender groups, a large number, representing 72.5 % of the respondents were males with women occupying only 27.5%. These results depicted a probable poor patronization or involvement of women in crop production at the study site. On the basis of education, most of the famers interviewed have had some form of formal education (68%).

Table 4.1 Demographic characteristics of respondents at the Dumasua farming community

Demographic feature	Frequency	Percentage
Age class		
18 – 30	18	9
31-45	64	32
45-60	54	27
Above 60	64	32
Total	200	100
Standard error of mean	0.07	
Educational level		
Primary	27	13.5
Middle School/JHS	82	41
SHS	18	9
Tertiary	9	4.5
Illiterate	64	32
Total	200	100
Standard error of mean	0.107	
Gender		
Male	145	72.5
Female	55	27.5
Total	200	100
Standard error of mean	0.032	
Marital Status		
Single	27	13.5
Married	146	73
Divorced	27	13.5
Total	200	100
Standard error of mean	0.037	

JHS = Junior High School, SHS = Senior High School

4.2.1.2 Crop Production

All farmers interviewed were mainly crop producers. Fifty-eight percent (58%) of interviewed farmers grew crops purposely for subsistence whilst 40% do sell few surpluses in the house most especially when prices are very good (Figure 4.1).

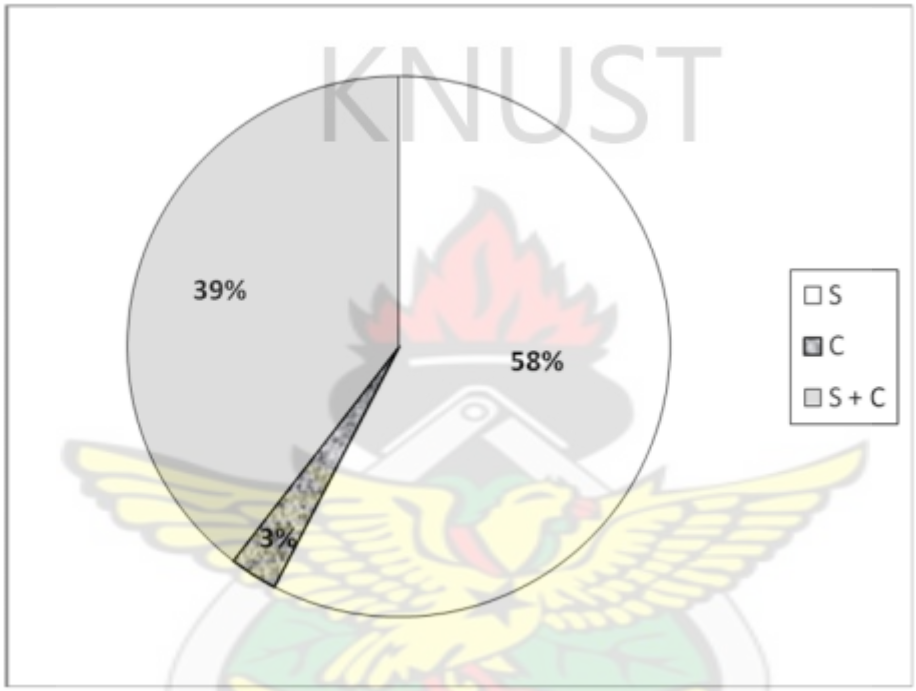

Figure 4.1 Purpose of growing crops by farmers at Dumasua in the transition zone of Ghana. S = subsistence, C = commercial, S + C = subsistence and commercial.

Whilst maize growers do more of monoculture, mixed or multiple cropping was a prevalent cropping system among farmers. Most preferred crops grown in the area were: tomatoes, pepper, okro, egg-plant, cassava, plantain, maize and cocoyam. Although most farmers could not tell what size of farms they had and what output of a growing crop could be obtained per unit area, they reported of reduced yields during certain seasons, by comparing to previous seasons. Farmers (especially maize growers) reported to have witnessed a progressive reduction trend in yield for the

past two to three years owing to erratic rains. In addition, farmers claimed to have abandoned certain lands for crop production due to declined soil fertility.

4.2.1.3 Adopted soil fertility improvement practices

Although farmers complained of soil fertility problems, 90% of respondents reported to have been cropping for decades without any external inputs. Meanwhile, mulching with crop or weed residues, poultry manure application and fertilizer application were prevalent among 10% of farmers interviewed. Poultry manure application was determined to be patronized mainly by vegetable growers whilst inorganic fertilizer application was prevalent among cocoa farmers. Although farmers were aware of the suitability of fertilizer and animal manure applications for soil fertility improvement, they complained of high purchasing costs of fertilizers and unavailability of poultry manures during certain seasons. No agroforestry soil fertility improvement practices were identified. Respondents showed keen interest in trying any technology that can help improve the soil nutrient status of their cropping fields.

4.2.1.4 Ethnobotanical knowledge and uses of *T. diversifolia*

Respondents confirmed to have seen *T. diversifolia* growing on farmlands, along roadsides and cemeteries. Respondents had no knowledge of the origin and local name of *T. diversifolia*. Meanwhile, 3% of respondents identified the plant as sunflower because of its floral appearance. Respondents could not confirm any agronomic uses or importance of *T. diversifolia*. However, one person had planted *T. diversifolia* as a hedge around his house for ornamental purposes. Another respondent confirmed the planting of *T. diversifolia* on grave lands during burial.

4.2.2 Field work (on-farm trials)

4.2.2.1 Initial soil properties

The soil used in this experiment was very close to neutral in pH with moderate organic matter, cation exchange capacity and a relatively high total N content.

Table 4.2 Initial properties of the soil (at the surface 0 – 20 cm) at the experimental site prior to treatment applications

Parameter	Value
pH (H_20) (1:1)	6.7
Organic C (g/kg)	24.8
Organic matter (g/kg)	42.7
Total N (g/kg)	5.0
Available Bray-1 P (mg/kg)	2.9
Available Bray-1 K (mg/kg)	321.4
Exchangeable cations ($cmol_c$/kg)	
Ca	17.9
Mg	4.3
K	1.6
Na	0.2
Exchangeable Acidity (Al + H) ($cmol_c$/kg)	
CEC_e ($cmol_c$/kg)	24.1
Base saturation (%)	99.6
Texture (%)	
Sand	63.1
Silt	33.8
Clay	3.1
Textural class	Sandy-loam

4.2.2.2 Effect of *T. diversifolia* biomass on soil properties

(a) Soil pH

The results of the ANOVA test carried out on the various soil properties measured are recorded in Table 4.3. The effect of treatments on soil pH tested significant ($p < 0.05$) with the highest (6.8) pH unit recorded in the combined *Tithonia* and mineral fertilizer treatments. Both the sole *Tithonia* treatment and the control recorded the lowest pH units (6.5).

(b) Total N

Analysis of variance test showed significant ($p < 0.001$) effect of treatments on total N. Total N generally increased with the application of treatments as all soil amendments (except sole *Tithonia* application) differed significantly from the control. Total N recorded decreased in the order: fertilizer > *Tithonia* + fertilizer > *Tithonia* only > control. In addition, significant differences occurred between treatments (Table 4.3).

(c) Mineral N

Mineral N was determined as nitrate (NO_3^-) and ammonium (NH_4^+). Treatments significantly ($p < 0.05$) affected both nitrate and ammonium levels in the soil. The highest NO_3^- was recorded in TF which differed significantly ($p < 0.05$) from all treatments. However, NO_3^- levels in F and T did not differ significantly ($p > 0.05$) from the control although they differed significantly from each other. Trends in the ammonium level were dissimilar to that of nitrate. Ammonium concentration was highest in fertilizer treated plots and lowest in the control. Meanwhile, only F and TF

differed significantly ($p < 0.05$) from the control. Ammonium levels in amended plots followed the increasing order: control < only *Tithonia* < *Tithonia* + fertilizer < fertilizer (Table 4.3).

Table 4.3 Soil chemical and biological properties as affected by different nutrient sources under field conditions

Treatments	pH	Total N (g/kg)	Organic C (g/kg)	NH_4–N (g/kg)	NO_3–N (µg/g)	CEC_e ($cmol_c$/kg)	Bray's P (mg/kg)	MBC (mg/kg)	MBN (mg/kg)	MBC: MBN
T	6.5	4.3	21.5	4.0	51.1	25.9	6.5	670	42.0	16.0
F	6.6	5.3	21.7	5.0	37.2	28.3	7.3	400	23.0	17.6
TF	6.8	4.9	21.4	4.7	75.5	26.0	8.9	780	24.0	32.6
C	6.5	4.1	21.1	3.9	61.6	17.2	6.1	700	42.0	16.9
p-value	0.014	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
$LSD_{0.05}$	0.2	2.1	0.2	0.3	3.3	2.1	0.7	25.9	4.3	2.9
C.V (%)	2.5	6.4	0.7	5.6	4.3	6.3	6.9	3.0	9.6	10.0

T = only Tithonia, F = fertilizer, TF = Tithonia + fertilizer, C = control (no inputs), MBC = microbial biomass carbon, MBN = microbial biomass nitrogen, MBP = microbial biomass phosphorus. Values represent means of five replicates.

(d) CEC_e

ANOVA test showed significant ($p < 0.001$) effect of treatments on CEC_e. The application of the soil amendments increased the effective cation exchange capacity of the soil as all treatments differed significantly ($p < 0.05$) from the control. The highest CEC_e was recorded in the fertilizer amended plots. Except between T and TF amended plots, all treatment pairs differed significantly.

(e) Organic C

Application of treatments increased soil organic C (SOC) as all treatments differed significantly ($p < 0.05$) from the control. The highest SOC occurred in F treated plots which differed significantly from all treatments. SOC levels followed the increasing order: control < *Tithonia* < *Tithonia* + fertilizer < fertilizer. Trend in SOC levels were similar to that of total N.

(f) Available P

Analysis of variance test showed significant ($p < 0.001$) effect of treatments on available P. Although available P levels recorded were generally low (Singh *et al*., 1977), the results showed an increase in available Bray's P with application of treatments as significant ($p < 0.005$) differences occurred between treatments and the control. In addition, there were significant differences among treatments with the highest available P level occurring in plots treated with combined *Tithonia* and fertilizer.

(g) Soil microbial biomass (C and N)

As can be observed in Table 4.3, ANOVA test showed significant ($p < 0.001$) effect of treatments on soil microbial C and N and their ratio. The highest microbial C occurred in the combined *Tithonia* and fertilizer plots with the lowest in the sole fertilizer treated plots. Significant correlations were observed between microbial biomass C (MBC) and total N, nitrate, and soil organic C (Table 4.4). Among treatments, microbial biomass N (MBN) either stabilized or decreased with the application of treatments as treatments did not differ significantly ($p < 0.05$) from the control. Meanwhile, significant correlations were observed between MBN and pH, CEC_e, total N, available P and soil organic C. Furthermore, ANOVA test showed significant ($p < 0.001$) effect of treatments on microbial biomass C and N ratio. The highest MB (C: N) ratio was observed in the combined *Tithonia* and fertilizer treated plots which differed significantly ($p < 0.05$) from the control and the other treatments. Moreover, significant correlations were observed between MB (C: N) ratio and pH, nitrate, available P, microbial biomass C and microbial biomass N.

Table 4.4 Pearson correlation coefficient (r) for the linear relationship among soil properties under field conditions

	pH	CEC_e	Total N	NH_4-N	NO_3-N	Av P	SOC	MBC	MBN	MB (C: N)
pH	1									
CEC_e	0.41	1								
Total N	0.56**	0.71***	1							
NH_4-N	0.53*	0.63**	0.79***	1						
NO_3-N	0.25	-0.36	-0.27	-0.18	1					
Av P	0.48*	0.49*	0.52*	0.50*	0.42	1				
SOC	0.05	0.74***	0.55**	0.50*	-0.58**	0.32	1			
MBC	0.08	-0.43	-0.50*	-0.44	0.91***	0.20	-0.60**	1		
MBN	-0.46*	-0.63**	-0.80***	-0.75***	0.05	-0.73***	-0.56**	0.35	1	
MB (C: N)	0.49*	0.23	0.30	0.32	0.71***	0.85***	0.03	0.51**	-0.62**	1

*CEC_e = Effective cation exchange capacity, Av P = available phosphorus, SOC = soil organic carbon, MBN = microbial biomass nitrogen, MBC = microbial biomass carbon, MB (C: N) = ratio of microbial biomass carbon and microbial biomass nitrogen; *, ** and *** means significant at 5%, 1% and 0.1% probability levels respectively.*

4.2.2.3 Effect of *T. diversifolia* biomass on the grain yields, dry matter production and harvest index of maize

Analysis of variance test showed significant effect of treatments on both biological and agronomic yield of maize (Table 4.5). Generally, the application of treatments increased both biological and grain yield of maize. For instance the application of *Tithonia* either alone or in combination with fertilizer increased yield by 24% and 54% respectively. The highest grain and biological yield occurred in the combined fertilizer and *Tithonia* treated plots. Grain yield recorded for sole *Tithonia* was higher than that of the control. Moreover, biological yield in sole *Tithonia* treated plots differed significantly ($p < 0.05$) from the control.

Table 4.5 Grain yield, dry matter production and harvest index of maize as affected by the different treatments under field conditions

Treatments	Dry matter production ($t\ ha^{-1}$)			Grain yield ($t\ ha^{-1}$)	Harvest index
	ABG	BG	Total		
T	7.2	1.7	8.9	1.7	0.19
F	8.3	1.2	9.5	2.2	0.24
TF	9.1	1.3	10.4	2.8	0.27
C	4.2	0.5	4.7	1.3	0.29
p-value	<0.001	0.011	<0.001	<0.001	0.021
$LSD_{0.05}$	1.1	0.6	1.5	0.3	0.1
C.V (%)	11.3	39.4	13.3	12.4	18.8

T = only Tithonia, F = fertilizer, TF = Tithonia + fertilizer, C = control (no inputs), ABG = aboveground biomass, BG = Belowground biomass

In addition, total dry matter production was significantly correlated ($p < 0.01$, r = 0.59) to grain yield. Harvest index increased in the order: *Tithonia* < fertilizer < *Tithonia* + fertilizer < control. As may be deduced from Table 4.5, the relative agronomic effectiveness of the combined *Tithonia* and fertilizer treatments compared to the sole *Tithonia* and sole fertilizer treatments was 375% and 167% respectively.

4.3 Discussion and conclusion

As discussed earlier, the high green manure quality of *Tithonia* (as depicted by the high N, P, low lignin and polyphenol contents, narrow C: N ratio) ensures rapid decomposition and net N and P mineralization (Palm *et al*., 2001). The high N, P and K concentrations make it a good source for plant nutrients on this ferric acrisol (Gachengo *et al*., 1999; Nziguheba *et al*., 2000). The high basic cation concentrations of *Tithonia* green manure also make it a fairly good acidity ameliorating amendment (George *et al*., 2002). Although previous researches have confirmed significant increases in yield with sole application of *Tithonia* green manure, results from this study confirms the beneficial effect of combining *Tithonia* and fertilizer. As observed, the combined *Tithonia* and fertilizer treatment generally resulted in comparable increase in soil properties. Generally all treatments resulted in increased pH levels which were within the optimum range reported by Troeh and Thompson (2005) for a reasonable availability of nutrients. This was confirmed by the strong positive correlation between pH and Total N, NH_4 – N and available P (Table 4.3). In addition, the application of treatments resulted in increased total N and organic matter which were strongly correlated to ammonium (released as available N by

microbial degradation). This confirms the assertion that the application of external inputs (particularly organic materials) results in increased biological activities in soils.

Over the experimental period, *Tithonia* either applied alone or in combination with mineral fertilizer generally increased soil microbial biomass C and N. Increased microbial biomass by organic C inputs has been well documented in various organic substrates such as green manures, cattle manure compost, saw-dust compost and rice husk compost (Goyal *et al*., 1999; Chowdhury *et al*., 2000), wheat straw and farmyard manure (Goyal *et al*., 1999), dairy shed effluent (Zaman *et al*., 1999), and municipal solid waste compost and cow manure (Garcı´a-Gil *et al*., 2000; Peacock *et al*., 2001). However, various qualities of organic substrates may differentially impact soil microbes since substrate composition has profound influences on microbial utilization of C and nutrients in the substrate (Tu *et al*., 2006; Cheshire and Chapman, 1996; Martens, 2000). This may account for the differential effects of the various treatments on soil microbial biomass. Meanwhile, the significance of C inputs for increased soil microbial biomass was confirmed in the results of this study as per the significant correlation observed between MBC and organic C (Table 4.4). This significant interaction explains why the effects of mineral fertilizer on microbial biomass (C and N) were less significant, obviously because extractable C inputs were nil although N, P and K inputs were high in the fertilizer applied. Further, since the application of easily decomposable organic materials with a significantly low total C/N ratio is associated with enhanced soil microbial biomass in cropping systems (Smith and Paul, 1990), it was undoubted to observe the highest MBC and a comparable MBN in plots with *Tithonia*. According to several authors (Zaman *et al*.,

1999; Tu *et al*., 2003; Wang *et al*., 2004), differences in soil microbial biomass under different organic amendments may have implications for nutrient availability to crops. This is because high microbial biomass often leads to high nutrient availability to crops through enhancing both the microbial biomass turnover and the degradation of non-microbial organic materials. The authors' assertions are confirmed by the significant interaction obtained between soil microbial biomass parameters and some of the soil properties (Table 4.4).

Generally, the application of treatments increased both biological and grain yield of maize. For instance the application of *Tithonia* either alone or in combination with fertilizer increased yield by 24% and 54% respectively. The highest grain and biological yield occurred in the combined fertilizer and *Tithonia* treated plots. Grain yield recorded for sole *Tithonia* was higher than that of the control. Moreover, biological yield in sole *Tithonia* treated plots differed significantly ($p < 0.05$) from the control. This also could be attributed to faster nutrient release patterns of *Tithonia* green manure (Gachengo *et al*., 1999). From the overall results, there were clear indications that the combined effect of *Tithonia* and mineral fertilizer is highly significant in the improvement of soil nutrient availability and crop yields.

CHAPTER FIVE

5.0 GENERAL SUMMARIES, CONCLUSIONS AND RECOMMENDATIONS

The rationale for carrying-out this research stemmed from the overall effort to mitigate soil fertility challenges for improved food security in Africa. With agriculture becoming critical in the achievement of the UN Millennium Development Goals particularly in Africa, it is imperative to explore and develop agricultural practices that are socially acceptable, ecologically sound and economically feasible. The idea for exploring the agronomic potentials of *Tithonia* emanated from the poor existing knowledge of its potentials for soil fertility improvement and crop production in Ghana, although it has been very much exploited in many parts of the tropics and have achieved tremendous positive impacts. The results of this study were expected to provide guidelines as to how *Tithonia* can be optimized and integrated into indigenous cropping systems in Ghana.

The first experiment appraised the quality of *Tithonia* green biomass in relation to its biochemical composition and decomposition and nutrient release patterns. This experiment was conducted in comparison with *Senna spectabilis*, *Gliricidia sepium*, *Leucaena leucocephala* and *Acacia auriculiformis* which are commonly used in biomass transfer systems. Results of the study confirmed significantly high N, P, K concentrations in *T. diversifolia* biomass comparable to levels recorded for the four leguminous species. In addition, *T. diversifolia* recorded the highest percent decomposition and nutrient release rates which differed significantly ($p < 0.05$) from rates of the four leguminous species. From the results of the experiment, it was

apparent that decomposition and nutrient release rates of species are related to quality of leaf material. However, unlike lignin, polyphenols, and C: N ratios; P and Mg concentration in particular were most influential in decomposition and nutrient release based on significant results. The study therefore inferred and recommended that it would be imperative to consider the concentrations of P and Mg among other factors in selecting high quality plant materials for green manuring. Results from this study have added to knowledge on how to tailor the application of *Tithonia* biomass in cropping systems and agroforestry for improved nutrient synchronization.

Secondly, with the growing concern of the potential of low input agriculture in mitigating soil fertility challenges, and the fact that *Tithonia* could be one viable alternative source of crop nutrients, an exploratory trial (on-station) was established to assess the suitability of *T. diversifolia* green biomass as a nutrient source for agroforestry soil improvement practices. Using okro as a test crop, the experiment compared *Tithonia* biomass to *Gliricidia sepium* and *Senna spectabilis* biomass and mineral fertilizer based on their effects on soil fertility indicators and agronomic characteristics of okro. The results of the study confirmed the green biomass of *T. diversifolia* to be of best quality based on its biochemical characteristics compared to *S. spectabilis* and *G. sepium*. In addition, the application of *T. diversifolia* biomass was observed to double okro yields in the minor and major season trials compared to the control and was comparatively higher than that of mineral fertilizer, *S. spectabilis* and *G. sepium* treatments. The results on yield were consistent with the effect of *T. diversifolia* biomass on soil properties, nutrient availability and growth characteristics of okro plants throughout the experimental period. The study therefore confirmed that smallholder farmers who are compelled to cultivate poor soils due to

limited affordability and availability of inorganic fertilizers can count on *T. diversifolia* as a potential source of nutrients for improved resilience of soil productive capacity and crop yields.

In addition, considering that long term productivity of biomass transfer systems require shrub or tree species that coppice vigorously after each cutting, and that biomass produced at each cutting is expected to be optimum to provide sufficient amount of nutrients that can mineralize to meet crop nutrient demands, investigations on the effect of cutting frequency and cutting height on coppicing and biomass production of *Tithonia* was carried out to provide useful information that can be factored into the management of *Tithonia* hedges for optimum biomass production. From the study, it was evident that height of cutting, pruning frequency and their interactions significantly affect dry matter production of *Tithonia*. The results also showed that a significantly higher biomass production can be produced when *Tithonia* is pruned at long pruning intervals. Pruning height was also of importance in the harvesting of *Tithonia* biomass and it was obvious that shoot and dry matter production are best when *Tithonia* is pruned at 50 cm height. This height will be comfortable to farmers as they do not have to bend so much. The study recommended that the management of *Tithonia* requires prudent decisions on when to harvest the biomass. With bi-monthly pruning frequency, dry matter production could be as high as 7.2 t $ha^{-1}yr^{-1}$ which might be a sufficient biomass to increase soil organic matter in biomass transfer systems.

Lastly, a sociological survey and on-farm trials were carried-out to confirm the ethnobotanical knowledge of *Tithonia* and the biophysical effects of its green

biomass on soil fertility indicators and harvest index of maize. Both studies were conducted at Dumasua in the transition agroecozone of Ghana. The sociological survey confirmed that farmers have had progressive decline of soil fertility owing to limited application of fertilizers. In addition, farmers confirmed to have seen *Tithonia* before but had no idea whether it could be used for soil fertility. This was also confirmed through field survey at places where *Tithonia* was found. In fact an insignificant number of respondents confirmed only the ornamental importance of *Tithonia* and it usage at grave yards for burying the dead. No local name was identified. It was only known as sunflower because of the nature of its flower. The on-farm trials revealed the significant synergistic effect of combining *Tithonia* and fertilizer on nutrient availability and harvest index of maize. It was inferred from the results that the application of *Tithonia* either alone or in combination with fertilizer can increase yield by 24% and 54% respectively compared to no input systems.

It is duly concluded based on the results of the overall study, that the emergence and implementation of *Tithonia* biomass transfer system in Ghana will help increase food security for poor and marginal farmers. *Tithonia* biomass transfer system can help raise agricultural productivity in Ghana by diversifying agroecosystems and optimizing yields, reducing costs of production and creating new income streams for smallholder farmers.

REFERENCES

Adoyo F, JB Mukalama and M Enyola (1997) Using *Tithonia* concoctions for termite control in Busia District, Kenya. ILEIA Newsletter 13: 24–25

AGVISE (2009) Microbial Biomass. AGVISE laboratories. **http://www.agvise.com/tech_art/biomass.php**. (Accessed on 24th November, 2009).

Anderson, JM (1991) The effects of climate change on decomposition processes in grassland and coniferous forests. Ecological Applications 1: 326–347.

Anderson JM and JSI Ingram (1998) Tropical Biology and Fertility: a Handbook of Methods. CAB International, Wallingford, England, 221 pp

Anderson JM., J Proctor and HW Vallack (1983) Ecological studies in four contracting rain forests in Gunung Mulu national park, Sarawak, III. Decomposition processes and nutrient losses from leaf litter. J. Ecol. 71: 503 – 527

Anette, M (1996) Evaluation of indigenous fodder trees and shrubs in different agro-ecological zones of western Kenya. Diplomarbeit. Institut für Pflanzenbau und Pflanzenzüchtung. Universität für Bodenkultur, Vienna, Austria

Arias, ME, JA González-Pérez, FJ González-Vila, and AS Ball (2005) Soil health—a new challenge for microbiologists and chemists. International Microbiology 8:13-21.

Ayeni, AO, DT Lordbanjou and BA Majek (1997) *Tithonia diversifolia* (Mexican sunflower) in south-western Nigeria: occurrence and growth habit. Weed Research (Oxford) 37: 443

Brady, NC and RR. Weil (2004) Elements of the Nature and Properties of Soils, Second Edition. Upper Saddle River, NJ: Prentice – Hall, Inc.

Baldwin, KR (2006) Organic production – soil quality considerations for organic farmers. North Carolina Cooperative Extension Service, USA. http://www.cefs.ncsu.edu/PDFs/Organic%20Production%20-%20Soil%20Quality.pdf. (Accessed on 24th November, 2009).

Balesdent J and A Mariotti (1996) Measurement of soil organic matter turnover using ^{13}C natural abundance. In: Boutton TW, Yamasaki S. I (eds) *Mass spectrometry of soil*. Marcel Dekker, New York, pp 83-111

Barrow, NJ and TC Shaw (1975) The slow reactions between soil and anions: 2. Effect of time and temperature on the decrease in phosphate concentration in the soil solution. Soil Science 119: 167-177.

Berg B, and H Staaf (1981) Leaching, accumulation and release of nitrogen in decomposing forest litter. In: FE Clark and T. Rosswall (Eds.). Terrestrial nitrogen cycles, pp. 163 – 178. Ecol. Bull. Vol. 33. Stockholm, Sweden.

Bloem, J and AM Breure (2003) Microbial indicators. In: Breure AM, Markert B, Zechmeister HG (eds) Bioindicators & biomonitors. Principles, assessment, concepts. Elsevier, Amsterdam, pp. 259-282

Brady, NC (1990) The Nature and Properties of Soils. Macmillan Publishing Company, New York.

Brady, NC and RR Weil (2004) Elements of the Nature and Properties of Soils, Second Edition. Upper Saddle River, NJ: Prentice – Hall, Inc.

Bray RH and Kurtz LT (1945) Determination of total, organic and available forms of phosphorus in soils. Soil Sci., 59: 30–45

Brookes PC, DS Powlson and D. Jenkinson (1982) Measurement of microbial biomass phosphorus in soil. Soil Biology and Biochemistry 14: 319- 329.

Chadhokar PA (1982) *Gliricidia maculata* a promising legume fodder plant. World Anim Rev 44:36-43

Charman, PEV (2007a) Cation Exchange Capacity. In: Charman, PEV and BW Murphy (Eds.). Soils: Their Properties and Management, Third Edition. Oxford University Press, UK.

Charman, PEV (2007b) Soil Nutrient Decline. In: Charman, PEV and BW Murphy (Eds.). Soils: Their Properties and Management, Third Edition. Oxford University Press, UK.

Cong PT, and R Merckx (2005) Improving phosphorus availability in two upland soils of Vietnam using *T. diversifolia* H. Plant and Soil 269: 11–23

Cobo JG, E Barrios, DCL Kass, RJ Thomas (2002) Decomposition and nutrient release by green manures in a tropical hillside agroecosystem. Plant Soil 240:331–342

Cheshire, MV and SJ Chapman (1996) Influence of the N and P status of plant material and of added N and P on the mineralization of C from ^{14}C-labelled ryegrass in soil. Biology and Fertility of Soils 21: 166–170.

Chowdhury MAH, K Kouno, T Ando and T Nagaoka (2000) Microbial biomass, S mineralization and S uptake by African millet from soil amended with various composts. Soil Biology & Biochemistry 32: 845–852.

Drechsel, P and B Reck (1998) Composted shrub-prunings and other organic manures for small-holder farming systems in southern Rwanda. Agroforestry Systems 39: 1–12

Duguma B, BT Kang and DUU Okali (1988) Effect of pruning intensity of three woody leguminous species grown in alley cropping with maize and cowpea on an alfisol. Agroforestry System 6: 19–35

Dutta P, RP Chaudhuri and RP Sharma (1993) Insect feeding deterrents from *Tithonia diversifolia* (Hemsl) Gray. Journal of Environmental Biology14: 27–33

Ella A, C Jacobsen, WW Stür and G Blair (1989) Effect of plant density and cutting frequency on the productivity of four tree legumes. Trop Grasslands 23: 28–34

Erdmann TK, PKR Nair and BT Kang (1993) Effects of cutting frequency and cutting height on reserve carbohydrates in *Gliricidia sepium* (Jacq.) Walp. For Ecol Manage 57: 45–60

Ezcurra E, and J Becerra (1987) Experimental decomposition of litter from the Tamaulipan cloud forest: a comparison of four simple models. Biotropica 19: 290 – 296

FAO (1988) FAO- UNESCO Soil map of the world. Revised legend. Reprinted with corrections. World soil resources report 60. Rome, FAO.

Fernandes, ECM and JC Matos (1995) 'Agroforestry strategies for alleviating soil chemical constraints to food and fiber production in the Brazilian Amazon' In: P R Seidl *et al* (eds) *Chemistry of the Amazon: Biodiversity, Natural products and Environmental issues,* Washington, American Chemical Society, Pp 279-310

Gachengo, CN, CA Palm, B Jama, C Othieno (1999) *Tithonia* and *Senna* green manures and inorganic fertilizers as phosphorus sources for maize in western Kenya. Agroforestry Systems 44:21–36

Ganunga R, O Yerokun and JDT Kumwenda (1998) *Tithonia diversifolia*: an organic source of nitrogen and phosphorus for maize in Malawi. In: Waddington SR *et al*. (eds) Soil Fertility Research for Maize-Based Farming Systems in Malawi

and Zimbabwe, pp 191–194. Soil Fert Net and CIMMYT-Zimbabwe, Harare, Zimbabwe

Garcı´a-Gil, JC, C Plaza, P Soler-Rovira and A Polo (2000) Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass. Soil Biology & Biochemistry 32: 1907–1913.

Garrity, DP and AR Mercado (1994) Nitrogen fixation capacity in the component species of contour hedgerows: How important? Agroforestry Systems 27: 241–258.

George TS, PJ Gregory, JS Robinson, RJ Buresh and B Jama (2002) Utilization of soil organic phosphorus by agroforestry and crop species in the field in western Kenya. Plant Soil 246: 53 – 63.

Getahun, A., GF. Wilson and BT. Kang (1982) The role of trees in farming systems of the humid tropics. In: Agroforestry in the African Humid Tropics (Ed) by L. H. Macdonald. Proceedings of a workshop held at Ibadan, Nigeria. 27th April – 1st May, 1981.

Goyal S, K Chander, MC Mundra, KK Kapoor (1999) Influence of inorganic fertilizers and organic amendments on soil organic matter and soil microbial properties under tropical conditions. Biology and Fertility of Soils 29: 196–200.

Gruhn P, F Goletti and M Yudelman (2000) Integrated Nutrient Management, Soil Fertility, and Sustainable Agriculture: Current Issues and Future Challenges. International Food Policy Research Institute, 2033 K Street, N.W. Washington, D.C. 20006 U.S.A, pp 31.

Guevarra AB, AS Whitney and JT Thompson (1978) Influence of intra-row spacing and cutting regimes on the growth and yield of *Leucaena*. Agronomy J 70: 1033–1037

Harrington, MG (1989) Gambel oak root response to spring, summer, and fall prescribed burning. J Range Manage 42: 504–507

Heal OW, JM Anderson and MJ Swift (1997) Plant Litter Quality and Decomposition: An Historical Overview, pp. 3-30. *In:* Cadisch, E. and KE Giller (editors.). Driven by Nature: Plant Litter Quality and Decomposition. CAB International.

Hillel, D (2008) Soil in the Environment: Crucible of Terrestrial life. Elsevier Inc. UK.

ICRAF (1997) Using the wild sunflower, *T. diversifolia* in Kenya. International Centre for Research in Agroforestry. Nairobi, Kenya. 5pp.

Ikerra, ST, E. Semu and J. Mrema (2006) Combining *T. diversifolia* diversifolia and minjingu phosphate rock for improvement of P availability and maize grain yields on a chromic acrisol in Morogoro, Tanzania. Nutrient Cycling in Agroecosystems 76:249 –260.

Ikerra ST (2004) Use of Minjingu phosphate rock combined with different organic inputs in improving phosphorus availability and maize yields on a Chromic Acrisol in Morogoro, Tanzania, Ph.D Thesis. Sokoine University of Agriculture, Morogoro, Tanzania.

Jama BA, CA Palm, RJ Buresh, AI Niang, C Gachengo, G Nziguheba and B Amadalo (2000) *Tithonia diversifolia a*s a green manure for soil fertility improvement in western Kenya: A review. Agroforestry Systems 49: 201 – 2

Jenkinson, DS (1988) Determination of microbial biomass carbon and nitrogen in soil. In: Wilson, J.R. (ed.). Advances in Nitrogen Cycling in Agricultural Ecosystems. Pp. 368- 386. C.A.B. International, Wallingford.

Jiri O and SR Waddington (1998) Leaf prunings from two species of *Tithonia* raise maize grain yield in Zimbabwe, but take a lot of labour! Newsletter of Soil Fert Net, Harare, Zimbabwe. Target 16: 4–5

Kachaka S, B Vanlauwe and R Merckx (1993) Decomposition and nitrogen mineralization of prunnings of different quality. In: Molungoy, K. and R. Merckx. (eds.). Soil organic matter dynamics and sustainability of tropical agriculture. John Willey and Sons Ltd.

Kang, BT (1991) Alley farming Production System of the Humid and Sub-humid Tropics. In: NAERIS South-West Zone 1991 Training Manuel for In-Service training for ADPs, pp 159-172.

King'ara G (1998) Establishment methods of *Tithonia diversifolia* from seeds and cuttings. Report for diploma certificate. Rift Valley Technical Training Institute. Eldoret, Kenya

Kotschi, J., A. Waters-Bayer, R. Adelhelm, and U. Hoesle (1988). Ecofarming in Agricultural Development. Margraf, Weikersheim

Koukoura Z, AP Mamolos and KL Kalburtji (2003) Decomposition of dominant plant species litter in a semi-arid grassland. Applied Soil Ecology 23: 13-23.

Kuo YH and CH Chen (1997) Diversifolol, a novel rearranged eduesmane sesquiterpene from the leaves of *Tithonia diversifolia*. Chemical and Pharmaceutical Bulletin 45: 1223–1224

Kwabiah, AB., NC Stoskopf, RP Voroney and CA Palm (2001) Nitrogen and phosphorus release from decomposing leaves under sub-humid tropical conditions. Biotropica 33, 229-240.

Ladd, JN and M Amato (1989) Relationship between microbial biomass carbon in soils and absorbance of extracts of fumigated soils. Soil Biology and Biochemistry 21: 457- 59.

Latt, CR (1996) Biomass Production in Agroforestry Trees as Influenced by Cutting Frequency and Reserve Carbohydrates. PhD dissertation. University of Florida, Gainesville

Latt CR, PKR Nair and BT Kang (2000) Interactions among cutting frequency, reserve carbohydrates, and post-cutting biomass production in *Gliricidia sepium* and *Leucaena leucocephala*. Agroforestry Systems 50: 27–46

Mafongoya, PL, BH Dzowela, and PKR Nair (1997) Effect of multipurpose trees, age of cutting and drying method on pruning quality, pp.167-174. *In*: G. Cadisch and K.E. Giller (editors), Driven by Nature: Plant Litter Quality and Decomposition. CAB International, Wallingford, UK.

Martens, DA (2000) Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. Soil Biology and Biochemistry 32: 361–369.

Martikainen, PJ and A Palojarvi (1990) Evaluation of the fumigation – extraction method for the determination of microbial carbon and nitrogen in a range of forest soils. Soil Biology and Biochemistry 22: 797- 802.

McClaugherty, CA. and B. Berg (1987) Cellulose, lignin and nitrogen concentrations as regulating factors in late stages of forest litter decomposition. Pedobiologia 30: 101-112.

McLaughlin, MJ and AM Alston (1986) The relative contribution of plant residues and fertilizer to the phosphorus nutrition of wheat in a pasture/cereal system. Australian J. Soil Research 24:517-26.

Meentemeyer, V (1978) Macroclimate and lignin control of litter decomposition rates. Ecology 59: 465 – 472.

Melillo JM and JD Aber (1983) Nutrient immobilization in decaying litter: An example of carbon–nutrient interactions. *In* Cooley and F.B. Golley (ed) Trends in ecological research for the 1980s. Proceedings of a NATOARW and INTERCOL workshop residues on the future and use of ecology after the decade of the environment, Louvain-la-Neuve, Belgium. 7–9 April 1983. NATO, Plenum Press, New York.

Mitchell, J., M. Gaskell, R. Smith, C. Fouche and ST Koike (2000) Soil management and soil quality for organic crops, UC ANR Publication 7248, 200. ANR Website, http://anrcatalog.ucdavis.edu/pdf/7248.pdf. (Accessed on 24th November, 2009).

Morel C., H. Tiessen and JWB Stewart (1997) Correction for P- sorption in the measurement of soil microbial biomass P by chloroform fumigation. Soil Biology and Biochemistry 29:1579-1583.

Moretto, AS., RA Distel and NG Didone (2001) Decomposition and nutrient dynamic of leaf litter and roots from palatable and unpalatable grasses in a semi-arid grassland. Applied Soil Ecology 18: 31-37.

Motsara, MR and RN Roy (2008) Guide to Laboratory establishment for plant nutrient analysis. FAO Fertilizer and Plant nutrition bulletin. Food and Agriculture Organization, Rome. 219pp.

Mugendi, DN, PKR Nair, JN Mugwe and PL Woomer (1999) Alley cropping of maize with *Calliandra* and *Leucaena* in the subhumid highlands of Kenya. Part 1. Soil-fertility changes and maize yield. Agroforestry Systems 46: 39-50.

Munson RD (1982) Potassium, calcium and magnesium in the tropics and subtropics. Technical Bull. Intern. Fert. Dev. Center T-23, 39p.

Nagarajah S and BM Nizar (1982) Wild sunflower as a green manure for rice in the mid-country west zone. Tropical Agriculturalist 138: 69–78

Nair, PKR (1984) Soil Productivity Aspects of Agroforestry. ICRAF Science and Practice of Agroforestry. No. 1, pp 85

Nair PK R, RJ Buresh, DN Mugendi and CR Latt (1999) Nutrient cycling in tropical agroforestry systems: myths and science. In: Buck LE, JP Lassoie and ECM Fernandes (eds) Agroforestry in Sustainable Agricultural Systems, pp 1–31. CRC Press/Lewis Publ., Boca Raton, Fl, USA.

Ng'inja, JO, A Niang, CA Palm and P Lauriks (1998) Traditional hedges in western Kenya: typology, composition, distribution, uses, productivity and tenure. Pilot Project Report No. 8. Regional Agroforestry Research Centre, Maseno, Kenya

Niang A, B Amadalo, S Gathumbi and CO Obonyo (1996) Maize yield response to green manure application from selected shrubs and tree species in western Kenya: a preliminary assessment. In: Mugah JO (Ed) Proceedings of the First Kenya Agroforestry Conference on People and Institutional Participation in Agroforestry for Sustainable Development, pp 350–358. Kenya Forestry Research Institute (KEFRI), Muguga, Kenya

Nyathi, P and BM Campbell (1993) The acquisition and use of *miombo* litter by small-scale farmers in Masvingo, Zimbabwe. Agroforestry Systems 22: 43 - 48.

Nziguheba G., R Merckx, CA Palm, and MR Rao (2000) Organic residues affect phosphorus availability and maize yields in a Nitisol of western Kenya. Biology and Fertility of Soils 32:328–339

Nziguheba G., CA Palm, RJ Buresh and PC Smithson (1998) Soil phosphorus fractions and adsorption as affected by organic and inorganic sources. Plant and Soil 198: 159–168.

Oberson A, DK Friesen, C Morel and H Tiessen (1997) Determination of phosphorus released by chloroform fumigation from microbial biomass in high P sorbing tropical soils. Soil Biology and Biochemistry 299: 1577- 1583.

Odunsi, AA, GO Farinu and JO Akinola (1996) Influence of dietary wild sunflower (*Tithonia diversifolia* Hemsl. A. Gray) leaf meal on layers performance and egg quality. Nigerian Journal of Animal Production 23: 28–32.

Olabode, OS., S Ogunyemi, WB Akanbi, GO Adesina and PA Babajide (2007) Evaluation of *T. diversifolia* diversifolia (Hemsl.) A Gray for Soil Improvement. In: World Journal of Agricultural Sciences 3 (4): 503-507, 2007. IDOSI Publications.

Otuma P, C Burudi, A Khabeleli, E Wasia, M Shikanga, C Mulogoli and SE Carter (1998) Participatory research on soil fertility management in Kabras, western Kenya: Report of activities, 1996–1997. Tropical Soil Biology and Fertility Programme (TSBF), Nairobi, Kenya.

Palm CA, CN Gachengo, RJ Delve, G Cadisch and K Giller (2001) Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. Agriculture, Ecosystems and Environment 83: 27-42.

Palm, CA and PA Sanchez (1990) Decomposition and nutrient release patterns of the leaves of three tropical legumes. Biotropica 22 (4), 330 – 338.

Palm CA, RJK Myers and SM Nandwa (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: Buresh R.J., Sanchez P.A. and Calhoun F. (eds), Replenishing Soil Fertility in Africa: SSSA Special Publication Number 51. ASA and SSSA, Madison, USA, pp. 193–217.

Parffit RL (1978) Anion adsorption by soils and soil materials. *Adv. Agron*. 30: 26 – 34.

Paustian, K., J Six, ET Elliott, HW Hunt (2000) Management options for reducing CO_2 emissions from agricultural soils. Biogeochemistry 48: 147–163.

Peacock AD, MD Mullen, DB Ringelberg, DD Tyler, DB Hedrick, PM Gale, and DC White (2001) Soil microbial community responses to dairy manure or ammonium nitrate applications. Soil Biology & Biochemistry 33: 1011–1019.

Phan Thi Cong (2000) Improving phosphorus availability in selected soils from the uplands of South Vietnam by residue management. A case study: *Tithonia diversifolia*, Ph.D Thesis No. 439. Katholieke University Leuven, Belgium.

Rao, MR and MN Mathuva (2000) Legumes for improving maize yields and income in semi-arid Kenya. Agriculture, Ecosystems and Environment 78 (2): 123-137.

Roothaert, R and RT Paterson (1997) Recent work on the production and utilization of tree fodder in East Africa. *Animal Feed Science and Technology* 69: 39–51

Ross, DJ and KR Tate (1993) Microbial carbon and nitrogen, and respiratory activity, in litter and soil of southern beech (Nothofagus) forest distribution and properties. Soil Biology and Biochemistry 25: 477- 483.

Sanchez, PA and R. Leakey (1997) Land use transformation in Africa; three determinants for balancing food security with natural resource utilization. European Journal of Agronomy 7: 15 – 23.

Sanchez, PA and Salinas, JE. (1981). Low input technology for managing oxisols and ultisols in tropical America. Adv. Agrom. 34:279 – 406

Sanchez, PA, KD Shepherd, MJ Soule, FM Place, RJ Buresh, AN Izac, AU Mokwunye, FR Kwesiga, CG Ndiritu and PL Woomer (1997) In: Buresh RJ, PA Sanchez and F Calhoun (Eds), *Replenishing Soil fertility in Africa*. SSSA Spec Publ 51, Soil Sci Soc Am, Madison, Wisconsin, USA, p. 1 – 46

Schlesinger WH and MH Hasey (1981) Decomposition of chaparral shrub foliage: losses of organic and inorganic constituents from deciduous and evergreen leaves. Ecology 62: 762 - 774

Schroth G (2003) Decomposition and Nutrient Supply from Biomass. In: Schroth G, and FL Sinclair (Eds). 2003. Trees, Crops and Soil fertility Concepts and Research Methods. CABI Publishing, UK. pg 131.

Scott BJ and AD Robson (1990) Changes in the content and form of magnesium in the first trifoliate leaf of subterranean clover under altered or constant root supply. Aust. J. Agric. Res. 41:511-519

Sharrock RA, FL Sinclair, C Gliddon, IM Rao, E Barrios, PJ Mustonen, P. Smithson, DL Jones and DL Godbold (2004) A global assessment using PCR techniques of mycorrhizal fungal populations colonizing *Tithonia diversifolia*. Mycorrhiza 14: 103 – 109

Smaling EMA, SM Nandwa, and BH Janssen (1997) Soil fertility in Africa is at stake In: Buresh RJ., PA Sanchez and F Calhoun. (eds), *Replenishing Soil*

Fertility in Africa: SSSA Special Publication Number 51. ASA and SSSA, Madison, USA, pp. 47 – 61.

Smith JL and EA Paul (1990) The significance of soil microbial biomass estimations. In: Bollag, J.M., Stotzky, G. (Eds.), Soil Biochemistry, vol. 6. Marcel Dekker, Inc., New York, NY, pp. 357–396.

Snapp SS, PL Mafongoya and S Waddington (1998) Organic matter technologies for the integrated nutrient management in smallholder cropping systems of southern Africa. *Agriculture, Ecosystems and Environment* 71: 185 - 200.

Sonke D (1997) *Tithonia* weed – a potential green manure crop. Echo Development Notes 57: 5–6

Sparling, GP and AW West (1998) A direct extraction method to estimate soil microbial carbon: Calibration in situ using microbial respiration and ^{14}C-labelled cells. Soil Biology and Biochemistry 20: 337- 43.

Sparling GP, CW Feltham, J Reynolds, AW West and P Singleton (1990) Estimation of soil microbial carbon by fumigation – extraction method. Use on soils of high organic matter content, and a reassessment of the KEc- factors. Soil Biology and Biochemistry 22: 301-07.

Swift MJ, A Russel-Smith and TJ Perfect (1981) Decomposition and mineral-nutrient dynamics of plant litter in a regenerating bush-fallow in sub-humid tropical Africa. J. Ecol. 69: 981 – 995.

Swift MJ, OW Heal and JM Anderson (1979) Decomposition in terrestrial ecosystems. Blackwell Oxford, UK.

Swift, MJ and P Woomer (1993) Organic matter and the sustainability of agricultural systems: definition and measurement. In: Mulongoy K and R Merckx (eds)

Soil organic matter and sustainability of tropical agriculture. IITA/K. U. Leuven.

Tona L, K Kambu, N Ngimbi, K Cimanga and AJ Vlietinck (1998) Antiamoebic and phytochemical screening of some Congolese medicinal plants. Journal of Ethnopharmacology 61: 57–65

Tongma S., K Kobayashi and K.Usui (1997) Effect of water extract from Mexican sunflower (*Tithonia diversifolia* (Hemsl.) A. Gray) on germination and growth of tested plants. Journal of Weed Science and Technology 42: 373–378

Troeh, FR and LM Thompson (2005) Soils and Soil Fertility, Sixth Edition. Blackwell Publishing Professional, USA. 489pp.

Tu C, B Jean, JB Ristaino and S Hu (2006) Soil microbial biomass and activity in organic tomato farming systems: effects of organic inputs and straw mulching. Soil Biology and Biochemistry 38: 247–255.

Uphoff, N. (ed) (2002) Agroecological Innovations: Increasing Food Production with Participatory Development. Earthscan Publications Ltd, London, UK.

Ure, AM and ML Berrow (1982) The Elemental constituents of soils. In: HJM Bowen (editor) Environmental Chemistry Vol. 2. Royal Soc. Chem. London, pp. 94-204

USDA (2010). Plant profile. *Tithonia diversifolia* (Hemsl). A. Gray. http://plants.usda.gov/java/profile?symbol=TIDI2. Accessed on 20th May, 2010.

van Straaten, P (2007) Agrogeology: The use of rocks for crops. Enviroquest Ltd, Cambridge, ON, Canada.

Vanlauwe, B., K Aihou, S Aman, ENO Iwuafor, BK Tossah, J Diels, N Sanginga, O Lyasse, R Merckx and J Deckers (2001) Maize yield as affected by organic

inputs and urea in the West African moist savannah. Agronomy Journal 93: 1191-1199.

Vitousek, PM (1984) Litterfall, nutrient cycling, and nutrient limitation in tropical forests. Ecology 65: 285 - 298

Vogt KA, CC Grier and DJ Vogt (1986) Production, turnover, and nutrient dynamics of above- and belowground detritus of world forests. Adv. Ecol. Res. 15: 303 - 377

VSN International Ltd. 2008. GENSTAT for Windows. Eleventh edition. VSN International, 5. The Waterhouse, Waterhouse Street, Hemel Hempstead, Hertfordshire HP1 1ES

Wang WJ, CJ Smith, D Chen (2004) Predicting soil nitrogen mineralization dynamics with a modified double exponential model. Soil Science Society of America Journal 68: 1256–1265.

Weber, MG (1987) Decomposition, litterfall and forest floor nutrient dynamics in relation to fire in eastern Ontario jack pine ecosystems. Canadian Journal of Forest Research 17: 1496-1506.

Wieder, R and Lang, G (1982) A critique of the analytical methods used in examining decomposition in litterbags. Ecology 63: 1636 – 1642.

Williams, CN and KT Joseph (1973) Climate, Soil and Crop Production in the Humid Tropics, revised edition. Oxford University Press, Banguman Loke Yew, Kuala Lumpur. 177pp.

Wolf, B. and GH Snyder (2003) Sustainable Soils: The Place of Organic Matter in Sustaining soils and their productivity. The Haworth Press Inc., NY, USA.

Woods, PV and Raison, RJ (1982) An appraisal of techniques for the study of litter decomposition in eucalyptus forests. Australian Journal of Ecology 7: 215-225.

Wu, J., ZL He, WX Wei, AG O'Donnell and JK Syers (2000) Quantifying microbial biomass phosphorus in acid soils. Biology and Fertility of Soils 32: 500-507.

Young, A (1989) Agroforestry for Soil Conservation. CAB International, Oxford, England.

Young, A (1997) Agroforestry for Soil Management. CAB International, Wallingford, UK. pp 320.

Zaman M, HJ Di, KC Cameron (1999) A field study of gross rates of N mineralization and nitrification and their relationships to microbial biomass and enzyme activities in soils treated with dairy effluent and ammonium fertilizer. Soil Use and Management 15: 188–194.

APPENDICES

Appendix 1 Analysis of variance test for nutrient concentrations in plant biomass as affected by species type

(a) Nitrogen

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.007080	0.001770	1.05	
Block *Units* stratum					
Treatment	4	4.168600	1.042150	619.41	<.001
Residual	16	0.026920	0.001682		
Total	24	4.202600			

d.f. = degrees of freedom, s.s = sum of squares, m.s. = mean sum of squares, v.r. = variance ratio, Fpr. = F probability

(b) Phosphorus

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.0014800	0.0003700	3.08	
Block.*Units* stratum					
Treatment	4	0.2136000	0.0534000	445.00	<.001
Residual	16	0.0019200	0.0001200		
Total	24	0.2170000			

(d) Potassium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.003680	0.000920	0.77	
Block.*Units* stratum					
Treatment	4	0.073600	0.018400	15.40	<.001
Residual	16	0.019120	0.001195		
Total	24	0.096400			

(d) Calcium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.009840	0.002460	1.11	
Block.*Units* stratum					
Treatment	4	2.643400	0.660850	297.35	<.001
Residual	16	0.035560	0.002223		
Total	24	2.688800			

(e) Magnesium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.0008000	0.0002000	1.45	
Block.*Units* stratum					
Treatment	4	0.9130000	0.2282500	1660.00	<.001
Residual	16	0.0022000	0.0001375		
Total	24	0.9160000			

Appendix 2 Analysis of variance test for the decomposition rates (k_D day^{-1}) of plant biomass as affected by period of decomposition

(a) Seven days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.00004120	0.00001030	0.85	
Block.*Units* stratum					
Treatment	4	0.12190400	0.03047600	2529.13	<.001
Residual	16	0.00019280	0.00001205		
Total	24	0.12213800			

(b) Fourteen days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.0002444	0.0000611	0.43	
Block.*Units* stratum					
Treatment	4	0.0437476	0.0109369	77.84	<.001
Residual	16	0.0022480	0.0001405		
Total	24	0.0462400			

(c) Twenty-eight days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.0002780	0.0000695	0.50	
Block.*Units* stratum					
Treatment	4	0.0138660	0.0034665	24.98	<.001
Residual	16	0.0022200	0.0001387		
Total	24	0.0163640			

(e) Fifty-six days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	3.480E-05	8.700E-06	3.08	
Block.*Units* stratum					
Treatment	4	3.514E-03	8.785E-04	310.97	<.001
Residual	16	4.520E-05	2.825E-06		
Total	24	3.594E-03			

(f) Eighty-four days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	1.480E-05	3.700E-06	1.59	
Block.*Units* stratum					
Treatment	4	3.524E-03	8.810E-04	378.92	<.001
Residual	16	3.720E-05	2.325E-06		
Total	24	3.576E-03			

Appendix 3 Nonlinear regression analysis for weight loss of leaf materials over 84 days of decomposition under field conditions

(a) A. auriculiformis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	2969.33	1484.66	61.88	0.004
Residual	3	71.97	23.99		
Total	5	3041.30	608.26		

(b) S. spectabilis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	5661.27	2830.63	94.95	0.002
Residual	3	89.44	29.81		
Total	5	5750.70	1150.14		

(c) L. leucocephala

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	3663.28	1831.64	91.08	0.002
Residual	3	60.33	20.11		
Total	5	3723.61	744.72		

(d) T. diversifolia

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	6934.64	3467.32	140.38	0.001
Residual	3	74.10	24.70		
Total	5	7008.74	1401.75		

(e) G. sepium

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	5936.71	2968.35	89.96	0.002
Residual	3	98.99	33.00		
Total	5	6035.70	1207.14		

Appendix 4 Analysis of variance test for the nitrogen release rates (k_N day^{-1}) of plant biomass as affected by period of decomposition

(a) Seven days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.00001600	0.00000400	0.13	
Block.*Units* stratum					
Treatment	4	0.25057600	0.06264400	1980.84	<.001
Residual	16	0.00050600	0.00003163		
Total	24	0.25109800			

(b) Fourteen days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.00018600	0.00004650	2.27	
Block.*Units* stratum					
Treatment	4	0.09022600	0.02255650	1100.32	<.001
Residual	16	0.00032800	0.00002050		
Total	24	0.09074000			

(c) Twenty-eight days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	1.960E-05	4.900E-06	1.18	
Block.*Units* stratum					
Treatment	4	2.702E-02	6.754E-03	1627.47	<.001
Residual	16	6.640E-05	4.150E-06		
Total	24	2.710E-02			

(d) Fifty-six days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.00002520	0.00000630	0.43	
Block.*Units* stratum					
Treatment	4	0.01085000	0.00271250	186.43	<.001
Residual	16	0.00023280	0.00001455		
Total	24	0.01110800			

(e) Eighty-four days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	1.320E-05	3.300E-06	0.90	
Block.*Units* stratum					
Treatment	4	2.534E-03	6.335E-04	172.38	<.001
Residual	16	5.880E-05	3.675E-06		
Total	24	2.606E-03			

Appendix 5 Analysis of variance test for the phosphorus release rates (k_P day^{-1}) of plant biomass as affected by period of decomposition

(a) Seven days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.0010012	0.0002503	1.22	
Block.*Units* stratum					
Treatment	4	0.2251300	0.0562825	273.48	<.001
Residual	16	0.0032928	0.0002058		
Total	24	0.2294240			

(b) Fourteen days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.0002200	0.0000550	0.28	
Block.*Units* stratum					
Treatment	4	0.0628340	0.0157085	78.59	<.001
Residual	16	0.0031980	0.0001999		
Total	24	0.0662520			

(c) Twenty-eight days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.00028920	0.00007230	1.43	
Block.*Units* stratum					
Treatment	4	0.03082400	0.00770600	152.44	<.001
Residual	16	0.00080880	0.00005055		
Total	24	0.03192200			

(d) Fifty-six days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	2.464E-05	6.160E-06	1.81	
Block.*Units* stratum					
Treatment	4	7.857E-03	1.964E-03	576.03	<.001
Residual	16	5.456E-05	3.410E-06		
Total	24	7.936E-03			

(e) Eighty-four days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	5.320E-05	1.330E-05	7.39	
Block.*Units* stratum					
Treatment	4	4.554E-03	1.139E-03	632.50	<.001
Residual	16	2.880E-05	1.800E-06		
Total	24	4.636E-03			

Appendix 6 Analysis of variance test for the potassium release rates (k_K day^{-1}) of plant biomass as affected by period of decomposition

(a) Seven days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	4.120E-05	1.030E-05	1.30	
Block.*Units* stratum					
Treatment	4	1.112E-01	2.779E-02	3506.75	<.001
Residual	16	1.268E-04	7.925E-06		
Total	24	1.113E-01			

(b) Fourteen days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.00039960	0.00009990	1.57	
Block.*Units* stratum					
Treatment	4	0.02833000	0.00708250	111.27	<.001
Residual	16	0.00101840	0.00006365		
Total	24	0.02974800			

(c) Twenty-eight days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.00024680	0.00006170	1.57	
Block.*Units* stratum					
Treatment	4	0.04234400	0.01058600	270.05	<.001
Residual	16	0.00062720	0.00003920		
Total	24	0.04321800			

(d) Fifty-six days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.00002520	0.00000630	0.44	
block.*Units* stratum					
Treatment	4	0.00481600	0.00120400	84.20	<.001
Residual	16	0.00022880	0.00001430		
Total	24	0.00507000			

(e) Eighty-four days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	5.640E-05	1.410E-05	2.52	
Block.*Units* stratum					
Treatment	4	9.286E-03	2.322E-03	414.55	<.001
Residual	16	8.960E-05	5.600E-06		
Total	24	9.432E-03			

Appendix 7 Analysis of variance test for the magnesium release rates (k_{Mg} day^{-1}) of plant biomass as affected by period of decomposition

(a) Seven days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.0023516	0.0005879	3.82	
Block.*Units* stratum					
Treatment	4	0.0838540	0.0209635	136.22	<.001
Residual	16	0.0024624	0.0001539		
Total	24	0.0886680			

(b) Fourteen days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	2.320E-05	5.800E-06	0.70	
Block.*Units* stratum					
Treatment	4	4.246E-02	1.062E-02	1279.04	<.001
Residual	16	1.328E-04	8.300E-06		
Total	24	4.262E-02			

(c) Twenty-eight days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.00003240	0.00000810	0.73	
Block.*Units* stratum					
Treatment	4	0.04224600	0.01056150	951.49	<.001
Residual	16	0.00017760	0.00001110		
Total	24	0.04245600			

(d) Fifty-six days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	7.560E-05	1.890E-05	4.30	
Block.*Units* stratum					
Treatment	4	1.399E-02	3.498E-03	795.11	<.001
Residual	16	7.040E-05	4.400E-06		
Total	24	1.414E-02			

Appendix 8 Analysis of variance test for the calcium release rates (k_{Ca} day^{-1}) of plant biomass as affected by period of decomposition

(a) Seven days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	1.080E-05	2.700E-06	0.41	
Block.*Units* stratum					
Treatment	4	1.095E-01	2.737E-02	4162.21	<.001
Residual	16	1.052E-04	6.575E-06		
Total	24	1.096E-01			

(b) Fourteen days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	3.560E-05	8.900E-06	3.36	
Block.*Units* stratum					
Treatment	4	3.643E-02	9.109E-03	3437.17	<.001
Residual	16	4.240E-05	2.650E-06		
Total	24	3.651E-02			

(c) Twenty-eight days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	0.00003000	0.00000750	0.43	
Block.*Units* stratum					
Treatment	4	0.01796600	0.00449150	256.66	<.001
Residual	16	0.00028000	0.00001750		
Total	24	0.01827600			

(d) Fifty-six days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	3.320E-05	8.300E-06	2.84	
Block.*Units* stratum					
Treatment	4	5.086E-03	1.271E-03	434.70	<.001
Residual	16	4.680E-05	2.925E-06		
Total	24	5.166E-03			

(e) Eighty-four days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	4	1.520E-05	3.800E-06	1.75	
Block.*Units* stratum					
Treatment	4	1.586E-03	3.965E-04	182.30	<.001
Residual	16	3.480E-05	2.175E-06		
Total	24	1.636E-03			

Appendix 9 Nonlinear regression analysis for nitrogen released from decomposition leaf materials over 84 days under field conditions

(a) A. auriculiformis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	3412.1	1706.0	15.31	0.027
Residual	3	334.4	111.5		
Total	5	3746.5	749.3		

(b) *S. spectabilis*

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	5299.12	2649.56	105.77	0.002
Residual	3	75.15	25.05		
Total	5	5374.27	1074.85		

(c) L. leucocephala

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	4297.9	2149.0	20.39	0.018
Residual	3	316.2	105.4		
Total	5	4614.1	922.8		

(d) T. diversifolia

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	7639.29	3819.643	464.39	<.001
Residual	3	24.68	8.225		
Total	5	7663.96	1532.792		

(e) G. sepium

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	6327.63	3163.814	407.49	<.001
Residual	3	23.29	7.764		
Total	5	6350.92	1270.184		

Appendix 10 Nonlinear regression analysis for phosphorus released from decomposition leaf materials over 84 days under field conditions

(a) A. auriculiformis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	4286.3	2143.17	60.08	0.004
Residual	3	107.0	35.67		
Total	5	4393.3	878.67		

(b) S. spectabilis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	6324.11	3162.06	228.16	<.001
Residual	3	41.58	13.86		
Total	5	6365.69	1273.14		

(c) L. leucocephala

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	4568.17	2284.09	97.27	0.002
Residual	3	70.45	23.48		
Total	5	4638.62	927.72		

(d) T. diversifolia

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	7602.05	3801.024	426.81	<.001
Residual	3	26.72	8.906		
Total	5	7628.76	1525.753		

(g) *G. sepium*

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	6158.0	3079.02	89.10	0.002
Residual	3	103.7	34.56		
Total	5	6261.7	1252.34		

Appendix 11 Nonlinear regression analysis for potassium released from decomposition leaf materials over 84 days under field conditions

(a) *A. auriculiformis*

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	6306.7	3153.33	71.26	0.003
Residual	3	132.8	44.25		
Total	5	6439.4	1287.89		

(b) *S. spectabilis*

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	7623.774	3811.887	1249.00	<.001
Residual	3	9.156	3.052		
Total	5	7632.930	1526.586		

(c) *L. leucocephala*

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	7110.4	3555.21	70.30	0.003
Residual	3	151.7	50.57		
Total	5	7262.1	1452.42		

(d) *T. diversifolia*

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	7585.46	3792.73	215.98	<.001
Residual	3	52.68	17.56		
Total	5	7638.14	1527.63		

(e) *G. sepium*

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	6999.60	3499.80	217.39	<.001
Residual	3	48.30	16.10		
Total	5	7047.90	1409.58		

Appendix 12 Nonlinear regression analysis for calcium released from decomposition leaf materials over 84 days under field conditions

(a) A. auriculiformis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	2792.3	1396.13	32.60	0.009
Residual	3	128.5	42.83		
Total	5	2920.7	584.15		

(b) S. spectabilis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	4570.78	2285.39	147.87	0.001
Residual	3	46.37	15.46		
Total	5	4617.14	923.43		

(c) *L. leucocephala*

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	3028.0	1514.0	6.50	0.081
Residual	3	698.7	232.9		
Total	5	3726.7	745.3		

(d) T. diversifolia

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	7217.75	3608.87	234.94	<.001
Residual	3	46.08	15.36		
Total	5	7263.83	1452.77		

(e) G. sepium

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	4399.7	2199.8	15.75	0.026
Residual	3	419.0	139.7		
Total	5	4818.7	963.7		

Appendix 13 Nonlinear regression analysis for magnesium released from decomposition leaf materials over 84 days under field conditions

(a) A. auriculiformis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	2574.	1287.0	2.39	0.240
Residual	3	1616.	538.8		
Total	5	4191.	838.1		

(b) *S. spectabilis*

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	6692.77	3346.38	117.55	0.001
Residual	3	85.40	28.47		
Total	5	6778.17	1355.63		

(c) *L. leucocephala*

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	3642.5	1821.27	39.73	0.007
Residual	3	137.5	45.84		
Total	5	3780.1	756.01		

(d) T. diversifolia

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	7447.57	3723.79	195.30	<.001
Residual	3	57.20	19.07		
Total	5	7504.77	1500.95		

(e) *G. sepium*

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	6665.1	3332.55	82.33	0.002
Residual	3	121.4	40.48		
Total	5	6786.5	1357.31		

Appendix 14 Sociological survey on soil fertility practices and ethnobotanical knowledge of *Tithonia diversifolia* at Dumasua in the transition zone of Ghana

A RESPONDENT DETAILS

A.1 Name of respondent: ……

A.2 Age class 18 – 30 [ ] = 1 31 – 45 [ ] = 2
45 – 60 [ ] = 3 Above 60 [ ] = 4

A.3 Sex Male [ ] = 1 Female [ ] = 2

A.4 Highest level of education Primary [ ] = 1 Secondary [ ] = 2
Tertiary [ ] = 3 Illiterate [ ] = 4

A.5 Marital status Single [ ] = 1 Married [ ] = 2
Divorced [ ] = 3 Deceased [ ] = 4

B. CROP PRODUCTION

B. 1 How long have you been engaged in crop production?
< 1 year [ ] = 1 2 – 5 [ ] = 2 6 – 10 [ ] = 3 more than 10 years [ ] = 4

B.2 Identify your crop production objective
Wholly subsistence [ ] = 1
Wholly commercial [ ] = 2
Subsistence and Commercial with subsistence a first priority [ ] = 3
Subsistence and Commercial with commercial a first priority [ ] = 4

B. 3 Name most produced crops
……
……

B. 4 Identify your regular cropping method or pattern

Monocropping [ ] = 1 Mixed cropping [ ] = 2

Crop rotation [ ] = 3 Monoculture [ ] = 4

B.5 Assign reasons to your choice of a cropping method

……

……

……

……

B. 6 What is your seasonal production target per acre for your your most preferred crop?

……..

B. 7 Is your target regularly met? Yes [ ] = 1 No [ ] = 2

B. 8 If yes or no, why?

……

……

……

……

B. 9 With reasons, mention whether or not you are encouraged to continue farming.

……

……

……

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C SOIL FERTILITY IMPROVEMENT

C. 1 How have you been able to improve and maintain the fertility of your land?

……

……

……

……

C. 2 State how long you have adopted the practice in (C.1 above) and why?

……

……

……

……

C. 3 With reasons, state whether or not your practice of maintaining soil fertility reflect in your seasonal production targets?

……

……

……

……

C.4 Is the practice promising and sustainable? Yes [ ] = 1 No [ ] = 2

C. 5 If no, do you require a new technology or practice? Yes [ ] = 1 No [ ] = 2

C. 6 If yes, state whether you know any alternative practice?

……

……

D. ETHNOBOTANICAL KNOWLEDGE OF *Tithonia diversifolia*

D.1 Have you seen or heard about the *Tithonia* plant before? (asked with a sample at hand)

Yes [ ] = 1 No [ ] = 2

D. 2 If seen, where?

……

D. 3 If heard, what?

……

……

……

D. 4 If yes to one or all (see question D. 1), can you give its local name?

……

D. 5 Have you personally used or seen someone using the plant for anything?

Yes [ ] = 1 No [ ] = 2

D.6 If yes to one or all, identify uses *Tithonia* have been put to?

……

……

……

D.7 If yes to one or all (see question D.5), identify any taboos all beliefs to the use of *Tithonia.*

……

……

D. 8 Do you know it can be used for soil fertility improvement?

Yes [ ] = 1 No [ ] = 2

D. 9 If yes, how did you know?

……

D. 9 Are you willing to try it on your farm?

Yes [ ] = 1 No [ ] = 2

D. 10 If yes or no, state why?

……

……

……

Appendix 15 Some parts of *T. diversifolia*

(a) Leaves and flowers

(b) Seeds