EFFECTS OF LITTER DIVERSITY OF SELECTED TREE SPECIES ON DECOMPOSITION IN AN AGROFORESTRY SYSTEM IN SEMI-ARID, KENYA (A CASE STUDY OF JUJA)

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Effects of Litter Diversity of Selected Tree Species on Decomposition in an Agroforestry System in Semi-Arid, Kenya (A Case Study of Juja)

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DECLARATION

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

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This thesis has been submitted for examination with our approval as the University supervisors.

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DEDICATION

I dedicate this work to almighty God for his mercy upon my life to this present moment, and to my wife for her love and moral support. She is indeed a rare gem.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATIONS

AE	Additive effect
ANOVA	Analysis of variance
ASAL	Arid and semi-arid land
C	Carbon
C:N	Carbon to nitrogen ratio
CO_2	Carbon dioxide
JKUAT	Jomo Kenyatta University of Agriculture and Technology
K	Potassium
L:N	Lignin to Nitrogen ratio
N	Nitrogen
NAE	Non additive effect
N:P	Nitrogen to phosphorus ratio
N_2	Nitrogen gas
P	Phosphorus
PFT	Plant functional type
SE	Standard error

ABSTRACT

Plant litter decomposition is an important ecosystem function that aid nutrient cycling in an ecosystem. However, there is little information on how diversity of agroforestry tree species affects the rate of decomposition of their resultant litter. This study was conducted on an established agroforestry experimental farm in JKUAT, Kenya. The site contains three treatments and a control, using seven agroforestry tree species from which eleven compositions of litter were made. Decomposition process and nutrient released was studied using the standard litter bag technique. Litter fall from the tree species was collected using conical litter traps to determine ecosystem nutrient release. Soil moisture content on each treatment plot was measured to determine its confounding effect on litter decomposition. The average biomass loss in litter of the compositions after 90 days of decomposition was highest in litter of *Acacia seyal* (48.75%) and lowest in *Cordia africana* (21.65%). The observed and the predicted litter biomass loss and nutrient released observed additive effect in biomass loss of all tested mixtures. Additive effect was also observed in Nitrogen, Phosphorus and Potassium released but a non-additive effect was observed in Carbon released. *A. seyal* had the highest litter fall and released the highest nutrient of N, P, K and C (23, 1.33, 3.0 and 127 kg ha^{-1} respectively). Treatment plots with *Faidhebia albida* had the highest soil moisture content (42.97%) while *C. africana* plot had the lowest (28.96%). However, the effect of soil moisture was not significant on the rate of decomposition (r^2=0.046). The findings from this study show that tree diversity increases rate of decomposition and nutrient release from low quality tree litter. The rate of decomposition and nutrient released in mixed compositions was regulated by individual species rather than species richness. There are other factors that aid soil moisture in litter decomposition. In conclusion, farmers should therefore use different agroforestry tree species to benefit from the synergy of the different ecosystem function that tree species could render such as enhanced decomposition and nutrient cycling from the low quality tree species.

CHAPTER ONE

INTRODUCTION

In the last few decades, ecological research on the importance of plant species diversity on ecosystem functioning has taken a front edge (Hooper *et al*., 2005). Due to different land management practices, residues from trees, crops and other plants usually mix up and decompose together in the soil (Zeng *et al*., 2009). The residues produced by each plant species differ in quality and quantity (Hoorens *et al*., 2002) and therefore affects the rate of decomposition and nutrient release in different ways. Interactive effects of litter mixtures on decomposition and nutrient release have been documented exclusively, including studies by Handa *et al*. (2014); Hattenschwiler *et al*. (2005); Hoorens *et al*., (2002) and Wardle *et al*. (1997). These studies have established both additive and non-additive interaction on litter mixtures.

Decomposition and nutrient release are controlled by biotic and abiotic factors such as litter quality, soil moisture, microbial activities and temperature (Aber *et al*., 1990; Aerts, 1997; Silver & Miya, 2001). Hence, preference cannot be attributed to one single factor (Prescott, 2005) and no single nutrient can dominate decomposition and nutrient release pattern (Waring, 2012). In a mixed community like agroforestry systems or practices, decomposition and nutrient release pattern from litter can be non-additive (there is difference between the observed effect in mixture and expected effect from the individual species).

Non-additive could be either synergistic non-additive (observed higher than expected) (Dijkstra *et al*., 2009) or antagonistic non-additive (observed lesser than expected) (Dijkstra *et al*., 2009). Additive effect (no difference between observed and predicted) on litter decomposition and nutrient release has also been documented (Hoorens *et al*., 2009; Salamanca *et al*., 1998). The expected is the calculated average of litter decomposition and nutrient release from individual species while the observed are the corresponding parameters of the combinations (Gartner and Cardon, 2004).

The synergistic non-additive effects (NAE) could be as a result of nutrient transfer (Seastedt, 1984) or improved atmosphere for microbial activity by the mixed litter. The antagonistic non-additive effect could be as a result of recalcitrant substances such as lignin (Melillo *et al*., 1982; Wardle *et al*., 1997), or high nitrogen (N) content which could bring about high nitrogen to phosphorus ratio (N:P) beyond the optimal level for decomposition (Knecht and Göransson, 2004). The additive effect (AE) in litter mixture could be as a result of balancing of interaction between the individual species present in the mixture (Hoorens *et al*., 2009) and some physical and biological factors such as loading ratio, mesh size of litterbags, placement of litter, litter components and time (Gartner and Cardon, 2004).

Trees impacts on soil depend on its chemical quality and decomposition of its litter (Singh and Tripathi, 1999). Litter chemistry is one of the key factors that determine the rate of decomposition of litter (Zhang *et al*., 2008). Hence, the amount of nutrient released in a particular area depends on the quality of the litter fall and leaf litter production dominates the amount of litter production (Bisht *et al*., 2014; Singh and Tripathi, 1999). In a research on the subalpine region of Himalaya, Bisht *et al*., (2014) established that leaf litter production was 75-79% compared to non leaf litter production. Singh and Tripathi, (1999) in a research on coal mine spoils at Singrauli, India estimated leave litter fall to 83–96% as compared to non-leaf litter fall of 4-17%. They found out that leaf litter produced nearly double the nutrient concentration in non-leaf litter. However, little is known about litter diversity effect on the decomposition and release of some major nutrients to the soil in agroforestry system in semi-arid regions of Kenya. Most studies on this topic have worked on forest and other ecosystems (Ball *et al*., 2008; Bisht *et al*., 2014; Dijkstra *et al*., 2009) but little attention has been given to agroforestry system most especially in the semi-arid zones.

Litter fall and its productivity are among the main factors that contribute to nutrient cycling in an ecosystem (Aerts and De Caluwe, 1997). The faster the litter nutrient release the more productive a site is (Moore *et al*., 2006). However, a combination of tree species on farm will bring about combination of their litter. Litter from species with high nutrient concentration could induce a priming effect on litter with low nutrient concentration (Liu *et al*., 2007). Immobilization of nutrient from the environment may occur when nutrient requirement by a decomposer organisms is low in the plant litter (Moore *et al*., 2006). The decomposer community in the soil needs to obtain enough N or phosphorus (P) from the litter to be able to consume the organic carbon (C) they require for energy (Abaye and Brookes, 2006). If the N or P in the litter is not enough, decomposers tends to acquire N or P through immobilization or other means to balance up the system (Moore *et al*., 2006). This could bring about an increase in nutrient content in litter during decomposition.

Agren *et al*., (2012) and Knecht and Göransson, (2004) postulated that N and P are nutrient limiting elements on crop growth in most ecosystems. Legume tree based agroforestry farming systems have the capacity to support microbial nitrogen gas (N_2) fixation and can increase soil N availability and therefore improve soil fertility, crop yields, and support long-term nutrient balance (Rosenstock *et al*., 2014). Improper combination of agroforestry trees could bring about failure in an agroforestry practice (Nair, 1993). The pattern of litter decomposition and nutrient release by trees therefore needs to be known prior to the introduction of trees for agroforestry practices (Daldoum *et al*., 2010; Nair, 1993). In spite of this, information is also needed on suitable tree combinations for the improvement of nutrient cycling which in turn can improve soil quality in agroforestry systems. Quantifying litter fall and productivity of litter is essential to assess the productivity of particular tree species (Fernando and Bandeira., 2009).

1.1 Background to the study

Agroforestry is practiced in arid and semi-arid (ASAL) region to improve soil fertility (Jama and Zeila, 2005) among other benefits. Previous research by Belsky *et al*., (1989); Burgess *et al*., (1998) and Ludwig *et al*., (2003) showed that agroforestry could improve crop productivity through micro climate improvement and water redistribution from wet to drier soil. Trees on farm could also take nutrients from deep down the soil beyond where crop roots can reach and bring the nutrients to the reach of crops through litter drops and decomposition (Smith, 2010).

Decomposition of agroforestry tree residues releases nutrients into the soil which is a very important ecosystem function (Aerts and De Caluwe, 1997). Decomposition also regulate nutrients recycling (Hobbie and Vitousek, 2000). The litter decomposition and nutrient release pattern are known to be controlled by biotic and abiotic factors such as litter quality, temperature, microbial activities and soil moisture (Aber *et al*., 1990; Aerts, 1997; Hättenschwiler and Jørgensen, 2010; Mungai and Motavalli, 2006; Silver and Miya, 2001). Initial litter quality and soil moisture contents are known to be the dominant factor that influences the decomposition rate (Melillo *et al*., 1984).

Agroforestry practices contain a mixture of plant species such as trees and crops (Muthuri *et al*., 2005) that have different growth forms and residue qualities (Nair, 1993). Hence, their mixed residues therefore may not decompose in a similar pattern to their individual components (Zeng *et al*., 2009). In the combinations of trees on farm there could be interactive effects of litter mixtures on decomposition rate which could be additive or non-additive (antagonistic or synergistic) (Hoorens et al., 2002; Wardle *et al*., 1997). Comparing the effect of the tree diversity on a long term may underestimate or over-estimate the short term dynamics of interaction (Gartner and Cardon, 2004).

Litter bags are widely used in litter decomposition studies (Hasanuzzaman and Hossain, 2014; Liu *et al*., 2007; Moore *et al*., 2006; Wardle *et al*., 1997; Xiao *et al*., 2014; Zhao *et al*., 2013). Gartner and Cardon, (2004) discussed the factors that could influence the rate of decomposition of litter in an experiment using litter bags. These effects include decomposer activity, soil moisture, and the loading ratio in mixed litter and litter bag mesh size. Activities of decomposer could depend on the ecosystems. Wet environments favor decomposer activities than drier environments (Hasanuzzaman and Hossain, 2014). Chapman and Newman, (2009) observed that decomposer activity is higher in mixed litter. Loading ratio (the actual amount of each species litter present in the mixtures) also influences the rate of decomposition depending on the quality of litter of species in the mix (Salamanca *et al*., 1998). Larger mesh size will allow meso and macro fauna like arthropods and worms to have access to the litter in the bag and this will improve decomposition rate but smaller mesh size will limit the effect of meso and macro fauna (Salamanca *et al*., 1998). Despite all this, use of litter bags still remain the best way to demonstrate litter diversity relationship in an ecosystem (Gartner and Cardon, 2004; Karberg *et al*., 2008).

In temperate regions, several studies have been conducted on the effects of litter diversity on litter decomposition (Hoorens *et al.*, 2002; Hattenschwiler *et al.*, 2005; Jabiol and Chauvet, 2012; Osono and Takeda, 2005; Pérez Harguindeguy *et al.*, 2008; Wu *et al.*, 2013) but limited attention has been given to semi-arid regions. Most of the studies conducted in the temperate regions have also mainly focused on lower diversity of tree species except for a research by Wardle *et al*., (1997) that worked on 32 plant species of four functional groups combined in mixtures of two to eight species. Using limited number of species for decomposition studies and nutrient release might not fully represent the actual dynamics in an ecosystem (Hattenschwiler *et al*., 2005). There is therefore a need for research using more species that closely or fully represent the dynamics of the real ecosystem. Most of the previous work by researchers on the tropic have observed non-additive and additive effects on litter diversity (Hattenschwiler *et al*., 2005; Hoorens *et al*., 2002, 2009) .

Research needs to be spread to touch on all ecosystems because the effect of litter diversity in one ecosystem might not predict the effect in another ecosystem (Gartner and Cardon, 2004). Litter decomposition studies have been done on various ecosystems including tropical forests (Finzi and Canham, 1998; Hättenschwiler and Jørgensen, 2010), temperate forest (Ball *et al*., 2008; Gao *et al*., 2015), subalpine forest (Bisht *et al*., 2014), mangrove forest (Fernando and Bandeira, 2009), terrestrial ecosystem (Hattenschwiler *et al*., 2005), peat lands (Hoorens *et al*., 2009), plantation farm (Daldoum *et al*., 2010; Hossain *et al*., 2011) but none of the above research work is on agroforestry systems specifically in semi-arid zone. In this study, litter diversity of three, five and seven species were observed to better understand species diversity effect on rate of decomposition in an agroforestry established system in a semi-arid zone.

Semi-arid zones or regions are known to be faced with soil infertility that is caused by low rainfall, high rate of evaporation to low rate of precipitation (Hasanuzzaman and Hossain, 2014). Trees on farm could be used to improve the quality of the soil among other benefits (Jama and Zeila, 2005), if properly planned. Proper evaluation of trees are needed to be done prior to introduction of trees in agricultural land because wrong choice of agroforestry trees could bring failure in an agroforestry practices (Nair, 1993).

Therefore, it is important to select agroforestry trees with limited competition with crops (Muthuri *et al*., 2005) especially for soil water in arid and semi-arid regions and also trees with better decomposition capability to bring about productive agroforestry practice.

Previous studies have discussed trees with potential benefits to agriculture such as nutrient release, moisture retention, protection against erosion (Akpo *et al*., 2005; Gindaba *et al*., 2005; Nair, 1993) but the influence of introduced diverse trees in an agroforestry system on litter decomposition and nutrient release have not been studied in semi-arid parts of Kenya. This research focused on the influence of diverse trees introduced to farmland on soil moisture content, how the tree diversity affects their rate of decomposition and nutrient release, the relationship between the decomposition and moisture content and also the ecosystem dynamics of nutrient release. The aim was to shed more light and give information that could help farmers to optimally benefit from ecosystem services that could be rendered by tree diversity.

1.2 Statement of problem

Only one third of land in Kenya can sustain productive agriculture with the remaining two third of land as arid and semi-arid land (ASAL) (Mutungwa and Orodho, 2014) which needs extra input like irrigation and addition of inorganic fertilizer to make them suitable for agricultural purposes. The ASAL are faced with soil infertility and agroforestry systems were introduced to improve ecosystem function and in turn improve soil quality. Wrong choice of species combination could bring about a failure in the practice (Nair, 1993). Therefore, understanding the pattern of tree leaf litter decomposition in single and mixed litter will complement the gap in the knowledge of nutrient cycling (Hui and Jackson, 2008) on agroforestry systems in semi-arid lands. Knowledge about this could help farmers in selecting the most suitable agroforestry trees for the eco-zone and benefits from all ecosystem services that could be rendered by the tree species.

1.3 Justification

Tree litter has been documented to help improve nutrient cycling in ecosystems (Muthuri *et al*., 2005). The nutrient cycling are enhanced through decomposition of plant litter (Koorem *et al*., 2011). Despite the knowledge about plant litter improving ecosystem functioning, previous studies have focused on natural ecosystem given little attention to agroforestry system and most especially in ASAL. Agroforestry systems are introduced to ASAL for the improvement of soil quality (Jama and Zeila, 2005).

The practice of agroforestry entails a mixture of plant species such as trees and crops that have different growth forms and residue qualities, their mixed residues therefore may not decompose in a similar pattern to their individual components (Zeng *et al*., 2009). Appropriate tree species selection based on nutrient cycling is a vital issue in agroforestry practices (Daldoum *et al*., 2010; Hasanuzzaman and Hossain, 2014).

Gartner and Cardon., (2004) also proposed the necessity of estimating short time decomposition and nutrient release rate of species in both monoculture and mixture to reduce the over estimation and underestimation of short term dynamics of species interactions. This study was carried out on an established agroforestry experimental farm. The tree species selection was based on the effectiveness of the trees to improve ecosystem services in ASAL (Muthuri *et al*., 2005; Nair, 1993; Ong, *et al*., 2006; Shelton, 2004; Shem, *et al*, 2009). The selected tree combination effect was estimated to document their inter-specific interaction during decomposition in the short growing season. This could help farmers in selecting tree species for optimal benefit from their ecosystem functions.

1.4 Hypothesis

Diversity of agroforestry trees has no significant effect on litter decomposition.

1.5 General objective

To determine the effect of selected agroforestry trees litter diversity on the rate of decomposition in an agroforestry system in a semi-arid zone in Juja.

1.6 Specific Objectives

1) To determine the effect of litter diversity of selected tree species on decomposition in an agroforestry system.
2) To determine the effect of litter diversity of selected tree species on nutrient release.
3) To determine the quantity and quality of litter from different tree species in an agroforestry system.
4) To determine the effect of selected tree species on soil moisture content.

5) To determine the effect of soil moisture on the rate of decomposition.

1.7 Scope of the study

This study focused on litter diversity effect on decomposition and nutrient release, effect of soil moisture on rate of decomposition and the relationship between litter quantity and quality of litter from different species. The study also looked at how the rate of litter fall from a tree species could predict the quality of such tree. A four year established agroforestry farm in a semi-arid area in Jomo Kenyatta University of agriculture and technology (JKUAT) was used. Short term (90 days) decomposition and nutrient release analysis was used to observe short term decomposition and nutrient release dynamics. Therefore, research on short term decomposition dynamics was a necessity to understand what transpire between different species in their early stage of decomposition. Litter fall was also collected for 6 months in order to cut across the two seasons of the study environment (dry and wet season). Moisture content on each treatment plot was also used to quantify the effect of tree diversity on each treatment plots and also to understand the effect of soil moisture content on decomposition rate.

1.8 Summary

The study set out to investigate the effect of litter diversity on decomposition rate in an agroforestry system. Using an established research farm in JKUAT, Kenya, and the plots have different agroforestry tree treatments which were setup using completely randomized experimental design. Due to food insecurity in developing countries and inability of farmers to purchase inorganic fertilizer to improve their productivity, more emphasis need to be thrown towards tree diversity effect on agroforestry farm to help farmers benefit from all form of ecosystem services that could be rendered by trees on farm. This research will document tree species with potential qualities both in monoculture and mixture to better enhance agroforestry practices in semi-arid region of Kenya.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The importance of plant species diversity on ecosystem functioning has taken the focus of ecological research (Hooper *et al*., 2005). Limited information is known on plant diversity effects on other key ecosystem processes such as decomposition and nutrient cycling (Jacob *et al*., 2010) particularly in the semi-arid zones. Due to some management practices such as on-site retention of straw and tillage, residues of trees and crops usually become mixed and decompose simultaneously within soil (Zeng *et al*., 2009). Plant species differ in the quality and quantity of the litter they produce (Hoorens *et al*., 2002). Therefore, different species will have different input in litter fall, decomposition and nutrient release. Addition of plant residues into the soils can sustain organic carbon content, improve soil physical properties, enhance biological activities and increase nutrient availability (Zeng *et al*., 2009). Agroforestry systems where tree interact with agriculture (Coe *et al*., 2014) were mostly introduced to improve soil quality in ecosystems (Jama and Zeila, 2005).

Agroforestry systems offer numerous potential benefits, including provision of multiple products and services, such as food, fuel, building materials, conservation of soil, conservation of water resources and also improving food security (Ong *et al*., 2006). Wrong choice of species combination, management practices, and lack of peoples' motivation and understanding may bring about failure in agroforestry practices (Nair, 1993).

Temperate regions are on the front edge because several studies have already been conducted on the effects of litter diversity on litter decomposition (Hattenschwiler *et al*., 2005; Hoorens *et al*., 2002; Jabiol and Chauvet, 2012; LeRoy and Marks, 2006; Liu *et al*., 2007; Osono and Takeda, 2005; Pérez Harguindeguy *et al*., 2008; Wu *et al*., 2013; Xiao *et al*., 2014) but limited attention have been given to semi-arid ecosystems.

Agroforestry, which is a suitable land use system where tree are intentionally planted to interact with agriculture to improve nutrient cycling and in turn increase soil quality has been widely introduced to developing nations to help solve the soil infertility challenges faced by farmers (Jama and Zeila, 2005). Trees on farm not only improve soil quality but also serve as an alternative food source to animals during drought and scarcity of feeds among other uses (Kebede *et al*., 2016).

Soil fertility can be improved in agroforestry systems through litter falls and decomposition (Tripathi *et al*., 2009). Litter falls and decomposition are unique ecosystem function which tree on farm use to improve nutrient cycling and also maintain soil fertility (Aerts and De Caluwe, 1997).

Agroforestry could satisfy the increasing food, fodder and fuel demands but the success or failure depends on trees/crops combinations selection (Nair, 1993). Trees in semi-arid areas have been documented by Belsky *et al*., (1989); Burgess *et al*., (1998) and Ludwig *et al*., (2003) to increase crop productivity through micro climate improvement and water redistribution from wet to drier soil. Better selection of agroforestry trees with efficient nutrient return ability will bring about a productive combination while wrong choice of tree selection for agroforestry practices will affect the effort of agroforestry on farm land (Nair, 1993). Therefore, pattern of decomposition of agroforestry species and their interaction among each other needs to be understood before their introduction for agroforestry practices. Many studies have been conducted on litter decomposition in the tropics but no study has discussed the effects of tree diversity on rate of litter decomposition in agroforestry system in semi-arid areas of Kenya.

2.2 Trees and their effect on land

Previous scolars have documented tree effects, litter decomposition and their nutrient dynamics in different natural ecosystems and managed ecosystems. Despite all the previous work on tree effect on land and nutrient dynamics, no research has particularly touched on diversity of trees and its effect in agroforestry system in semi-arid region of Kenya.

Tree on farm could affect understory crops through shading (Lott *et al*., 2000) or competition with crops for underground nutrients and soil water (Akpo *et al*., 2005; Gindaba *et al*., 2005; Lott *et al*., 2000). Getahun *et al*., (2014); Hadgu *et al*., (2009) and Kalinda *et al*., (2015) have documented the benefits that trees on farm could render. With the mix effect that has been observed from trees on farm, there is a need for proper documentation of trees interaction and effect on land prior to their introduction to better benefit from the numerous ecosystem functions that tree on land could offer.

Semi-arid lands are known worldwide to be water limited ecosystems due to low and unpredictable seasonal rainfall, high mean annual temperatures and high evaporative demands (Jama and Zeila, 2005). Hasanuzzaman and Hossain, (2014) postulated that agroforestry systems could increases cycling of nutrients, and this increase in nutrient cycle could be a benefit to the ecosystem more specifically in semi-arid lands that are faced with soil infertility. Substantial quantities of carbon and nutrient elements are returned to the soil via litter fall (Daldoum *et al*., 2010) and this make trees on land highly important in the process of nutrient cycling in the ecosystem.

Nutrient release during decomposition of litter in agroforestry practices increases plant available nutrients (Koorem *et al*., 2011). Plant litter input also constitutes the main resource of energy and matter for the community of soil organisms (Hattenschwiler *et al*., 2005) that improve nutrient cycling process. Agroforestry systems contain a mixture of plant species such as trees and crops that have different growth forms and residue qualities and their mixed residues therefore may not decompose in a similar pattern to their individual components (Zeng *et al*., 2009). Even tree effects and nutrient dynamics vary from ecosystem to ecosystem. Wet ecosystem aid litter decomposition and nutrient cycling than dry ecosystem therefore it is necessary to document the effect and dynamics of tree litter diversity in all ecosystems.

2.3 Plant litter decomposition and nutrient release

Plant litter decomposition and nutrient release have been widely studied (Bisht *et al*., 2014; Bothwell *et al*., 2014; Hasanuzzaman and Hossain, 2014; Jacob *et al*., 2010). Different methods have been used in the studies of plant decomposition and nutrient release based on the authors' or researchers' aims and objectives. Some studies have treated individual plant decomposition and nutrient release (Daldoum *et al*., 2010; Dhanya *et al*., 2013; Fernando and Bandeira, 2009; Parsons *et al*., 1990) this studies have observed litter quality as the main predicting factor affecting the rate of decomposition and nutrient release. Nitrogen and C:N ratio dominates in the early stage of decomposition while lignin content dominates the latter stage of decomposition. Others relate diversity effect on rate of decomposition and nutrient release (Ball *et al*., 2008; Chapman and Newman, 2009; Dijkstra *et al*., 2009; Gao *et al*., 2015; Gartner and Cardon, 2004; Hattenschwiler *et al*., 2005) and observed litter diversity could improve the rate of decomposition and nutrient release.

In the previous studies that relate the effect of litter diversity on rate of decomposition and nutrient release, limited numbers of species like two to three were mostly used (Dijkstra *et al*., 2009; Gao *et al*., 2015; Liu *et al*., 2007; Sariyildiz *et al*., 2005) and some authors have also used higher number of species (above three) (Ball *et al*., 2008; Chapman and Newman, 2009) but the research by Wardle *et al*., (1997) was more robust with the use of 32 different species and mixture of two to eight species in a single experiment. Using of higher number of species will better represent the dynamics of ecosystems (Gartner and Cardon, 2004) because all ecosystems involve combination of many species.

The decomposition of plant litter involves the physical and chemical processes of reducing litter to its elemental chemical constituents (Aerts, 1997). Litter decomposition rates and nutrient release patterns are controlled by biotic and abiotic factors (Aber *et al.*, 1990; Aerts, 1997; Hättenschwiler and Jørgensen, 2010; Mungai and Motavalli, 2006; Silver and Miya, 2001) such as litter quality, temperature and moisture where initial litter quality, moisture contents are the dominant factor that influences decay rate (Melillo *et al.*, 1984).

High levels of nutrients lead to faster decomposition rates in leaf litter (Aerts, 1997), whereas high levels of lignin slow decomposition rate (Aerts, 1997; Melillo et al., 1982; Osono and Takeda, 2005). The concentration of carbon dioxide (CO_2), N, P, lignin, and ratios of carbon to nitrogen (C:N), Nitrogen to Phosphorus (N:P), lignin to nitrogen (L:N) are recognized as main litter quality variable influencing rate of decomposition (Abaye and Brookes, 2006; Aerts and De Caluwe, 1997; Liu *et al.*, 2007; Mafongoya *et al.*, 2000; Melillo *et al.*, 1982; Raiesi, 2006; Silver and Miya, 2001; Zeng *et al.*, 2009).

The early stages of decomposition are dominated by the easily decomposable carbohydrates, while at later stages, lignin controls the decomposition rate (Corbeels, 2001). When litter of different species are mixed, there can be interactive effects of the mixtures on decomposition rate (Hoorens *et al.*, 2002; Wardle *et al.*, 1997). In a mixed community like in agroforestry systems, the decomposition of litter may be additive with no difference between the observed and the expected or non-additive (there is difference between observed and expected) (Dijkstra *et al*., 2009) the non-additive may be synergistic if one of species is rich in nutrients or antagonistically if one of the specie contains high secondary compounds (Hoorens *et al*., 2002).

Litter decomposition has mostly been studied using litter bags. Gartner and Cardon, (2004) have sighted some short comings that could affect the mixed litter when litter bags are used (such as loading ratio, litter bags mesh sizes, placement of the litter bags, time and separation of litter components) but despite all these short comings, use of litter bags still remain the best way to observe litter decomposition dynamics in an ecosystem.

There is need for research that will focus more on higher number of species. The observation by Wardle *et al*., (1997) was highly exceptional because of the higher number of species involved. The research by Zeng *et al*., (2009) on tree and crop residues in a temperate agroforestry system was also a great work, they observed carbon mineralization of tree leaf litter and crop residues but their observation was done under laboratory condition and not in the natural ecosystem. Research mixing tree, crops, grasses and forbs litter using litter bags on natural ecosystems need to be the focus of researcher to better understand and estimate the dynamics of nutrient release in ecosystem.

This study observed tree litter diversity effect on litter decomposition, nutrient release using a higher number of trees and also uses an agroforestry setup in a semi-arid Zone.

Therefore, this research is unique because agroforestry system was used and a higher number of species were put into consideration.

2.4 Legume trees in Agroforestry

Soil quality has been a challenge for small holder farmers in semi-arid zones (Osuji *et al*., 2010) and this has increased food insecurity. Degradation of soil could affect soil water retention capacity and in turn affect plant growth (Kalinda *et al*., 2015). Legume tree based agroforestry farming systems has the capacity to improve soil water (Kalinda *et al*., 2015; Muthuri *et al*., 2005; Osuji *et al*., 2010), support microbial N_2 fixation and can increase soil N availability and therefore improve soil fertility, crop yields, and support long-term nutrient balance (Rosenstock *et al*., 2014) in semi-arid lands. The need for tree plantation is a major necessity to improve soil quality in semi-arid eco-zone (Muthuri *et al*., 2005).

Leguminous trees in agroforestry systems are planted for either of two purpose; productive or protective or both (Nair, 1984). Tree legumes have high adaptive capability. In arid and semi-arid zones tree legumes serves as a source of protein and herbage intake for livestock (Shelton, 2004). The multipurpose role of tree legumes make them crucial in agroforestry systems (Kebede *et al*., 2016). They help in nitrogen fixing, ecosystem stability, soil improvement (Kebede *et al*., 2016; Mafongoya *et al*., 2000), livestock feeding, improve productivity of farming systems, and protection of the environment (Shelton, 2004). Though legume trees are highly documented for their capacity to improve soil quality, Kebede *et al*., (2016); Mafongoya *et al*., (2000). Lott *et* *al*., (2000) postulated that there is a challenge in agroforestry system in semi-arid zone on how to reduce trees' negative effects. Therefore, there is a need to observe legume trees effect on litter decomposition and their interaction with other species in the ecosystem.

2.5 Soil Moisture

The soil moisture in a particular area predicts the climatic condition of such a region (Legates *et al*., 2011). Soil moisture shows available water for plant growth in soil. In arid and semi-arid eco-zone, rate at which evaporation occurs is greater than the rate of infiltration to the soil (Legates *et al*., 2011) and that makes the region dry during most of the season. Soil water content has been a great challenge to farmers in arid and semi-arid zones (Lott *et al*., 2000; Osuji *et al*., 2010) but tree on farm have been documented to help in improving soil water retention (Kalinda *et al*., 2015; Muthuri *et al*., 2005).

Vegetation can affect soil moisture through tree canopy (Legates *et al*., 2011). Therefore, vegetation type can control transpiration rates and in turn cause changes in soil moisture (Lyons, 2002; McPherson, 2007). Plants use water in the soil in form of soil moisture for photosynthesis and therefore soil moisture is a very important tool in understanding vegetation patterns of a particular area (Legates *et al*., 2011). Soil properties favoring rapid decomposition of plant litter include a near neutral soil pH, sufficient soil moisture, good aeration, warm temperatures and adequate nutrient availability (Mungai and Motavalli, 2006). At soil pH of 6–7, most nutrients are available allowing diverse microbial populations to be active (Mungai and Motavalli, 2006).

A very important aspect to be considered when choosing a tree for agroforestry practices is the leaf phenology (Muthuri *et al*., 2005). Leaves with higher shade could pose threat on adjacent crops (Muthuri *et al*., 2005). Another challenge is the belowground competition by trees with crop plants for moisture content (Lott *et al*., 2000). Some trees have been documented to improve soil moisture content while others compete with crop plant for below ground water. Muthuri *et al*., (2005) observed that semi deciduous trees are less competitive for soil moisture than the evergreen trees. Kalinda *et al*., (2015) documented that leguminous tree could improve soil water retention but Lott et al., (2000) documented that *Grevillea robusta* affects understory crops (maize and cowpea) due to competition for soil water. Therefore, it is necessary to choose tree species that will have limited competition for soil water when planning an agroforestry farm.

Due to the great impact of moisture on crop growth, increase moisture content could bring about increased crop growth (Kalinda *et al*., 2015). Therefore, there is a need to better understand its impact on decomposition rate and nutrient release. Trees on farm have been documented to improve soil moisture content and other organic parameters in the soil (Akpo *et al*., 2005) and soil moisture improve the environment for soil microbes that will aid litter decomposition and nutrient release (Jabiol and Chauvet, 2012). Hence, the effects of trees on soil moisture content could add more knowledge to the understanding of the dynamics of decomposition and nutrient release in an ecosystem.

2.6 Summary

Plant species diversity effect on the ecosystem functions is an important area of research, yet little information is available on how plant diversity affects key ecosystem processes such as decomposition and nutrient cycling. Uninformed choices of tree species combinations are likely to lead to failure in agroforestry practices. Although ample information is available on this area in temperate regions but there is little information available on how combination of tree species affect litter decomposition in semi-arid agroforestry system. Therefore, proper understanding of species interaction in all available ecosystems needs to be documented to better understand and benefit from the ecosystems function that each ecosystem could render. Understanding interaction of species in agroforestry practices should take the front edge in the developing nation because of the increasing problem of food insecurity.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

Litter bags techniques were used to study rate of decomposition of litter from different agroforestry tree species. The litter bags were evacuated on each sampling date and brushed to remove unwanted particles attached to it. The litter in the bag was weighed and the composite of the evacuated bags was taken for plant nutrient analysis. Soil moisture was measured using portable soil moisture probes. The litter fall by each of the tree species was collected using conical litter traps. Data collected were used to determine the effect of tree diversity on decomposition, nutrient release and soil moisture content.

3.2 Study Area

The research site is located in Jomo Kenyatta University of Agriculture and Technology (JKUAT), Juja, Kiambu County, Central, Kenya. JKUAT is in Juja sub-county, 35 km from Nairobi, latitude 1°06´S, longitude 37°01´E and 1520m altitude (Muthuri et al., 2005). The study site has a flat topography, soil are characterized as chromic vertisols, poorly drained, dark grey and extremely firm cracking clay (Kiambu, 2013). The pH ranges from 5.2 to 5.8 in the top soil and from 4.8 to 7.0 in the sub soil. The temperature averages 19.7 °C and mean annual rainfall is 856 mm and is bimodal, with primary and secondary peaks in April and November respectively (Muthuri et al., 2005). The least amount of rainfall occurs in July with average of 12 mm, while the highest precipitation occurs in April with an average of 175 mm. The month of March is the hottest with 21.3°C and July the coolest with 18.4°C (Muthuri et al., 2005). Juja has low fertile shallow soils which are sandy or clay and can support drought resistance crops like soya beans, sunflowers and ranching (Kiambu, 2013).

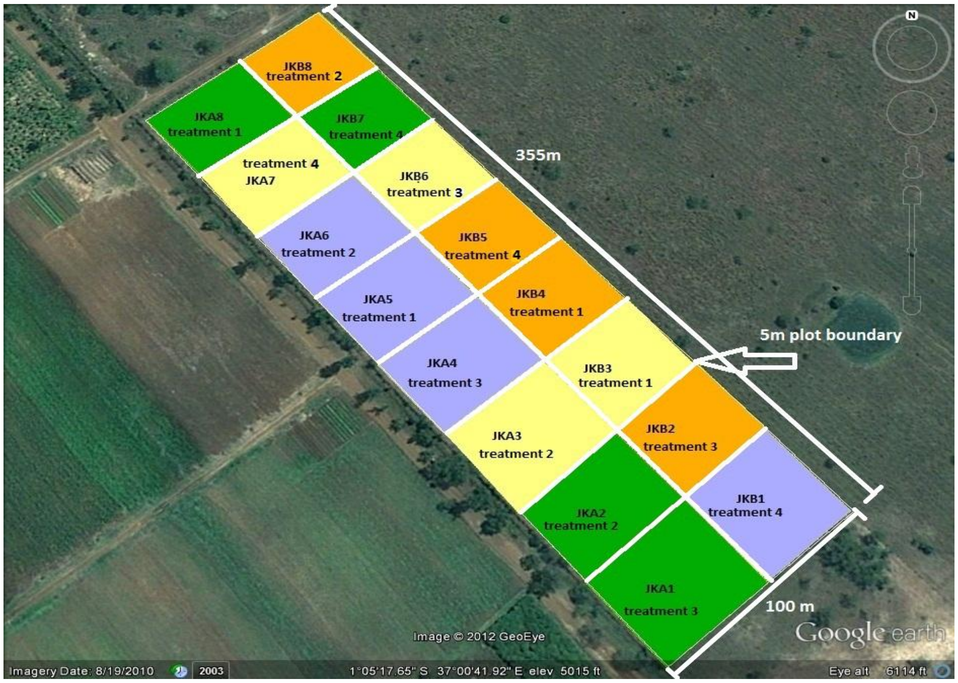

Figure 3.1: Satellite image of the research site showing each treatment

Treatment 1 - treatment with *C. africana*; treatment 2 - treatment with *F. albida*; treatment 3 - mixed treatment containing *C. africana*, *F. albida*, *G. robusta*, *A. seyal* and *A. xanthophloea* and treatment 4 - the control plot.

3.3 Research Design

This research was carried out in Jomo Kenyatta University of Agriculture and Technology, Kenya as a case study to represent semi-arid region. Experimental research design was used in data collection.

The experiment was carried out on an eight acres area that was subdivided into 16plots of 50m by 40m with a pathway of 5m. Each plot has 7 rows; 4 rows have treatment tree species inter planted with two exotic legumes (*Calliandra calothyrsus* and *Gliricidia sepium*) and 3 rows have the treatment tree species alone. It comprises of three treatments and a control; each with four replicates. The treatments include *Faidherbia albida*, *Cordia africana*, and mixture of *F. albida*, *C. africana*, *Grevillea robusta*, *Acacia seyal* and *Acacia xanthophloea*. The control plots have three rows without trees and four rows with the two exotic legumes. The trees are planted in seven rows of 5m apart with spacing of 5m between the trees. The treatments were randomly assigned into the plots (see figure 3.1 for the site image) using completely randomized experimental research pattern. Complete randomized design was used to assign the treatment to prevent biasness.

Leaf litter and mature senescence leaves of the seven agroforestry species were collected from the study site and dried to constant weight at 65°C. Litter of each of the tree species was crushed to (1-3 cm) sizes and used to form eleven compositions which were used for the study. The compositions were based on the site design. The eleven compositions are (*C. africana*, *F. albida*, *G. robusta*, *A. seyal*, *A. xanthophloea*, *C.*

calothyrsus and *G. sepium*) for single species, (*C. africana*, *C. calothyrsus* and *G. sepium;F. albida, C. calothyrsus* and *G.* sepium) for mixture of three species, (*C. africana, F. albida, G. robusta, A. seyal, A. xanthophloea*) for mixture of five species and (*C. africana*, *F. albida*, *G. robusta*, *A. seyal, A. xanthophloea*, *C. calothyrsus* and *G. sepium*) for the mixture of seven species. Crushing of the litter was to allow homogeneity in the mixture compositions. The independent variables used were the agroforestry species, plot treatments and the time. While the dependent variables examined were mass loss, moisture content, nutrient content and litter falls.

3.4 Sampling Design

Sampling size was determined based on previous studies (Gao *et al*., 2015; Salamanca *et al*., 1998). The tree treatments on the plots were allocated through completely randomized experimental research pattern. The site is fairly flat but slightly raised at the edge which tends to cause flood in some part during raining season due to the poor water absorption capacity of the soil. The site was a grazing land before it was abandoned and it is bordered by a farm road and a grazing land.

A total of 220 litter bags of (20×13cm) with 1mm mesh size were used on eleven sample compositions with four replicate and 5 sampling dates (11×4×5) representing 11 composition, 4 replicates and 5 sampling period including the samples retained for initial nutrient analysis. One millimeter mesh size litter bags were used because some of the species used in this research has smaller leaf size, 1mm mesh will prevent given bias data on litter mass loss. One hundred and forty bags were filled with single species, 40 bags contained mixture of 3 species, 20 bags contained mixtures of five species and 20 bags contained mixtures of seven species. Five grams of each species litter were put in the litter bags and each species in any of the mixtures was equally represented in mass. Forty four litter bags were retained for initial nutrient analysis while the remaining 176 bags were installed in the plots based on the experimental treatment on each plots. Four bags in each composition were evacuated from the study site on the 15th, 30th, 56th and 90th day.

The evacuated bags were brushed to remove soil attached to them and oven dried at 65°C until constant mass and weight recorded. The bags with same litter content were mixed and composite taken for litter nutrient analysis. The compositions analyzed for nutrients were five monocultures (*C. africana*, *F. albida*, *G. robusta*, *A. xanthophloea* and *A. seyal*) and 3 mixtures (*C. africana*, *C. calothyrsus* and *G. sepium*), (*F. albida*, *C. calothyrsus* and *G. sepium*) and (*C. africana*, *F. albida*, *G. robusta*, *A. xanthophloea* and *A. seyal*).

Carbon, nitrogen, phosphorus and potassium content that was present in each composite were analyzed at the horticulture laboratory of Jomo Kenyatta University of Agriculture and Technology, Kenya. Carbon (C) was determined by chromic digestion and spectrophotometry; total nitrogen (N) by microscopic Kjeldahl digestion followed by distillation. Using the same digestion solution for N, phosphorus (P) was determined calorimetrically using spectrophotometer (uv mini 1240) while potassium (K) was determined using potassium flame photometer.

Rate of litter fall was monitored using conical litter traps (Ball *et al*., 2008), conical litter trap of 31.8cm diameters (area= 794.33cm^2) were installed at 30cm from the ground and 50cm from the base of the target species (*C. africana*, *F. albida*, *G. robusta*, *A. xanthophloea* and *A. seyal*). Each species has three replicate that were randomly selected. Litter trapped was collected monthly for six months (cutting across the two seasons), dried at 65°C until constant mass and weighed. The total litter fall by each species in grams per square centimeter (g cm^{-2}) to the area of the conical litter trap was used to estimate litter fall by each species in kg per hectare (kg ha^{-1}) for the six month and the mean of the sum of the litter of the five species was used as prediction for litter fall of the mixed.

Quantifying the dynamics of nutrient released by each of the species and mixture to the ecosystem, mean of litter fall of each of the species and their mixture was used to estimate nutrient released to the ecosystem based on the litter mass loss and nutrient released in the litter bag experiment throughout the 90 days of decomposition. Ball *et al*., (2008) proposed that litter mass of a species multiplied by nutrient content throughout decomposition period can be used to estimate nutrient dynamic of such species in an ecosystem.

Soil moisture was measured in each treatment plot using a soil moisture probe (ML3 Theta Probe). On each plot five trees were randomly selected from the rows with the treatment species alone and five trees from the rows containing the treatment species interplant with the legumes and soil moisture was measured at 50cm and 100cm from the base of the tree and at 10cm and 20cm below top soil. On the control plots soil moisture was measured at four points near each edge and at the middle of the plot; in rows with legume on the control plots, the measurement was taking from five randomly selected trees.

3.5 Data collection and analysis methods

The loss in dry mass of litter samples was calculated as difference between the initial dry mass and remaining mass at each sampling time. The rate of decomposition was calculated using the percentage of mass loss divided by respective days of sample collection (Hasanuzzaman and Hossain, 2014). Decay constant for leaf litter was calculated using the negative exponential decay model of (Olson, 1963) as sited by Liu *et al*., (2009) as follows:

$$X_t / X_o = e^{(-kt)} \quad (1)$$

Where X_o is the initial weight and X_t is the remaining weight at time exponential function and K represent the decay constant. Half-life calculated using equation 2 (Daldoum *et al*., 2010)

$$(t_{50}) = 0.693/K \quad (2)$$

Predicted mass loss was calculated as

$$PML= (S1\times\%S1) + (S2\times\%S2).....+ (S_n\times\%S_n) \quad (3)$$

where PML is the Predicted Mass Loss, S is the observed mass loss in pure species and % S the proportion of the pure species in the mixture (Salamanca *et al*., 1998).

Calculation was done on data collected on each sampling day. To test for additive or non-additive effect, the predicted and observed (mass loss in combination) mass loss was compared by independent sample t-tests (Gao *et al*., 2015).

The nutrient mass at each sampling period was calculated by multiplying the % nutrient content at that sampling time by the dry mass at the sampling time (Ball *et al*., 2008). The percentage nutrient remaining was calculated as percentage of initial nutrient value. The nutrient release at each sampling period was calculated by subtracting the nutrient remaining from the initial nutrient content.

The average nutrient mass released in the monocultures was compared with the corresponding combination of the monocultures to determine the additive or non-additive effect in nutrient loss (Gartner and Cardon, 2004). The average nutrient mass released in all compositions was used to determine the nutrient that had a significant difference between the compositions. Agren *et al*., (2012); Knecht and Göransson, (2004) assumed N and P are nutrient limiting crop growth in most ecosystem and Liebig's law of minimum states that nutrient in least supply relative to plant requirement will limit plant growth. Therefore, the relationship between nutrients and their ratios was also determined using correlation to know which nutrient influences the nutrient dynamics in this present study. Analysis of variance (ANOVA) was used to compare the average of each nutrient loss between the eight litter compositions analyzed which were ((monocultures *F. albida*, *C. africana*, *G. robusta*, *A. xanthophloea*, *A. seyal*, (mixture of *C, africana*, *C. calothyrsus* and *G. sepium*), (mixture of *F. albida*, *C. calothyrsus* and *G.*

sepium) and (mixture of *F. albida*, *C. africana*, *G. robusta*, *A. xanthophloea*, and *A. seyal*)). Independent sample t-test was used to compare each nutrient between the calculated expected and corresponding observed (Santonja *et al*., 2015).

The nutrients released in 90 days of decomposition was used to calculate the nutrients released by each species in Kg ha^{-1} for 90 days and the result was used to relate the litter falls with nutrients released. This was used to estimate nutrient dynamics of the ecosystem. Ball *et al*., (2008) proposed that litter mass of a species multiplied by nutrient content throughout decomposition period can be use to estimate nutrient dynamics of such species in an ecosystem. One-way analysis of variance (ANOVA) was used to identify if there were significant differences among species for average litter fall (Ball *et al*., 2008) and nutrient released.

Plot treatment effect on soil moisture content was determined by one-way analysis of variance (ANOVA). The relationship between soil moisture content and rate of decomposition was analyzed using scattered box. All statistical analysis was carried out using IBM SPSS version 21 with accepted significance level of $p < 0.05$. All data met the assumption of normality so no data was transformed.

3.6 Summary

The research site was established in 2011 on eight acres of land which include three treatments and a control. The treatment involves seven tree species from which eleven compositions was prepared and used for litter decomposition experimental process. Standard little bags of 1mm mesh size were used in the course of this research. The litter bags were collected from the field on each sampling date, brushed to remove all extraneous materials attached to it. Data on mass remaining on each sampling day were measured and recorded. The evacuated litter with same litter content was homogenized and sub samples were taken for plant tissue nutrient analysis on each sampling date. Conical litter traps were used for the collection of litter and portable moisture probe was used for soil moisture data collection.

CHAPTER FOUR

RESULTS

4.1 Effect of litter diversity on decomposition

The litter mass loss of the compositions followed a biphasic mode of decomposition with initial rapid mass loss in the first 15 days followed by a gradual mass loss in the remaining sampling period (Figure 4.1 and 4.2). *Cordia africana* and *G. robusta* had a lower mass loss than the rest of the species among the single species compositions. The graph shows two cluster of low decomposing compositions and fast decomposing compositions (Figure 4.1).

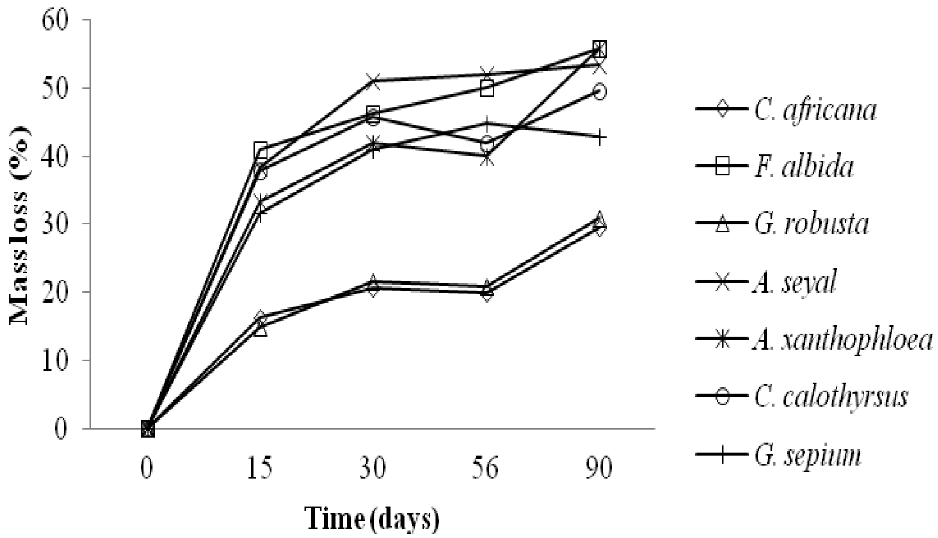

Figure 4.1: Biomass losses across the sampling period of 90 days for the single species compositions

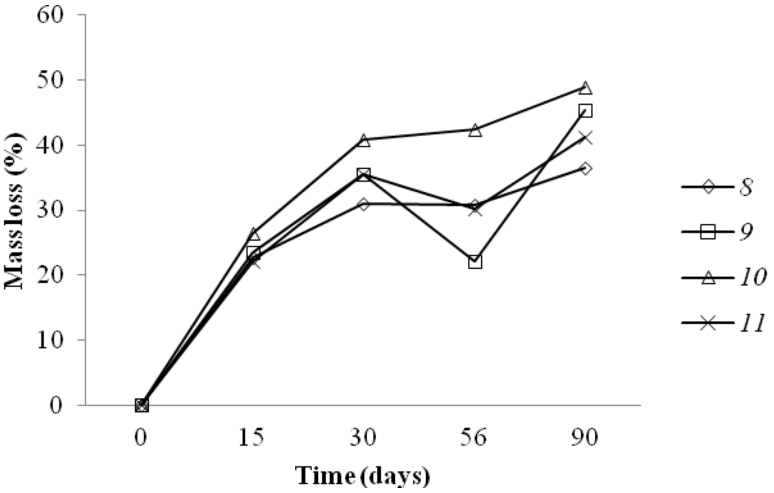

Figure 4.2: Biomass losses in 90 days in the mixed compositions

8 - Mixture of *C. africana*, *C. calothyrsus* and *G. sepium*; 9 - Mixture of *F. albida*, *C. calothyrsus* and *G. sepium*; 10 - Mixtures of *C. africana*, *F. albida*, *G. robusta*, *A. xanthophloea* and *A. seyal*; 11 - Mixture of *C. africana, F. albida, G. robusta*, *A. xanthophloea* , *A. seyal, C. calothyrsus* and *G. sepium*.

A. seyal had the highest biomass loss (48.75%) while *C. africana* had the lowest biomass loss (21.65%) (Table 4.1), in addition, results shows that it would require 106 days for 50% of *A. seyal* and *F. albida* litter to decompose while *C. africana* would require 288 days for 50% of its litter to decompose (Table 4.1). Biomass loss in mixtures containing *C. africana* and *G. robusta* was higher than when these species decompose alone while *F. albida*, *A. seyal* and *A. xanthophloea* had a higher biomass loss than all their co-occurring mixtures (Table 4.1).

Mixture of *C. africana* with the two legumes (*C. calothyrsus* and *G. sepium*) had the lowest biomass loss among the mixture compositions (30.3%). The mixture of the five tree species had a higher biomass loss than the mixture of the five tree species plus the two exotic legumes (*C. calothyrsus* and *G. sepium*) (Table 4.1). Figure 4.3 shows the mean biomass loss in the tree species compositions. The biomass loss varies among the compositions but there was no significant difference between the eleven compositions ($F_{10,165} = 0.90$, $p > 0.05$).

Table 4.1: Mean biomass loss, percentage biomass loss and the predicted number of days for half of the litter to decompose

Compositions	Mean biomass loss (%)	Mean biomass moss	T_{50} (days)
C. africana	21.65	0.27 ± 0.1	288
F. albida	48.4	0.61 ± 0.2	106
G. robusta	22.1	0.28 ± 0.1	279
A. seyal	48.75	0.61 ± 0.2	106
A. xanthophloea	42.85	0.54 ± 0.2	124
C. calothyrsus	43.8	0.55 ± 1.0	126
G. sepium	40.1	0.50 ± 0.2	140
C. africana, *C. calothyrsus* and *G. sepium*	30.3	0.38 ± 0.2	195
F. albida, *C. calothyrsus* and *G. sepium*	31.65	0.40 ± 0.2	198
C. africana, *F. albida*, *G. sepium*, *A. xanthophloea* and A. seyal	39.65	0.50 ± 0.2	136
C. africana, *F. albida*, *G. sepium*, *A. xanthophloea*, *A. seyal*, *C. calothyrsus* and *G. sepium*	32.3	0.40 ± 0.2	181

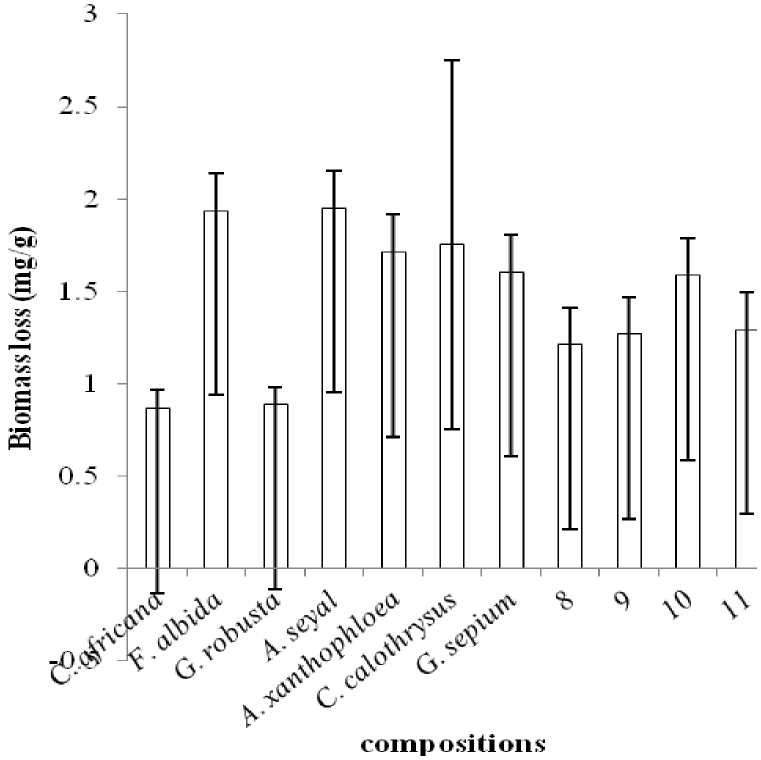

Figure 4.3: Mean biomass losses by each composition in 90 days

8 - Mixture of *C. africana, C. calothyrsus* and *G. sepium*; 9 - Mixture of *F. albida, C. calothyrsus* and *G. sepium*; 10 - Mixtures of *C. africana*, *F. albida, G. robusta, A. xanthophloea* and *A. seyal*; 11 - Mixture of *C. africana, F. albida, G. robusta, A. xanthophloea* , *A. seyal, C. calothyrsus* and *G. sepium*. Bar represent mean of biomass loss (n=4) and error bar represent standard error (SE).

Table 4.2 (A-D) shows the mean biomass loss of individuals that make up a mixture among the seven single species (Predicted mass loss) was compared with the biomass loss in the co-occurring mixture (observed mass loss). There were no significant differences between the predicted and observed biomass loss in all tested mixtures ($p > 0.05$) indicating an additive effect was observed from all the tested mixtures.

Table 4.2: Observed and predicted biomass loss in all mixtures across the 90 days of decomposition

A. Observed and predicted biomass loss in *C. africana*, *C. calothyrsus* and *G. sepium*

Time	*C. africana*, *C. calothyrsus* and *G. sepium* (Predicted in g)	Mixed (Observed in g)
15 days	1.41	1.41
30 days	1.78	1.55
56 days	1.76	1.54
90 days	2.02	1.83

B. Observed and predicted biomass loss in *F. albida*, *C. calothyrsus* and *G. sepium*

Time	*F. albida, C. calothyrsus*, *G. sepium* (Predicted in g)	Mixed (observed in g)
15 days	1.82	1.17
30 days	2.21	1.78
56 days	2.26	1.11
90 days	2.45	2.27

C. Observed and predicted biomass loss in *C. africana*, *F. albida*, *G. sepium*, *A. seyal* and *A. xanthophloea*

Time	*C. africana*, *F. albida*, *G. sepium*, *A. seyal* and *A. xanthophloea* (Predicted in g)	Mixed (observed in g)
15 days	1.43	1.32
30 days	1.82	2.04
56 days	1.83	2.12
90 days	2.27	2.54

D. Observed and predicted biomass loss in *C. africana*, *F. albida*, *G. sepium*, *A. seyal*, *A. xanthophloea*, *C. calothyrsus* and *G. sepium*

Time	*C. africana*, *F. albida*, *G. sepium*, *A. seyal* , *A. xanthophloea*, *C. calothyrsus* and *G. sepium* (Predicted in g)	Mixed (observed in g)
15 days	1.43	1.11
30 days	1.87	1.78
56 days	1.88	1.51
90 days	2.24	2.06

4.2 Effect of litter diversity on nutrient release

Table 4.3 shows the different initial nutrient concentration (nitrogen, phosphorus, potassium and carbon) from the eight compositions that was studied. After 90 days of decomposition, there were variedly released of different nutrients by the different compositions.

Acacia seyal had the highest initial N content (198mg/g) while *C. africana* had the lowest (40mg/g). The content of P was between 4mg/g and 9mg/g and K content was between 10mg/g and 16mg/g among the compositions (Table 4.3). The C:N ratio was lowest in *F. albida* and *A. seyal* and highest in *C. africana* (Table 4.3).

When nutrient released (difference between initial nutrient content and final nutrient content) were compared, there was a significant differences in N and P released when nutrient released were observed using ANOVA ($p < 0.001$ and $p < 0.05$ respectively) among the eight compositions but no significant difference in K and C ($p > 0.05$) released.

Table 4.3: Mean of the initial nutrient concentration and final nutrient concentration of the eight compositions analyzed for nutrient release of the studied species compositions

Compositions	Initial nutrient content (mg/g)						Final nutrient content (mg/g)			
	N	P	K	C	C:N	N:P	N	P	K	C
C. africana	40	9	16	998	25	5	12	4.6	2.8	669
F. albida	190	8	12	808	4	25	83	2.6	0.7	226
G. robusta	50	6	13	855	17	9	43	5.9	2.1	505
A. seyal	198	9	13	855	4	23	103	3.3	0.7	353
A. xanthophloea	108	9	10	665	6	13	59	2.2	1.3	43
C. africana, C. calothyrsus,G. sepium	76	6	12	1235	16	13	55	3.2	1.6	843
F. albida, C. calothyrsus,G. sepium	103	8	10	855	8	14	56	2.5	2.6	405
C. africana, F. albida, A. seyal, G. robusta, A. xanthophloea	50	4	18	855	17	12	85	4.3	2.3	485

Table 4.4 shows relationship between nutrients and their corresponding ratios. The relationship between initial nutrient content and their corresponding ratios show that N was positively correlating with N:P ratio (R = 0.64, $p < 0.001$) and negatively correlating with C:N ratio (R = -0.65, $p < 0.05$). There was a weak correlation and no significant relationship between C, P and their corresponding ratios.

Table 4.4: Relationship between nutrients and their corresponding ratios

Nutrient	Ratio	Relationships
N	N:P	R = 0.64, $p < 0.001$
P	N:P	R = -0.20, $p > 0.05$
N	C:N	R = -0.65, $p < 0.05$
C	C:N	R = 0.24, $p > 0.05$

Table 4.5 (A-D) shows the mean of predicted and observed nutrient released from the five tree species. The predicted nutrient released by the five single species compositions (average of the mass of nutrient released by the single species) and the observed nutrient released by the mixture of the five tree species (*C. africana*, *F. albida, G. robusta, A. xanthophloea* and *A. seyal*) were compared using T-test. there was no significant difference between the predicted and observed nutrient released on N, P and K ($p > 0.05$) indication an additive effect (Table 4.5 A-C) and there was a significant difference in C ($p < 0.05$) indication a non-additive effect occur (Table 4.5D).

Table 4.5: Mean of observed and predicted nutrient released

A. Mean of observed and predicted nitrogen released in (mg/g)

Time (days)	N released predicted	N released observed
15	-3.14	-34.40
30	0.79	7.47
56	-8.5	25.60
90	5.58	-35.42

B. Mean of observed and predicted phosphorus released in (mg/g)

Time (days)	P released predicted	P released observed
15	0.78	-0.42
30	1.28	0.15
56	0.42	1.98
90	0.78	-0.34

C. Mean of observed and predicted potassium released in (mg/g)

Time (days)	K released predicted	K released observed
15	1.60	12.35
30	45.40	14.24
56	1.18	14.04
90	2.54	15.21

D. Mean of observed and predicted carbon released in (mg/g)

Time (days)	C released predicted	C released observed
15	24.78	92.87
30	0.16	292.60
56	77.90	307.80
90	65.74	370.50

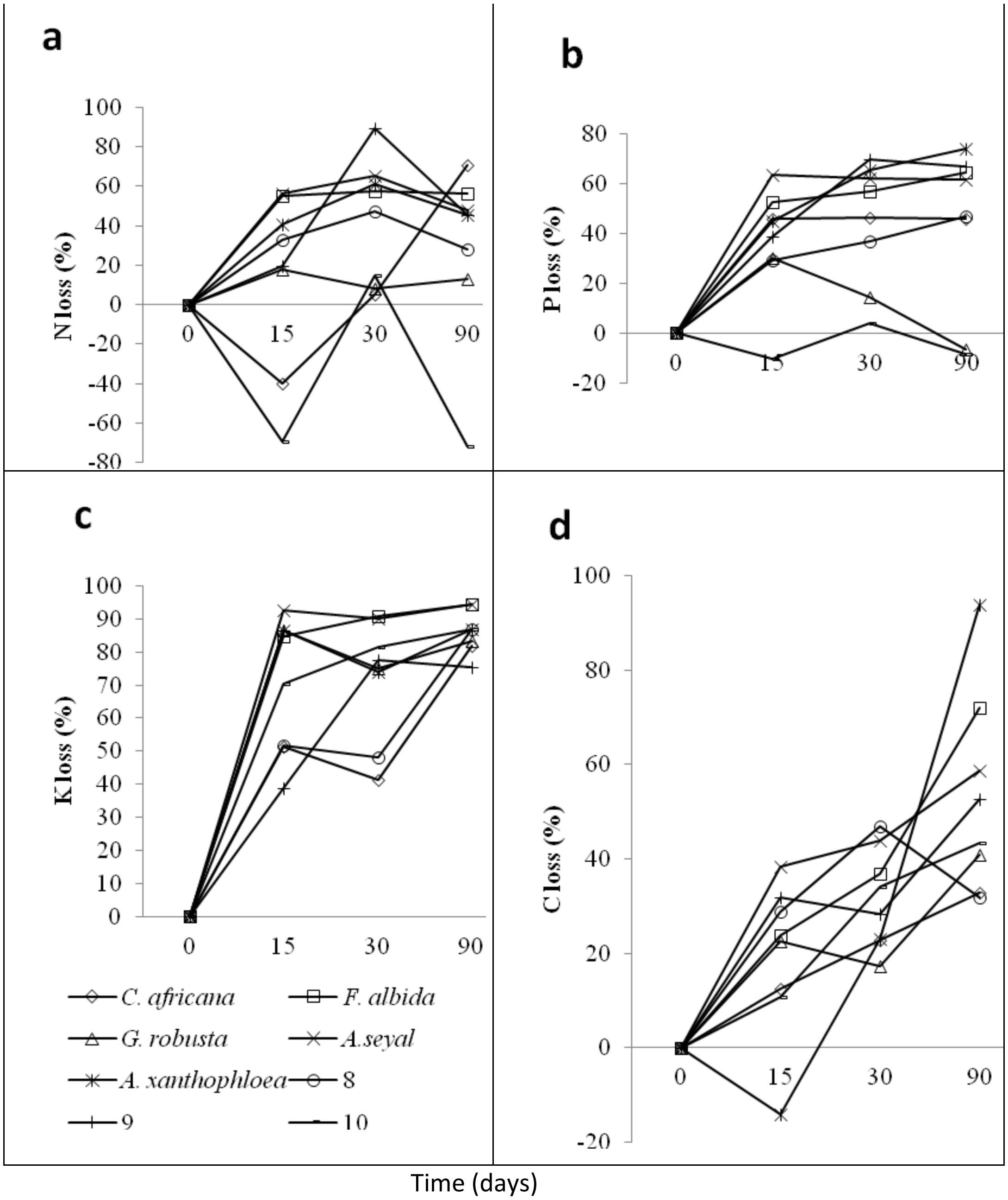

Figure 4.4: Litter nutrient released after 15, 30 and 90 days of decomposition

8 - Mixture of *C. africana*, *C. calothyrsus* and *G. sepium*; 9 - Mixture of *F. albida*, *C. calothyrsus* and *G. sepium*; 10 - Mixture of *C. africana*, *F. albida*, *G. robusta*, *A. seyal* and *A. xanthophloea*. (Figure 4.4a. nitrogen loss; b. phosphorus loss; c. potassium loss and d. carbon loss).

In Figure 4.4, Immobilizing of N occurred in *C. africana* in the first 15 days but had the highest percentage of N released on the 90th day of decomposition (71%) see figure 4.4a, while the mixture of the five tree species had the lowest (-72%). The percentage P released on the 90th day was highest in *A. xanthophloea* (74%) and lowest in the mixture of the five tree species -8 (Figure 4.4b). The percentage K released on the 90th day was highest in *A. seyal* 94% and lowest in the mixture of *F. albida* with the two legume species (75%) (Figure 4.4c). Carbon released on the 90th day was highest in *A. xanthophloea* (94%) that immobilize C in the first 15 days (Figure 4.4d) while the mixture of *C. africana* with the two legume species had the lowest C release (32%).

Table 4.6 shows that the percentage average nutrient released was highest in the composition of *A. seyal* (66%; 68%; 92% and 50% N, P, K and C respectively). The composition of the mixture of the five tree species released the lowest N and P (-19% and 9% respectively). Potassium released was lowest in the composition of *C. africana* (53%) and C released was lowest (22%) in the composition of *G. robusta*. Nitrogen, potassium and carbon released were higher in the mixture of *C. africana* with the two legumes than *C. africana* alone but that was not the case in P release. *F. albida* alone released N, K and C than in mixture with the two legumes but P released was slightly higher in the mixture. The mixture of the five tree species released lower N and P than the composition of the tree species when alone, but released higher K and C than the low nutrient species (*C. africana* and *G. sepium*).

Table 4.6: Mean percentage nutrient release by each of the eight compositions after 90 days

Compositions	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Carbon (%)
C. africana	-18	41	53	27
F. albida	58	56	88	40
G. robusta	19	22	81	22
A. seyal	66	68	92	50
A. xanthophloea	39	58	83	30
C. africana, C. calothyrsus, G. sepium	36	39	62	37
F. albida, C. calothyrsus, G. sepium	45	57	62	34
C. africana, F. albida, G.robusta, A. seyal, A. xanthophloea	-19	9	80	31

4.3 Quantity and quality of litter from different agroforestry trees

Total litter falls by each species in six months was used to predict the litter that will be produced by each species in kg ha^{-1}. *Acacia seyal* tree had the highest litter fall production (2539 kg ha^{-1}) and *F. albida* had the lowest (797 kg ha^{-1}) (Figure 4.5). There was no significant difference in litter fall collected from the five tree species (*C. africana, F. albida, G. robusta, A. seyal* and *A. xanthophloea*) after six months ($F_{4,85} = 1.71$, $p > 0.05$).

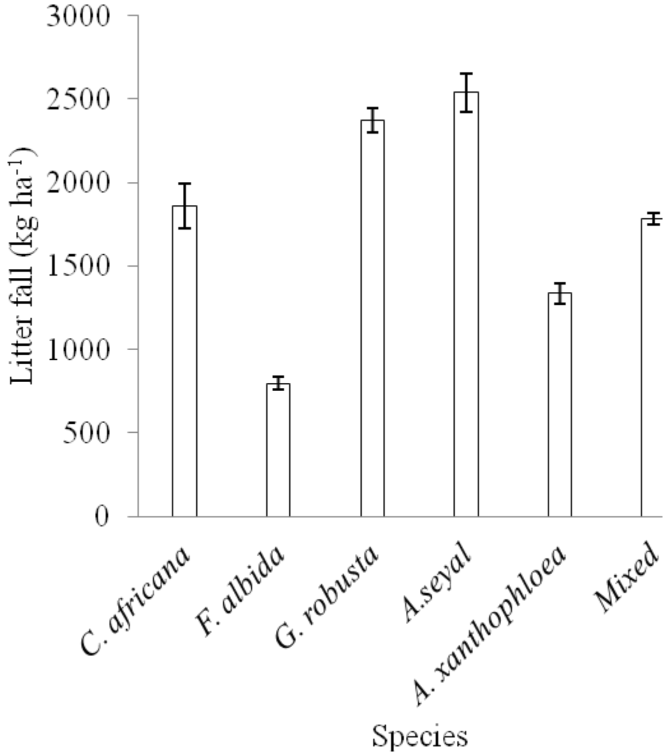

Figure 4.5 Litter fall (kg ha^{-1}) by each of the five tree species and their mixture in six months

The mixed on the figure 4.5 represent the average of the litter fall by the five tree species. Bar represent mean of litter falls (n = 5) and error bar represent standard error (SE)

Table 4.7 shows the initial nutrient concentration and final nutrient concentration after 90days among single trees and the mixture of the trees. *A. seyal* had the highest initial nutrients concentration from all the nutrients analyzed (50, 2.16, 3.18 and 217 kg ha^{-1}) N, P, K and C respectively while *C. africana* had the lowest N (7kg ha^{-1}) and *F. albida* had the lowest (0.60, 0.92 and 64kg ha^{-1}) P, K and C respectively.

Table 4.7: Initial nutrient concentration and final nutrient concentration Kg ha^{-1}

Species	Initial nutrient concentration				Final nutrient concentration			
	N	P	K	C	N	P	K	C
C. africana	7	1.58	2.88	186	2.23	0.85	0.52	124
F. albida	15	0.60	0.92	64	6.62	0.21	0.05	18
G. robusta	12	1.31	2.97	203	10.22	1.39	0.49	120
A. seyal	50	2.16	3.18	217	26.16	0.83	0.18	90
A. xanthophloea	14	1.14	1.34	89	7.89	0.29	0.18	6
Mixed	9	0.71	3.12	152	15.15	0.77	0.41	86

N – Nitrogen; P – Phosphorus; K – Potassium and C - Carbon

The highest litter decomposition was observed in *A. seyal* when litter decomposed and nutrient released was estimated based on biomass loss, initial nutrient content and its rate of release from species composition litter bags. The highest litter fall was observed in *A. seyal* and it also released the highest nutrients in the form of N, P, K and C (24, 1.33, 3.0 and 127 kg ha^{-1} respectively) in 90 days (Table 4.8). Initial nutrient (N and C:N ratio) content could predict the rate of nutrient released among the monoculture but the initial nutrient content in the mixture could not predict the rate of nutrient released in mixture.

Nutrients released in the mixture of the five tree species after 90 days of decomposition showed that immobilization of N and P occurred (-6 and -0.06 kg ha^{-1} respectively) while the rate of K and C release was 2.71 and 66 kg ha^{-1} respectively (Table 4.8).

When the estimated nutrient released from the species / mixtures were compared there was a significant difference in N ($p < 0.05$) but other nutrient observed has no significant difference.

Table 4.8: Litter fall in 6 months and the nutrient released in 90 days by each of the five species their mixture in kg ha^{-1}

Species/mixture	Litter falls (6months kg ha^{-1})	Nutrient released in 90 days (kg ha^{-1})			
		N	P	K	C
C. africana	1859	5	0.73	2.36	61
F. albida	797	9	0.39	0.87	46
G. robusta	2376	2	-0.09	2.48	83
A. seyal	2539	24	1.33	3.0	127
A. xanthophloea	1337	7	0.84	1.16	83
Mixed	1782	-6	-0.06	2.71	66

4.4 Effect of tree diversity on soil moisture content

Figure 4.6 shows moisture content between treatment plots and within rows. The soil moisture content between treatments was highest in *F. albida* treatment plots (42.97%) and lowest in *C. africana* treatment plots (28.96%) (Figure 4.6). The soil moisture content between the treatments plots was significantly different ($F_{3,76} = 24.66$, $p < 0.001$) with treatment plot of *C. africana* significantly different from other treatment plots. The soil moisture content on the treatment plot was *F. albida* > control > mixed > *C. africana.*

The soil moisture content within rows was higher on the mixed rows with exotic legumes (39.67%) than the pure rows (35.99%) (Figure 4.6) but the difference between pure and mixed rows was not significant ($p > 0.05$).

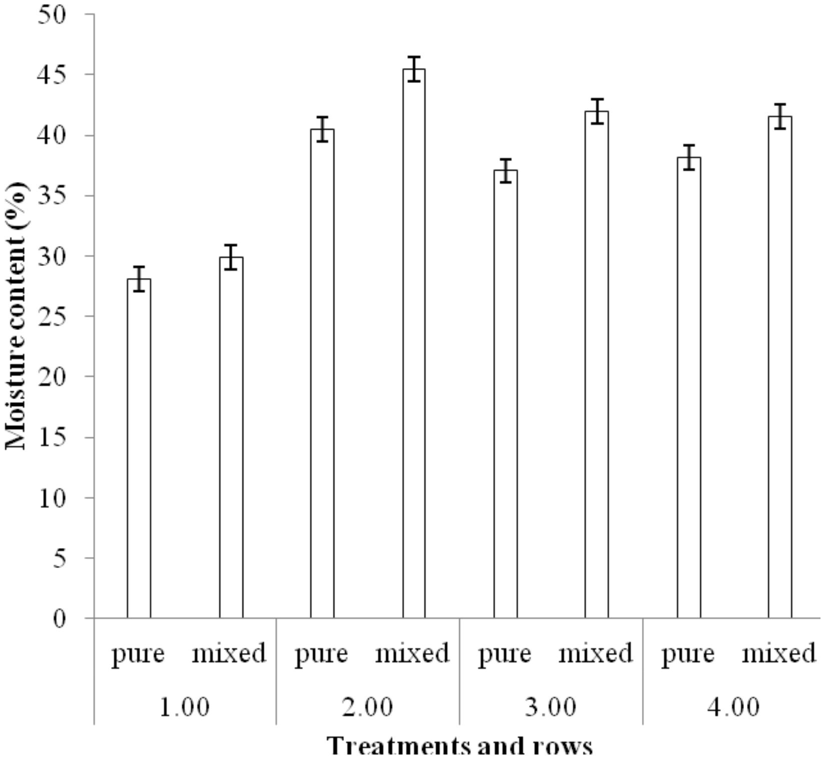

Figure 4.6: Moisture content in each treatment plots and rows

1 - *C. africana* plots ; 2 - *F. albida* plots; 3 – *C. africana*, *F. albida*, *G. robusta*, *A. seyal* and *A. xanthophloea* plots; 4 - Control plots. Pure represent rows with research treatment tree species alone and mixed represent rows with research treatment tree species mixed with the two exotic legumes *C. calothyrsus* and *G. sepium*. Bar represent mean of moisture content on row (n = 5) and error bar represent standard error (SE)

4.5. Effect of soil moisture on rate of decomposition

The relationship between soil moisture contents in all treatment plots and rate of decomposition of litter on all treatment plots reflect a weak relationship ($r^2 = 0.046$) (Figure 4.7).

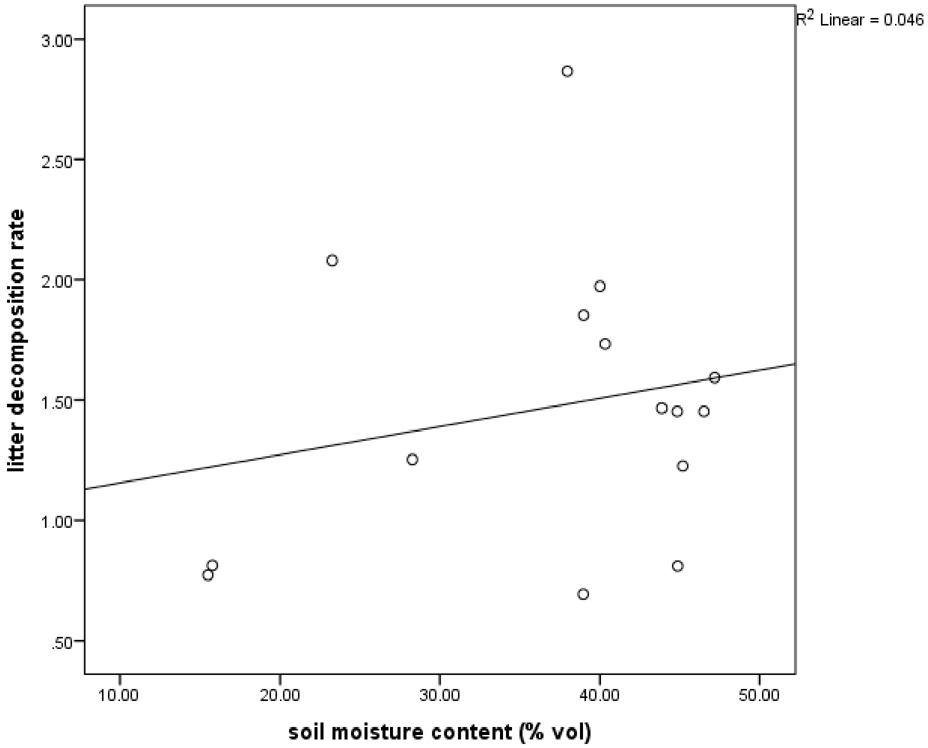

Figure 4.7: Relationship between decomposition rate and moisture contents

Figure 4.8 shows that decomposition rate was higher on treatment plots of *F. albida* and lowest in treatment plots of *C. africana* but there was no significant difference in the rate of litter decomposition between all the three treatment plots ($F_{2,173} = 0.05$, $p > 0.05$). The decomposition rate among treatment plots was *F. albida* plot > Mixed plot > *C. africana* plot.

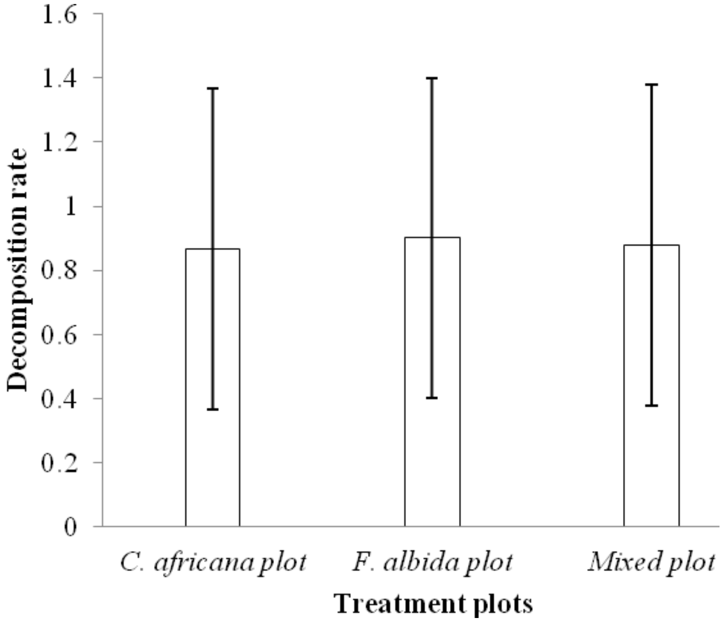

Figure 4.8 Average rate of decomposition between treatment plots

Bar represent mean decomposition on each treatment plot (n=4) and error bar represent standard error (SE).

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The productivity of a particular ecosystem mainly depends on the litter fall, decomposition and nutrient released by the species litter (Bisht *et al*., 2014). The pattern of litter fall, influence of litter diversity on decomposition and nutrient release could be used to predict their effect on ecosystem. Tree species could also have effects on the environment which in turn could affect the rate of decomposition and nutrient release dynamics.

5.2 Discussion

5.2.1 Effect of litter diversity on litter decomposition

Rapid mass loss in the first 15 days of decomposition among all the compositions could be attributed to breakdown of non-lignified carbohydrates, such attributes have been observed by Corbeels, (2001); Parsons *et al*., (1990) and Prescott, (2005). The gradual slower rate of mass loss after the 15th day may be attributed to breakdown or decomposition of lignified carbohydrates as observed by Corbeels, (2001); Liu *et al*., (2007) and Melillo *et al*., (1982) in Europe and in Asia.

The mass loss of litter was lower in some *C. africana* and *G. robusta* than in their corresponding mixture while *F. albida, A. seyal* and *A. xanthophloea* were having higher mass loss in monocultures than in their corresponding litter mixtures. This could be attributed to mixing effect. When the predicted mass loss from single species compositions were compared with the observed mass loss in mixtures, the result was not significant in all tested mixtures. Previous work by Gartner and Cardon, (2004) showed that when mass loss in the mixed litter matches calculated mass loss from the individual species, then the dynamics in the mixtures can be predicted from the monoculture and this is known as additive effect. The results show that the monoculture litter mass loss could be used to predict the mass loss in the co-occurring mixture they are present. The additive effect observed in the mass loss could be attributed to some factors such as time duration, species interaction or size of litter bags mesh (1mm) which is believed to likely exclude meso and macro decomposer organism from entering during decomposition. Time duration, mesh sizes, study location or the quality of individual species has been previously reported by Gartner and Cardon, (2004) as the factors which could affect decomposition rate of mixed litter during experimental research. Gartner and Cardon (2004) postulated that methods, location and differences in litter chemistry of species used to test mixing effect can bring about an additive effect in the mixture. Handa *et al*., (2014) reported that large fauna had a significant effect on decomposition, C and N loss in litter mixture. Therefore, the exclusion of meso and macro fauna could be a reason for the additive effect observed in this study.

The fact that our predicted litter mass loss was not significantly different from the expected did not suggest that there was no interaction in the mixtures, but could be that the effect of low decomposing litter was balanced up by the effect of the high decomposing litter. Gartner and Cardon, (2004) also made a similar suggestion. This finding also conforms with the research by Hoorens *et al*., (2009) that found no significant interaction at the plant functional type (PFT) level on mixtures due to balancing up of interaction between the negative values and the positive values. The results ascertain that short duration of litter decomposition of the species used in this present study can be predicted by the individual species litter decomposition parameters. This did not conform to the previous study by Gartner and Cardon, (2004) and Salamanca *et al*., (1998) that found mixing effect on litter decomposition when predicted and observed litter mass loss were compared. This additive effect observed might be attributed to our short time experimental frame, the exclusion of meso and macro fauna in the present study due to size of the mesh size (1mm) or species interaction.

5.2.2 Effect of litter diversity on nutrient release

Comparisons of nutrient released between the eight compositions analyzed showed that nutrient released was significant in N and P but K and C released were not significant. This observation might be attributed to the fact that N and P are the major nutrients that regulate nutrient dynamics in most ecosystems. Moore *et al*., (2006) reported that N and P are the main nutrients used by decomposer community to consume the organic carbon that they require for energy. Agren *et al*., (2012) and Knecht and Göransson, (2004) also reported that N and P are the nutrients limiting elements in crop growth in most ecosystems. Therefore, they are the elements that determine the quality of a tree species. Potassium was not significantly different and this might be attributed to the fact that loss of K can be controlled by leaching (Dhanya *et al*., 2013) and also it is a labile element (Hossain *et al*., 2011).

There was a significant relationship between N and N:P ratio and also between N and C:N ratio when the initial nutrient concentration and the ratios of the compositions were compared. These showed that N was the main nutrient that regulated the nutrient dynamics in this present study. Santonja *et al*., (2015) reported that C:N and N:P are the key factors that determine the dynamic of litter decomposition and nutrient release. Therefore, the result showed that N is the main regulator of the nutrient ratios and that proves that it is the main nutrient that regulates the nutrient dynamics in this study.

The nutrient released showed an additive effect on N, P and K and a non-additive effect on C. When there is no significant difference between the observed and the expected an additive effect (AE) occurs but when there is a significant difference a non-additive effect (NAE) occurs. The result did not conform to previous studies that showed prevalence of NAE on decomposition and nutrient release (Hattenschwiler *et al*., 2005; Hector *et al*., 2000) both studies were carried out in Europe but it conforms to the study by Santonja *et al*., (2015) in the south of France that observed a prevalence of 54% additive effect in their study. Though the result showed a good rate of litter nutrient released by each of the species tested and a high percentage positive interaction, this suggest that the effects of litter diversity on nutrient release are mediated by species identity rather than species richness (Santonja *et al*., 2015).

The additive effect observed could be as a result of balancing up of effects between the litter that induced negative effect and those that induced positive effect during decomposition and nutrient release. Balancing up of effect could lead to no significant difference between the observed and expected nutrient release (Hoorens *et al*., 2009). Hattenschwiler *et al*., (2005); Santonja *et al*., (2015) and Wardle *et al*., (1997) observed an increase in nutrient release when species with low C:N and high initial N content are mixed with species with high C:N and low initial N content. In the observation by Zhao *et al*., (2013) with Mongolian pine and understory species (*Artemisia scoparia* and *Setaria viridis*) they found an additive effect on N release and associate the effect to the translocation of nutrients from a nutrient rich litter to nutrient poor litter. In this study nutrient were balanced up and there was no significant difference between the observed and the expected nutrients except for C.

Mixture of *C. africana* with the two legumes released higher average percent of N, K and C than *C. africana* alone which might be as a result of mixing effect or nutrient translocation. Mixture of *F. albida* with the two legumes released higher P than *F. albida* alone which might be as a result of mixing effect or nutrient translocation but average percentage of N, K and C released was higher in *F. albida* alone. Zhao *et al*., (2013) observed that translocation of nutrients reduced the rate of nutrients released in mixed species in their research on two plantations in northeast China.

Immobilization of N and P occurred in the mixture of the five tree species, and immobilization of P occurred in *G. robusta* at the final sampling day (90 days). Increase in Nitrogen during decomposition process could be through various mechanisms such as nitrogen fixation, absorption of atmospheric ammonia, and microbial immobilization (Swarnalatha and Reddy, 2011). Increase in P mass during decomposition might be attributed to P deficiency which could bring about reduction in nutrient release (Moore *et al*., 2006).

In this study, it was observed that N and P released in the mixture of the five tree species was lower than in monoculture of each of the tree species litter. This effect can be explained by the fact that lower quality litter was affecting the high quality litter thereby balancing up the rate of nutrients released in the mixture. Such effect has been observed by Ball *et al*., (2008) and Hoorens *et al*., (2009). The initial litter quality in form of N and C:N ratio could be used to predict the nutrient release in single species composition but not in mixed species composition, therefore it is believed that individual species drives the rate of nutrient release than species richness in the mixture (Hoorens *et al*., 2009). From litter mixture effect observed it was concluded that individual species litter quality drives the litter nutrient release rather than species richness. Such result has been observed by Hoorens *et al*., (2009) and Jacob *et al*., (2010).

5.2.3 Quantity and quality of litter from different agroforestry trees

The productivity of a particular ecosystems depends on the litter fall, decomposition and nutrient released by the litter (Bisht *et al*., 2014). Litter contributions were similar among the five tree species measured. This may be attributed to the litter shedding pattern of the tree species during the sampling period. Deciduous tree like *C. africana* are known to shed majority of its leaf before the growing season and start re-flushing during the growing season (Akpo *et al*., 2005). Therefore, during growing season its rate of litter fall reduces. Trees like *G. robusta* and *A. xanthophloea* are known to be ever green; hence their rates of litter fall are constant throughout the year (Muthuri *et al*., 2005). *F. albida* has a reversed phenology and shed its leaves at the onset of the raining seasons (Roupsard *et al*., 1999; Spevacek, 2011) . The litter shedding patterns of the tree might be the reason why there was no significant difference in the litter falls from the tree species observed, the litter fall collection was three months before the raining season and 3 months in the raining season.

Scaling from litter bag to ecosystem level, the nutrient contributed in relation to litter fall to the ecosystem was only significantly different in N among the five tree species tested. These really supported the importance of N as the main nutrient controlling the dynamic of nutrient released among the five agroforestry trees sampled.

Litter fall was highest in *A. seyal* after 6 months of litter fall collection which cut across the period of our litter decomposition data collection. It was also chosen to cut across the two seasons of our study site. During dry seasons most species tend to have higher rate of litter falls and reduced rate of litter fall in wet season (Parsons *et al*., 2014). *Acacia seyal* with the highest litter fall and also the highest initial N, P, K and C content released the highest nutrients in form of N, P, K and C which shows that it is the best tree among the tree species observed. It also proves that the initial N and C:N ratio can be used to predict the performance of a tree because N content in *A. seyal* was highest and its C:N ratio was the lowest. Bisht *et al*., (2014) postulated that nutrients released could be associated to rate of litter fall. Corbeels, (2001) postulated that litter amount determine the amount of C release during decomposition.

The estimated result of the combination of the five tree species indicates that it could help to increase litter fall in the ecosystem. The immobilization of N and P in the litter mixture of the five tree species might be as a result of lower initial P content in the mixed litter. It might also be as a result of interaction between the different compositions of litter that make up the mixed litter. When the N or P content in the litter is not enough to consume the C that the decomposer required for energy, the decomposers tend to acquire N or P through immobilization to balance up the ecosystem (Moore *et al*., 2006), the N and P immobilized will then be available to the ecosystem in the future. The immobilization of N and P in this research agree support the work of Ball *et al*., (2008) which report that lower quality litter will immobilize nutrient released by higher quality litter in mixed compositions. Ball *et al*., (2008) also suggested that species with low quality litter in mixture can promote nutrient retention in an ecosystem thereby providing nutrient resources for future decay process and long term storage of nutrient in the litter layers. Therefore, the immobilization of N and P in the mixed species in this study could promote nutrient retention in the ecosystem and make the nutrient available for future decay process.

5.2.4 Effect of tree diversity on soil moisture content

Soil moisture content in *C. africana* treatment plots was significantly different (lower than) from other treatment plots which might be attributed to higher water usage capacity by *C. africana* during the growing season for its re-flushing. Gindaba *et al*., (2005) found fine roots of *C. africana* extending three times more than their crown radius in his research on *C. africana* in Ethiopia, which reduces the soil water content around the tree. Observation by Akpo *et al*., (2005) also found soil moisture content in the open land higher than under tree shade of *Acacia tortilis* and *Balanites aegyptiaca* during the second half of growing season (June-September) in North Senegal due to the same reason as above.

Though there was no significant difference in the soil moisture within the treatment but there was higher soil moisture content on rows of tree mixed with legumes than on rows with tree species alone on each treatment plots. This align with the study by Kalinda *et al*., (2015) and Spevacek, (2011) who observed that leguminous trees could help to increase soil moisture retention in semi-arid lands. The non significant difference found might be attributed to the age of the trees during our research period. Most tree species reaches their maturity from age seven (Spevacek, 2011) but the tree age during our research period was just four years.

5.2.5 Effect of soil moisture on rate of decomposition

Zhang *et al*., (2008) explained that a single environmental factor (e.g. temperature, moisture, soil or climate) could account for less than 50% of decomposition rate while combination of factors could explain higher percentage of decomposition. The weak relationship (r^2= 0.046) between the rate of decomposition and soil moisture content observed in this study showed that there are other factors contributing to decomposition of litter in this study besides the soil moisture content alone. It align with the studies by Aerts (1997); Bothwell *et al*., (2014); Kirschbaum, (2004); Lellei-kovács *et al*., (2011) and Xiao *et al*., (2014) that confirms that there are other factors that contribute to litter decomposition than moisture content alone. The study by Xiao *et al*., (2014) showed that relationship between soil moisture and litter decomposition was low (r^2=0.043, p=0.051) on *Pinus massoniana* Forests in China. Study by Bothwell *et al*., (2014) also reported a lower relationship between moisture content and litter decomposition (r^2 = 0.03, p = 0.67) in an experiment conducted in a tropical montane wet forest in Hawaii. This result confirms that soil moisture content was not the only predictor of leaf litter decay rates.

There was no significant difference when rate of decomposition between the treatment plots were compared. The age of the tree on our study site could be a factor because the trees on our study site were only four years old at the period this research was conducted. The tree age might also have impact on the potential of the trees to have significant effect on its immediate environment. Spevacek, (2011) speculated that *F. albida* reach its maturity at above seven years old.

5.3 Conclusions

Diversity of agroforestry trees could help to improve decomposition and nutrient released from agroforestry trees with low quality litter. Balancing up of effect or nutrient translocation between the poor and rich quality tree litter was observed in this study and these gave a reason for the encouragement of planting mixed trees.

Initial litter qualities determine the rate of decomposition and nutrient released in the monoculture but such was not the case in the mixture, therefore individual species drives the process of litter decomposition and nutrient release in mixture rather than species richness. The immobilization of N and P in the mixed can help in nutrient retention which can later be mineralized and useful after a while. Therefore, mixing of species will help in continuous availability of N and P for crop usage.

Quantity of litter falls could be used to determine nutrient released as observed in this study. Planting of diverse tree species could help in nutrients retention and give way for continuous availability of N and P for crop usage. Therefore, planting of diverse tree species was encouraged for future nutrient availability but for fast nutrient release, *A. seyal* and other leguminous species are recommended to be planted in monoculture.

Tree diversity could have both positive and negative effect on the environment mostly on soil water content therefore, it is necessary to investigate a tree before introducing it for agroforestry practices to reduce tree competition with crops for soil water content.

Soil moisture content was not the only predicting factor for litter decomposition as other factors like temperature, litter quality and microbial effect are also important and aid in litter decompositions.

Finally, conclusion was made that diversity of tree species could help to improve decomposition and nutrient release in low quality tree species and also assist in nutrient retention for long term nutrient availability. Individual species rather than species richness drives the decomposition and nutrient release pattern. Therefore, individual species need to be examined before they are introduced for agroforestry system or practices for optimal benefits from their ecosystem functions. The study reject the null hypothesis, results from the study indicated that tree species diversity have significant difference on rate of decomposition most especially on species with low nutrient quality (species with lower mass loss, lower N concentration and high C:N ratio.

5.4 Recommendations

Farmers are encouraged to use different agroforestry tree species in order to benefit from the synergy of the different ecosystem functions from different tree species such as enhanced decomposition rate and nutrient release from low quality tree species. The mixture of trees in agroforestry eco-zone could facilitate the availability of nutrient in long term but for immediate or fast nutrient release in agroforestry system in arid or semi-arid zones, leguminous tree species like *A. seyal*, *F. albida* and *G. sepium* are recommended. Farmers can benefit from legume trees introduction to agroforestry beyond nutrient cycling and soil improvement alone. Legume trees have been documented to serve as alternative food source to livestock during drought and food scarcity (Kebede *et al*., 2016; Shelton, 2004).

More research on young trees is recommended to help farmers document how they can benefit from young trees before they reach their maturity stage. Gartner and Cardon, (2004) reported that higher percentage of plant biomass is present underground, therefore more research work need to be carried out on roots of plants and also on root diversity effect on litter decomposition and nutrient release.

Previous research have focused more on relationship between tree diversity and single ecosystem services and this has limited the knowledge on trade-offs and complimentarity. Therefore, research on effect of tree diversity on multiple ecosystem services are encouraged to bridge the gap on the knowledge of trade-offs and complimentarity in tree species diversity.

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APPENDICES

Appendices i: Species classifications

Specie name	Local name	Exotic/native	Identification
C. africana	Mukumari, Mukebu	Native	Deciduous
F. albida	Mkababu, Altarara	Native	Leguminous
G. robusta	Mgrivea,Mukima	Exotic	Deciduous
A. seyal	Mgunga	Native	Leguminous
A. xanthophloea	Murera, Sengei	Native	semi-deciduous
C. calothyrsus	Mkaliandra	Exotic	Leguminous
G. sepium	mother of cocoa	Exotic	Leguminous

Appendices ii: Research plot trees arrangement

Appendices iii: Litter bags placement

Appendices iv: Conical litter trap

Appendices v: Soil moisture probe (ML3 Theta Probe)

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