EFFECT OF *GLIRICIDIA SEPIUM* AND *SENNA SPECTABILIS* PRUNINGS ON SOIL NUTRIENTS, MACROFAUNA, AND MAIZE YIELD IN BUGESERA DISTRICT, RWANDA

MWUNGURA MARC

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE IN SOIL SCIENCE, DEPARTMENT OF LAND RESOURCE MANAGEMENT AND AGRICULTURAL TECHNOLOGY, FACULTY OF AGRICULTURE, UNIVERSITY OF NAIROBI

2020

DECLARATION

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

Mwungura Marc

Signature ………………….Date 30th July 2020…………………………

This MSc thesis has been submitted for examination with our approval as university supervisors.

Dr. Fredrick O. Ayuke

Signature ……… Date …06th August 2020………………………….

Department of Land Resource Management and Agricultural Technology

Prof. Richard N. ONWONGA

Signature ………………….... Date …*06/08/2020*…………………………

Department of Land Resource Management and Agricultural Technology

DECLARATION OF ORIGINALITY

Name of Student: MWUNGURA MARC

Registration number: A56/88223/2016

College: COLLEGE OF AGRICULTURE AND VTERINARY SCIENCES (CAVS)

Faculty/School/Institute: FACULTY OF AGRICULTURE

Department: LAND RESOURCE MANAGEMENT AND AGRICULTURAL TECHNOLOGY

Course name: SOIL SCIENCE

Title of the work: EFFECT OF *GLIRICIDIA SEPIUM* AND *SENNA SPECTABILIS* PRUNINGS ON SOIL NUTRIENTS, MACROFAUNA, AND MAIZE YIELD IN BUGESERA DISTRICT, RWANDA

DECLARATION

1. I understand what plagiarism is and I am aware of the University's policy in this regard.
2. I declare that this THESIS (Thesis, project, essay, assignment, paper, report, etc.) is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.
3. I have not sought or use the services of any professional agencies to produce this work.
4. I have not allowed, and shall not allow anyone to copy my work with the intention of passing it off as his/her own work
5. I understand that any false claim in respect of this work shall result in disciplinary action in accordance with university plagiarism Policy.

Signature ______________________________ Date July 30th 2020 ________________.

DEDICATION

To the memory of my late Grandfather Mzee Ruberwa Damien you had great influence on some of my decisions and you were never wrong. You inspired me to take this path, but never lived to see me reach the destination

ACKNOWLEDGEMENT

This research work was conducted with financial support received from the United states Agency for International Development, as part of the feed the future initiative, under the CGIAR fund, award number BFS-g-11-00002, and the predecessor fund the food security and crisis mitigation II grant, award number EEM-G00-04-00013. I am so much grateful to this organization without which this work would not have been accomplished.

First and foremost I would like to acknowledge the role played by the government of Rwanda through Rwanda Agriculture and Animal Resources Development Board (RAB) who granted me study leave and other necessary administrative requirements for this masters training to be undertaken, and the University of Nairobi (UoN) for admission into MSc program. I also thank my university supervisors Dr. Fredrick O. Ayuke and Prof Richard N. Onwonga for their unwavering support during the whole research process.

My sincere gratitude also goes to all field technicians, especially Batamuriza Aneth and Baranyikwa Francois for their help during data collection and their encouragement during hard times. Not forgetting my best friend Gasore Alfred and Ant Nyiramajana Julienne for their encouragement and help in different ways. Once again, I express my deepest gratitude to my wife Mutoni Isabelle and our child Mwungura Norman who accepted to remain at home alone during the whole period of studies. Not forgetting parents and all the family members for raising me up and teaching me to be patient, for all the encouragement and support.

I extend many thanks to all the farmers in Karama station and Kintambwe village for allowing me to conduct the research in their farms. I don’t have enough words to thank my greatest provider the ALMIGHTY GOD; Forever I shall praise him.

TABLE OF CONTENTS

DECLARATION i

DECLARATION OF ORIGINALITY ii

DEDICATION iii

ACKNOWLEDGEMENT iv

TABLE OF CONTENTS v

LIST OF TABLES viii

LIST OF FIGURES ix

LIST OF PLATES x

ACCRONYMS AND ABBREVIATIONS xi

ABSTRACT xii

CHAPTER ONE 1

INTRODUCTION 1

1.1 Background 1

1.2 Statement of the problem 3

1.3 Justification 4

1.4.1 Broad Objective 5

1.4.2 Specific objectives 5

1.5 Hypotheses 5

CHAPTER TWO 6

LITERATURE REVIEW 6

2.1 Role of soil organic matter in soil fertility and productivity 6

2.2 Soil fertility management strategies 7

2.3 Management of organic resource for soil fertility improvement 10

2.4 Role of plant residues on soil fauna 11

CHAPTER THREE 13

MATERIALS AND METHODS 13

3.1 Description of the study site 13

3.2 Initial chemical characterization of the study site 14

3.3 Sampling and chemical characterization of *Gliricidia sepium* and *Senna spectabilis* prunings 15

3.3.1 The criteria for the selection of tree shrubs 15

3.3.2 Chemical characterization of prunings 16

3.4 Determination of chemical properties and mineralization rates of *Gliricidia sepium* and *Senna spectabilis* prunings 17

3.4.1 Litter decay field experiment 17

3.4.2 Litterbags sampling procedure 18

3.5 Evaluating the effects of *Gliricidia sepium* and *Senna spectabilis* prunings on maize performance 19

3.5.1 Experimental design and treatment combinations 19

3.5.2 Land preparation, planting and harvesting 20

3.5.3 Chemical characterization of soils treated with prunings 21

3.6 Evaluating effects of *Gliricidia sepium* and *Senna spectabilis* prunings application on soil macrofauna 21

3.6.1 Macrofauna sampling protocol for macrofauna identification 21

3.7 Statistical analysis 23

CHAPTER FOUR 24

RESULTS 24

4.1 Initial nutrient composition of *Gliricidia sepium* and *Senna spectabilis* prunings 24

4.2 Decomposition patterns of *Gliricidia sepium* and *Senna spectabilis* prunings 25

4.3 Nutrient Release patterns of *Gliricidia sepium* and *Senna spectabilis* prunings 26

4.3.1 Nitrogen 26

4.3.2 Phosphorus 27

4.3.3 Potassium 27

4.3.4 Calcium and Magnesium 28

4.4. Initial soil chemical characteristics of the study sites 29

4.5. Influence of *Gliricidia sepium* and *Senna spectabilis* prunings on soil chemical properties 30

4.6 Effectiveness of treatment on maize yield 33

4.7 Initial macrofauna groups identified within the study sites 34

4.7.1 Treatment effect on soil macrofauna abundance 36

4.7.2 Correlation between soil chemical properties and soil macrofauna abundance 39

CHAPTER FIVE 41

DISCUSSION 41

5.1 Chemical quality of organic resources incorporated 41

5.2 Soil chemical characteristics of the study sites prior to conducting the experiments............ 43

5.3 Effect of *Gliricidia sepium* and *Senna spectabilis* pruning incorporation on soil chemical properties.. 43

5.4 Agronomic effectiveness of *Gliricidia sepium* and *Senna spectabilis* prunings on maize performance 44

5.5 Effect of *Gliricidia sepium* and *Senna spectabilis* prunings on soil macrofauna abundance . 45

5.6 Conclusion and Recommendations 47

5.6.1 Conclusions 47

5.6.2 Recommendations 47

REFERENCES 48

LIST OF TABLES

Table 1. Study site characterization 15

Table 2. Chemical characteristics of foliar prunings of *Gliricidia sepium* and S*enna spectabilis*.. 24

Table 3. Comparison of the soil chemical characteristics from the two sites 30

Table 4. Chemical characteristics of the soil amended with foliar prunings from *Gliricidia sepium* and *Senna spectabilis*... 32

Table 5. Maize grain yields across different treatments in Karama and Kintambwe sites. 33

Table 6. Macrofauna baseline information at Karama and Kintambwe sites 35

Table 7a *Gliricidia sepium* and *Senna spectabilis* effect on soil macrofauna in Karama......... 37

Table 7b. *Gliricidia sepium* and *Senna spectabilis* effect on soil macrofauna in Kintambwe. 38

Table 8. The Pearson correlation (r) between soil macrofauna abundance and soil chemical properties.. 40

LIST OF FIGURES

Figure1. A map showing the study sites 13

Figure 2. Layout of the experiment 19

Figure 3. The decomposition patterns of *Gliricidia sepum* and *Senna spectabilis* prunings with time 25

Figure 4. Total nitrogen (% of the original) in the undecomposed foliar prunings of *Gliricidia sepium* and *Senna spectabilis* at different periods 26

Figure 5. Total phosphorus (% of the original) in the undecomposed foliar prunings of *Gliricidia sepium* and *Senna spectabilis* at different periods 27

Figure 6. Total potassium (% of the original) in the undecomposed foliar prunings of *Gliricidia sepium* and *Senna spectabilis* at different periods 28

Figure 7. Total calcium and magnesium (% of the original) in the undecomposed foliar prunings of *Gliricidia sepium* and *Senna spectabilis* at different periods. 29

LIST OF PLATES

Plate 1: A. Free growing and B. Farmer-managed (through pruning) *Senna spectabilis* trees. *Gliricidia sepium* planted C. Along the road, D. On the contours to fence the field. 16

Plate 2: A, B, C - Sampling of prunings along farm boundaries. 17

Plate 3: A - Weighing of prunings, B - Pruning put into litterbags, C, D - Burying of litterbags into experimental plots. 18

Plate 4: A and B – Organic prunings spread on plots, C – Inorganic (DAP) fertilizer broadcast and planting. 20

Plate 5: A and B –sampling, C –Taxonomic identification of the macrofauna 22

ACCRONYMS AND ABBREVIATIONS

AES	Atomic Emission Spectrophotometer
ANOVA	Analysis of Variance
C:N	Carbon to nitrogen ratio
CEC	Cation exchange capacity
Cmol	Cent moles
DCA	Detrended Correspondence Analysis
GDP	Gross domestic product
ICP	Inductively coupled plasma
ISFM	Integrated soil fertility management
LSD	Least significant difference
NH_3	Ammonia gas:
NH_4^+	Ammonium ions
NO_3^-	Nitrate ions
Ppm	Parts per million
PRQI	Plant residue quality index
p-value	Probability value
RAB	Rwanda Agriculture Board
RCBD	Randomize complete block design
RDA	Redundancy analysis
SOM	Soil Organic Matter
SSA	Sub-Saharan Africa

ABSTRACT

The continuous cultivation of land in most of sub-Saharan Africa (SSA) countries has led to a decline in soil fertility as a result of both low organic resource and sub-optimal fertilizer application. A study was conducted at Karama Research station (RAB) and Kintambwe village located in Bugesera District, Rwanda for one season (September 2017 to March 2018) to evaluate the potential influence of two locally available organic residues namely, *Gliricidia sepium* (Gliricidia) and *Senna spectabilis* (Cassia) prunings on soil nutrient, soil fauna diversity and maize yields. Organic resource comprised of *Gliricidia sepium* and *Senna spectabilis*. The treatment were *G. sepium* alone (5 t ha^{-1})=T1; *S. spectabilis* alone (5 t ha^{-1})=T2; *G. sepium* + *S. spectabilis* (5 t ha $^{-1}$)=T3; *G. sepium* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T4; *S. spectabilis* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T5; *G. sepium* + *S. spectabilis* (3.75 t ha^{-1} + 50 kg ha $^{-1}$ DAP)=T6; *G. sepium* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T7; *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T8; *G. sepium* + *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T9; inorganic fertilizer alone (200 Kg ha^{-1} DAP)=T10; Control=T11. The treatments arranged in randomized complete block design (RCBD) replicated four times. Data obtained were subjected to analysis of variance (ANOVA) using GENSTAT whereas differences were evaluated using Fisher's least significant difference (LSD) at 5% level of significance. Statistical significance of the relationship between soil chemical properties and macrofauna abundance and richness were also conducted using GENESTAT. The decomposition and mineralization rates of nitrogen, phosphorus, potassium, calcium, magnesium for pruning *Gliricidia sepium* and *Senna spectabilis* prunings were measured using litter bags for 16 weeks. Rate of weight loss was highest between the 6th and 8th week, where *Gliricidia sepium* and *Senna spectabilis* lost 97% and 88% of the weight, respectively. By the end of the 16th week, *Senna spectabilis* and *Gliricidia sepium* had lost nearly 100% of the biomass. Nitrogen and phosphorus release was relatively faster in the first two and four weeks for Gliricidia and Senna, respectively. Adding prunings of Gliricidia *sepium* and *Senna spectabilis* and their combination significantly ($P<0.001$) increased soil C, N, and P across all treatment compared to the control. Inorganic fertilizer alone (200Kg ha^{-1} DAP) doubled maize yields compared to the control and the prunings +inorganic fertilizers increased maize yield significantly compared to where they were applied alone. However, Gliricidia + inorganic fertilizers and /or without fertilizers increased maize yield significantly, while Senna + inorganic fertilizers and /or without did not increase yields. The combination of the two prunings, however, showed a higher yield when combined with inorganic fertilizers compared to where they were applied alone. These yield results were consistent with the faster release of N and P from the mineral fertilizers compared to the organic prunings. Addition of prunings from both sources of organic matter applied at different rates positively influenced the macrofauna diversity and abundance. Among the treatments, 5t ha^{-1} of prunings increased macrofauna diversity and abundance compared to the control and fertilizer treatment (200 Kg ha^{-1} DAP) and or where they were applied in three quarter supplemented with inorganic fertilizer (3.75t ha^{-1} + 50Kg t ha^{-1}) and half dose supplemented with inorganic fertilizers (2.5 t ha^{-1} + 100 Kg DAP ha^{-1}) respectively. Only earthworms and millipedes positively correlated with Mg and Na, respectively. All other macrofauna groups weakly correlated with total N and extractable P. Earthworms, grasshoppers and cockroaches positively correlated with soil pH, K, Mg while flies and moths negatively correlated with the soil pH. Results of this study demonstrated the potential of the use of *Gliricidia sepium* and *Senna spectabilis* prunings in maintaining soil fertility and health and therefore increasing maize productivity.

.

CHAPTER ONE

INTRODUCTION

1.1 Background

Agriculture sector drive the Rwandan's economy by directly contributing annually a third of the National GDP (World Bank, 2015). It accounts for 70% of Rwanda's total exports and provides more than 80% of employment in the rural and urban areas (World Bank, 2015). In addition, the sector provides food security and livelihood for 90% of the Rwandan population. Therefore, the agricultural sector is not only the backbone of Rwandan's economy, but also a means for livelihood of the majority of Rwandan people (World Bank, 2015). Thus, strengthening the agricultural sector is a prerequisite for maintaining economic growth**.**

Over the years, an increase in population and a slow growth in other economic sector in Rwanda, have increased pressure on land resources through continuous farming on poor soils without replenishing lost nutrients (Kabirigi et al., 2016). The net result of increased population growth in many developing countries has been associated with deforestation, wind and water erosion, and declining land productivity and thus, has resulted in declining soil fertility, low crop productivity and general environmental degradation. Increasing population pressures and widespread food deficit in sub-Saharan Africa, and Rwanda in particular, have compelled national programs to place a high priority on increased agricultural productivity and alleviation of poverty among smallholder farmers (Nabahungu and Visser, 2011)**.** This calls for a soil maintenance technical package which is able to raise the net returns without deteriorating the environment and thereby achieving and sustaining high crop yields (Bationo et al., 2006). A balanced approach that addresses both human needs and environmental concerns is hence, imperative (Ayuke et al., 2011; Mbau et al., 2015).

Among the balanced approaches of improving soil fertility, incorporation of maize stover and weeds were among the most widely used traditional methods. Nonetheless, the immobilization of nitrogen in critical stages of plant growth is a common drawback due to poor quality of some of these residues (Ganunga et al., 2017). The incorporation of high quality biomass from the locally available trees on the other hand, has great potential to replenish soil nutrients if properly utilized (Rutunga et al., 1999; Jama et al., 2000; Palm et al., 2001; Akinnifesi and Kwesiga, 2006).

The agricultural system that integrate the use of locally available resources can be highly suitable for managing soil fertility by smallholder farmers (Gichangi et al., 2007). Such an opportunity can be offered through the use of *Gliricidia sepium* (Gliricidia) and *Senna spectabilis* (Cassia) prunings which farmers use to fence around their farms and as boundaries to separate the farms, but are hardly used for fertility improvement (Partey et al.,2011).

The prunings from *Gliricidia sepium* and *Senna spectabilis* can contribute a significant amount of nutrients required by the plant from the early stages of plant growth to maturity thereby increasing crop yields (Chirwa et al., 2003). Chirwa et al. (2003) highlighted the importance of trees especially leguminous for soil fertility improvement through biomass transfer technologies, and many studies have shown that applications of green manure from trees increased maize yield (Chirwa et al., 2003). For instance, Gachengo et al. (1998) observed that *Tithonia diversifolia* applied at a rate of 5 t ha^{-1} fresh weight improved the maize grain yield almost two times than without input.

The incorporation of biomass from local free growing trees such as *Gliricidia sepium* and *Senna spectabilis* could therefore be important not only for improving farm productivity, but also in enhancing soil flora and fauna diversity hence the ecosystem functions (Maeder et al., 2006). The soil fauna activities contribute to decomposition of organic materials and therefore, improve soil physical and chemical properties (Fründ et al., 2011). Mbau et al. (2015) pointed out the significance of macrofauna such as earthworms and termites in the formation of soil pores and stabilization of macro aggregates which improves soil-water relations such as transmission and retention capacities further improving the soil conditions as well as the overall ecosystem functions (Paul et al., 2013). Research that focus on the decomposition of plant residues and their effects on soil properties improvements should be expanded to include those that address how best to conserve natural resources and biodiversity while achieving optimum sustainable yields.

1.2 Statement of the problem

The greatest challenge among the smallholder farmers of Bugesera is food insecurity. Upon harvesting their crops, which can only last them for two months, farmers are forced to rely on external sources, such as markets for the remaining months till the next crop harvest (Rwibasira, 2016). As in other parts of the country, human population is increasing rapidly in Bugesera, where most of the farmers have less than 0.5 ha yet more food must be produced (Rwibasira, 2016). The problem is further exacerbated by poor crop yields resulting from declining soil fertility arising from continuous cropping and non-application of inorganic fertilizers due to high cost. In addition, the quantity of farmyard manure (organic source of nutrients) which are commonly known and relied on, are insufficient and their quality often low (Mureithi et al., 2008). The potential for using short duration planted trees fallows and green manuring has been rarely considered in increasing crop productivity due to limited information about their usefulness in increasing crop production and reducing land degradation (Hadas et al., 2004). Therefore, low utilization of plant residues in fertilizing the soil and subsequent low soil organic matter content reduce soil fauna diversity and abundance, thereby impacting negatively on soil physical and chemical properties, and overall reduction in crop productivity (Fründ et al., 2011)

1.3 Justification

A major challenge in low inputs production systems in SSA is lack of awareness on the potential of the use of locally available organic residues in fertilizing the farms; the appropriate application technique and the necessary site specific amount of residues to be applied on farms in order to fulfill the crop nutrient requirement. As such, use of these unexploited organic resources within the smallholder farming systems has great potential to reverse soil nutrient decline thereby contributing to sustained crop yields and building long-term soil fertility reserves (Studdert and Echeverria, 1993; Bationo et al., 2006).

The use of shrubs and trees based organic resources has gained importance in some parts of SSA, but in parts of Rwanda (e.g. in Bugesera District), where biomass from *Gliricidia sepium* (Gliricidia) and *Senna spectabilis* (Cassia) trees are widespread across landscapes, they are largely managed by farmers and used for construction, stakes for climbing beans, and as an effective mulch to conserve soil moisture, but rarely used as sources of soil nutrients.

The results of the study conducted by Gachengo et al. (1998) and Partey et al. (2011) reported 3% and 0.23% mean N and P concentrations, respectively and an intermediate decomposition rate for *Senna spectabilis* (Cassia), highlighting the potentials of these residues in the conservation of soil moisture and nutrient release. As such, the potential sources of organic nutrients that could be utilized for the benefit of smallholder resource-poor farmers are as a result not exploited.

In low inputs systems based on use of organic resources, soil flora and fauna contribute to the regulation of the transformation of heavily organic bound nutrients into plant available forms through mineralization (Vanlauwe et al., 2006). Sugiyarto (2009) also observed that application of maize residues increased fauna diversity indices by 44 and 73% for surface and deep soil macro invertebrates, respectively. Besides, long-term manure application in combination with other inorganic inputs results in higher earthworm biomass and diversity and therefore enhanced effects of improved soil aggregation and stable structure. In spite of its limitations, the use of organic resources continues to be most viable options in soil fertility management in SSA.

1.4 Objectives

1.4.1 Broad Objective

This study seeks to contribute to soil fertility through use of locally available (*Gliricidia sepium* and *Senna spectabilis*) resources for sustainable maize production in Bugesera District, Rwanda.

1.4.2 Specific objectives

i. To determine chemical properties and mineralization rates of *Gliricidia sepium* and *Senna spectabilis* prunings.

ii. To determine the effect of *Gliricidia sepium* and *Senna spectabilis* prunings on soil N, P, organic carbon and maize yields.

iii. To determine the effects of *Gliricidia sepium* and *Senna spectabilis* prunings on soil macrofauna diversity and abundance.

1.5 Hypotheses

i. Prunings of *Gliricidia sepium* and *Senna spectabilis* vary in chemical properties and in decomposition and mineralization rates.

ii. The prunings from *Gliricidia Sepium* and *Senna spectabilis* positively influence soil nutrient availability and improve maize yield.

iii. Short-term incorporation of *Gliricidia sepium* and *Senna spectabilis* prunings increases soil fauna diversity and abundance.

CHAPTER TWO

LITERATURE REVIEW

2.1 Role of soil organic matter in soil fertility and productivity

Soil organic matter (SOM) is an important regulator of many soil constraints to crop productivity (Halpern, 2009; Ayuke et al., 2011). The contribution of soil organic matter (SOM) on soil productivity is well recognized especially for soil health attributes such as supplying the needed plant nutrients, increasing the soil cation exchange capacity (CEC), improving soil aggregation and hence soil moisture retention capacity. Moreover, it supports various soil biological activities (Rutunga et al., 1999; Nsabimana et al., 2008). In highly weathered soils with little fertility minerals, decomposing plant materials could remain an alternative to supply crop nutrients.

.

The current agricultural practices such as tillage that removes the residues in the farming system results in a serious degradation of arable land and therefore loss of expected production. In various cropping systems in the tropics for example, limited quantities of agricultural residues are ploughed back to the soil in most of the small holder farming systems (Ayuke et al.,2011; Mbau et al., 2015). They are either burnt to clear the ground for field preparation, utilized as fuel wood or are grazed by livestock. This practice may results to a decline in soil organic matter (SOM) that subsequently lead to a low biomass production and thus low crop yields (Paul et al., 2013).

Soil organic matter (SOM) has a great role in soil fertility improvement, mostly attributed to the presence of soil fauna. Its proper handling is therefore, an important factor in the maintenance of high soil fertility. Among other constraints to the production potential is mainly nitrogen and phosphorus deficiency due to the agricultural production practices undertaken by the smallholder farmers (Pholsen and Somsungnoen, 2004; Onwonga et al., 2015)**.** The affordable cost of mineral fertilizers renders its use very low by a large proportion of farmers. Nevertheless, the soil nutrients lost during crop production, could not adequately turned back (Vanlauwe et al., 2006). Integration of organic-based technologies in small-scale farming systems, such as intercropping of crops and legumes, crops and shrubs, crop rotation and use of high quality plant residues can improve soil fertility and provide a sustainable alternative to the reduction of imported inorganic fertilizers while increasing crop yield (Onwonga et al., 2015).

Ayuke et al. (2010) reported that different soil management practices such as use of organic inputs, crop rotation; mulching and cover cropping enhanced macrofauna diversity and functions through improvement of soil conditions as well as increasing supply of substrates. Agricultural systems like no till and minimum tillage is encouraged due to their impact in reducing losses of soil organic carbon, nitrogen and phosphorus in addition to enhancing symbiotic association such as mychorizae. Through relative losses in C and N from soil are related to the original content of these elements, tillage method and cropping systems have significant effects on long-term content of the elements.

2.2 Soil fertility management strategies

Traditionally, production systems were based on shifting cultivation which provided more time to the soil to buildup of nutrients lost. However, due to high population growth, coupled with severe declining soil fertility, soils could lack sufficient time to accumulate enough soil organic matter and other nutrients which is a challenging task in many cropping systems in tropical ecosystems. Among other crop nutrients nitrogen and phosphorus are mainly deficient, therefore lowering maize yield in many low income countries (Lelei et al., 2009). In the continuously cultivated land the major nutrients such nitrogen and phosphorous from either sources (organic and inorganic) need to be applied continuously to sustain high crop yield potential (Hartemink et al., 2000).

According to Smestad et al. (2002), the access to inorganic fertilizer by small landholding poor farmers in low income countries in Africa is low, due to high cost. In this context, farmers either do not use or use sub-optimal quantity of fertilizers to avoid crop failure, therefore posing a threat to food security and hence decline in per capita food production in Africa. For variability of food systems in this region to be eliminated, then soil fertility decline must be addressed. Therefore integrated soil fertility management system (ISFM) which is a sustainable alternative to soil fertility management can increase crop production and therefore, ensure food security. Integrated soil fertility management (ISFM), has been employed to address the challenge in attempt to improve crop productivity (Vanlauwe et al., 2011). Through the use of combined application of plant residues and fertilizers, use of improved varieties, adaptation of input application rates and proper management of this strategy has been perceived to give satisfactory results.

According to Vanlauwe and Giller (2006), nutrient-use efficiency in organic materials applied alone is low and cannot fully match with nutrient ratios required by crops, since their nutrient depend on the quality and composition of the organic residues applied to the soil. The ISFM helps not only in overcoming the crop production related constraints such as nutrients availability, but also those not directly associated with soil nutrient supply such as improved soil structure, moisture content and soil organic matter. The ISFM which a combination of the use of fertilizer with organic inputs resulted in greater enhancement of soil fertility properties, efficiency in crop nutrient use and uptake when compared to the same materials applied separately (Nziguheba et al., 2002).

The results from a study conducted by Jama et al. (2000), has shown that maize yield was much higher where the biomass of *Tithonia diversifolia* combined with mineral fertilizers, but *Tithonia diversifolia* green biomass provided a high yield than mineral fertilizers (urea, triple superphosphate and potassium chloride) applied separately. This was attributed to the rapid decomposition of green leaf biomass of *Tithonia diversifolia* after incorporation into the soil.

Gachengo et al. (1998) showed that the half-life for the disappearance of *Tithonia diversifolia* dry matter was about one week during the rainy season in western Kenya.

Different experiments conducted using a combination of water harvesting practices, fertilizer micro-dosing and use of organic matter led to a yield increase of between 25-40% in Burkina Faso compared to the controls, thereby increasing the value of their grain stocks by between 21-42% (Sawadogo-Kaboré1 et al., 2008). This yield increase was attributed to improved fertilizer-use efficiency resulting from improved soil moisture storage. This practice is supposed to restore crusted and compacted soils by attracting beneficial macrofauna such as termites which open up voids on the sealed soil surface further increasing the benefits of an improved soil environment (Brussaard et al., 2007).

On-farm integration of green manure, cover crops provides potential to enhance soil productivity through an increase of soil organic matter content (SOM), soil microbial activities and therefore, improving physical properties in soil (Ayuke et al., 2011). Establishment of on-farm biomass banks such as hedgerows and live fences has also been shown to be important sources of organic materials for improvement of maize yields.

2.3 Management of organic resource for soil fertility improvement

The rising cost of inorganic fertilizers in low-input systems can be compensated through the integration of agricultural practices which focus on the combination of fertilizers and organic inputs in reversing nutrients loss (Vanlauwe et al., 2006). In addition, ISFM provide the benefits in maintenance and efficiency use of soil organic matter stocks water and nutrients as a result of persistence of soil fauna diversity, generally improving productivity of soils (Place et al., 2003). Ayuke et al. (2010) observed the influence of soil fauna on soil organic matter dynamics through mineralization-immobilization processes. In this context, soil health and the major ecosystem functions such as material breakdown and nutrient cycling, soil structure improvement and aggregate stabilization could be attributed to the soil biota.

The crop productivity is influenced by the interaction between soil fauna and organic matter since, the activity of these organisms enhance various soil processes that control the availability of crop nutrients such as nitrogen (Barrios, 2007) through the processes like nitrification, nitrogen-fixation, denitrification and volatilization. Furthermore, this interaction can be a useful bio indicators of site productivity (Bird et al., 2004; Sayad et al., 2012).

The organic resources vary in terms of decomposition rate and nutrients release patterns in the soil due to quality of organic resources and hence, greatly affect the diversity of soil fauna (Vanlauwe et al., 2005). The quality of organic resources is defined by the relative ratios of carbon and nitrogen constitutes the materials, lignin and polyphenols. The organic materials with a high C: N ration and which releases nutrients slowly or immobilized N as it decomposes is classified as a low-quality organic residue. A plant residue with low C:N ration and that which doesn’t immobilize but release nutrients faster is considered a high quality plant residue (Vanlauwe et al., 2005; Karanja, 2006). In addition the quality of organic resources can be an essential fundamental determinant in controlling the rate of decomposition as well as nutrient release pattern of the end product of decomposition (Ayuke et al., 2007). The adoption of the use of plant materials (quality prunings) combined with inorganic fertilizers, is therefore a powerful determinant of soil quality, aggregation as a result of sustainable crop productivity (Carter, 2002).

2.4 Role of plant residues on soil fauna

The diversity and abundance are mainly influenced by the favorable microclimate (humid environment), availability of food resources, and land use practices which do not pose treat to the soil fauna communities (Ayuke et al., 2010).

The technologies that supply organic residues in the soil such as alley cropping, and biomass transfer systems can restore micro-arthropod activities to improve litter decomposition (Ayuke et al., 2010). The populations of earthworms and ants have been shown to be influenced by the application of plant residues (Ayuke et al., 2010; Paul et al., 2013). Similarly addition of farmyard manure to soils will favor earthworm population (Ayuke et al., 2010; Paul et al., 2013).Marked improvement in crop performance has been achieved with application of plant residues (Paul et al., 2013).Litter cover is used for feeding arthropods and their predators within natural ecologies. The litter cover modifies the microclimate for these organisms. This results in complex food webs and habitat structures. The combination of soil and litter-dwelling species results in a diverse faunal community. Limited studies have indicated the diversity and populations of soil fauna depend on the quantity and quality of organic residues (Mbau et al., 2015). Higher quality residues increase the soil microbial activities, and exert a stimulating effect on the decomposition of lower quality materials. As such, the decomposition rates of different organic materials are not kinetically independent (Gaisie et al., 2016). Different plant residues, decomposing in the same environment, may show significant differences in the rates of breakdown and nutrient release (Ayuke et al., 2010). Differences in the rates of decomposition of the material can be explained by the regulation of microbial activities by factors such as a variation in nitrogen, lignin and polyphenol contents (Ayuke et al., 2010). The decomposition patterns may also be modified by the intervention of soil fauna, which are also influenced by chemical composition. Full access of the material to the soil fauna results in increased rates of decomposition (Ayuke et al., 2010). The effects of biotic controls on the pattern of nutrients cycling at the cropping system scale remains to be demonstrated. However, it may result in variation through space and over-time of the pattern of partitioning of nutrients between organic residues and soil solution (Paul et al., 2013). Changes in the abundance and diversity of soil macrofauna could be manipulated by applying prunings of different quality such that processes of the litter decomposition and nutrients dynamics are enhanced and therefore improve soil physical and chemical properties.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study site

The study was conducted based at Karama research station and Kintambwe village, Bugesera District, Eastern province of Rwanda (Figure 1). The two experimental sites are about 45 Km South Nyamata Town. The region lies at latitudes: 2.23°, 2.21° S; longitudes: 30.11°, 30.15° E, respectively; elevations of 1000 and 1500 m above sea level.

Figure1. A map showing the study sites

The area is characterized by two rain season with an annual total ranging between 700-900 mm (Verdoodt and Ranst, 2003). The long rain starts from March to July while short rains occur between September and December (Habiyaremye et al., 2015). The mean annual temperatures are somehow constant throughout the year with 21˚C (Verdoodt and Ranst, 2003). The soils are predominantly luvisols and haplic Ferralsols at lower and higher landscape positions, respectively with moderately to slightly acidic conditions (pH 5.3–6.2), and low inherent fertility as shown by low amounts of nitrogen, soil organic carbon and exchangeable bases (Verdoodt and Ranst, 2003; Habiyaremye et al., 2015; Ndoli et al., 2018) (Table 1).

3.2 Initial chemical characterization of the study site

At the beginning of the season, soil samples were randomly taken from four points to 15 cm depth for site characterization, and at 8 weeks after application of treatments. These soil samples were bulked and a sub-sample obtained for analysis of chemical elements such as N, C, P, K, Na, Ca, Mg: In this study Kjeldahl digestion and distillation procedures was used to determine the soil total nitrogen (N) (Parkinson and Allen, 1975) and it was estimated in percentage (%) while the wet oxidation using modified Walkley-Black method as described by (Nelson, 1996) was used to determine the Organic carbon(C) . Phosphorus (P), Potassium(K), Sodium (Na) exchangeable calcium (Ca) and magnesium (Mg) were extracted by Mehlich-3 procedure (Mylavarapu et al., 2014) and then measured by automated calorimetry using an inductively coupled plasma Atomic Emission Spectrophotometer (ICP-AES) (Kalra & Maynard, 1991). The analysis was done at Chemistry Laboratory, Nairobi.

Table 1. Study site characterization

Site description parameters	Karama station	Kintambwe
Latitude and Longitude	2.23° S, 30.11° E,	2.21° S, 30.15° E,
Altitude	1335 m	1382 m
Temperature (˚ C)	21-30˚ C	21-30˚ C
Rainfall (mm)	700-900 mm	700-900 mm
Soil type	Luvisols	Ferrasols
pH (water)(1;2.5)	6.2	5.3
Organic carbon (%)	2.3	0.9
Total N (%)	0.2	0.1
Extractable P (ppm)	19.1	11.2
Exchangeable Ca (cmol/kg)	2.5	2.8
Exchangeable K (cmol/kg)	2.1	1.9
Exchangeable Mg (cmol/kg)	1.8	1.4
Exchangeable Na (cmol/kg)	0.7	0.5
CEC (cmol/kg)	10.4	9.5

The study sites involved on-station research farm and farmers field adjacent to Gaharwa and Rweru lakes, respectively. The latter area was initially under existence oriented agriculture and basically characterized by smallholder farming system due to the increase of immigrants into the area (from 181 inhabitants/km^2 in 1980, 205 inhabitants in 2002 and 282 inhabitants/km^2 in 2008) consequently the household land holding has reduced to about 0.75 ha (Kabirigi et al., 2017). The selected experimental plots had subsistence crops such as maize or sorghum grown in rotation with bush beans in previous seasons. Generally the study sites are could be categorized as a low soil fertility area which lead a low crop yield and, therefore low farm income. (Kabirigi et al., 2016).

3.3 Sampling and chemical characterization of *Gliricidia sepium* and *Senna spectabilis* prunings

3.3.1 The criteria for the selection of tree shrubs

Gliricidia sepium (Gliricidia) and *Senna spectabilis* (Cassia) trees that are found in large quantities in the study area were selected for the purpose of our study. The choice of the residues was based on the availability in the region for easy access by farmers, nutrients (N, P, K, Ca and Mg) concentrations and residues quality index (PRQI) (Plate 1). The residues with a high C: N ration and which releases nutrients slowly or immobilized N as it decomposes is classified as a low quality organic residue. A plant residue with low C: N ration and that which doesn't immobilize but release nutrients faster is considered a high quality plant residue. Based on this quantification criteria, *Gliricidia sepium* (Gliricidia), with relatively lower C:N than *Senna spectabilis* (Cassia) is considered a higher quality material (Ayuke et al., 2011).

Plate 1: A. Free growing and B. Farmer-managed (through pruning) *Senna spectabilis* trees. *Gliricidia sepium* planted C. Along the road, D. On the contours to fence the field**.**

3.3.2 Chemical characterization of prunings

Gliricidia and Cassia prunings were collected from nearby established hedges in the farms prior to field incorporation (Plate 2). Prunings of Gliricidia and Cassia were picked from the field plots at Karama Station. Sub-samples (about 200 g) of each of the organic materials were weighed in the field, carried to the laboratory and oven-dried at 40°C in order to determine the dry matter (DM). The oven-dried samples were then used for initial chemical characterization using procedures outlined by Anderson and Ingram, (1993), where by total organic carbon was determined by Hanes' improved 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 by spectrophotometer while exchangeable bases (potassium: K, magnesium: mg and calcium: Ca) were measured by flame photometry (Anderson and Ingram, 1993).

Plate 2: A – C; Sampling of prunings along farm boundaries.

3.4 Determination of chemical properties and mineralization rates of *Gliricidia sepium* and *Senna spectabilis* prunings

3.4.1 Litter decay field experiment

A litterbag decay experiment was superimposed onto the main experimental plots in which the effect of Gliricidia and Cassia on soil nutrients, soil macrofauna and maize yield were tested. The main experiment was laid out in a randomized complete block design (RCBD) (Figure 2). The standard TSBF litterbag technique was employed to recover the residual experimental materials after they had undergone some decomposition (Gaisie et al., 2016). The experiment was conducted during the cropping season which started in March 2016 to compare the rates of decomposition of the resource materials under investigation, therefore Gliricidia and Cassia prunings were collected from the nearby farms to be tested. A standard samples of 200g each from *G. sepium* and *S. spectabilis* were weighed and placed into 5-mm mesh litterbags measuring 30 cm × 30 cm, and the labeled bags buried at a depth of 10-cm below the soil surface in the two experimental plots within each block consisting of prunings treatment only (Full dose) (Plate 3).

Plate 3: A - Weighing of prunings; B - Pruning put into litterbags; C, D - Burying of litterbags into experimental plots.

3.4 2 Litterbags sampling procedure

The plant materials in the litter bags were recuperated from the soil at an interval of 2, 4, 6, 8, 12, 16 weeks. Six litterbags consisting of three each from Gliricidia and Cassia replicated four times were randomly placed in the soil, especially in those plots that received full dose at 5 t ha^{-1} rate of each of the organic materials and two litterbags were randomly retrieved from each plot during the sampling period. At sampling determined period, litterbags were carefully removed from each of the plots. The soil particles and other impurities attached to the litterbags were washed away and fresh weight of the litter left undecomposed determined. The undecomposed litter material conveyed into paper bags and oven-dried at 70˚C for 48 hours for dry weight determination (Gaisie et al., 2016). The dry weights were expressed as percentage of sample weight remaining undecomposed and recorded in a research notebook. The oven-dry pruning sample were ground and passed through a 1.0 mm sieve. Sub-samples obtained were analyzed for nitrogen, phosphorus, potassium, calcium and magnesium contents using TSBF procedures (Anderson and Ingram, 1993) (see sub-section 3.3.2).

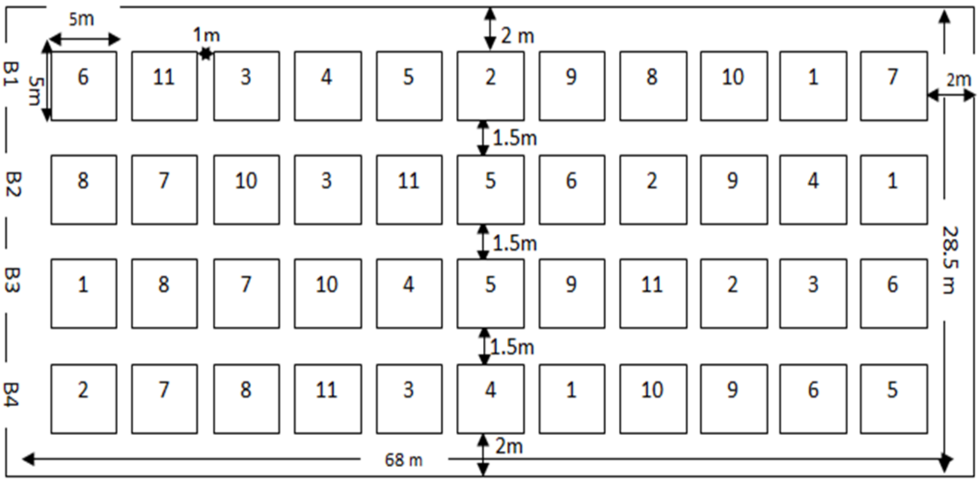

Figure 2. Layout of the experiment

Key. *G. sepium* alone (5 t ha^{-1})=T1; *S. spectabilis* alone (5 t ha^{-1})=T2; *G. sepium* + *S. spectabilis* (5 t ha $^{-1}$)=T3; *G. sepium* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T4; *S. spectabilis* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T5; *G. sepium* + *S. spectabilis* (3.75 t ha^{-1} + 50 kg ha $^{-1}$ DAP)=T6; *G. sepium* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T7; *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T8; *G. sepium* + *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T9; inorganic fertilizer alone (200 Kg ha^{-1} DAP)=T10; Control=T11.

3.5 Evaluating the effects of *Gliricidia sepium* and *Senna spectabilis* prunings on maize performance

3.5.1 Experimental design and treatment combinations

The trials were established during the short rains (October 2017 to March 2018) to determine soil nutrient status and maize yields following sole application of *Gliricidia sepium* and *Senna spectabilis* green manures and their combinations, or when supplemented with inorganic fertilizers. Both green manures consisted of leaves collected from farm hedges. A randomized complete block design (RCBD) in four replications, was used (Figure 2). A set of 11 treatments comprising of: *Gliricidia sepium* prunings (GS), *Senna spectabilis* prunings (SS) and combined *Gliricidia sepium* prunings and *Senna spectabilis* prunings (GS+SS) applied alone and or supplemented with inorganic fertilizer at three levels (0, 50 and 100 kg ha^{-1} DAP), fertilizer treatment alone (200Kg ha^{-1} DAP) and no input control; *G. sepium* alone (5 t ha^{-1})=T1; *S. spectabilis* alone (5 t ha^{-1})=T2; *G. sepium* + *S. spectabilis* (5 t ha $^{-1}$)=T3; *G. sepium* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T4; *S. spectabilis* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T5; *G. sepium* + *S. spectabilis* (3.75 t ha^{-1} + 50 kg ha $^{-1}$ DAP)=T6; *G. sepium* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T7; *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T8; *G. sepium* + *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T9; inorganic fertilizer alone (200 Kg ha^{-1} DAP)=T10; Control=T11 (see Figure 2).

The plant materials and the DAP were broadcast and applied into the soil manually with a hoe to 15 cm depth in 5 m by 5 m plots (Plate 4).

Plate 4: A and B – Organic prunings spread on plots, C – Inorganic (DAP) fertilizer broadcast and seed planting.

3.5.2 Land preparation, planting and harvesting

Land preparation was done using a hoe for each plot to retain the treatment effects as they were applied. In this study, maize (ZM 607) was sown by two seeds per hole after which thinning was done to one seedling to two weeks after seedling emergence using a spacing of 0.25 m by 0.75 m. Prunings were incorporated at a rate of 5t ha^{-1}, 3.75 ha^{-1} and 2.5 t ha^{-1}. Hand weeding was done twice during the growing season at four and eight weeks after sowing, respectively. For fertilizer treated plot, topdressing was carried out six weeks after sowing using urea fertilizer.

To determine maize grain yields an area of 3.37 m^2 leaving one border row on all sides was delineated and a total of 16 plants were harvested in March 2018. Maize Cobs and stover fresh weight per plot were measured in the field and their weight were recorded separately, while Sub-samples were carried to the laboratory and oven-dried at 65˚ C to constant weight to determine the dry matter content of the samples. The grains of maize were separated from the cobs by shelling and total weight of grains recorded and then expressed per unit area.

3.5.3 Chemical characterization of soils treated with prunings

Sampling for soil chemical analysis was done to a depth of 15 cm from each plot. The parameters measured were, the CEC, Total N, Phosphorus, Organic C and the bases (K, Na, Mg, and Ca). Analysis of these elements was done as explained on section 3.2

3.6 Evaluating effects of *Gliricidia sepium* and *Senna spectabilis* prunings application on soil macrofauna

3.6.1 Macrofauna sampling protocol for macrofauna identification

For consistency with the overall rational of TSBF, a standardized and readily applicable method of sampling using the monolith unit was used to quantify macrofauna groups. Its choice was largely due to widely reported successes when used by other scientist (Anderson and Ingram, 1993, Brown et al., 1996). This method has the advantage that both mobile and sedentary fauna can be extracted and is also independent of the behavior of the animals or the condition of the substrate. It was found to be simple method that could be used to assess inner-site and inter-treatment comparisons. Weakness of this method lies on the fact that unless care is taken when driving the monolith down the soil, more animals may be killed. It is also tiring particularly when the ground is dry. Besides, those animals burrowing into the soil may be missed during sorting. As such extreme care has to be observed during the extraction. Using the monolith measuring 25 cm long 25 cm width and 30 cm depth, samples were taken at two periods in this study: (1) at the beginning of the experiment before treatment were applied (October 2017) to determine the baseline, (2) eight weeks after treatment were applied (December,2017) when the macrofauna are mature for taxonomic identification. At each sampling time, two samples were taken randomly from each plot whereby a monolith was placed over a randomly selected spot and excavated using shovels in two stratified layers of 0-15 and 15-30 cm (Nuria and Lavelle, 2008). The soils from the monolith were placed in plastic dishes, after which earthworms and other macrofauna were sorted using hands (Plate 5).

Plate 5: A and B –sampling, C –Taxonomic identification of the macrofauna.

Earthworms were particularly preserved in 75% alcohol after which they were fixed in 4% formaldehyde and stored in a labeled centrifuge tube. Identification was done at the microbiology laboratory in Rubona station. The soil fauna abundance was calculated as a number of individuals per square meters and biomass of individuals per square meters.

3.7 Statistical analysis

The data obtained on chemical properties of pruning materials were entered into excel spreadsheets after which, they were subjected to analysis of variance (ANOVA) with Genstat 17.1 (GENSTAT, 2016). A linear mixed model (LMM) was fitted by Restricted Maximum Likelihood (RELM) procedure using Genstat package. This procedure allows for inclusion of both fixed and random effect terms in the model such that profiled deviance of RELM is optimized for the parameter estimates (Bates et al., 2015; Kuznetsova et al., 2014). Treatments corresponding to sampling period were included in the model as fixed factors, whereas the types of pruning material were defined as a random factor. The statistical significance was determined at $p \leq 0.05$ and levels of significance among the treatments were evaluated using Fisher's least significant difference (LSD).

Correlation analysis (Pearson correlation) was conducted to establish the significance of the relationships between soil fauna and soil chemical properties. Because soil fauna and soil variables had different units of measurements, they were standardized first so that each variable received equal weight in the analysis and also to make the coefficient (r) values comparable (Cao et al., 1999; Jongman et al., 2005).

CHAPTER FOUR

RESULTS

4.1 Initial nutrient composition of *Gliricidia sepium* and *Senna spectabilis* prunings

The initial nutrient composition of *Gliricidia sepium* and *Senna spectabilis* organic materials are shown in Table 2. Nutrient concentration (organic C and Ca) in the foliar prunings differed significantly between the two species (Table 2). Organic C was higher in *Senna spectabilis* than in *Gliricidia sepium* although a reverse trend was noted for Ca. The other parameters (dry matter, P, K, total N and Mg) did not differ between the organic materials.

Table 2. Chemical characteristics of foliar prunings of *Gliricidia sepium* and *Senna spectabilis.*

Chemical characteristics	**Organic prunings**		**Summary statistics**		
	SS	GS	Sed	Lsd 5%	P-value
Dry matter (DM) (%)	88.00	76.50	3.20	13.78	0.070
Organic carbon (%)	47.69	38.40	1.56	6.72	**0.027**
Phosphorus (%)	0.21	0.30	0.02	0.10	0.057
Potassium (%)	0.50	0.75	0.15	0.65	0.238
Total N (%)	3.95	3.75	0.16	0.68	0.333
Calcium (%	0.43	0.95	0.06	0.24	**0.011**
Magnesium (%)	0.50	0.65	0.10	0.44	0.279
C:N Ratio	12.07	10.24	0.38	0.38	**0.040**

Key: SS = *Senna spectabilis;* GS = *Gliricidia sepium;* Sed: Standard error of the difference; Lsd 5%; least significance difference. P-values in bold are significant at 5% probability level.

The two species have enormous potential to supply adequate nutrients to the soil for plant growth. Although C/N ratios were below 20:1, indicating the possibility of net N-mineralization for both materials during decomposition, *Senna spectabilis* had significantly higher C: N ratio than *Gliricidia sepium*.

4.2 Decomposition patterns of *Gliricidia sepium* and *Senna spectabilis* prunings

The decomposition patterns for the two prunings (*Gliricidia sepium* and *Senna spectabilis*) are shown in figure 3. The analysis of variance showed that species type and sampling period were highly significant ($p<0.001$). Decomposition rate was significantly higher in *Gliricidia sepium* than in *Senna spectabilis* throughout the study period (Figure 3). A relatively faster soil organic matter turnover was observed when biomass was applied (Figure 3), with half-life of material attained within four to six weeks of decomposition for the two species. Three different phases were observed in the decomposition of *Gliricidia sepium* and *Senna spectabilis* prunings. A moderate rapid phase in the first four weeks after incorporation of the prunings into the soil, which was then followed by a rapid phase in the subsequent four weeks, and a final slow phase in the 8th to 16th week were observed. The results showed that the decomposition of *Gliricidia sepium* was faster than that of *Senna spectabilis*. In the first two weeks, 37% of *Gliricidia sepium* had decomposed compared to 17% for *Senna spectabilis* during the same period. There were hardly any materials recovered after eight weeks for *Gliricidia sepium,* while 10% of materials were recovered for *Senna spectabilis* (Figure 3).

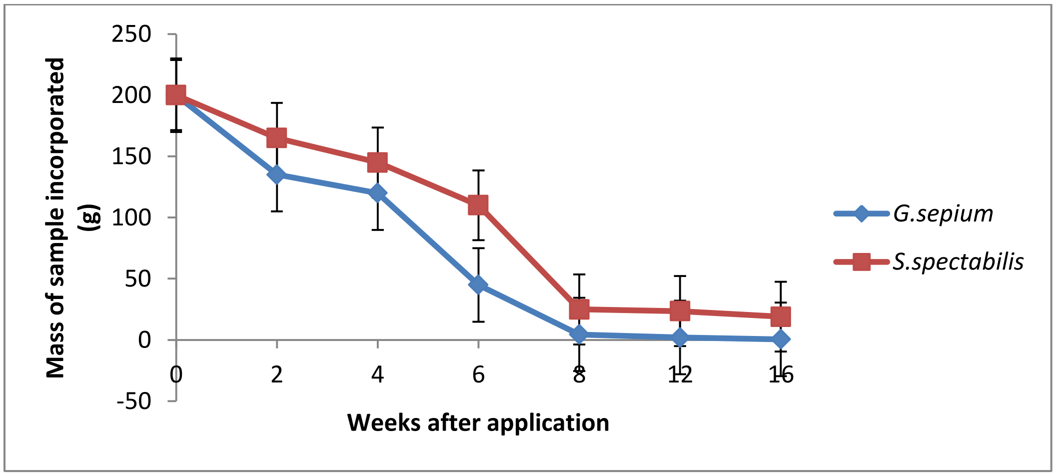

Figure 3. The decomposition patterns of *Gliricidia sepium* and *Senna spectabilis* prunings with time**.**

4.3. Nutrient Release patterns of *Gliricidia sepium* and *Senna spectabilis* prunings

4.3.1 Nitrogen

Analysis of variance indicated no significant difference between the species, but highly significant differences among sampling time ($p<0.001$) the interaction between species and sampling time was also not significant. Nitrogen release from prunings of Gliricidia and Senna proceeded at a fast rate with time (figure 4). About 83% N were released in two weeks in *Gliricidia sepium* while in *Senna spectabilis* prunings 55% were released for the same period. Nitrogen release was rapid in the first two weeks. During this period, 83% N was released for Gliricidia compared to 55% N from Senna mineralization. Between the fourth and twelfth week, N release progressed at a very slow rate for both species. There was hardly any N recovered in the *Gliricidia sepium* material at 16 weeks, while 15% N remained in *Senna spectabilis* materials.

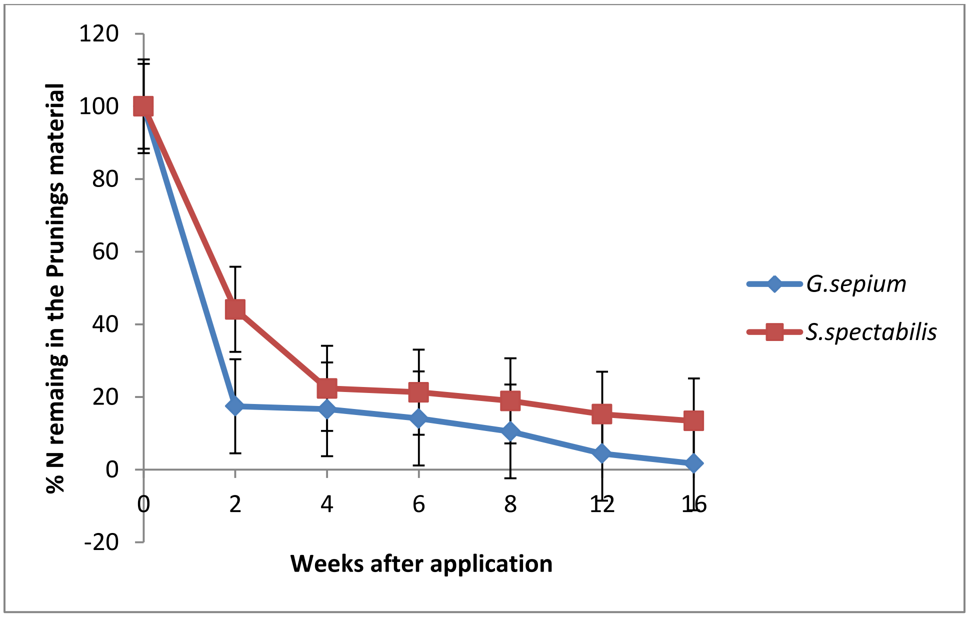

Figure 4. Total nitrogen (% of the original) in the undecomposed foliar prunings of *Gliricidia sepium and Senna spectabilis* different periods**.**

4.3.2 Phosphorus

The analysis of variance indicated highly significant effects between pruning types as well sampling time (<0.001). The interaction between species and sampling time indicated also a highly significant difference (<0.001). Phosphorus release from prunings of *Gliricidia sepium* proceeded at a fast rate with time than in *Senna spectabilis* (figure 5). Phosphorus was rapidly released in the first two and four weeks in *Gliricidia sepium* and *Senna spectabilis*, respectively. About 80% of P was released in two weeks with 50% of P being released from *Senna spectabilis* prunings in the same period. In one month, about 75% P was released from *Senna spectabilis* prunings compared to 85% P in *Gliricidia sepium*. In *Gliricidia sepium* prunings there was hardly any undecomposed material at the end of 16 weeks while in *Senna spectabilis* about 9% remained undecomposed.

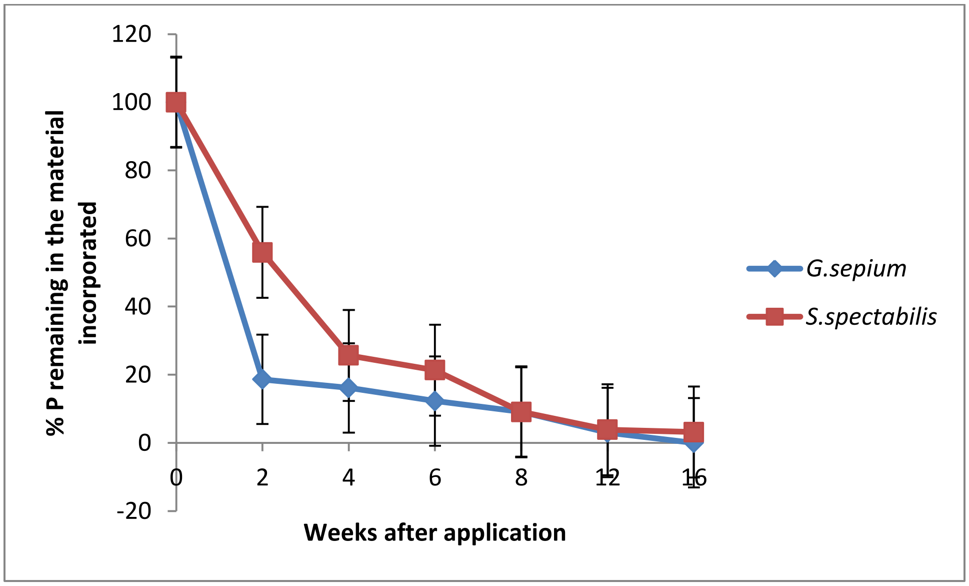

Figure 5. Total phosphorus (% of the original) in the undecomposed foliar prunings of *Gliricidia sepium* and *Senna spectabilis* different periods**.**

4.3.3 Potassium

The analysis of variance indicated a highly significant effect among tree prunings as well as sampling periods (<0.001), but the interaction between species and sampling periods was not significant. Potassium release from prunings of *Gliricidia sepium* and *Senna spectabilis* proceeded at a faster rate with time (Figure 6). In one month, about 90% of K was released from *Gliricidia sepium* materials with 75% of K being released from *Senna spectabilis* in the same period. After 12 weeks, hardly any K remained in both materials.

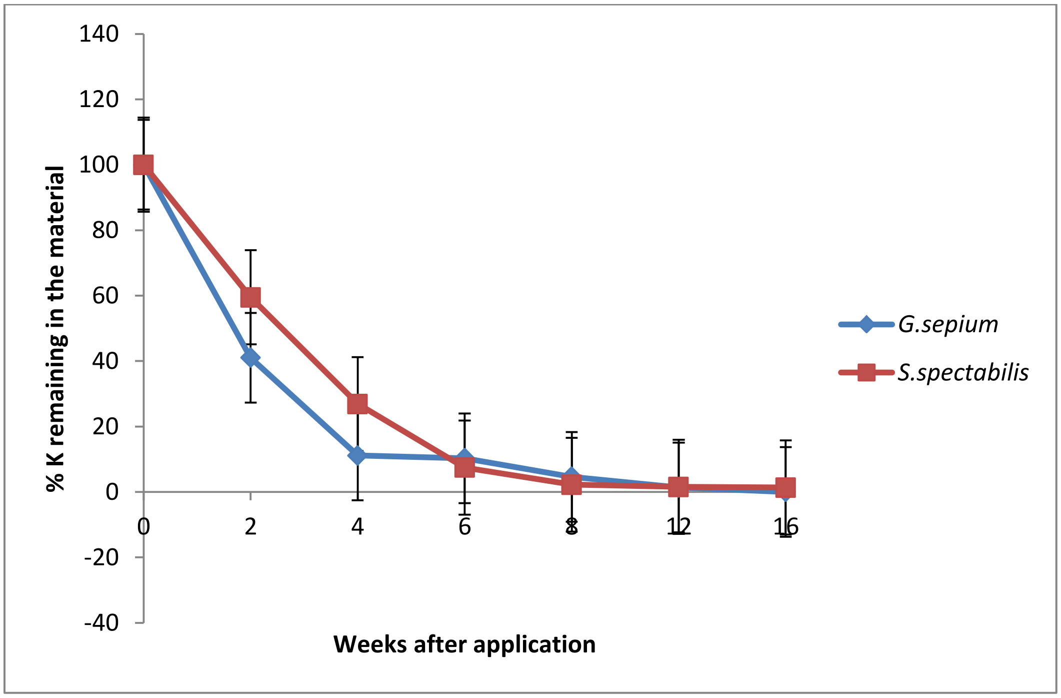

Figure 6. Total potassium (% of the original) in the undecomposed foliar prunings of *Gliricidia sepium* and *Senna spectabilis* at different periods

4.3.4 Calcium and Magnesium

Calcium and Magnesium release from prunings of *Gliricidia sepium* and *Senna spectabilis* proceeded at faster rates with time (Figure 7). Calcium was rapidly released in the first four weeks for both materials, while Mg release was rapid in the first six weeks for both materials. In one month, 90 % Ca was released from *Gliricidia sepium* materials compared to 75% Ca in *Senna spectabilis*. The rate of Ca release between fourth and eight weeks progressed at a very slow rate and leveled towards the eight weeks with a considerable quantity (22%) still remaining in *Senna spectabilis* at 16 weeks, unlike *Gliricidia sepium* that had only 2% remaining in the materials. Magnesium release rate was faster in both materials in the first six weeks with signs of Mg immobilization in the subsequent weeks (Figure 7).

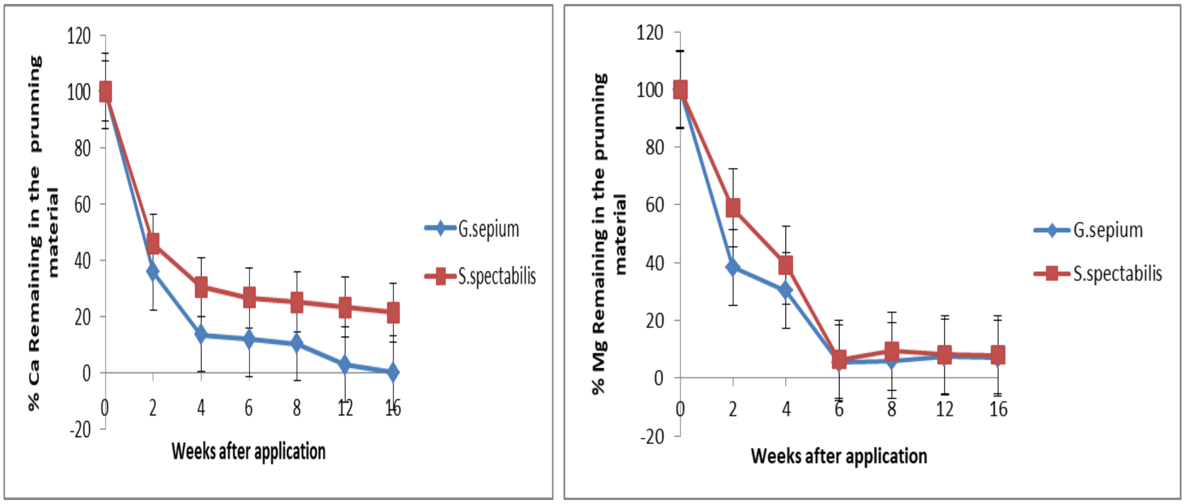

Figure 7. Total calcium and magnesium (% of the original) in the undecomposed foliar prunings of *Gliricidia sepium* and *Senna spectabilis* at different periods.

4.4 Initial soil chemical characteristics of the study sites

Results of initial soil characterization on selected parameters from the two sites are presented in Table 3. The soils were found to be moderately acidic with the pH ranging between 5.3 and 6.2, but this was significantly lower in Kintambwe than in Karama site. Soil organic C, total N, extractable P and the exchangeable bases (Mg and Na) were significantly higher in Karama than in Kintambwe site. However, the other soil parameters (Ca, K and CEC) did not differ between the two sites

Table 3. Comparison of the soil chemical characteristics from the two sites.

Soil characteristics	Sites		Summary of analysis		
	Karama	Kintambwe	SED	LSD (5%)	P-value
pH(water)(1;2.5)	6.20	5.30	0.08	0.24	<0.001
Organic carbon (%)	2.30	0.90	0.14	0.33	<0.001
Total N (%)	0.20	0.10	0.02	0.06	**0.014**
Extractable P (ppm)	19.10	11.20	1.74	5.55	**0.020**
Exchangeable Ca (cmol/kg)	2.50	2.80	0.26	0.84	0.304
Exchangeable K (cmol/kg)	2.10	1.90	0.19	0.62	0.594
Exchangeable Mg (cmol/kg)	1.80	1.40	0.09	0.28	**0.033**
Exchangeable Na (cmol/kg)	0.70	0.50	0.05	0.17	**0.016**
CEC (cmol/kg)	10.40	9.50	0.37	1.19	0.091

SED: Standard error of the difference. LSD: Least significant difference. P values in bold are significant at 5% probability level.

4.5 Influence of *Gliricidia sepium* and *Senna spectabilis* prunings on soil chemical properties

The chemical characteristics of soil amended with *Gliricidia sepium* and *Senna spectabilis* in different combinations with mineral fertilizers in the two study sites were summarized in table 4. The analysis of selected soil chemical properties across different treatments on both sites showed a significant difference between the treatment at ($P<0.05$). For most of the soil parameters, except the total N, extractable P and the exchangeable bases (K and Ca) which differed significantly ($P<0.005$) in Karama and extractable P and exchangeable K in Kintambwe across all treatments. Other soil parameters did not vary significantly at ($P<0.05$). However, in Karama station, the application of mineral fertilizers full dose (200kg DAP +100kg ha^{-1} Urea) treatment resulted to a higher increase of soil total N compared to other treatment while the control treatment resulted in a lower total N contribution to the soil. Other treatments resulted in an intermediate contribution of N to the soil. The soils treated with inorganic fertilizer (full rates=T10) also led to highest increase of available P in Karama station and Kintambwe compared to all other treatments. Soils amended with prunings alone (Full rate =5t ha$_{-1}$) and soils amended with prunings supplemented with low amount of fertilizers (3.75 t ha^{-1}+50 kg ha^{-1}DAP), irrespective of the types of prunings, resulted in intermediate soil available P increase while the control plots resulted in a low increase of soil available P. The results further showed that application of *Gliricidia sepium* and *Senna spectabilis* prunings alone (Full rate =5t ha^{-1}) and/ or supplemented with low (3.75 t ha^{-1}+50 kg ha^{-1} DAP) led to a higher increase of exchangeable bases (K and Ca) in Karama and (K) in Kintambwe compared to all other treatments. However, K level declined in all treatments except in the soil treated by *Gliricidia sepium* full dose in Karama station but this declined in all treatments in Kintambwe site

Table 4. Chemical characteristics of the soil amended with foliar prunings from *Gliricidia sepium* and *Senna spectabilis*.

	Karama													
	Treatments type											Statistical summary		
Chemical properties	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**T11**	**Sed**	**Lsd (5%)**	***p*-value**
Soil pH(water)1:2.5	6.9	6.9	6.5	6.6	6.9	6.8	7.0	7.0	5.8	6.8	6.3	0.5	0.91	0.274
Organic C (%)	3.5	3.1	3.2	2.4	2.5	2.4	2.5	2.4	2.3	2.5	2.3	0.5	0.95	0.19
Total N (%)	0.4bc	0.2525d	0.3cd	0.3d	0.3d	0.2425de	0.4ab	0.4ab	0.4ab	0.5a	0.2e	0.0	0.09	**0.001**
Extra P (ppm)	31.0bc	32.3bc	30.7bc	41.6ab	30.8bc	30.4bc	30.1bc	40.8ab	27.4c	52.1a	26.9c	6.0	12.15	**0.005**
Exc. Ca (cmol(+)kg-1	2.7cd	4.6ab	3.2bcd	3.5bcd	5.6a	4.2abc	4.6ab	3.9abc	3.8bcd	3.4bcd	2.2d	0.9	1.73	**0.024**
Exc. K (Cmol(+)Kg-1)	3.6a	2.1bcd	2.2b	2.1bc	2.0bcd	2.0bcd	2.0bcd	2.1bcd	1.3d	1.4cd	1.6bcd	0.4	0.76	**<0.001**
Exc. Mg (Cmol(+)kg-1)	1.8	1.5	1.4	1.5	1.6	1.5	1.7	1.7	1.5	1.6	1.6	0.1	0.30	0.410
Exc. Na (cmol(+)kg-1)	0.7	0.7	0.8	0.7	0.8	0.8	0.9	0.8	0.6	0.8	0.7	0.1	0.20	0.492
CEC (cmol(+)kg-1)	10.9	12.0	10.2	11.5	13.7	12.6	12.9	12.3	11.3	11.8	11.4	1.1	2.33	0.200
	Kintambwe													
Soil pH(water)1:2.5	6.0	5.8	5.5	5.8	5.5	5.8	5.6	5.8	6.1	5.9	5.3	0.4	0.77	0.595
Organic C (%)	3.1	3.3	3.0	3.1	2.7	2.9	3.0	2.7	2.7	2.4	2.8	0.3	0.72	0.481
Total N (%)	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.1	0.11	0.644
Extr P (ppm)	32.5cd	32.1bcd	26.1cd	21.0d	17.6d	23.4cd	20.5d	53.2a	41.2abc	48.7ab	21.2d	9.5	19.31	**0.005**
Exc. Ca (cmol(+)kg-1	4.4	4.9	7.4	3.6	6.0	5.4	5.1	7.5	3.8	4.5	4.3	1.9	3.96	0.537
Exc. K (Cmol(+)Kg-1)	1.2bcd	1.4abcd	1.3abcd	1.7ab	1.8a	1.1cd	1.1d	1.7ab	1.6abc	1.4abcd	1.0d	0.3	0.55	**0.047**
Exc. Mg (Cmol(+)kg-1)	1.5	1.3	1.6	1.4	1.4	1.3	1.6	1.5	1.5	1.5	1.4	0.1	0.22	0.365
Exc. Na (cmol(+)kg-1)	0.6	0.6	0.5	0.6	0.5	0.7	0.5	0.8	0.8	0.6	0.4	0.1	0.29	0.304
CEC (cmol(+)kg-1)	12.0	11.0	14.7	12.5	12.2	11.7	12.5	14.1	11.5	11.5	11.2	1.5	3.06	0.315

Across rows, means followed by different lowercase letters are statistically significant at $p < 0.05$. Significant *p*-values are in bold. *G. sepium* alone (5 t ha^{-1})=T1; *S. spectabilis* alone (5 t ha^{-1})=T2; *G. sepium* + *S. spectabilis* (5 t ha $^{-1}$)=T3; *G. sepium* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T4; *S. spectabilis* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T5; *G. sepium* + *S. spectabilis* (3.75 t ha^{-1} + 50 kg ha $^{-1}$ DAP)=T6; *G. sepium* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T7; *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T8; *G. sepium* + *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T9; inorganic fertilizer alone (200 Kg ha^{-1} DAP)=T10 ; Control=T11.

4.6 Effectiveness of treatment on maize yield

Table 5 shows maize grain yield from the two study sites. The analysis of variance indicated a highly significant difference among treatments (<0.001) in both sites compared to the control plots. Fertilizer treatment plot (200 Kg ha^{-1} DAP plus 100 Kg ha^{-1} Urea) resulted to the highest grain yield of maize in the two study sites over one season. In Karama station, fertilizer treated plots obtained 7.68 t ha^{-1} while in Kintambwe recorded 6.75 t ha^{-1}, which led to 63% and 79%, respectively above the control plots. The control treatment had the lowermost grain yield of maize, while other treatment recorded intermediate maize yields.

Table 5. Maize grain yields across different treatments in Karama and Kintambwe sites.

Treatment	**Grain yield (t ha^{-1})**	
	Karama	**Kintambwe**
T1	6.20 bcd	5.88 ab
T2	5.21 e	5.15 b
T3	5.38 de	5.15 b
T4	6.30 bc	5.88 ab
T5	5.58 cde	5.40 b
T6	5.68 cde	5.05 b
T7	6.66 ab	6.08 ab
T8	5.80 bcde	5.35 b
T9	6.08 bcde	5.50 ab
T10	7.21 a	6.75 a
T11	4.24 f	3.78 c
S.e.d	0.45	0.62
Lsd (5%)	0.89	1.27
P-value	**<.001*** **	**0.012***

Within columns, means followed by different lowercase letters are statistically significant at p < 0.05. Significant p-values are in bold. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$; *G. sepium* alone (5 t ha^{-1})=T1; *S. spectabilis* alone (5 t ha^{-1})=T2; *G. sepium* + *S. spectabilis* (5 t ha $^{-1}$)=T3; *G. sepium* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T4; *S. spectabilis* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T5; *G. sepium* + *S. spectabilis* (3.75 t ha^{-1} + 50 kg ha $^{-1}$ DAP)=T6; *G. sepium* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T7; *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T8; *G. sepium* + *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T9; inorganic fertilizer alone (200 Kg ha^{-1} DAP)=T10; Control=T11

4.7 Initial macrofauna groups identified within the study sites

Different soil macrofauna groups were recorded at the beginning before land preparation begun. Table 6 summarizes the macrofauna groups recorded in Karama Research station farms and in Kintambwe farms. Fifteen macrofauna groups recorded in Karama research station farm included: Earthworms (Oligochaeta), ants (Hymenoptera), beetles (Coleoptera), crickets (Orthoptera/Ensifera), grasshoppers (Orthoptera/Califera), termites (Isoptera), centipedes (Scolopendromorpha), flies (Diptera), spiders (Araneae), cockroaches (Diplopoda), millipedes (Myriapoda), centipedes (Myriapoda), moths (Lepidoptera), earwigs (Dermaptera), true bugs (Hemiptera). In Kintambwe, only 12 macrofauna groups were recorded in Kintambwe farms including earthworms (Oligochaeta), ants (Hymenoptera), beetles (Coleoptera), crickets (Orthoptera/Ensifera), grasshoppers (Orthoptera/Califera), termites (Isoptera), centipedes (Scolopendromorpha), flies (Diptera), spiders (Araneae), cockroaches (Diplopoda), Millipedes (Myriapoda), moths (Lepidoptera).

Faunal composition and abundance within the agro ecosystem were dominated by earthworms and termites with the two groups constituting 48% and 67% of the total macrofauna in Karama and Kintambwe sites, respectively. A higher number of termites (56%) were recorded in Kintambwe farms compared to 23% recorded in Karama research station farm. However, a higher number of earthworms (23%) were recorded in Karama research station farm than in Kintambwe farms which recorded 13% of the total macrofauna groups. Other groups of macrofauna were found in low numbers per /m^2. Except for beetles which constituted 18% of the total fauna recorded in Karama, all the macrofauna groups were found in very low numbers (<10%) (Table 6).

Table 6. Macrofauna baseline information at Karama and Kintambwe sites.

	Karama		**Kintambwe**	
Macrofauna Group	Number/m^2	% Total	Number/m^2	% Total
Earthworms	288	25.7	64	12.5
Ants	80	7.1	32	6.3
Beetles	208	18.6	32	6.3
Crickets	16	1.4	16	3.1
Grasshoppers	32	2.9	0	0.0
Termites	256	22.9	288	56.3
Scolopendra	48	4.3	32	6.3
Flies	16	1.4	16	3.1
Spiders	32	2.9	16	3.1
Cockroaches	32	2.9	0	0.0
Millipedes	32	2.9	0	0.0
centipedes	0	0.0	0	0.0
Moths	48	4.3	16	3.1
Earwigs	0	0.0	0	0.0
True bugs	32	2.9	0	0.0
Mean Total	**1120**	**100.0**	**512**	**100.0**

4.7.1 Treatment effect on soil macrofauna abundance

Overall, significant treatment effects on soil macrofauna abundance were found for both study sites (Table 7a and 7b). The analysis of variance across different treatments showed significant differences for most of the macrofauna groups except spiders, earwigs and true bugs in Karama site and grasshoppers, flies, cockroaches, millipedes, centipedes, moth, earwigs in Kintambwe site. Soils treated with organic prunings full rate (5t ha $^{-1}$) recorded higher number of macrofauna in almost all the groups while control and fertilizer treatments had the lowest numbers of macrofauna almost across all groups. Addition of organic residues from both sources of prunings but supplemented with inorganic fertilizers recorded an intermediate abundance of macrofauna. Addition of prunings (5t ha^{-1}) irrespective of the type resulted in the highest number of earthworms and Termites in both sites compared to the other treatments. Nonetheless; inorganic fertilizer treatment and the control treatment recorded the lowest number of the earthworms and termites obtained in Karama and Kintambwe, respectively. However, treatments in which the prunings were supplement with inorganic fertilizers recorded intermediate numbers. Other soil macrofauna sampled varied between the treatments as well as within the sites. Beetles and Ants constituted 8 and 7% in Kintambwe and 8 and 9% in Karama station, while other groups such as crickets, spiders, cockroaches, flies, which constituted less than 5% of the total macrofauna each. Analysis of variance indicated highly significant differences on most of the macrofauna groups except in spiders, earwigs and true bugs groups in Karama. However, a big number of macrofauna groups (Cockroaches, millipedes, and centipedes, moths, earwigs, Flies and Grasshoppers), did not vary significantly among the treatments in Kintambwe

.

Table 7a. *Gliricidia sepium* and *Senna spectabilis* effect on soil macrofauna in Karama.

Karama station															
	Treatment type										**Summary statistics**				
Macrofauna group/Order	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	Total	%Total	Sed	Lsd	p-value
Earthworms	120ab	124a	116ab	88abc	80bc	88abc	92abc	72c	68c	68.5c	72.5c	989.0	26.9	20.2	41.21	0.049
Ants	24bc	48ab	20bc	60a	48ab	20bc	16c	20bc	20bc	20bc	24bc	320.0	8.7	14	28.54	0.034
Beetles	39.5bc	60.2a	47.5b	31.5c	33c	28.8cd	16.5ef	19.5de	18def	7.5f	9.8ef	311.8	8.5	5.27	10.77	<.001
Crickets	28a	24a	4bc	16ab	8bc	8bc	8bc	4bc	4bc	0c	4bc	108.0	2.9	7.22	14.75	0.008
Grasshoppers	24ab	36a	24ab	4c	8c	24ab	16bc	12bc	12bc	8c	16bc	184.0	5.0	7.7	15.73	0.010
Termites	114ab	129.2a	108.5b	71c	73.8c	63.8cd	46de	45.8de	37.2ef	25f	32ef	746.3	20.3	9.82	20.05	<.001
Scolopendra	36a	36a	20b	12bc	8bc	12bc	12bc	12bc	16bc	4c	8bc	176.0	4.8	7.37	15.05	<.001
Flies	24ab	32a	20abc	28a	4cd	8bcd	8bcd	4cd	0d	0d	4cd	132.0	3.6	9.48	19.35	0.008
Spiders	24	40	8	12	12	16	12	24	20	4	4	176.0	4.8	11.3	23.09	0.114
Cockroaches	32a	16ab	8b	8b	4b	8b	0b	12b	0b	0b	0b	88.0	2.4	8.04	16.41	0.012
Millipedes	16ab	20a	16ab	16ab	12abc	16ab	4bc	0c	0c	0c	0c	100.0	2.7	7.83	15.99	0.046
centipedes	24a	4b	4b	4b	4b	4b	8b	8b	12b	4b	8b	84.0	2.3	5.17	10.57	0.016
Moths	24ab	32a	16bc	16bc	16bc	4cd	8cd	0d	0d	4cd	4cd	124.0	3.4	7.21	14.72	0.001
Earwigs	8	4	4	4	12	16	4	0	0	0	0	52.0	1.4	6.4	13.06	0.237
True bugs	12	20	12	4	4	4	4	4	8	0	12	84.0	2.3	8.6	17.56	0.540
Mean total	**549.5**	**625.4**	**428**	**375**	**326.8**	**320.6**	**254.5**	**237.3**	**215.2**	**145**	**198.3**	**3675.1**	**100.0**			

Across rows, means followed by different lowercase letters are statistically significant at $p < 0.05$. Significant *p*-values are in bold. *G. sepium* alone (5 t ha^{-1})=T1; *S. spectabilis* alone (5 t ha^{-1})=T2; *G. sepium* + *S. spectabilis* (5 t ha $^{-1}$)=T3; *G. sepium* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T4; *S. spectabilis* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T5; *G. sepium* + *S. spectabilis* (3.75 t ha^{-1} + 50 kg ha $^{-1}$ DAP)=T6; *G. sepium* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T7; *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T8; *G. sepium* + *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T9; inorganic fertilizer alone (200 Kg ha^{-1} DAP)=T10 ; Control=T11.

Table 7b. *Gliricidia sepium* and *Senna spectabilis* effect on soil macrofauna in Kintambwe.

	Treatment type											Summary of Analysis				
Macrofauna Group/Order	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**T11**	Total	%Total	Sed	Lsd (5%)	*p*-value
Earthworms	59ab	62a	58abc	45bcd	42de	44cd	34def	27efg	26fg	16g	14g	427	13.22	7.7	15.7	<0.001
Ants	32a	40a	24ab	24ab	24ab	24ab	8b	12b	8b	8b	12b	216	6.69	8.8	18	0.009
Beetles	36ab	48a	28bc	20bcd	24bcd	28bc	24bcd	20bcd	12cd	8d	12cd	260	8.05	9.3	19	0.008
Crickets	32a	28ab	28ab	20bcd	24abc	20bcd	12d	12d	20bcd	13cd	12d	221	6.84	5.6	11.4	0.005
Grasshoppers	16	20	8	4	0	0	0	4	12	0	0	64	1.98	3.1	6.4	0.465
Termites	119ab	136a	87bc	64c	82bc	61c	58c	62c	64c	58c	66c	857	26.53	21.9	44.8	0.012
Scolopendra	32a	36a	30ab	17.5cd	21bc	18.5c	12.5cde	12cde	12cde	9de	8e	208	6.44	4.6	9.5	<0.001
Flies	32	26	23	23	23	25	20	24	20	17	24	257	7.96	5.2	10.6	0.388
Spiders	24	52	32	16	24	20	20	12	20	17.5	24	262	8.10	9.1	18.6	0.015
Cockroaches	4	4	4	4	0	0	0	0	0	5	0	21	0.65	3.1	6.4	0.465
Millipedes	4	8	8	0	4	0	0	0	0	0	0	24	0.74	3.4	6.9	0.088
centipedes	8	16	16	0	4	4	0	0	0	0	0	48	1.49	7.1	14.6	0.166
oths	28	44	28	16	20	16	24	20	16	13	12	237	7.34	11	22.6	0.228
Earwigs	12	16	12	0	12	8	8	0	0	0	0	68	2.11	6.4	13.1	0.081
True bugs	12	20	4	8	4	4	0	0	4	0	4	60	1.86	5	10.2	0.012
Mean Total	**450**	**556**	**390**	**262**	**308**	**272**	**220**	**205**	**214**	**165**	**188**	**3230**	**99.98**			

Across rows, means followed by different lowercase letters are statistically significant at $p < 0.05$. Significant *p*-values are in bold. *G. sepium* alone (5 t ha^{-1})=T1; *S. spectabilis* alone (5 t ha^{-1})=T2; *G. sepium* + *S. spectabilis* (5 t ha $^{-1}$)=T3; *G. sepium* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T4; *S. spectabilis* (3.75 t ha $^{-1}$ + 50 kg ha $^{-1}$ DAP)=T5; *G. sepium* + *S. spectabilis* (3.75 t ha^{-1} + 50 kg ha $^{-1}$ DAP)=T6; *G. sepium* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T7; *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T8; *G. sepium* + *S. spectabilis* (2.5 t ha $^{-1}$ + 100 kg ha $^{-1}$ DAP)=T9; inorganic fertilizer alone (200 Kg ha^{-1} DAP)=T10; Control=T11.

4.7.2 Correlation between soil chemical properties and soil macrofauna abundance

Table 8 shows the Pearson correlation (r) between soil chemical properties and macrofauna abundance. The abundance of soil macrofauna was significantly (<0.05) affected by the chemical properties of the soil. Macrofauna groups reacted differently towards soil chemical properties table 8. Most of the macrofauna groups identified in this study were found to be strongly and positively correlated with organic C and some bases (K, Ca, respectively) but poorly and negatively correlated with Mg and Na. Only earthworms and millipedes positively correlated with Mg and Na, respectively. All other macrofauna groups weakly correlated with total N and extractable P. Earthworms, grasshoppers and cockroaches positively correlated with soil pH, K, Mg while Flies and moths negatively correlated with the soil pH. However, other macrofauna groups did not significantly correlate with soil pH. The Pearson correlation (r) showed that the correlative relationship between soil chemical properties and in most of the macrofauna groups were highly significant ($P<0.05$).

Table 8. The Pearson correlation (r) between soil macrofauna abundance and soil chemical properties

Macrofauna group	CEC	Ca	K	Mg	Na	P	TOC	N	pH
Earthworms	-0.06	-0.09	**0.39*** **	**0.37*** **	0.19	-0.03	0.15	**0.21***	**0.46*****
Ant	-0.16	-0.12	0.12	-0.09	0.15	-0.13	0.03	0.04	0.08
Beetles	-0.16	0.02	**0.23***	-0.06	0.12	**-0.24***	**0.36*** **	0.02	0.11
Crickets	0.11	**0.21***	0.02	**-0.20***	-0.08	-0.12	**0.36*** **	-0.16	-0.17
Grass shops	-0.02	-0.05	**0.30*** **	0.10	0.10	0.07	0.18	0.16	**0.22***
Termites	-0.06	**0.19***	**0.19***	-0.10	-0.09	-0.07	**0.37*** **	-0.09	-0.02
Scolopendra	-0.01	-0.14	**0.20***	-0.06	**-0.22***	-0.15	**0.47*** **	0.00	-0.15
Flies	0.11	**0.21***	0.10	-0.17	-0.15	-0.09	**0.39*** **	**-0.22***	**-0.30****
Spiders	-0.06	0.16	0.04	-0.14	**-0.26****	0.00	**0.20***	-0.13	-0.14
Cockroaches	-0.17	-0.17	**0.33*** **	0.14	0.04	0.01	**0.26****	0.11	**0.28****
Millipedes	-0.09	-0.13	0.40	-0.01	**0.20***	-0.06	0.16	0.03	0.16
Centipedes	-0.10	-0.07	**0.22***	-0.06	-0.03	-0.01	0.12	**0.20***	0.07
Moths	-0.15	0.15	0.01	**-0.32*** **	**-0.24***	-0.12	**0.44*** **	**-0.22***	**-0.27****
Earwigs	0.11	**0.22***	0.03	-0.13	-0.02	-0.09	0.11	-0.13	-0.03
True bugs	**-0.20***	-0.14	**0.20***	-0.10	0.04	-0.17	0.15	-0.15	0.07

CHAPTER FIVE

DISCUSSION

5.1 Chemical quality of organic resources incorporated

Residues available in the neighboring farms are relatively high in nutrients and these may be ranked as high quality materials. It was apparent in this study that *Gliricidia sepium* residues had considerably lower C: N ratio than *Senna spectabilis*. Since C: N ratio has commonly been used as a measure of quality of organic resources the high C: N ratio observed on these materials could have had effects on the quality of soil where they were applied. The residues with a high C: N ration and which releases nutrients slowly or immobilized N as it decomposes is classified as a low quality organic residue. A plant residue with low C:N ration and that which doesn't immobilize but release nutrients faster is considered a high quality plant residue (Vanlauwe et al., 2005). This support the idea of Gaisie at al. (2016), who stated that decomposition of plant materials is influenced by resource quality, decomposer organisms and environmental conditions. Given the C:N ratio obtained in this study were lower than the critical level of 20:1 (Palm et al, 2001), both materials can be classified as high quality organic resources, and are therefore likely to decompose much faster and release nutrients needed by crops. Both prunings materials have recorded high nutrients content in their green biomass and therefore, recognized as effective source of crop nutrients. The highest decomposition trend obtained in *Gliricidia sepium* is perhaps caused by the relatively low C: N value. A faster decomposition rate have been documented on the material with high C:N ratio while the materials with a low C:N ratio has shown a slow decomposition (Karanja et al., 2006). Nitrogen is normally a limiting factor for some organisms. With a low C:N ratio (with a higher amount of nitrogen), the organisms are likely to move to areas of high N concentrations, since nutrient cycling through the decomposing of leaves is also faster (Chivenge et al., 2011). In our study, the rate of decomposition was higher in *Gliricidia sepium* than in *Senna spectabilis* and this is attributed to the C: N ratios.

Various studies to compare the breakdown and nutrient release rates of biomass of different leguminous and non-leguminous trees has been conducted with an aim to improve soil fertility. When the biomass is applied in the soil, it would be associated with a relatively faster organic matter turnover although the half-life of material is varied. The results measured in 16 weeks, showed that the half -life was attained within four to six weeks in *Gliricidia sepium* and six to eight weeks in *Senna spectabilis*. This is however, faster than the results of Gaisie et al. (2016) who observed that half-life of different multipurpose trees, was within the similar ranges of six to eight weeks**.** But results of our study concur with the findings of Partey et al. (2011**),** who estimated that the half- life of *Gliricidia sepium* is faster than *Senna spectabilis*.

Plant production is a function of the quantity of nutrients in the soil system, and this recognize decomposition as an important biophysical process in transforming organic resource into a stable form of organic matter (humus), thus release of the nutrient it contains. Studies conducted by Ayuke et al. (2011) documented soil fauna as a factor that highly influenced the decomposition of plant materials mainly through their ability to release catalytic substrates. The decomposition rates difference described in this document may be the result, in part, of the influence of soil fauna and the biophysical factors on the other part. The nutrients especially nitrogen and phosphorus content of decomposing materials change over time with a tendency towards net retention in relation to dry matter, depending on the pruning type. In the first two weeks the net nutrient (N and P) release was observed only in *Gliricidia sepium*. Conversely, the mineralization and nutrient release from the decomposing pruning is recognized to be affected by many aspects. The high decomposition and nutrient release of *Gliricidia sepium* observed in this study concur with findings by Zaharah et al. (1999) who reported plant material with low C: N ratio decompose very fast than in plant materials with high C:N ratio

The result showed higher rate of N, P, and K release from *Gliricidia sepium* compared to *Senna spectabilis* and findings corroborates those investigating multipurpose trees for crop production leaf decomposition rates and nutrient release pattern by Gaisie et al. (2016). *Gliricidia sepium* was found to contain high extractable P compared to *Senna spectabilis* which could have been as a result of higher amounts of bases in *Gliricidia sepium* than in *Senna spectabilis*.

5.2 Soil chemical characteristics of the study sites prior to conducting the experiments

The main critical crop nutrients required to sustain crop demand were found to be inadequate in the two study sites. However, the crop nutrients such as soil organic C, total N, extractable P and some of the exchangeable bases (Mg and Na) were found to be significantly higher in Karama than in Kintambwe site. Other soil parameters such as CEC and exchangeable Ca, and K did not differ between the two sites. Therefore, the soils could lack the positive soil qualities delivered by soil organic matter such as, improved soil water holding capacity, supply of crop nutrients and improved microbial activities. The low crop nutrients observed in Kintambwe site could be due to continuous cropping associated with inadequate inorganic and organic fertilizer use. Woomer et al. (1994) and Karanja et al. (2006) documented that the agricultural practices that reduce organic resources in the soil results in a reduction in water and nutrients retention capacity which in turn has negative effects on crop productivity since it plays a role in reduction in toxic substances that could render production of specific crops a challenge. Hence to reverse these conditions the long-term application of organic and inorganic inputs could act as an alternative (Bationo and Burkert, 2001).

5.3 Effect of *Gliricidia sepium* and *Senna spectabilis* pruning incorporation on soil chemical properties

The incorporation of prunings from organic residues in the soil increased soil nutrients especially C and N across all treatments in general compared to the control plots, while inorganic fertilizer treatment increased N and P levels in the soil. This was in agreement with Mbau et al. (2015)

who observed that compost remarkably built C and N levels compared to inorganic fertilizer treatments. Also Gachengo et al. (1998), revealed organic residues such as *Tithonia diversifolia* incorporation had the most beneficial effects on soil biophysical and chemical properties and maize grain yield compared to the control treatments.

Soil organic matter regulate N content as it holds 90 to 95% of total N. Addition of high quantity of soil organic matter through return of crop residues as composts and other organic amendments is thus imperative if a balanced supply of available N is to be recognized. This reinforces the importance of incorporating organic residues in soil nutrient fertility budget. Soil pH and CEC tend to increase following the application of Prunings which concurs with Adeniyan et al. (2011) who equally noted an increase in CEC, exchangeable bases and soil pH upon application of composts and other types of organic manure.

5.4 Agronomic effectiveness of *Gliricidia sepium* and *Senna spectabilis* prunings on maize performance

A Comparison of change in crop yields and soil nutrients obtained in this study reflect the differences in quantities of the tree pruning and mineral fertilizer supplement added to the soil. Higher yields obtained in fertilizers treatments (DAP +Urea=200Kg ha $^{-1}$ +100Kg ha^{-1}) could be attributed to easy availability from the fertilizers. Since the necessary crop nutrients from organic residues take more time to be available for crop uptake since it must first undergo the process of decomposition. In tree pruning (leaves) treatments, nutrients availability depends on nutrients concentration in the prunings and rate of release. Probably, prunings from *Gliricidia sepium* underwent a rapid decomposition and mineralization more than *Senna spectabilis* even though their nutrients concentration (N and P) are within similar range. The slow release of the P and N observed in organic material might be as a result of the late release of P and faster release of N that lead to poor synchrony between crop nutrient demand and supply by the soil. Perhaps the higher relative yield could be observed in the following seasons for prunings treatment compared to the current season since nutrients became available later and resulted in a delayed crop response. Therefore, higher yield has been reported due to incorporation of the fast decomposing organic resources than the slow decomposing organic resources (Gachengo et al., 1996).

5.5 Effect of *Gliricidia sepium* and *Senna spectabilis* prunings on soil macrofauna abundance

The study found that the application of *Gliricidia sepium*, *Senna spectabilis* sole or in combination or when supplemented with inorganic fertilizers generally influenced macrofauna abundance. Earthworms and termites, in particular, were observed high numbers in Karama and Kintambwe, respectively compared with other macrofauna groups under the application of prunings compared to the control plots, whereas use of inorganic fertilizers sole did not significantly affect them considerably. This is in line with the findings of the study carried out in the central highlands of Kenya which investigated the fauna diversity and abundance under different land use that showed earthworms, termites and beetles accounted for more than 90% of the faunal biomass (Ayuke et al., 2010). Also a similar study conducted to examine the effect of compost application on maize yield, soil macrofauna diversity and abundance in nutrient deficient soils showed that earthworms constituted over 22% of the total fauna recovered across all treatments (Mbau et al., 2015), whereas termites were the most abundant constituting 57% of the total fauna recovered. However, this is slightly higher than the findings of this study which recorded 13% of total earthworms and 26% of termites in Kintambwe farms and 26% of earthworms and 23% of termites in Karama station**.** The low number of earthworms in Kintambwe compared to Karama may be due to altitude which is somehow higher in Kintambwe and dryness of the soils explained by fact that the experiments were established in low land around the lakes in Karama while in Kintambwe they are at the summit.

The results also showed that different types of pruning (*Gliricidia sepium*, *Senna spectabilis* and their combination) did not significantly influence macrofauna abundance across the treatments while the quantities applied affected the macrofauna abundance differently, especially earthworms and termites. Among the treatments, soils amended with full rate of pruning (5 t ha^{-1}) led to the highest increase in soil faunal abundance compared to the control rate, while the three quarter and the half rates supplemented by a quarter and a half rates of inorganic fertilizers plots, respectively, slightly increased the earthworms and termites abundance. This concurs with Ayuke (2010), who observed that agricultural management options that resulted in high carbon storage led to significant increase in earthworm population. Fonte et al. (2009) also documented that cropping systems which received crop residues had significantly higher earthworm's densities and biomass than those under bare fallow management. Riley et al. (2008) observed that the incorporation of large amount of organic matter led to higher earthworm biomass and density than conventionally managed plots. The results showed that organic matter inputs could have profound effect on earthworm density. Litter quality plays an important role in determining abundance and species diversity due to selective nature of some organism (Rothwell et al., 2011). The exceptionally high bases (Ca and K) and C content in prunings could have contributed to a high quality soil amendments justifying the higher earthworm abundance that was recorded on plots treated with prunings.

Pearson correlation showed significant relationships between macrofauna and soil chemical properties. This could be possibly due to the response macrofauna had on application of different amendments. The high increase of macrofauna observed in plots amended with the high quantities of prunings (full rate), followed by a three quarter and half, respectively, could be attributed to the vital substrate that the organic matter offer to the soil. Most of the macrofauna groups strongly and positively correlated with the organic carbon which perhaps is due to the effect of prunings providing energy and a favorable environment to increase. The results reach agreement with Ayuke et al. (2009) who perceived strong and significant correlation between soil chemical properties with selected macrofauna groups under different land use systems. Also the study conducted by Mbau et al. (2015) who observed strong and significant correlation between soil chemical properties with selected macrofauna groups under application of compost from different organic residues (Maize stover, Bagasse, Sugarcane straw, Filtermud). Filtermud compost has been shown to positively improve the quality of soils

5.6. Conclusion and Recommendations

5.6.1 Conclusions

The decomposition and nutrient release pattern from the prunings of the studied species demonstrated the potential to sustainably provide nutrients for growing crops. The quantities of nutrients of the two species were within sufficiency ranges for growing crop especially for N and a relatively fast nutrient release. Therefore, addition of prunings into the soil had positive effects on contents of major nutrients namely, total N, organic carbon, extractable P, and bases. They also increased abundance of macrofauna.

Addition of prunings plus inorganic fertilizers increased maize yield significantly compared to where they were applied alone, though inorganic fertilizer alone (200Kg ha^{-1} DAP) recorded the highest maize yields. This ensures that sufficient high quality and cost-effective materials are available to the farmers doubled.

5.6.2 Recommendations

The utilization of unused organic residues especially (*Gliricidia sepium* and *Senna spectabilis* prunings) should be promoted to the farmers in Bugesera. This will ensure that sufficient high quality and cost-effective materials are available.

REFERENCES

Anderson, J.M and Ingram, J.S.I. (1993). Tropical soil biology and fertility. A Handbook of methods, 2nd Ed. Wallingford: C.A.B. International.

Ayuke, F.O. (2010). Soil macrofauna functional groups and their effects on soil structure, as related to agricultural management practices across agroecological zones of sub-Saharan Africa. PhD thesis, Wageningen University,Wageningen, 202p.

Ayuke, F.O., Karanja, N.K. and Bunyasi, S. (2007). Evaluating effect of mixtures of organic Resources on nutrient release patterns and uptake by maize. *In*: Bationo, A., Waswa, B., Kihara, J., Kimetu, J. (Eds), *Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities*. Springer Publishers, Dordrecht, pp: 833-834.

Ayuke, F.O., Pulleman, M.M., Vanlauwe, B., De Goede, R.G.M., Six, J., Csuzdi, C. and Brussaard, L. (2011). Agricultural management affects earthworm and termite diversity across humid to semi-arid tropical zones. *Agriculture, Ecosystems and Environment, 140:148-154.*

Ayuke, F. O., Brussaard, L., Vanlauwe, B., Six, J., Lelei, D. K., Kibunja, C. N. and Pulleman, M. M. (2011). Soil fertility management: Impacts on soil macrofauna , soil aggregation and soil organic matter allocation. *Applied Soil Ecology, 48(1):53-62.*

Barrios, E. (2007). Soil biota, ecosystem services and land productivity. *Ecological Economic 64:269-285.*

Bates, D. Machler, M., Bolker, B.M. and Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software, 67(1):1-48.*

Bationo, A., Vanlauwe, B., Kihara. J. and Kimetu, J. (2006). Soil organic carbon dynamics, Functions and management in West African. *Agricultural Systems, 1:1-13.*

Bird, S.B., Coulson, R.N. and Fisher, R.F. (2004). Changes in soil and litter arthropod abundance

Following tree harvesting and site preparation in a loblolly pine (*Pinus taeda L* .) plantation, *Forest Ecology and Management, 202(1/3):195-208.*

Boserup, E. (1965). The conditions of agricultural growth. *Population Studies*, *20*(1):1-108.

Brussaard, L., De Ruiter, P.C. and Brown, G.G. (2007). Soil biodiversity for agricultural sustainability. *Agriculture, Ecosystems and Environment, 121, (3):233-244*.

Carter, M.R. (2002). Soil Quality for Sustainable Land Management : Organic Matter and Aggregation Interactions that Maintain Soil Functions. *Agronomy Journal*, *94*:38-47.

Chirwa, P.W., Black , C.R., Ong, C.K., and Maghembe, J.A. (2003). Tree and crop productivity in gliricidia/maize/pigeonpea cropping systems in southern Malawi. *Agroforestry Systems*, *59(3):265-277.*

Chivenge, P., Vanlauwe, B., Gentile, R., and Six, J. (2011). Organic resource quality influences short-term aggregate dynamics and soil organic carbon and nitrogen accumulation. *Soil Biology and Biochemistry, 43(3):657-666*.

Cyamweshi, A.R., Kayumba, J. and Nabahungu, N.L. (2017). Optimizing Fertilizer Use within The Context of Integrated Soil Fertility Management in Rwanda. *In*: Wortmann, C.S. and Sones, K. (Eds), Fertilizer Use Optimization in sub-Saharan Africa. CABI Publishers, pp:164-175.

Gachengo, C.N., Palm, C.A., Jama, B., and Othieno, C. (1998). Tithonia and senna green manures and inorganic fertilizers as phosphorus sources for maize in Western Kenya. *Agroforestry Systems, 44(1):21-35.*

Gaisie, E., Sadick, A., Agyeman, K., Adjei-Gyapong, T., and Quansah, G. (2016). Leaf Decomposition and the Nutrients Release from Multipurpose Trees for Crop Production. *International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), (2)1:345-352.*

Ganunga, R.P., Yerokun, O.A. and Kumwenda, J.D.T. (2005). Contribution of *Tithonia* *diversifolia* to yield and nutrient uptake of maize in Malawian small-scale agriculture, South *African Journal of Plant and Soil*, 22(4):240-245.

Fründ, H.C., Graefe, U. and Tischer, S. (2011). Earthworms as Bioindicators of Soil Quality. *Biology of Earthworms.* Springer Publishers, pp:261-278.

Gichangi, E.M., Karanja, N.K. and Wood, C.W. (2007). Managing manure heaps with agro-organic wastes and cover to reduce nitrogen losses during storage on smallholder farms. *In*: Bationo, A., Waswa, B., Kihara, J., Kimetu, J. (Eds), *Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities.* Springer Publishers, Dordrecht, pp:611-618.

Hadas, A., Kautsky, L., Goek, M., and Kara, E.E. (2004). Rates of decomposition of plant residues and available nitrogen in soil , related to residue composition through simulation of carbon and nitrogen turnover. *Soil Biology and Biochemistry, 36*(2):255-266.

Hartemink, A.E., Buresh, R.J., Bodegom, P.M. Van Braun, A.R., Jama, B. and Janssen, B.H. (2000). Inorganic nitrogen dynamics in fallows and maize on an Oxisol and Alfisol in the highlands of Kenya. *Geoderma, 98(1-2):11-33.*

Jama, B., Palm, C.A., Buresh, R.J., Niang, A., Gachengo, C., Nziguheba, G. and Amadalo, B. (2000). Tithonia diversifolia as a green manure for soil fertility improvement in western Kenya: A review. *Agroforestry Systems, 49(2):201–221.*

Habiyaremye, J.D., Muthuri, C., Matiru, V., Nyaga, J., Mukuralinda, A., Ruganzu, V., Yoneda, M. and Sinclair, F. (2015). Occurrrence and abundannce of arbuscular mycorrhizal fungi (AMF) in agroforestry systems of Rubavu and Bugesera Districts in Rwanda. *African Journal of Microbiology, 9(12): 838–846.*

Kabirigi, M., Musana, B., Kagabo, D. M., Mukuralinda, A. and Nabahungu, N. L. (2016). Nutrients Flow as Affected by Cropping System and Production Niche in Smallholder Farmers of Cyabayaga Watershed. *Agricultural Sciences, 7(7):287-294.*

Kalra, Y. P. and Maynard, D. G. (1991). Methods Manual for Forest Soil and Plant Analysis. D.G. Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, Alberta. Information Report NOR-X-319E. Canadian Forest Service Publications, 116p.

Karanja, N., Ayuke, F.O. Suift, M. J.(2006). Organic Resources Quality and Soil Fauna: their role on the microbial biomass, decomposition and nutrient release patterns in kenyan soils. *Tropical and Subtropical Agroecosystems, 6:73-86.*

Karanja, N., Mutua, G.K., Ayuke F.O., Njenga, M., Prain, G. and Kimenju, J. (2010). Dynamics of soil nematodes and earthworms in urban vegetable irrigated with wastewater in the nairobi river basin, Kenya . *Tropical and Subtropical Agroecosystems, 12: 521-530.*

Kuznetsova,A., Brockhoff, P.B., Rune, C.H.B. (2017). Tests in Linear Mixed Effects Models: *Journal of Statistical Software, 82, (13).*

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science, 304:1623–1627*.

Lelei, J.J., Onwonga, R.N. and Freyer, B. (2009). Organic based nutrient management strategies : Effect on soil nutrient availability and maize (*Zea mays* L.) performance in Njoro, Kenya. *African Journal of Agricultural Research, 4(2):92-99.*

Maeder, P., Ma, P., Flie, A., Dubois, D., and Gunst, L. (2006). Soil Fertility and Biodiversity in Organic Farming. *Science, 296:1694-1697.*

Mafongoya, P.L., Giller, K.E. and Palm, C.A. (1998). Decomposition and nitrogen release patterns of tree prunings and litter. *Agroforestry Systems, 38:77-97.*

Manyong, V. M., Makinde, K. O., Sanginga, N., Vanlauwe, B. and Diels, J. (2001). Fertiliser use and definition of farmer domains for impact-oriented research in the northern Guinea savanna of Nigeria. *Nutrient Cycling in Agroecosystems*. Springer publishers, pp:129-141.

Mbau, S.K., Karanja, N. and Ayuke. F.O.(2015). Short-term influence of compost application on maize yield , soil macrofauna diversity and abundance in nutrient deficient soils of

Kakamega County Kenya. *Plant and soil*. Springer publishers, pp:379-394.

Melinda, S., Derek, B. and Thom J. (2011). Maize Revolutions in sub-Saharan Africa. Policy Research Working Papers. Https://doi.org/10.1007/978-94-007-5760-8.

Mureithi, J.G., Gachene, C.K.K. and Wamuongo, J.W. (2008). Participatory Evaluation of Residue Management Effects of Green Manure Legumes on Maize Yield in the Central Kenya Highlands. *Journal of Sustainable Agriculture, 25(4):49-68.*

Mylavarapu, R., Obreza, T., Morgan, K., Hochmuth, G., Nair, V. and Wright, A. (2014). Extraction of Soil Nutrients Using Mehlich-3 Reagent for Acid-Mineral Soils of Florida. *Nutrient Management of Vegetable and Row Crops Handbook*. Florida Institute of Food and Agricultural Science, University of Florida, pp:1-7.

Nabahungu, N.L. (2012). Problems and opportunities of wetland management in Rwanda. PhD Thesis, Wageningen University, Wageningen. 134p.

Nelson, D.W. (1996). Chapter 34 Total Carbon , Organic Carbon , and Organic Matter.In Methodes of soil analysis. *Soil Science Society of America (SSSA), 2(5):961.*

NISR (2014). Fourth Population and HousingCensus, Rwanda, (2012). Thematic Report: Population size, structure and distribution. Statistics.gov.rw/index.php/catalog/65/download/516.

Nziguheba, G., Merckx, R., Palm, C.A. and Mutuo, P. (2002). Combining *Tithonia diversifolia* and fertilizers for maize production in a phosphorus deficient soil in Kenya. *Agroforestry systems*. Springer publishers, pp:165–166.

Nziguheba, G., Palm, C.A., Buresh, R.J. and Smithson, P.C. (1998). Soil phosphorus fractions and adsortion as affected by organic and inorganic sources. *Plant and Soil, 198(2):159-168.*

Onwonga, R.N., Namoi, N.L. and Lelei, J.J. (2015). Influence of organic based technologies on soil nutrient status in semi-arid Yatta sub-County, Kenya. *Journal of Agricultural Science, 7(8):56-80.*

Palm, C.A., Gachengo, C.N., Delve, R.J., Cadisch, G. and Giller, K.E. (2001). Organic inputs for soil fertility management in tropical agroecosystems: Application of an organic resource database. *Agriculture, Ecosystems and Environment, 83(1-2):27-42.*

Partey, S.T., Thevathasan, N.V, and Gordon, A.M. (2011). Decomposition and nutrient release patterns of the leaf biomass of the wild sunflower (Tithonia diversifolia): a comparative study with four leguminous agroforestry species. *Agroforestry Systems, 81(2):123-134.*

Parkinson, J.A. and Allen, S.E. (1975). A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological material. *Communications in Soil Science and Plant Analysis, 6(1):1-11.*

Pholsen and Sungnoen, S. (2004). Effect of nitrogen and potassium rate and planting distances on growth, yield and foffer quality of a forage sorghum (*Sorghum bicolor* L. Moench). *Pakistan Journal of Biological Sciences,7(10):1793-1800.*

Place, F., Barrett, C.B., Freeman, H.A., Ramisch, J.J., and Vanlauwe, B. (2003). Prospects for integrated soil fertility management using organic and inorganic inputs: evidence from smallholder African agricultural systems. *Food policy, 28(4): 365–378.*

Paul, B. K., Vanlauwe, B., Ayuke, F.O., Gassner, A., Hoogmoed, M., Hurisso, T.T., Koala,S., Lelei, D., Ndabamenye, T., Six, J. and Pulleman, M.M. (2013). Medium-term impact of tillage and residue management on soil aggregate stability, soil carbon and crop productivity. *Agriculture, Ecosystems and Environment, 164:14-22.*

Ruiz, N,. Lavelle, P. and Jimenez, J. (2008). Soil macrofauna field manual. Food and Agriculture Organization (FAO) of the United Nations, Rome, 100p.

Rutunga, V., Karanja, N.K., Gachene, C.K.K., and Palm, C.A. (1999). Biomass production and nutrient accumulation by *Tephrosia vogelii* Hook F. and *Tithonia diversifolia* (Hemsley) A . Gray. fallows during the six-month growth period at Maseno, Western Kenya. *Biotechnology, Agronomy, Society and Environment, 3(4):237-246.*

Sanchez, P.A., Shepherd, K.D., Soule, M.J., Place, F.M., Buresh, R.J., Izac, A.M.N., Uzo Mokwunye, A., Kwesiga, F.R., Ndiritu, C.N. and Woomer, P.L. (1997). Soil Fertility Replenishment in Africa: An Investment in Natural Resource Capital. *In*: Buresh, R.J., Sanchez, P.A. and Calhoun, F. (Eds), Replenishing Soil Fertility in Africa, *Soil Science Society of America (SSSA)* Special issue No 51, pp:1-46.

Sawadogo,K. S., Fosu M., Tabo R., Kanton R., Buah S., Bationo A., Ouédraogo S., Pale S., Bonzi M., Ouattara K., Hassane O., Fatondji D., Sigue H., and Abdou A.(2008). Improving crop productivity and farmer income using fertilizer microdosing and the warrantage system in the Volta Basin. *In*: Humphreys, E., Bayot, R.S., van Brakel, M., Gichuki, F., Svendsen, M., White, D., Wester, P., Huber-Lee, A.,Cook, S., Douthwaite, B., Hoanh, C.T., Johnson, N., Nguyen-Khoa, S., Vidal, A., MacIntyre, I., and MacIntyre, R. (Editors), *Fighting Poverty Through Sustainable Water Use: Volumes I, II, III and IV*. Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10-14, 2008. The CGIAR Challenge Program on Water and Food, Colombo. 297pp.

Sayad, E., Hosseini, S.M., and Hosseini, V. (2012). Soil macrofauna in relation to soil and leaf litter properties in tree plantations. *Journal of Forest Science, (4):170–180.*

Smestad, B. T., Tiessen, H., and Buresh, R. J. (2002). Short fallows of *Tithonia diversifolia* and *Crotalaria grahamiana* for soil fertility improvement in western Kenya. *Agroforestry systems, 55(3):181-194.*

Studdert, G.A. and Echeverrı´a, H.E. (1993). Crop Rotations and Nitrogen Fertilization to Manage Soil Organic Carbon Dynamics. *Science Society of America Journal (SSSA), 64 (4): 1496-1503.*

Sugiyarto, S. (2009). Enhancing Diversity of Soil Macro invertebrates in Sengon-based Agroforestry Systems by Mulching Technology. Biodiversitas. *Journal of Biological*

Diversity, 10(3):129-133.

Vanlauwe, B., Gachengo, C., Shepherd, K., Barrios, E., Cadisch, G. and Palm, C.A. (2005). Laboratory Validation of a Resource Quality-Based Conceptual Framework for Organic Matter Management. *Soil Science Society of America (SSSA) Journal, 69(4):1135-1145.*

Vanlauwe, B., and Giller, K.E. (2006). Popular myths around soil fertility management in sub-Saharan Africa. *Agriculture, Ecosystems and Environment, 116(1-2):34-46.*

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R. and Six, J. (2011). Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant and Soil, 339 (1-2):35-50.*

Verdoodt, A. and Van Ranst, E. (2006). Environmental assessment tools for multi-scale land resources information systems: A case study of Rwanda. *Agriculture, Ecosystems and Environment, 114(2-4): 170-184.*

World Bank 2015, Rwanda economic update. *Maintaining momentum. With a special focus on Rwanda's pathway out of poverty*. World Bank.

Zaharah, A.R. and Bah, A.R. (1999). Patterns of decomposition and nutrient release by fresh Gliricidia (Gliricidia sepium) leaves in an ultisol. *Nutrient Cycling in Agroecosystems, 55(3): 269–277.*