PHYSIOLOGICAL, BIOCHEMICAL AND YIELD RESPONSES OF MAIZE AND BANANA PLANTS UNDER C*alliandra calothyrsus*, *Sesbania sesban* and *Leucaena diversifolia* INTERCROPPING IN VIHIGA COUNTY, KENYA

BY

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:

DECLARATION

Candidate's declaration

The content in this thesis is my original academic work and has never been submitted for a degree in any other institution. No part of this thesis may be reproduced in any form without prior consent from the author or Maseno University.

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DEDICATION

This Thesis is dedicated to my dear wife Juliet Misiko, my beloved daughters Sharleen Wamalwa and Valentine Wamalwa, my mum Annah Nafula, my brothers and sisters. Their love always kept me going.

ABSTRACT

Increasing population leads to demand for more food. Consequently, there is need to expand agricultural land, necessitating cutting down of trees. This however, leads to soil degradation. Nutrient depleted soils and poor cropping systems such as continuous cropping, have contributed to the declining yield, which is a major problem facing farmers in Western Kenya. Intercropping with agroforestry tree species can alleviate soil infertility problems and increase crop productivity through enhanced biological nitrogen fixation, growth and photosynthesis hence ensuring food security. However, intercropping with agroforestry trees may lead to competition for both above ground and below ground resources between crops and trees hence affecting growth, physiology, biochemistry and yield of the component crops. Intercropping maize and bananas with agroforestry trees such as C*alliandra calothyrsus*, *Sesbania sesban* and *Leucaena diversifolia* have the potential to improve the growth and productivity of both maize and bananas and as a result alleviate food insecurity. However, the influence of the agroforestry trees species on the growth, gas exchange, nutrient uptake and yield of the crops is yet to be established. This study sought to investigate the influence of intercropping agroforestry tree species on maize and banana height, number of green leaves, leaf area, stem diameter, transpiration rate, intercellular CO_2 concentration, net photosynthesis, total chlorophyll content, uptake of N, P, K, Mg, Ca nutrients and yield. The field trials were set up at Maseno University farm in Vihiga County. Seeds of agroforestry trees were acquired from KEFRI – Muguga, planted in a seedbed and the seedlings raised in nurseries. Five months old Williams' variety tissue banana seedlings were obtained from KALRO-Thika. Hybrid maize seeds, H513 were bought from Kenya seed company Kitale. Banana holes were dug 90cm x 90cm x 60cm deep and 20 Kg of cow dung manure + 20 Kg of top soil + 200g of NPK fertilizer added before planting the banana at a depth of 0.3m for proper anchorage. Maize were planted at 0.75 m inter row by 0.3 m spacing. Randomized Complete Block Design with 3 replications and seven treatment levels (maize without fertilizer, maize banana *Calliandra calothyrsus*, maize banana *Leucaena diversifolia*, maize banana *Sesbania sesban*, maize-banana, banana monocrop and maize with fertilizer) were used. Fifteen maize and four banana plants in each treatment were sampled in a zigzag method and tagged for data collection. Data on plant height, stem diameter, number of leaves, leaf area, and yield (grain weight, banana bunch weight, banana number of fingers and finger length) were determined. Gas exchange and chlorophyll content index parameters were measured using infrared gas analyser and SPAD meter, respectively on the 3^{rd} fully sun exposed leaf of the tagged plants. Kjeldahl method was used to determine plant tissue N content. Ca, Mg and P contents were determined using atomic absorption spectrophotometer, while atomic emission spectrophotometer was used to determine K contents. Data collected from the study was subjected to analysis of variance using GenStat statistical package. Treatment means were also separated and compared using the least significant difference. Correlation analysis was carried out on plant height, leaf area, net photosynthetic rate, intercellular CO_2 concentration and transpiration rate to determine the relationship between the parameters. There were significant increases ($P \leq 0.05$) in plant height of maize, stem diameter, number of leaves, net photosynthesis, intercellular CO_2 concentration, transpiration rate, chlorophyll content, nutrient uptake and yield under maize + banana + *sesbania sesban* (MBS) intercropping. There were no significant differences ($P \geq 0.05$) in plant height of banana plants under the agroforestry tree species intercropping. Bunch weight and finger length were significantly higher under MBS. There was significant strong positive correlations ($P \leq 0.05$) between net photosynthesis and leaf area, net photosynthesis and transpiration rate, net photosynthesis and intercellular CO_2 concentration, leaf area and intercellular CO_2 concentration in both maize and banana plants. These agroforestry trees enhanced growth, physiological, biochemical and yield of maize and bananas. Therefore, intercropping of maize, banana and *Sesbania sesban* is recommended as it increased the yields of both maize and banana through improved growth, photosynthetic rate and mineral nutrient uptake. This study allows us understand the interaction mechanisms of the crops of maize and banana crops with the three agroforestry tree species to resources.

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ABBREVIATIONS AND ACRONYMS

A	Photosynthetic rate
Ci	Intercellular CO_2 concentration
PAR	Photosynthetic Active radiation.
Ca	Calcium
C int.	Intercellular CO_2 gas exchange
E	Transpiration rate
GoK	Government of Kenya
GS	Stomatal Conductance.
FAO	Food and Agriculture Organization
IBPGR	International Board for Plant Genetic Resources
ICRAF	International Center for Research in Agroforestry
ICRAFSA	International Center for Research in Agroforestry for Southern African
IPAR	Intercepted Photosynthetic Active Radiation
K	Potassium
KFSSG	Kenya Food Security Steering Group
Mg	Magnesium
MoA	Ministry of Agriculture
MoE	Ministry of Education
N	Nitrogen
P	Phosphorus
PN	Net photosynthesis
TPS-200	The Photosynthesis System 200
UNDP	United Nations Development Program
M	maize without fertilizer
M+F	Maize with fertilizer
M+B	Intercrop of banana and maize
M+B+S	Intercrop of banana-Maize with *Sesbania sesban* tree species
M+B+C	Intercrop of banana-Maize with *Calliandra calothyrsus* tree species
M+B+L	Intercrop of banana-Maize with *Leucaena diversifolia* tree species

DEFINITION OF TERMS

Intercropping farming system:	Growing more than two different crops on the same land at the same time
Perennial crop plants:	Crops that take more than two seasons or more than one year in the field
Agroforestry system:	Growing trees and crops on the same land simultaneously
Resources partitioning (niche partitioning):	Describes more comprehensive utilization of available resources by crops when intercropped rather than separately grown
Resource facilitation:	

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CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Vihiga is the third most populated county in Kenya after Nairobi and Mombasa with a population density of 1046 persons per km^2 on a land area of 563.8 km^2 and a total population of 590,013 (KNBS, 2019). This high population density coupled with declining food production has led to cutting down of trees to provide land for crop production. According to Hansen *et al*. (2010) the clearing of forests has led to loss of global forest cover estimated at 3.1% per year resulting to reduced soil fertility and crop yields (Ibid, 2008). The smallholder farmers are the major drivers to food security in sub Saharan African (FAO, 2011). However, these farmers face the challenges of low soil nutrient fertility arising from monocropping and continuous cultivation without fallows resulting to low crop productivity (Mugwe *et al*., 2007). Therefore, this calls for improved farming practices that can incorporate crop farming and tree growing in the limited land resource of Vihiga County.

According to FEWS-NET, (2003) crop yields have decreased in the Sub Saharan Africa, despite global increase in food production. The decline in production is because of soil infertility in Sub Saharan Africa (Hilhorst *et al*., 2000). Landers, (2007) observed that food security could be achieved if farmers practiced sustainable farming practices. Western Kenya being a high agriculture potential region cannot be an exception to this problem. Agroforestry farming system could offer a significant potential to alleviate food insecurity and loss of soil nutrients. According to Anja and Alain (2001) maize production, nitrogen fixation and phosphorus uptake has been reported to increase when maize is planted under improved fallows with *Crotolaria grahamia* or *Tephrosia candida* in Western Kenya. However, intercropping of trees with crops may result to both interspecific and intraspecific competition of moisture and nutrients and this might result in reduced plant height, stem diameter, leaf formation and enlargement through reduced meristematic activities.

Agroforestry trees may have an impact on crop productivity. This can be manifested in physiological responses of the crop plants such as photosynthetic efficiency, nutrient uptake efficiency, transpiration rate and intercellular CO_2 concentration within the intercellular spaces of the leaves. For this reason, such parameters can be ascertained under the proposed agroforestry system. In Western Kenya, information on the effects of intercropping trees to such responses of crop plants is yet to be demonstrated. Previous studies on agroforestry farming have majorly reported on the increased soil nutrient, yield and decrease in Striga weed infestation. *Sesbania sesban* fallows have been found to increase maize yield and a reduction in *Striga hermonthica* plant populations in Vihiga County (Sjögren *et al*., 2010). Despite the *Sesbania sesban* having the potential to increase the yield of maize and striga weed suppression, there is need to establish the effects of these agroforestry trees on competition for growth resources like moisture and nutrients. These resources are vital to crop physiological responses like net photosynthesis, intercellular CO_2 concentration and transpiration rate which have direct influence on the growth and development of plants.

The adoption of sustainable land management practices using agroforestry tree species to increase yield without depleting soil and water resource has been reported (World Bank, 2006). This practice has helped in reinstating soil fertility (IFAD, 2011) and increasing resilience of farming systems to mitigate climate change (FAO, 2010). Due to high population, planting of *Crotalaria grahamiana*, *Crotalaria paulina*, *Tephrosia vogelli* and *Tephrosia candida* fallows under farmer-managed conditions in Western Kenya has become popular in order to maximize their benefits of improving soil fertility and providing fuelwood at the same time on the limited land resource (Jama *et al*., 2008). Despite reporting soil fertility improvement, other factors that affect crop growth and development such as growth parameters that are influenced by limited nutrient and water resources have not been reported. Competition for water will result to water stress to the plant cells and consequently leading to reduced cell expansion hence reduced plant growth in terms of plant height, leaf area, number of leaves and stem diameter. The soil water moisture also affects the transpiration rate, CO_2 intake and net photosynthesis of the intercropped crops.

According to Kermah *et al.* (2017) declining soil fertility and unpredictable rainfall pattern has resulted to low yields under monocrop in the Sub Saharan. As a result, this has called for the development of viable production systems such as agroforestry farming system (Massawe *et al.*, 2016). Previously, agroforestry-farming systems has been practiced by smallholder farmers worldwide and proved beneficial (El Naim *et al.,* 2013). In Western Kenya, *Calliandra calothyrsus* has been popularized for seed production and animal feeds by smallholder farmers (Technoserve, 2003). Similarly, *Calliandra calothyrsus* and *Sesbania sesban* have also been grown by smallholder dairy farmers as animal feeds (Makau *et al*., 2019). For this reason, there is a growing interest to these tree species on farms as agroforestry to meet fodder, mitigate soil fertility and fuel demands (Jama *et al*., 2008). However, their presence may directly affect resource sharing between food crops and trees. Despite the widespread adoption by farmers, no study has been done to investigate their effect on the crop physiological processes; transpiration rate, intercellular CO_2 concentration, net photosynthesis and nutrient uptake that have direct impact on the crop productivity.

The ability of soils to provide vital nutrients such as N, P, K, Ca and Mg is a measure of soil fertility that promotes growth, physiology, biochemistry and yield of plants (Foth and Ellis, 1997). Maize-legume intercrop has been a common farming practice among smallholder farmers in Kenya (Pierre *et al*., 2018). This has been practiced as a way of increasing nitrogen in the impoverished soils to boost maize production. Zhang *et al*. (2015) reported that, maize – soybean intercrop increased soil organic carbon, Mg, Ca, N, than in monocrops. Despite the positive findings from the previous studies outlined above, maize production has kept declining over the years. This could be due to both crops utilizing resources from same soil depth and over-cropping similar crop combinations for long hence limiting nutrient complementarity and facilitation among the intercropped plants.

Application of inorganic and organic fertilizers has recorded improved soil fertility within the tropics, however inorganic fertilizers is not readily available to most smallholder farmers (Mwangi 1999) and where available, it is very costly (Hargrove 2008). Earlier reports have pointed to significant pollution effects on the environment such as increased soil acidity and low exchangeable cations (Juo *et al*. 1995). Therefore, there is need for these smallholder farmers to get a substitute to the costly inorganic farming through intercropping of maize and bananas with agroforestry tree species. Incorporation of *Calliandra calothyrus*, *Tithonia diversifolia*, *Senna spectabilis* and *Sesbania sesban* tree species has reported increased soil fertility and maize yield when planted along the farm boundaries in Western Kenya among smallholder farmers because of increased nutrient uptake through nutrient fixation (Sjogren, (2015) and Palm *et al*. (2001). However, the agroforestry tree species may have some effect on the competition for water and nutrients that may interfere with the physiological and gas exchange responses of the associated crops. Despite the positive attributes of such trees to maize production, it remains unknown if similar results can be produced in the new farming practice where banana has been introduced. More so, no study has been done to establish physiological responses such as photosynthetic efficiency, transpiration rate, intercellular CO_2 concentration, nutrient uptake and yield within an intercrop involving maize and banana plants.

The World Agroforestry Centre for Southern African Programme has reported that *Leucaena leucocephala*, *Sesbania sesban* and *Calliandra calothyrsus* can promote soil fertility through nitrogen fixation and biomass decomposition of the plant materials (ICRAFSA, 2007). The tree species have also been reported to restore fertility in depleted soils through intercropping practices (Nduwayezu, 2001). For this reason, the same agroforestry trees have been adopted by smallholder farmers in Western Kenya to improve farm productivity (Niang *et al*., 2000). Apart from these trees promoting soil fertility, their association with crops may have direct influence on the productivity due to competition for growth resources such as water and soil nutrients. Such competition influences negatively the physiological and biochemical functions by the associated crops. This eventually limits crop productivity in terms of yields. Netondo (1991) had reported an increase in the maize plant transpiration rates and yield under agroforestry system. The agroforestry trees resulted to low soil evaporation, which increased soil water status thus elevating stomatal conductance and thus promoting CO_2 intake. There is need to establish if similar results of net photosynthesis, intercellular CO_2 concentration and transpiration rate could be obtained when maize-banana are intercropped with the selected agroforestry trees. Such information is necessary as it affects the opening of the stomata which is the primary pathway for the passage of the CO_2, water for photosynthesis and oxygen for respiration which directly affect crop production.

Growing crops with different maturation periods such as maize and banana crops can be adopted in agroecologies with growing seasons of variable length such as Vihiga County to exploit the occasional favourable season and to insure against total crop failure in case of unfavorable seasons (Rao, 1986). Vihiga County is located in the same agro-ecological region facing climate change, food insecurity, high poverty index, declining soil fertility and land degradation (GOK, 2005) courtesy of poor farming systems. It is thus necessary to adopt intercropping system of maize and banana, which are the main food crops that Western Kenya relies on with selected agroforestry trees species.

1.2. Statement of the Problem

Demand for food production continues to increase in Western Kenya due to continuing population increase (KNBS, 2019 and Mutoko *et al*., 2016). Smallholder farmers have been forced to engage in forest encroachment, continuous cultivation without any fallows and conversion of fallow land to farmland. The high magnitude of food insecurity and poverty levels among rural smallholder farmers is a major concern. A number of agroforestry trees have been reported to increase soil available nutrients and yield. The adoption of *Sesbania sesban*, *Leucaena diversifolia* and *Calliandra callothyrsus* has become more popular among smallholder farmers in Western Kenya. However, in Western Kenya, there is little documented information on the effects of intercropping trees on physiological and biochemical responses of crop plants. Previous studies on agroforestry farming system have majorly focused on the improved soil nutrient, yield and decrease in Striga weed infestation (Sjögren *et al*., 2010). *Sesbania sesban* has the potential to increase the maize yield and good weed management. The effects of these trees on competition for growth resources such as moisture and nutrients with crops has not been studied. The role of improved fallows have been reported to improve soil properties, control run off, increase production and nitrogen fixation (Anja and Alain, 2001). However, information of these fallows on the growth and gas exchange responses is yet to be documented on maize and banana crop plants under an intercropping system. Moreover, there is paucity of information regarding the effect of the intercrop of trees with crop plants on the total chlorophyll content. The association of agroforestry tree species with crop plants may have direct influence on the productivity due to competition for growth resources such as water and soil nutrients, which negatively influences the nutrient uptake and chlorophyll formation of the food crops. This eventually limits crop productivity in terms of yields. The adoption of agroforestry tree species is pegged on their ability to increase fertility and yield, however no studies has been done on how they will affect the gas exchange responses, growth and nutrient uptake which directly impact on the crop productivity. This agroforestry combination has the potential to improve on crop production for both maize and bananas. However, the influence of the trees on the growth, physiology, nutrient uptake and yield has not been established. These agroforestry combination of maize - banana and tree has potential to improve on crop productivity of both maize and banana.

1.3. Justification of the study

The assessment of the effects of intercropping maize and banana plants under C*alliandra calothyrsus*, *Sesbania sesban* and *Leucaena diversifolia* agroforestry tree species would provide an insight on the growth, physiological, biochemical traits which are very important to crop productivity. This assessment could lead to increased understanding on the benefits of trees to crop production when intercropped on the same piece of land. This will further enhance the development of sustainable land management and increase forest cover hence mitigating against climate change. Agricultural sector needs to be strengthened through sustainable agriculture by incorporating agroforestry trees to mitigate climate change and improve soil fertility. Positive response of agroforestry trees intercrop on the yield of maize and bananas may promote food security, improve income generation, offer employment to the rural population and in the long run enhance achievement of the government's big four agenda alongside mitigating climate change. The findings of this study could further benefit farmers and other stakeholders to providing an understanding on the effects of the trees species on growth, physiology, biochemistry and yield of maize and banana intercrop. This should further stimulate more study on the interactions of different tree species with the maize and banana crop to enable the smallholder farmers to make cognizant decisions on the selection of the trees to be grown with food crops. The ever increasing human population in Vihiga County could result to rapid land degradation thus worsening the climate change. These changes could eventually result to increased food insecurity in the region. Therefore, the farmers in Vihiga can promote food production and increased livelihoods by adopting the outcomes of this study in the long run.

1.4. Study Objectives

1.4.1. Main objective

Physiological, biochemical and yield responses of maize and banana plants under C*alliandra calothyrsus*, *Sesbania sesban* and *Leucaena diversifolia* intercrop in Vihiga County, Kenya.

1.4.2. Specific objectives

i. To determine the effect of intercropping maize and banana plants under C*alliandra calothyrsus*, *Sesbania sesban* and *Leucaena diversifolia* intercrop on maize and banana plant height, number of green leaves, leaf area and stem diameter.

ii. To determine the effect of intercropping maize and banana plants under C*alliandra calothyrsus*, *Sesbania sesban* and *Leucaena diversifolia* intercrop on maize and banana net photosynthetic rates intercellular CO_2 concentration and transpiration rate.

iii. To establish the effect of intercropping maize and banana plants under C*alliandra calothyrsus*, *Sesbania sesban* and *Leucaena diversifolia* intercrop on maize and banana total chlorophyll content.

iv. To investigate the effects of intercropping banana and maize plants under C*alliandra calothyrsus, Sesbania sesban* and *Leucaena diversifolia* intercrop on maize and banana N, P, K, Mg and Ca nutrient uptake.

v. To find out the influence of intercropping maize and banana plants under C*alliandra calothyrsus, Sesbania sesban* and *Leucaena diversifolia* intercrop on maize yield, number of maize with cobs, number of rotten cobs, biomass and banana bunch weight, finger length, number of fingers per bunch and number of hands per bunch.

1.4.3. Hypotheses

i. Intercropping maize and banana plants with C*alliandra calothyrsus*, *Sesbania sesban* and *Leucaena diversifolia* intercrop has no effect on maize and banana plant height, number of green leaves, leaf area and stem diameter.

ii. Intercropping maize and banana plants with C*alliandra calothyrsus*, *Sesbania sesban* and *Leucaena diversifolia* intercrop has no effect on maize and banana plant net photosynthetic rates intercellular CO_2 concentration and transpiration rate.

iii. Intercropping maize and banana plants with C*alliandra calothyrsus, Sesbania sesban* and *Leucaena diversifolia* intercrop has no effect on maize and banana plant total chlorophyll content.

iv. Intercropping maize and banana plants with C*alliandra calothyrsus*, *Sesbania sesban* and *Leucaena diversifolia* intercrop has no effect on maize and banana plant N, P, K, Mg and Ca nutrient uptake.

v. Intercropping maize and banana plants with C*alliandra calothyrsus, Sesbania sesban* and *Leucaena diversifolia* intercrop has no effect on maize yield, number of maize with cobs, number of rotten maize cobs, biomass and banana bunch weight, finger length, number of fingers per bunch and number of hands per bunch.

1.5. Scope and limitations of the study

The study involved investigation of physiological, biochemical and yield responses of maize and banana plants under C*alliandra calothyrsus*, *Sesbania sesban* and *Leucaena diversifolia* intercrop in Vihiga County, Kenya.

However, the following are some of the limitations of the study.

1. This study did not determine the water use efficiency (WUE) of maize and banana plants to establish the amount of water used up by the intercropped plants in metabolic processes and the amount of water lost by the same crops through transpiration.
2. This study did not evaluate the below ground and above ground dry matter allocations of maize and banana crops to understand the nature of interactions occurring between the crops and the agroforestry tree species in terms of biomass accumulation.
3. This study used agroforestry trees species which were 6 months old hence could not provide large amounts of prunings for applying to the plots.
4. This study did not establish the amount of biological nitrogen fixation due to the agroforestry tree species.

CHAPTER TWO

LITERATURE REVIEW

2.1. The intercropped agroforestry tree species

2.1.1. The *Calliandra calothyrsus* tree species

The *Calliandra calothyrsus* is a very rapid growing small tree reaching averagely 12 m tall, its native to Mexico and Central Africa and is extensively promoted and embraced as a complement to Napier grass (Wambugu *et al*., 2001). The foliage are appropriate for silage and its yield is superior to other shrub legumes, especially when predominantly grown on soils with extremely low pH, the plant does grow well in soil sufficiently permeable to allow root penetration and water infiltration (Maghembe and Prins, 1994). The main reason for its adoption has been due to its encouraging agronomic qualities like rapid growth, increased biomass yield, tolerance to acidic soils and effective nitrogen fixation (Chamberlain, 2001; ICRAF, 2001) *Calliandra calothyrsus* has widespread and deep roots suitable to mitigate soil erosion on the slopes thus stabilization of soil and conservation of water (ICRAF, 2001).

Calliandra calothyrsus grown for two years have restored soil fertility and consequently increased crop yields on degraded soils (Mafongoya, 1995). *Calliandra calothyrsus* however, has been reported to be a poor fallow species due to its slow breakdown rate and nutrient discharge resulting from its high concentration of polyphenolic compounds (Lehmann *et al*., 1995). *Calliandra calothyrsus* competes with crops if left unpruned (Gerrits, 2000) as a result of competition between crop plants and agroforestry tree species for water and nutrient resources. The information on how the intercrop of maize and banana with agroforestry trees influences on the maize and banana biochemistry, physiology and productivity has not been determined.

2.1.2. The *Sesbania sesban* tree species

Sesbania sesban is a short fallow tree species originating from southern and East Africa known for its nitrogen fixation, soil conservation and soil nutrient restoration (Kwesiga *et al*., 1999). *Sesbania* species have greater effect on yield, N availability and provision of fuelwood (Kwesiga *et al*., 1999). According to Retnowarti, (2003) agroforestry enhances carbon capture thus promoting sustainable land management. The use of perennial trees in reducing carbon from the atmosphere has been recommended as a way of mitigating climate change (Scherr and Sthapit 2009). Greater maize yields under *Sesbania sesban* have been reported and has been credited to improved soil mineral nitrogen resulting from breakdown and mineralization of nitrogen rich organic deposits (Sjögren *et al*., 2010). The smallholder farmers in western Kenya are adopting the agroforestry farming system because of their capacity to promote yield, soil fertility and soil water holding within rhizosphere (Phiri *et al*., 2003). However, physiological and gas exchange responses which directly affect crop production has not been studied.

2.1.3 The *Leucaena diversifolia* tree species

Leucaena diversifolia belongs Leguminosae family, a medium-sized tree, a familiar companion tree to coffee in most parts of Indonesia and Mexico (Santos *et al*., 2012). *Leucaena diversifolia* has deep root system to reach deeper horizon to access water and nutrients (Cooksley *et al*. 1988). *Leucaena diversifolia* can be used for soil improvement, soil conservation and erosion control in diverse agroforestry combinations and systems including alley farming, live-barriers on terrace boundaries, shelter belts or windbreaks, or simply as dispersed trees over crops (Shelton et al., 1998). The wood is used for fuel and charcoal production and for small dimension poles (Dalzell, 2019). In its native range, *L. diversifolia* grows in deep, free-draining soils of mildly acid reaction (pH 5.5– 6.5).

2.2. Crop plant under study

2.2.1. Maize Taxonomy, Origin and production and production constraints

According to Chhidda *et al*. (2003), maize belongs to Poaceae family having originated from Mexico. Maize is the third most useful cereal in the world after wheat and rice in terms of productivity (Asghar *et al*., 2010). Morris (2001) states that maize is a widely distributed crop being cultivated both in the tropics and in the temperate zones. Its production is close to 100 million hectares in developing countries where 70% of the production being reported in the developing world comes from smallholder farmers (FAOSTAT, 2010). Globally maize production has been estimated at 5 t/ha in 2009 (Edgerton, 2009). Maize production in Vihiga County averages below 1 ton/ha, occasioned by Soil infertility (Mutoko *et al*., 2016). Despite the increased maize production globally, the developing countries still record low yields (Pixley *et al*., 2009). Maize production in Vihiga is far below its potential productivity (Seward, 2005). Additionally it offers caloric requirements to nearly a half of the population (Wekesa *et al*., 2003). According to Smale and Jayne (2003) maize farming accounts for over 60% of the total cropped area in Kenya. However, its production has not kept pace with the consumption and Kenya imports more than 10 million tonnes of maize yearly (Cassman 2007).

Approaches such as the use of nitrogen-fixing tree species, improved fallows, cover crops and use of green manure can restore soil fertility (Mafongoya *et al*. 2006). Smallholder farmers have been the main drivers to food production, by contributing over 70% of the country's maize production (Ouma *et al*., 2002). Despite maize being significant in food security and generating income in Vihiga County, its production has remained low resulting to frequent food insecurity. The low maize production could be attributed to the decline in the soil nutrients. This results to reduced uptake of the nutrients which are essential in the physiological and growth of maize and banana crops. Intercropping of the said crops with agroforestry tree species may be a solution. However, information on the effects of the agroforestry on the maize and banana nutrient uptake, gas exchange, chlorophyll content is unknown.

2.2.2. Banana Taxonomy, Origin, Production and Production Constraints

According to Karamura, (1998) Bananas are in the *Musaceae* family *that* comprises two genera. Genus *Ensete* varies from *Musa* as it has one carpel, non-suckering and enlarged base (Cobley and Steele, 1976). The genus *Musa*, has its origin from the Southeast Asia (Masanza, 2003). The crop was first introduced in Africa between the 1^{st} and the 19^{th} century (Masanza, 2003).

The banana plant is perennial and has an underground stem called as the corm (Karugaba and Kimaru, 1999). The roots grow up to a depth of 60 cm (Masanza, 2003). Leaf sheaths encircle forming a pseudostem (Swennen and Vulysteke, 2001). The terminal bud of the corm develops to form the inflorescence from the centre of the leaf cluster after 8 months which eventually develops in to the bunch, with 6 –12 hands, and each with a minimum of 12 fingers (Karugaba and Kimaru, 1999).

Globally, 55 million metric tonnes of banana is annually produced (FAOSTAT, 2011). Banana is among the valuable food crops globally after rice, wheat and potatoes (INIBAP, 2005). It is a staple diet to more than 30 million people especially those living in highly populated areas (Karamura *et al.*, 1999).

Kenya is among the leading African countries in banana production together with Uganda, Cameroon and South Africa (FAOSTAT, 2010). Its production in Kenya was estimated at 82,518 hectares as reported by the Ministry of Agriculture, (2006). However, over the past decade the production of banana in Kenya has been declining (HCDA, 2008). The decline has been caused by soil infertility due to environmental degradation (Wambugu *et al.,* 2000) arising from continuous cultivation without fallows. Studies by Sjogren (2015) reported improved soil fertility and maize yield under *Sesbania sesban* and *Calliandra carlothyrsus* fallows. The use of organic biological fertilizers like introduction of agroforestry trees in an intercrop system to improve soil fertility is regarded as remedial measure among most smallholder farmers. The agroforestry farming system have shown positive effect on the soil fertility. This could be manifested through nitrogen fixation, pruned biomass decomposition and improved microclimate. However, some other responses such as gas exchange responses, yield and chlorophyll content need to be established. These responses have significant effects on the production of crop.

2.2.3. Intercropping studies on maize and banana growth

The goal of intercropping is to intensify output and guarantee the effective land use. The cereal with adventitious root system and legume with a deep tap root system are the common crop combinations in intercropping systems (Matusso *et al.* 2012). Difference in the design and spatial extension of root growth is one of the important factors influencing the relative success of the two crops that are grown together. There is need to establish a farming system that will give relatively higher yields such as agroforestry farming system. Yields of intercropping have been often higher, resources such as water, light and nutrients have also been effectively utilized compared to sole cropping (Li *et al*, 2006). Traditionally maize and bananas have been grown on separate farms but due to the population increase, there is increased pressure on land. Due to decrease in land for farming, it therefore calls for agroforestry farming system with the trees and crops grown under same piece of land. Therefore, there is need to practice agroforestry farming system as a remedy to balance forest cover and food production. Combining maize and banana crops and agroforestry trees have the ability to improve crop production of bananas and plants if the effect of these plants on the physiology, growth, nutrient uptake and yield is ascertained.

2.3.1. The effect of intercropping food crops with agroforestry tree species on crop plant growth

Plant height is a significant factor that influence plant growth and development (Muranyi and Pepo, 2013). According to Becham *et al.* (2018) positive relationship of plant height with the yield components have been reported to show that taller plants produced heavy cobs, longer cob length and higher grain weight in the intercrops of the maize and soya bean according to the research carried out in the humid forest zone of Mount Cameroon. Efhami *et al*. (2008) reported increased growth of *Populus nigra*-alfalfa under the intercrop with poplar trees. Cowpeas and sorghum intercrop showed significant high plant height for both cowpeas and sorghum compared to their sole crops in Botswana (Gabatshele *et al*., 2019). Ashraf *et al*. (2019) has shown that tree height of sweet basil are significantly increased under intercropping with aromatic tree plants. Competition for soil moisture reduces stem girth, tallness and produce in maize under agroforestry systems (Muthuri, 2005). Emechebe (2006) had earlier indicated that competition for plant nutrients during the vegetative development negatively affects plant height. Complementary use of growth resources like nutrients and light within the intercrop environment (Liu *et al*., 2017) has been attributed to positive increase in the plant height. Intercrop of sorghum with cowpeas have previously recorded taller plants and high grain yield per plant as a result of nitrogen fixed by the cow pea legume which spearheaded the apical meristematic activity that increased growth (Rafay *et al.* 2013). Hamd Alla *et al*. (2014) also found out that there was improved height and grain weight in cowpeas under intercrop with maize that was credited to high nitrogen uptake due to nitrogen fixation responsible for grain filling. The earlier intercropping studies have been reported to increase soil fertility. These studies have however, majorly focused on the intercrop involving food crops alone. This has further neglected other factors that have effect on crop production such as the gas exchange, physiological and nutrient uptake of the associated food crop plants. Majority of farmers are certain that the taller the plant, the higher the yields (Wambugu, 2006). Bhatt (1988) reported maximum sorghum plant height in sole crop and significantly superior over inter crops. The performance of alley lemongrass, with *Sesbania* prunings resulted to significant increase in the plant height (Ebeid *et al*., 2015).

Cowpeas and sorghum intercrop showed significant high number of leaves and plant height for both cowpeas and sorghum at six weeks after planting as compared to monocrop in a research conducted in Botswana (Gabatshele *et al*., 2019). Iderawumi (2014) showed that the number of leaves in cowpeas and maize intercrop were more in monocrops. Amos *et al.* (2012) reported high growth of legumes under maize intercrop. However, information on the effects of the agroforestry trees on the number of green leaves of maize and bananas in Vihiga County is unavailable. This information is important because the number of leaves in a plant influences the photosynthetic efficiency since they affect the light harvesting necessary for primary production. The number of leaves on a plant is necessary, as it is a key determinant in photosynthesis as they provide large surface area to harvest carbon dioxide and light.

Leaf area is an influential factor in the crop physiology. However, large leaf area under reduced light intensity is a modification to compensate for maximum light harvest (Morita *et al.*, 1994). Bhat (1988) observed significantly higher leaf area in sole cropping groundnuts compared to intercropped groundnuts. Becham *et al*. (2018) showed that larger maize leaf area were reported under the intercrops of the maize and soybean. Ghosh, (2004) reported large leaf area in sole cropped plants compared to intercropped species. However, little information is available on the effects of the selected agroforestry trees on the leaf growth of maize and bananas in Vihiga County.

It has previously been reported that plants with larger stem diameter produce cobs with larger weight, longer cob and a higher grain weight when intercropped (Becham *et al*., 2018). Reduced growth and yield of maize in agroforestry farming systems have been reported in the agroforestry system accompanied by soil moisture competition (Muthuri, 2005). Chaudhry, (2003) reported that *P. deltoides* intercrop with wheat and maize had larger maize diameter, than sole maize plants. Efhami *et al*. (2008) found that crop diameter in tree-crop intercropped systems was greater than sole crop and tree diameter increased with decreasing tree density. The *Grevillea robusta* has been reported to suppress maize plant stem girth due to light competition resulting from shading (Ndlovu *et al*., 2016).

2.3.2. Effect of intercropping food crops with agroforestry tree species on net photosynthetic rate, intercellular CO_2 concentration and transpiration rate

Stomata regulate primary productivity by regulating the balance between loss of water and carbon fixation. Primary productivity is negatively affected by water stress by limiting CO_2 intake to the leaf due to reduced stomatal rhythm (Chaves *et al*., 2002). Sanjeev (2016) found that net photosynthesis was higher in the garlic intercropped with quava, plum and poplar compared to the sole cropped garlic. The higher net photosynthesis in garlic is a result of reduced water lost and competition between the intercropped plants that eventually increased stomatal conductance. The opened stomata facilitated CO_2 uptake hence promoting productivity. Huxman and Monson (2003), reported high sensitivity of stomatal conductance of *Flaveria* species to light and intercellular CO_2 concentration. Nissanka and Sangakkara (2008) found that maize photosynthetic efficiency and yields were significantly greater under intercrop with Gliricidia as compared to monocrop maize. However, it is not clear if similar findings can be recorded when modification is with maize-banana under the selected agroforestry trees.

The ratio of intercellular CO_2 concentration to transpiration rate at the stomatal level may be one of the means of achieving higher productivity per unit rainfall (Condon *et al*., 2002). A study by Retnowarti, (2003) in Indonesia showed that agroforestry increases carbon capture from the atmosphere therefore enhancing ecologically friendly land management. Sanjeev (2016) found that there is higher intercellular CO_2 concentration in the garlic intercropped with quava, plum and poplar compared to the sole cropped garlic. Intercellular CO_2 concentration of maize was higher in the *Paulownia fortunei* than in the *Grevellia robusta* and A. *acuminata* maize intercrops (Muthuri *et al*., 2009). Chaves *et al.* (2002) indicated plant primary production relies to water; consequently, drought decreases primary productivity. The reduction in primary productivity has a limitation on the CO_2 diffusion into the leaf resulting from the diminished stomatal resistance to gaseous diffusion related with stomatal closure to conserve water (Chaves *et al*., 2002). Retnowarti, (2003) found that agroforestry trees increase carbon capture hence promoting sustainable land management according to research contacted in Indonesia. Scherr and Sthapit (2009) reporting on the alleviation of climate change had suggested use of perennial trees in reducing carbon from the atmosphere. Intercellular CO_2 concentration has a direct effect on the growth and development of the plant. According to Netondo (1991), agroforestry system has reported significant reduction on soil moisture evaporation. This has consequently resulted to high stomatal conductance, promoting CO_2 intake through the opened stomata. Agroforestry system has the potential to reduce competition for resources such as moisture. The proposed agroforestry trees have reported increased CO_2 intake under maize intercrop. However, the effect of *Calliandra calothyrsus*, *Sesbania sesban* and *Leucaena diversifolia* agroforestry trees affect the intercellular CO_2 concentration of maize and banana crops needs to be established.

Transpiration rate of a crop is useful in determining the effect of crop competition for water in the agroforestry system. Maize and cowpea intercrop has been reported to reduce water evaporation and improve conservation of the soil moisture (Ghanbari *et al.*, 2010). However, the combination of maize-cowpea intercrop are both food crop and may not give a clear picture in terms of competition when agroforestry trees are used instead. Mithamo, (2013) reported higher transpiration rates under coffee intercropped with fruit trees than the monocrop coffee. Sanjeev (2016) found that transpiration rate was lower in the garlic intercropped with quava, plum and poplar compared to the sole cropped garlic. Kanten and Vaast (2006) reported higher transpiration rate in monocropped coffee than those under intercrops, implying that the monocropped coffee faced a higher level of environmental stress than those within the intercrop. Soil moisture content is a major determinant for transpiration rate and hence nutrient uptake and translocation since it affects the water potential in the plant surrounding (Mithamo, 2013). Monocropped coffee showed high transpiration rates compared to coffee under the intercrop with other trees species (Mithamo, 2013). Previous studies by Netondo, (1991) have reported higher maize plant transpiration rates and yields under agroforestry trees in semi-arid conditions of Machakos. The agroforestry system involving maize has proved beneficial in terms of transpiration rate and yields. The agroforestry modifications of *Sesbania sesban, Calliandra calothyrsus* and *Leucaena diversifolia* with banana and maize which is being popularized in Vihiga County is not clearly known how it will impact on photosynthetic efficiency and nutrient uptake efficiency. Transpiration rate which is a measure of water stress under agroforestry system has a significant influence to crop productivity. Water stress restricts photosynthesis, cell division, reduces leaf area and accelerates leaf senescence.

2.3.3. Effect of intercropping food crops with agroforestry tree species on total chlorophyll content

Total chlorophyll content is a valuable indicator of both potential primary productivity and general plant vigour (Alonso *et al*., 2002). Chlorophyll content in plants is affected by the availability of some key elements such as nitrogen and magnesium which are a subject of competition under agroforestry system. Kordi *et al*. (2017) reported significant increase in maize total chlorophyll under different intercropping systems involving maize and cowpeas compared to monocrop. Ashraf *et al*. (2019) stated that leaf total chlorophyll of sweet basil were significantly increased under intercropping with aromatic tree plants. The positive effect of the intercrop to chlorophyll is due to nitrogen fixed by the leguminous plant. *Grevillea robusta* intercropped with maize have shown reduced total chlorophyll on maize in Trans Nzoia, Kenya (Ndlovu 2013). The reduction in chlorophyll is because of competition for nutrients with the associated food crops. Chu *et al*. (2004) recorded increased total chlorophyll content of rice leaves under monocropped rice under rice-peanut intercrop. Agroforestry trees have the ability to increase the chlorophyll content, however, the effect of *Sesbania sesban*, *Calliandra calothyrsus* and *Leucaena diversifolia* on maize and banana chlorophyll content is yet to be established. The chlorophyll content is very crucial in the plants within agroforestry system to enhance light absorption required for photosynthesis.

2.3.4. Effect of intercropping food crops with agroforestry tree species on plant N, P, K Mg and Ca mineral nutrient uptake

According to Bationo *et al*. (2004) soil fertility decline has been the main limiting factor to food security in sub Saharan Africa. The declining soil fertility is due to continuous cultivation without any fallows. As a remedy, most smallholder farmers are embracing agroforestry farming. Studies by Ashraf *et al*. (2019) reported increased leaf nitrogen, phosphorus and potassium percentages of sweet basil under intercropping with aromatic tree plants, increased nutrient uptake due to the decomposition of the aromatic tree leaves. Maize grains, leaves, roots and stems recorded highest nitrogen concentrations under maize-gliricidia (Nissanka and Sangakkara, 2008). Mafongoya *et al*. (2008) characteristics such as high nitrogen levels, small amounts of lignin and polyphenols as evident in Gliricidia and *Sesbania sesban* increases maize yields compared with species such as *Calliandra calothyrsus* which have low nitrogen levels and high levels of lignin and polyphenols. Makumba *et al*. (2005) have also reported nutrient uptake by maize supplied with tree prunings combined with inorganic fertilizers. Nitrogen uptake in manure and *Leucaena diversifolia* combined with inorganic fertilizer treatments has been reported (Mugwe, 2007). In addition, Suvera *et al.* (2015) found that N, P and P of *Pongamia pinnata* trees were increased when intercropped with *Ocimum basilicum* spp. plants.

Chen *et al*. (2010) reported that legumes transfer fixed nitrogen to cereal crops when planted as an intercrop. Akinnifesi *et al*. (2006) has reported increased soil nutrient in *Gliricidia* - maize compared to sole cropped maize, the increased fertility was due to nitrogen fixed by the Gliricidia. Increased N, P, K has been reported when *Tithonia* biomass grown outside fields was applied to the farms (Gachengo, 1996). Apart from potential benefits of recycling nutrient elements from deep soil, prunings of leguminous trees have higher nitrogen content than that of non-legumes because they fix nitrogen symbiotically with rhizobia (Mugendi *et al*., 2003; Giller, 2001). Mugendi *et al*. (2003) found that non-legumes accumulate substantial quantities of nutrients (N, P, K, Mg, Ca) in their leaves, which are released for crop use upon soil incorporation and subsequent decomposition (Giller, 2001).

Studies by Sanginga and Woomer, (2009) reported positive effects of legumes on fertility enhancements. Mugwe *et al.* (2009) reported improved soil Calcium, potassium and Magnesium, which in turn were taken up by the annual maize crops under herbaceous plants. *Leucaena diversifolia* has been reported to produce high biomass in the range of 10 to 25 t dry matter ha^{-1} yr^{-1}, and to contain high levels of nitrogen in the leaves of about 2.5 to 4.0% (Delve *et al*., 2000). Consequently, prunings of calliandra and leucaena combined into the soil have been found to improve soil fertility (Delve *et al*., 2000). However, the sustainability of tithonia use by farmers to recycle nutrients in farming systems could be limited by the long-term availability of the plant material and intensive labour involved in biomass collection, processing and application (Mafongoya *et al*., 2003).

According to Zaharah (2008) leaf prunings of *Paraserianthes falcataria* and *Gliricidia sepium* has been reported to contribute higher levels of the nitrogen uptake by the maize in an alley cropping system. Zaharah (2008) further reported that the Ca and Mg released by the legume trees reduced Al saturation on the exchange complex thereby promoting the uptake of the essential minerals by crop plants. Legumes in alleys and fallows increase Nitrogen, Phosphorus and exchangeable cations (Bünemann *et al.*, 2004). Phosphorus is deficient in Western Kenya soils despite being the second most important nutrient to plant growth after nitrogen (Kwabiah *et al*., 2003). Nissanka and Sangakkara (2008) found that higher N was partitioned in the maize leaves followed by the grain, stems and lastly roots in Gliricidia-maize alley-cropping system.

Nitrogen improves growth by promoting increased leaf size, enhancing chlorophyll formation and promoting fruiting (INIBAP, 1998). Regulation of stomatal rhythm and protein utilization are stimulated by Potassium nutrients (Robinson, 1996). Calcium promotes cell wall formation, nitrogen absorption and reducing soil acidity. Magnesium is critical for photosynthesis since it is a constituent of chlorophyll molecule and regulation of cell division (Karugaba and Kimaru, 1999). Inorganic chemical are the main sources of the macronutrients however, use of chemical fertilizer has been undesirable due to high cost and pollution (Abdullah *et al.*, 1999).

Rutunga *et al.* (1999) has reported increased maize yield when intercropped with *Tephrosia vogelii* tree species. Ignacio *et al*. (2013) while studying on nitrogen, phosphorus, potassium and magnesium nutrient partitioning in maize crop found that nitrogen and phosphorus uptake was higher in the order of grain, leaf, stem, cobs, potassium uptake was in the order of grain, stem, leaf and cob while magnesium uptake were in the order of leaf, stem, grain and cob. Karlen *et al*. (1988) found N uptake to follow a different pattern with two distinct accumulation periods; first when flowering, and the second during the grain-filling period in high yielding maize.

Studies by Oke (2001) and Olujobi *et al*. (2013) reported increased maize macronutrient uptake in the nutrient impoverished soils of Nigeria when intercropped with gliricidia tree species. Ajayi *et al*. (2011) reported various benefits of *gliricidia sepium* on improving soil nutrient status of N, P, K, Mg and Ca macronutrients owing to its deep-rooted system that enhanced pulling up nutrients from below ground to the maize crop rhizosphere. In a different finding involving gliricidia and maize intercrop by Akinnifesi *et al*. (2007), it was reported that the green manure from the gliricidia prunings contained 4% N and other valuable nutrients such as P, K, Mg and Ca in the soils of Southern Malawi. Bertalot *et al*., (2014) have stated that concentrations of N, K and Mg tended to have greater values in foliar tissue where *Leucaena diversifolia* biomass coverage was present and the cumulative effect of mineralization and maize straw and oats, along the experiment. The concentration of N was greater owing to nitrogen fixed through the rows of *Leucaena diversifolia*, the P concentration was higher because plants in agroforestry system suffer little environmental stress (Bertalot *et al*., 2014). Maximum banana yields require higher nitrogen and potassium nutrients then followed by phosphorus, calcium and potassium nutrients (Abdullah *et al.*, 1999).

2.3.5. The effect of intercropping food crops with agroforestry tree species on crop yield, yield component responses and biomass

Smallholder farmers in the Sub Saharan Africa region have practiced intercropping farming of cereals – legumes, cereal - grain (Odendo *et al.*, 2011). Kwesiga *et al.* (2003) indicated that maize yields in the intercropping system increased in two fold compared to the monocropped maize after fourth year due to facilitation processes on macro nutrient uptake that enhanced maize grain filling. Phiri *et al*. (1999) established a substantial increase in yields of maize when intercropped with *Sesbania sesban* in southern Malawi. Contrarily, Baijukya (2004) and Kaizzi *et al*. (2006) reported reduced maize yields under Mucuna intercropping due to low biomass production. Higher maize produce has been reported when biomass of tithonia, calliandra and leucaena are applied (Sanchez and Jama, 2002; Gachengo, 1996). Maize grown following legume cover crops produced significantly higher yield than those without green manures mainly through benefits of higher amounts of N and P and partly through nutrient pumping from deeper layers (Amede, 2003). In Western Kenya, increased yield have been reported up to 200% when tithonia biomass was applied (Gachengo *et al*., 1999; Jama et al., 2000). Similarly, in central Kenya application of tithonia, calliandra and leucaena biomass has been reported to increase maize yield (Mugwe and Mugendi, 1999; Micheni *et al*., 2003). Dudal (2002) demonstrated that use of organics could enhance efficiency of chemical fertilizers. Gruhn *et al*. (2000) and Bado and Bationo (2004) showed that combination of organic and inorganic nutrient sources result into interaction, enhanced management and increased fertilizer efficiency and higher yields. Mucheru-Muna *et al,* (2007) reported higher grain yields of maize under application of organic and mineral fertilizers. Maize has been reported to increase by more than 300% when intercropped for more than four seasons with Gliricidia as opposed to monocropped maize (Akinnifesi *et al.,* 2007). Increased regular pruning within the intercrop increases carbon-based matter and nutrient recycling to the soil (Dossa *et al*., 2008). Nutrients are assimilated in to biomass of trees and returned to soil surface over time through litter fall, decomposition and mineralization process availing them to crops (Nair *et al*., 1999). Ability of trees to utilize nutrient pools deeper in the soils from different layers in the soil profile minimizes the competition for nutrients between crops and trees in an intercrop system (Schaller *et al*., 2003). The area under banana production has shrunk over the past years with Western Kenya being the most affected (Technoserve, 2009). Bertalot *et al*., (2014) have reported higher productivity in the agroforestry system between maize and *Leucaena diversifolia* have earlier been reported in maize because of biological nitrogen fixation, water retaining and reduced risky microclimate. The biomass prunings of *Leucaena diversifolia* increased black oats productivity (Bertalot *et al*. 2014). *Leucaena diversifolia, Sesbania sesban* and *Calliandra carlothyrsus* are being popularized in Western Kenya within maize and banana intercrop to establish their influence on the physiology, biochemistry and yield.

Nissanka and Sangakkara (2008) reported highest biomass in maize grown without hedgerows and nitrogen fertilizer, whereas under hedgerow showed the lowest biomass because of hedgerow plants competing for nutrients, water and light. Therefore, there is need for adoption of tree species that are complementary to food crops. In the sub-humid region of Embu, significant increase of maize yield was reported under *Calliandra calothyrsus* and *Leucaena diversifolia* pruned biomass application (Mugwe and Mugendi, 1999). Rice yield increased when it was intercropped with fruit trees compared to monocrop rice (Tomar and Bhatt, 2004). Incorporation of trees with food crops have resulted into increased productivity. *Calliandra calothyrsus* and *Leucaena diversifolia,* may be used to enhance production of maize and bananas in Vihiga. The legume trees and green manure cover crops provide biomass that increased maize yields (Akinnifesi *et al*. (2007) and Sileshi *et al*. (2008). Intercrop of maize with legumes has been reported to provide substantial amount of carbon-based matter and available soil nitrogen (Mubiru and Coyne, 2009). Nitrogen is the key soil nutrient whose deficiency limits crop production due to unaffordability of inorganic fertilizers by most subsistence farmers (Ariga *et al*., 2006). Early findings by Ali *et al*. (2014) had reported higher strong and significant correlation values for morpho-physiological traits of maize.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of the study site

On-field experiments were carried out for two consecutive seasons from August 2018 to September 2019 at Maseno University farm in Vihiga County (00^{o} 00'15.5''S; 034^{o} 35'53.1''E; 1522 masl) in Western Kenya. The soils at the site have very low N, P, K, Ca and Mg amounts hence highly impoverished. For instance, the Maseno soils are acidic with a pH of 4.65, and have low nutrient contents, that is N = 0.16%, P = 2.57 mg/kg, K = 46.8 mg/kg Ca = 105 mg/kg Mg = 22.3 mg/kg and Al = 1.88 meq/100g (Wamalwa, D. unpublished data). The site receives a bimodal annual mean precipitation of 1750 mm, from August to November short rains and March to July long rains. The mean temperature during the study was 28.7 degrees Celsius with relative humidity of 40%. Maize, bananas, sorghum, millet, beans, cowpeas, cassava, sweet potatoes, groundnuts and finger millet are the commonly grown food crops in the region.

Map of the Study Area

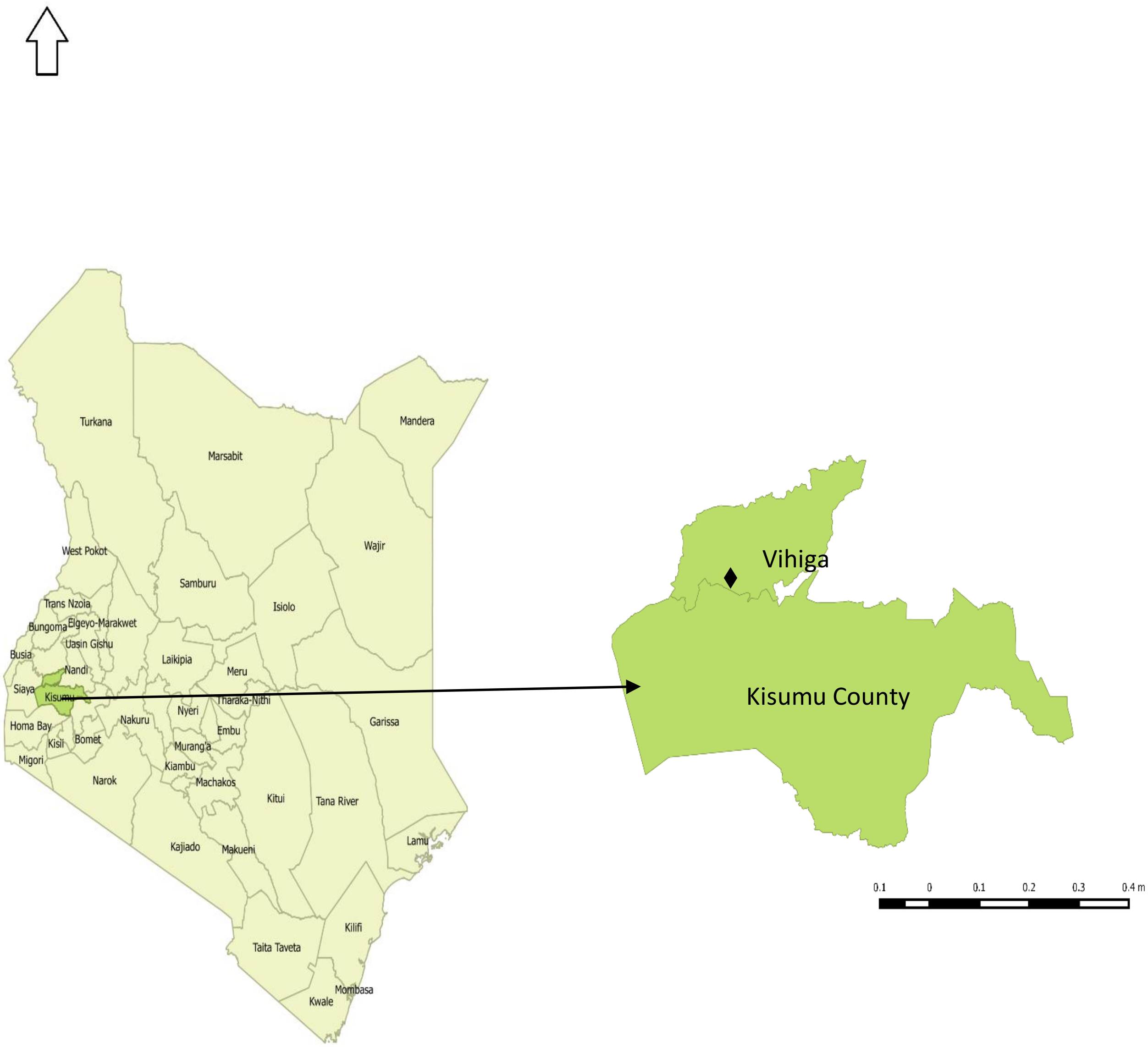

Figure 3.1: Map showing the Vihiga study site at Maseno University farm. Source, Google maps.

3.2. Experimental Treatment and Design

Randomized complete block design experiment with seven treatments of maize + fertilizer (MF), maize + no fertilizer (M), banana monocrop (B), maize + banana + *Calliandra calothyrsus* (MBC), maize+ banana+ *Leucaena diversifolia* (MBL), maize+ banana+ *Sesbania sesban* (MBS) and maize + banana (MB) and three replications was laid. Seeds of agroforestry trees were purchased from KEFRI-Muguga, sown and raised in nurseries. When the agroforestry tree species seedlings were three months old, they were transplanted into the field at a spacing of 0.5m by 3m. The agroforestry tree species seedlings were then allowed to grow for three months before maize seeds were sown, to give them time to establish. Five months old, Williams' tissue banana variety from the green house were purchased from KALRO-Thika. Banana holes were dug at 0.9m by 0.9m by 0.6m deep and banana planted at a depth of 0.3m for proper anchorage. Under agroforestry, treatments a maximum of nine bananas plants were planted at a spacing of 3m by 3m while monocrop banana had a maximum of twelve banana plants with a spacing of 3m by 2.5m. In maize-banana plots, the banana spacing was 6m by 2.5m having a maximum of six banana plants. The bananas were planted three months prior planting maize. Hybrid seeds maize, H513 were obtained from Kenya seed company Kitale. The Maize was planted at a spacing of 0.75m by 0.3m for both inter-rows and intra-rows and NPK (13-40-13) fertilizer applied in the maize fertilizer plots. In maize plots alone, twelve rows were planted giving a maximum of 480 maize plants. The plots containing agroforestry trees, nine rows were planted in each plot giving a maximum of 216 maize plants. Two maize seeds were planted in each hole and thinned to one plant, one week after emergence. Gapping was done five days after emergence. The agroforestry trees were regularly pruned and the prunings applied between the maize and banana rows after every fourteen days. The shoot prunings of the three agroforestry tree species used in this study have been reported to have quality chemical properties of N, P, K, Mg and Ca (Appendix 8). Plot sizes measured 9m by 12 m, holes for bananas were dug at a spacing of 2x2 feet and added 200g NPK fertilizer 200g of Nitrogen Phosphorus potassium (NPK) (N=14%, P=29%,K=6%, S=4%, Zn=0.1%, Cao=4%, B=0.1% and MgO= 1%) + 20 kg cow dung manure whose chemical composition was pH 9.6, N=12.8, P = 1.78, K = 1.14, Ca = 3.47 and Mg =1.36 (Appendix 7) + 20 kg of top soil before planting in the Banana. Spacing of bananas in agroforestry treatments was 3m x 3m, monocropped banana 3m x 2.5m, maize and banana was 6m x 2.5m and 0.75m by 0.30m in maize and 2 rows of banana x 4 within row in maize + banana+Agroforestry trees, (Appendix 1).

Plate 1: The research plot at study site, Maseno University farm at tassling stage. (Source, Photo taken by researcher).

3.3.1. Determination of plant growth parameters

Four banana plants and 15 maize plants in each treatment and replication were selected randomly using a zigzag method and tagged (Pierre *et al*. (2018). The growth parameters of the tagged plants were determined from 28 days after planting (DAP) until the maize plants attained physiological maturity and bananas at 143 DAT and 360 DAT for 1st and 2nd season of banana plants at an interval of 28 days so as to give sufficient time for decomposition of twig and leaf biomass prunings that was being pruned after two weeks.

3.3.1.1. Determination of maize and banana plant height

The height of four bananas and fifteen maize plants were measured in centimeter (cm) using a meter rule from the stem base or soil surface to shoot apex after every two weeks. The plant height was determined from 28 days after planting (DAP) until the maize plants attained physiological maturity and 143 DAT and 360 DAT for 1st and 2nd season of banana plants. Measurements were taken at an interval of 28 days up to the dough stage following procedure by International Board for Plant Genetic Resources (IBPGR, 1985). The plant height was then recorded.

3.3.1.2. Determination of number of green leaves per plant

The leaf number of four bananas and fifteen maize plants were determined by counting fully expanded leaves after 28 days after planting (DAP) until the maize plants attained physiological maturity and bananas at 143 DAT and 360 DAT for 1st and 2nd season of banana plants. The counting was done at intervals of 28 days following procedure by International Board for Plant Genetic Resources (IBPGR, 1985). The leaf numbers per selected plants in each plot were then recorded.

3.3.1.3. Determination of stem diameter

The stem diameter was determined from four bananas and fifteen maize plants per treatment and per replication after thinning with a vernier caliper at 28 days after planting for maize and bananas at 143 DAT and 360 DAT for 1st and 2nd. Measurement were taken after every 28 days after planting (DAP) until the maize plants attained physiological maturity following procedures by International Board for Plant Genetic Resources (IBPGR, 1985).

3.3.1.4. Determination of leaf area

The leaf width and length were measured using a 150-centimeter tape measure. The leaf length was measured along the leaf blade and the leaf width at the broadest point of the third youngest leaf from the four bananas and fifteen maize plants in each plot. Leaf area measurements began at 28 days after planting (DAP) until the maize plants attained physiological maturity and bananas at 143 DAT and 360 DAT for 1st and 2nd season of banana plants at an interval of 28 days according to the procedures by International Board for Plant Genetic Resources (IBPGR, 1985). The leaf area was then calculated as a product of length and width according to the formula of Musa *et al*. (2016) for banana leaf and Maddoni and Otegui, (1996) for maize as shown below.

$$LA = k (L \times W)$$

Where; LA = Leaf area

L = Length of the leaf from tip to the base of a leaf

W = Width of leaf from the broadest point of a leaf

k= k-coefficient constant for banana 0.5 and 0.75 for maize

3.3.2. Determination of gas exchange measurements

The TPS-200 Photosynthesis System, CIRAS-3 was used to measure net photosynthetic rate, intercellular CO_2 concentration and the transpiration rate from an area of 2.5 cm^2 of the third fully sun exposed leaf from the top of tagged maize and banana plants (Ludwik *et al*. 2017). The following were the specifications or adjustments during measurements, vapour pressure deficit (VPD) range of 1.3 – 2.6 kPa, cuvette air temperature range of 23-4 ^{0} ^{c} – 38.3 ^{0} ^{c} and the Photosynthetically active radiation (PAR) of 400 – 2200 µmol/m²/s. This data was collected in the morning between 10.00 - 12.00 hours to avoid high afternoon temperatures (Akunda and Kumar, 1982). The sensor clamp was opened up to clamp the leaf so that the aperture was at the centre of the leaf for 45 seconds to stabilize readings before releasing the leaf. This was repeated for all the plants sampled in all treatment and replicates after every two weeks. Measurements commenced 28 days after germination (DAG) for maize and readings taken consistently after every two weeks throughout the study period. Data on banana plants commenced 143 day after planting (DAP) during season 1 and 360 DAP during season 2 and recordings done after 28 days during the study period. The data collected was downloaded and analyzed.

3.3.3. Determination of total chlorophyll Content

Chlorophyll content Index of the 3rd fully sun exposed leaf from the top was estimated non-destructively using a portable chlorophyll meter SPAD-502 meter, Minolta, Japan. Fifteen maize and four banana plants were tagged in each treatment for data collection and the average calculated. Chlorophyll content index was recorded at 28 days after planting (DAP) until the maize plants attained physiological maturity and bananas at 143 DAP and 360 DAP for 1st and 2nd season of banana plants at an interval of 28 days

3.3.4. Determination of plant mineral nutrient content

The plant mineral analysis was done on the leaf, shoot, roots and maize cob for Ca, Mg, N, P and K at harvest. Maize plants from eight middle rows were harvested where five maize plants were randomly selected and partitioned in to leaves, shoots, roots, cobs and maize grains. Two banana plants were sampled and the leaves were analyzed for the same mineral nutrient uptake. The soil on the roots was removed by washing in tap water before they were oven dried to a constant weight at 72 ^{0}C for three days to get rid of any moisture. The plant materials were ground into powder form, placed in air tied plastic bags and taken to the laboratory for nutrient analysis.

3.3.4.1. Determination of Nitrogen content

Motsara and Roy (2008) procedures were followed to determine maize and banana nitrogen content at plant harvest. Plant sample of 0.5g were digested using di-acid in a Kjeldahl flask. 0.7g and 1.5g of copper sulphate and potassium sulphate respectively were added before adding 30 ml of 0.05M sulphuric acid. 30 ml of 0.05M sulphuric acid was added to the resultant solution and left for 15 minutes. The flask was cooled, 50 ml of distilled water added and transferred into distilling flask. 23 ml of 0.1M of hydrochloric acid was added. Methyl red indicator was added to the sodium hydroxide and heated for 15 minutes. Surplus acid in the extract was titrated with 0.1M NaOH. Blank solutions were prepared using similar amount of 0.1M hydrochloric acid. Nitrogen nutrient in plant tissue (N %) was calculated according to Motsara and Roy (2008) as below:

$$N\,\% = \frac{\{(V_1M_1 - V_2M_2) - (V_3M_1 - V_4M_2)\}}{W} \times \textit{dilution factor}\ (df) \quad \text{where}$$

V_1 – Volume of hydrochloric acid put in the samples.

V_2 – Volume of sodium hydroxide used during titration

V_3 – Volume of hydrochloric acid in the flask for blank

V_4 – Volume of sodium hydroxide used in titration of the blank

M_1 – Concentration of hydrochloric acid

M_2 – Concentration of sodium hydroxide

W – Sample weight

df – sample dilution factor

3.3.4.2. Measurement of phosphorus content

The procedures by Motsara and Roy (2008) were used to measure phosphorus content in maize and banana. Plant sample of 0.5g of maize and banana plant sample were dissolved in di-acid and volume topped up to 100ml. 5 ml of the 100ml were placed in a 50ml volumetric flask where standard phosphate solution was then added. 0.3 g of analytical-grade KH_2PO_4 was dissolved to make standard solution which was further diluted to 1000 ml. 10 ml of vanadomolybdate reagent were added to the volumetric flask and the volume topped up to 50ml using distilled water while shaking thoroughly. Atomic Absorption Spectrophotometer (Model UV-2600, Shimadzu-Japan) was used to determine the phosphorus content from the solution. The standard curve was drawn, by plotting it on a graph the absorbance of the sample solution (y-axis) versus the concentration of the standards (x-axis) which was a straight line. Using the absorbance measurement of the sample, it was read along the graph to the curve, and then read off the concentration which corresponds to the absorbance. This was the concentration of the phosphorus in the sample. The phosphorus concentration was read from the standard curve according to the absorbance range as shown below:

Phosphorus content (µg) contained in 0.5 g of sample = C x df; where;

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

df= dilution factor (1000).

3.3.4.3. Measurement of potassium content

Potassium content was measured at plant harvest from five plants from each plot using an atomic emission spectrophotometer (Model 969, UNICAM, Cambridge, UK) according to Motsara and Roy, (2008) protocols. Maize and banana plant samples of 0.5 g were dissolved in a di acid and then topped up to 100ml. 5 ml was placed in 50ml volumetric flask and 10ml of potassium chloride solution added. The content in the flask was topped up with distilled water. A standard curve was drawn, by plotting it on a graph the absorbance of the sample solution (y-axis) versus the concentration of the standards (x-axis) which was a straight line. Using the absorbance measurement of the sample, it was read along the graph to the curve, and then read off the concentration which corresponds to the absorbance. This was the concentration of the phosphorus in the sample. The absorbance was used to determine the amount of potassium content from the standard curve as per the formula below;

Potassium concentration (µg) in a sample = *C* x *df*; where;

C – Potassium concentration (µg/ml) as read from the standard curve;

df – sample dilution factor,

3.3.4.4. Measurement of magnesium content

The procedure by Motsara and Roy (2008) was used to determine magnesium content of maize and banana. The plant sample of weight 0.5 g was dissolved in a di-acid and topped up to 100 ml. 5 ml of the solution was mixed with 10 ml of the standard magnesium reagent in a 50 ml volumetric flask. 10 µm Mg/ml was made by diluting 10 ml of the resultant solution with 100 ml of de-ionized water. The magnesium absorbance was determined by Atomic Absorption Spectrophotometer (Model UV-2600, Shimadzu-Japan). The absorbance range and the standard curve was then used to ascertain the magnesium concentration in the sample as per the formula below;

Magnesium content in µm in 0.5 g of sample = C x df. Where;

C = Magnesium concentration (µm/ml) read from the standard curve; df = Dilution factor.

3.3.4.5. Measurement of calcium content

Maize and banana plant samples of 0.5 g were dissolved in a di-acid and then topped to 100 ml volume. 5 ml of the solution was then put in a 50 ml volumetric flask. 5 ml of the resultant solution was mixed with 10 ml of Calcium carbonate standard solution reagent and the volume topped up to 50 ml and finally diluted to 1000 ml with de-ionized water. The content in the volumetric flask were diluted to 1000 ml with the distilled water. Absorbance of mixture was read in Atomic Absorption Spectrophotometer (Model UV-2600, Shimadzu-Japan) and the content was determined by use of the formular.

Calcium concentration in 0.5 g of sample = C x df

Where; C = Ca concentration (µm/ml) read from the standard curve;

df = Dilution factor.

3.3.5. Determination of yield and yield component responses

3.3.5.1. Harvest yield for maize and banana

Eight middle rows of maize from each treatment were harvested and the maize weight determined with a spring balance. One fully matured banana per treatment was harvested and weighed.

3.3.5.2. Yield component responses

Total number of plants harvested were determined by physically counting the number of plants harvested from the eight middle rows from each treatment. The total number of maize with cobs, total number of maize without cobs, total number of rotten maize cobs and total number of fresh maize cobs were determined through physical counting and their numbers recorded for each treatment (IBPGR 1985). The banana bunch weight was determined using spring balance, number of hands and fingers per bunch were physically counted and recorded. The finger length was determined from five fingers randomly selected per hand in the bunch.

3.3.5.3. Determination of biomass production for the whole plant

Five maize plants were randomly selected from each treatment at plant harvest, uprooted and partitioned into different plant parts such as roots, stem, leaves, maize cob and maize grains. The roots were rinsed with tap water and immersed in a bucket of water to remove soil that had adhered to the root surfaces. The plant parts were oven dried at 72 ^{0}C to a constant weight. The dry weight was then determined using balance (Denver instrument XL-3100).

3.3. Data analysis

Analysis of Variance (ANOVA) using Genstat statistical package version 15.2 was used to analyze the data. Fischers' protected LSD test at 95% confidence level was used to separate the means. Correlation analysis was conducted to compare the relationship between intercellular CO_2 concentration, transpiration rate, plant height, leaf area and net photosynthetic rates.

CHAPTER FOUR

RESULTS

4.1 Effect of intercropping maize and banana with agroforestry tree species on maize plant height

There was increase in the maize plant height over time (Table 4.1). The maize intercropped with *Sesbania sesban* with bananas (MBS) were significantly (P≤0.05) taller than those under maize intercropped with banana and *Leucaena diversifolia* (MBL) and maize intercropped with banana and *Calliandra callothyrsus* (MBC) treatments during the 1st season at 84 DAP (Table 4.1). The maize under MBS did not show significant difference in plant height from the maize in MF, M and MB treatments respectively. In the 2nd season, MBS treatment recorded tallest maize plants which were not significantly different from the rest of the treatments at 84 DAP (Table 4.2). The maize under agroforestry trees were taller in comparison to other treatments.

4.2 Effect of intercropping maize and banana with agroforestry tree species on maize leaf area

There was an increasing trend in the leaf area of maize over time (Table 4.1 and 4.2). There were no significant difference (P≤0.05) in maize leaf area among the treatments for both seasons (Table 4.1 and 4.2). No significant differences in leaf area were noted among treatments, however, the highest leaf areas were recorded under MBS and MF treatments at 84 DAP during 1st season. During 2nd season, the largest leaf areas were recorded under MBS and MF. The least leaf area were registered under maize without fertilizer application (M) during the two seasons however, it was not significantly different from those treatments that registered larger leaf areas.

4.3 Effect of intercropping maize and banana with agroforestry tree species on maize leaf number

The number of green leaves increased with the number of days after planting (DAP). The highest number of leaves were observed under MBS at 84 DAP in 1st season (Table 4.1). The number of green leaves at 84 DAP was however not significantly different from the rest of the treatments. In the 2nd season a similar trend was reported, however the highest number of leaves were recorded under MBS, MBL, MF and M treatments respectively but there were not significantly different from the rest of the treatments (Table 4.2).

4.4 Effect of intercropping agroforestry tree species on maize stem diameter

The maize stem diameter increased with an increase in the number of days after planting (DAP). The largest stem diameters were recorded under MBL and MF treatments, which were significantly different ($P \leq 0.05$) from MBC treatment during season one (Table 4.1). However, MBL and MF treatments were not significantly differently from MB, MBL, MBS and M treatments. The maize under MBC treatment recorded the least maize stem diameters. In the 2nd season, significantly larger stem diameters for maize were recorded in MBS and MF treatments (Table 4.2). However, it was not significantly different from the maize stem diameters under MBL and M treatments. The lowest maize stem diameters were recorded under MBC treatment for both seasons.

Table 4.1. Effect of intercropping maize and banana with agroforestry tree species on maize growth during the first season

Parameter	Treatment	28 DAP	56 DAP	84 DAP
Height (cm)	M+B	30.6 b	42.9 ab	84.2 ab
	M+B+C	24.3 b	33.2 b	58.6 b
	M+B+L	29.2 b	37.3 ab	71.8 b
	M+B+S	42.8 a	56.6 a	133.4 a
	M+F	32.4 ab	46.1 ab	102.1 ab
	M Alone	31.7 ab	47.6 ab	99.0 ab
	LSD	**11.4**	**20.1**	**51.8**
Leaf Area (cm^2)	M+B	169.0 a	299.0 a	379.0 a
	M+B+C	197.0 a	340.0 a	394.0 a
	M+B+L	139.0 a	303.0 a	362.0 a
	M+B+S	159.0 a	282.0 a	422.0 a
	M+F	173.0 a	299.0 a	422.0 a
	M Alone	188.0 a	380.0 a	361.0 a
	LSD	**90.6**	**121.9**	**94.6**
Leaf Number	M+B	7.7 a	9.5 a	9.8 a
	M+B+C	7.8 a	9.2 a	10.0 a
	M+B+L	7.8 a	9.8 a	11.2 a
	M+B+S	6.8 a	8.3 a	12.0 a
	M+F	8.1 a	9.8 a	11.1 a
	M Alone	8.1 a	9.3 a	11.1 a
	LSD	**1.5**	**1.6**	**1.9**
Stem Diameter (cm)	M+B	1.0 ab	1.2 a	2.3 ab
	M+B+C	1.0 ab	1.1 a	2.1 b
	M+B+L	1.2 a	1.4 a	2.4 a
	M+B+S	0.8 b	1.0 a	2.2 ab
	M+F	1.1 ab	1.2 a	2.4 a
	M Alone	1.1 ab	1.2 a	2.2 ab
	LSD	**0.39**	**0.43**	**0.18**

Treatments with same letter along the columns are not significantly different following LSD at $p \leq 0.05$. DAP- Days after planting of maize.

Table 4.2. Effect of intercropping maize and banana with agroforestry tree species on maize growth during second season

Parameter	Treatment	28 DAP	56 DAP	84 DAP
Height (cm)	M+B	56.8 a	76.0 b	162.0 a
	M+B+C	73.4 a	140.0 ab	221.0 a
	M+B+L	92.9 a	130.0 ab	233.0 a
	M+B+S	85.5 a	162.0 a	240.0 a
	M+F	96.0 a	147.0 ab	232.0 a
	M Alone	66.9 a	116.0 ab	212.0 a
	LSD	**46.5**	**79.1**	**101.0**
Leaf Area (cm^2)	M+B	139.0 a	137.4 a	276.0 a
	M+B+C	119.0 a	151.8 a	268.0 a
	M+B+L	235.0 a	161.4 a	232.0 a
	M+B+S	225.0 a	124.3 a	284.0 a
	M+F	243.0 a	127.5 a	332.0 a
	M Alone	153.0 a	117.3 a	234.0 a
	LSD	**146.9**	**50.7**	**153.0**
Leaf Number	M+B	9.3 b	9.7 a	10.9 a
	M+B+C	10.3 ab	9.8 a	11.1 a
	M+B+L	10.3 ab	10.2 a	12.0 a
	M+B+S	11.3 a	11.3 a	12.1 a
	M+F	11.2 a	12.1 a	12.5 a
	M Alone	10.3 ab	10.1 a	11.6 a
	LSD	**1.3**	**3.3**	**3.1**
Stem Diameter (cm)	M+B	1.4 c	1.9 c	2.0 bc
	M+B+C	1.2 c	1.8 c	1.7 c
	M+B+L	1.4 c	2.0 bc	2.1 ab
	M+B+S	2.1 ab	2.3 ab	2.5 a
	M+F	2.2 a	2.4 ab	2.5a
	M Alone	1.5 bc	2.0 bc	2.3 ab
	LSD	**0.53**	**0.49**	**0.42**

Treatments with same letter along the columns are not significantly different following LSD at $p \leq 0.05$. DAP- Days after Planting of maize

4.5 Effect of intercropping maize and banana with agroforestry tree species on banana height

Banana height increased with an increase in the number of days after transplanting. During the 1st season the tallest banana plants were recorded under MBL and MBS treatments (Table 4.3). Nonetheless, there were no significant differences under all treatments at 199 DAT. In the 2nd season, tallest banana plants were reported at 416 DAT although not significantly different from the rest of the treatments (Table 4.4). The least banana height was recorded in banana monocrop treatment throughout the days of measurement. The banana height under agroforestry tree species treatments recorded superior heights compared to the rest of the treatments.

4.6 Effect of intercropping maize and banana with agroforestry tree species on banana leaf area

There was significant differences ($P \leq 0.05$) during season one at 143 DAT in MBS, MBL and B and at 171 DAT in MBS. During the second season, significant differences were recorded at 143 DAT and 171 DAT. The banana leaf area increased with increase in the number of days after transplanting. However, few reductions were noted, under banana monocrop and in MBL treatments during the last day of measurement. During the 1st season MBL treatments recorded the largest leaf areas of 4615 cm^2 at 199 DAT though not significantly different from other treatments (Table 4.3). There were no significant differences of treatments on the leaf areas during the period of observation period. Monocropped banana had the smallest leaf areas. The agroforestry tree species treatments recorded larger leaf areas of banana than the banana and maize-banana treatments. In the 2nd season, MBS recorded the largest leaf areas at 416 DAT but not significantly different from the rest of the treatments (Table 4.4). The banana intercropped with agroforestry tree species had larger leaf areas than those without agroforestry tree intercrop.

4.7 Effect of intercropping maize and banana with agroforestry tree species on banana number of green leaves

There was increase in the number of green leaves as number of days after transplanting (DAT) increased. The highest number of green leaves were recorded under MBS and MBL at 199 DAT which was not significantly different from the other treatments during 1st season (Table 4.3). The monocropped banana recorded lowest number of green leaves. The bananas under agroforestry tree treatments recorded higher number of green leaves when compared to MB and B. Similarly, during the 2nd season the agroforestry tree treatments resulted to increased leaf number, MBS reporting more green leaves at 416 DAT (Table 4.4). However, it was not significantly different with the rest of the treatments apart from MB at 360 DAT and B at 416 DAT. Additionally, the banana plants under B and MBL treatments recorded lower number of green leaves at 388 DAT and 416 DAT during the entire period of measurement.

4.8 Effect of intercropping maize and banana with agroforestry tree species on banana stem diameter

The banana stem diameter increased with an increase over time (Table 4.3). The MBS treatment recorded largest stem diameters at 199 DAT during the 1st season though not significantly different (Table 4.3). The banana monocrop reported the least stem diameters at the 199 DAT. During the 2nd season, banana plants under MBS recorded large stem diameters at 416 DAT (Table 4.4).

Table 4.3 Effect of intercropping maize and banana with agroforestry tree species on banana growth during the first season

Parameter	Treatment	143 DAT	171 DAT	199 DAT
Height (cm)	B	89.2 a	102.2 ab	117.6 a
	M+B	89.8 a	103.7 ab	113.3 a
	M+B+C	88.3 a	100.6 b	112 a
	M+B+L	88.5 a	109.7 ab	129.4 a
	M+B+S	93.1 a	120.3 a	128.2 a
	LSD	**23.27**	**19.03**	**35.71**
Leaf Area (cm^2)	B	1451 a	1842 a	2570 a
	M+B	1578 a	2181 a	3846 a
	M+B+C	1581 a	1751 a	2782 a
	M+B+L	1393 a	2035 a	4615 a
	M+B+S	1801 a	2206 a	3704 a
	LSD	**480.2**	**645.7**	**1429.1**
Number of Leaves	B	6.7 a	7.4 b	7.5 a
	M+B	5.7 b	7.2 b	7.9 a
	M+B+C	6.7 ab	7.9 b	7.9 a
	M+B+L	7.1 a	7.6 b	9.5 a
	M+B+S	8.7 a	8.7 a	9.2 a
	LSD	**2.9**	**1.6**	**5.62**
Stem Diameter (cm)	B	7.1 a	7.5 a	7.8 a
	M+B	7.4 a	7.9 a	8.0 a
	M+B+C	7.2 a	7.6 a	8.1 a
	M+B+L	7.3 a	7.8 a	8.1 a
	M+B+S	7.6 a	7.9 a	8.2 a
	LSD	**1.133**	**0.99**	**1.204**

Treatments with same letter along the columns are not significantly different according to LSD at $p \leq 0.05$. DAT- Days after Transplanting of bananas

Table 4.4. Effect of intercropping maize and banana with agroforestry tree species on banana growth during the second season

Parameter	Treatment	360 DAT	388 DAT	416 DAT
Height (cm)	B	146.0 a	147.0 a	155.0 a
	M+B	149.0 a	161.0 a	178.0 a
	M+B+C	165.0 a	173.0 a	189.0 a
	M+B+L	176.0 a	182.0 a	193.0 a
	M+B+S	186.0 a	208.0 a	219.0 a
	LSD	**123.4**	**122.0**	**116.4**
Leaf Area (cm^2)	B	2500.0 a	2550.0 a	2923.0 a
	M+B	3061.0 a	3249.0 a	3667.0 a
	M+B+C	2584.0 a	3033.0 a	3702.0 a
	M+B+L	2602.0 a	2843.0 a	2765.0 a
	M+B+S	3241.0 a	3761.0 a	3481.0 a
	LSD	**2096.9**	**2671.1**	**2629.9**
Number of Leaves	B	6.8 ab	7.4 a	6.6 b
	M+B	5.8 b	7.2 a	7.6 ab
	M+B+C	6.8 ab	7.3 a	8.1 ab
	M+B+L	7.1 ab	7.9 a	6.8 ab
	M+B+S	9.6 a	9.0 a	10.3 a
	LSD	**2.9**	**3.5**	**3.6**
Stem Diameter (cm)	B	7.8 b	8.6 a	8.8 a
	M+B	8.0 ab	8.6 a	9.0 a
	M+B+C	8.2 ab	8.7 a	9.1 a
	M+B+L	8.2 ab	8.5 a	8.5 a
	M+B+S	9.3 a	9.9 a	10.0 a
	LSD	**1.3**	**2.3**	**2.2**

Treatments with same letter along the columns are not significantly different according to LSD at $p \leq 0.05$. DAT- Days after Transplanting of bananas

4.8.1 Effect of intercropping maize and banana with agroforestry tree species on the maize net photosynthesis (µmol CO_2 m^{-2} s^{-1})

The highest net photosynthesis was shown by MBS treatment at 84 DAP, however it was not significantly different from rest of treatments at the same observation stage during the first season (Table 4.5). The highest net photosynthetic rate was reported under maize in agroforestry tree treatments and the lowest under the monocropped maize treatment. Among all the treatments, maize under *Sesbania sesban* tree species had higher net photosynthesis. It was however noted that the net photosynthetic rate significantly reduced at 56 DAP compared to 28 DAP and 84 DAP.

During the second season significantly ($P \leq 0.05$) highest net photosynthesis was reported under MBS at 56 DAP which was not significantly different from that of MBL and MBC during the same observation stage (Table 4.6). The maize under agroforestry tree treatments recorded highest net photosynthesis than those treatments without agroforestry trees during the study period. The lowest net photosynthetic rate were reported under M and in MB treatments. On the overall, significantly lowest net photosynthetic rates were observed at 84 DAP in comparison to the similar observation period in the 1st season.

4.8.2 Effect of intercropping maize and banana with agroforestry tree species on the maize intercellular Carbon dioxide concentration (µmol CO_2 mol^{-1})

There was no consistent trend in the intercellular CO_2 concentration during the study period. The intercellular CO_2 concentration among the MBS and MBL showed higher values at 84 days after planting (DAP) (Table 4.5). However, intercrop treatments with agroforestry tree species recorded the highest intercellular CO_2 concentration with MBS recording the highest.

In the second season, significant differences were observed during the entire observation period (Table 4.6). MBS had significantly higher intercellular CO_2 concentration at 84 DAP as compared to the other treatments. Similarly, the maize treatments without agroforestry trees recorded lower intercellular CO_2 concentration compared to those with agroforestry trees.

4.8.3 Effect of intercropping maize and banana with agroforestry tree species on the maize transpiration rate (mmol H_2O m^{-2} s^{-1})

The transpiration rates of maize crops during 1st season showed no significant differences among treatments in all observation stages (Table 4.5). However, maize plants under agroforestry tree intercrop had higher transpiration rates with MBS recording high rates compared to other treatments. The M treatment showed low transpiration rates. High transpiration rates were recorded at early growth stages at 28 DAP during the first observation stage.

During the 2nd season significant differences was observed at 28 DAP and 84 DAP (Table 4.6). MBS treatment consistently recorded high transpiration rate throughout the days of measurement. In the same way as the 1st season, higher transpiration rates were recorded during the first observation stages at 28 DAP. Maize plants planted in agroforestry trees showed high transpiration rates for the two seasons during all observation stages compared to other treatments. The maize without fertilizer application (M) treatment had the lowest transpiration rates during the two seasons. The highest transpiration rate were recorded under MBS treatments for both seasons. However, the transpiration rates values tremendously reduced in the second season especially at the late stages of development. Transpiration rates under the MBC treatments recorded the lowest rates among the agroforestry treatments during the entire period of study.

Table 4.5. Intercropping effects on maize and banana with agroforestry tree species on maize net photosynthesis, intercellular CO_2 concentration and transpiration rate during the during the first season

Parameters	Treatment	28 DAP	56 DAP	84 DAP
Net Photosynthesis (μmol CO_2 m^{-2} s^{-1})	M+B	16.4 a	3.2 b	39.0 a
	M+B+C	35.9 a	9.7 ab	36.0 a
	M+B+L	25.8 a	10.9 ab	39.0 a
	M+B+S	15.3 a	13.2 a	53.0 a
	M+F	14.3 a	5.1 b	36.0 a
	M Alone	15.1 a	9.2 ab	36.0 a
	LSD	**30.9**	**17.3**	**21.2**
Intercellular CO_2 Concentration (μmol CO_2 m^{-2} s^{-1})	M+B	59.0 a	49.0 a	41.0 a
	M+B+C	31.0 b	31.0 a	47.0 a
	M+B+L	30.2 b	62.0 a	61.0 a
	M+B+S	32.4 ab	59.2 a	67.0 a
	M+F	28.8 b	41.0 a	49.0 a
	M Alone	33.2 ab	41.2 a	50.1 a
	LSD	**27.3**	**35.2**	**29.9**
Transpiration Rate (mmol H_2O m^{-2} s^{-1})	M+B	16.8 a	7.4 a	8.1 a
	M+B+C	13.1 a	7.1 a	7.3 a
	M+B+L	15.8 a	8.0 a	8.2 a
	M+B+S	16.9a	8.0 a	8.5 a
	M+F	11.9 a	7.2 a	6.5 a
	M Alone	12.7 a	6.5 a	7.8 a
	LSD	**6.7**	**2**	**3.1**

Treatments with the same letter along the columns are not significantly different according to LSD at $p \leq 0.05$. DAP- Days after planting of maize.

Table 4.6. Effect of intercropping maize and banana with agroforestry tree species on maize net photosynthesis, intercellular CO_2 concentration and transpiration during the during the second season

Parameters	Treatment	28 DAP	56 DAP	84 DAP
Net Photosynthesis (µmol CO_2 m^{-2} s^{-1})	M+B	1.6 e	11.2 b	2.2 a
	M+B+C	3.8 c	9.7 ab	4.0 a
	M+B+L	5.2 b	10.9 ab	7.3 a
	M+B+S	5.9 a	13.2 a	5.7 a
	M+F	2.3 d	12.2 ab	5.3 a
	M Alone	0.6 f	11.1 b	3.7 a
	LSD	**5.9**	**8.7**	**8.9**
Intercellular CO_2 Concentration (µmol CO_2 m^{-2} s^{-1})	M+B	58.0 ab	23.6 b	14.6 b
	M+B+C	40.0 b	32.1 ab	28 b
	M+B+L	22.0 b	19.6 b	19.6 b
	M+B+S	73.0 a	55.2 a	57.2 a
	M+F	33.0 b	16.5 b	16.5 b
	M Alone	49.0 b	28.5 ab	14.2 b
Transpiration Rate (mmol H_2O m^{-2} s^{-1})	**LSD**	**61.6**	**45.5**	**43**
	M+B	4.1 b	4.0 a	0.3 f
	M+B+C	4.8 b	1.8 a	2.6 d
	M+B+L	7.6 b	2.2 a	3.6 c
	M+B+S	8.2 a	7.3 a	4.9 a
	M+F	4.9 b	5.3 a	4.3 b
	M Alone	3.6 b	1.6 a	1.4 e
	LSD	**5.2**	**8.9**	**0.3**

Treatments with same letter along the columns are not significantly different according to LSD at $p \leq 0.05$. DAP- Days after planting of maize

4.8.4 Effect of intercropping maize and banana with agroforestry tree species on banana net photosynthesis (µmol CO_2 m^{-2} s^{-1})

There were significant differences ($P \leq 0.05$) in net photosynthesis of bananas among the treatments in the first season at 171 DAT and 199 DAT (Table 4.7). MBL treatment had slightly higher net photosynthesis of 62.3 at 171 DAT compared to MBC and MBL treatments. Banana plants under agroforestry tree treatments had higher net photosynthetic rates than the ones in B and MB treatments.

Significantly, higher differences were observed 388 DAT during the second season with net photosynthetic rate of 70 (Table 4.8). High net photosynthetic rates were shown under banana crops intercropped with agroforestry trees compared to monocropped bananas and banana-maize intercrop. The MBS and MBL had slightly higher net photosynthetic rates than the rest of the treatments during the study period. The B treatment had the least net photosynthesis.

4.8.5 Effect of intercropping maize and banana with agroforestry tree species on banana intercellular CO_2 concentration (µmol CO_2 mol^{-1})

The banana intercellular CO_2 concentration were not significantly influenced by the treatments throughout the study period (Table 4.7 and Table 4.8). However, the banana plants under agroforestry trees had high intercellular CO_2 concentration followed by the maize banana intercrop and the least intercellular CO_2 concentration was measured under monocrop banana plants during the study period. MBS treatments had slightly higher intercellular CO_2 concentration at 171 DAT and 360 DAT for 1st and 2nd season respectively, however it was not significantly different from MBC and MBL treatments during days of measurement. The monocrop banana treatment showed the lowest intercellular CO_2 concentration throughout the days of measurement.

4.8.6 Effect of intercropping maize and banana with agroforestry tree species on banana transpiration rates (mmol H_2O m^{-2} s^{-1})

There were significant differences ($P \leq 0.05$) in transpiration rates banana leaves among the treatments during the first season at 143 and 199 DAT (Table 4.7). MBS had the highest transpiration rates of 14.1 at 143 DAT (Table 4.7). The bananas under agroforestry tree species had the highest transpiration rates. The monocropped banana had the least transpiration rates.

During the second season, significant differences ($P \leq 0.05$) in the banana leaf transpiration rates were shown under MBS treatment throughout the observation stages (Table 4.8). The highest transpiration rate were observed under MBS with 13.4 at 360 DAT. High transpiration rates was observed under banana crops in agroforestry trees plots compared to monocropped bananas and banana intercropped with maize. Bananas planted under the MBL and MBS comparatively had slightly higher transpiration rates than the ones in MBC.

Table 4.7 Effect of intercropping maize and banana with agroforestry tree species on net photosynthesis, intercellular CO_2 concentration and transpiration during the during the first season

Parameters	Treatment	143 DAT	171 DAT	199 DAT
Net Photosynthesis (µmol CO_2 m^{-2} s^{-1})	B	10.5 a	14.9 b	15.4 b
	M+B	17.6 a	15.9 b	16.1b
	M+B+C	10.5 a	34.2 a	17.9 ab
	M+B+L	22.1 a	62.3 a	24 ab
	M+B+S	20.2 a	45.1 a	30.2 a
	LSD	**15.2**	**20.3**	**14.1**
Intercellular CO_2 Concentration (µmol CO_2 m^{-2} s^{-1})	B	38.0 a	19.0 a	30.0 a
	M+B	25.0 a	30.0 a	73.0 a
	M+B+C	39.0 a	74.0 a	78.0 a
	M+B+L	49.0 a	42.0 a	70.0 a
	M+B+S	25.0 a	70.0 a	92.0 a
	LSD	**40.9**	**57.1**	**30.7**
Transpiration Rate (mmol H_2O CO_2 m^{-2} s^{-1})	B	6.8 a	10.7 a	3.9 d
	M+B	9.8 ab	11.0 a	4.0 d
	M+B+C	12.7 a	10.6 a	4.7 c
	M+B+L	9.6 ab	12.5 a	5.3 b
	M+B+S	14.1 a	13.5 a	6.3 a
	LSD	**5.9**	**4.5**	**0.2**

Treatments with the same letter along the columns are not significantly different according to LSD at $p \leq 0.05$. DAT- Days after transplanting of bananas

Table 4.8 Effect of intercropping maize and banana with agroforestry tree species on banana the net photosynthesis, intercellular CO_2 concentration and transpiration during the second season

Parameters	Treatment	360 DAT	388 DAT	416 DAT
Net Photosynthesis (µmol CO_2 m^{-2} s^{-1})	B	7.8 b	41.0 a	24.5 a
	M+B	9.6 b	45.0 a	45.1 a
	M+B+C	12.2 a	54.0 a	54.8 a
	M+B+L	7.8 b	70.0 a	46.3 a
	M+B+S	11.6 b	63.0 a	50.2 a
	LSD	**7.6**	**38.1**	**33**
Intercellular CO_2 Concentration (µmol CO_2 m^{-2} s^{-1})	B	23.0 a	41.0 a	19.0 a
	M+B	24.0 a	41.0 a	47.0 a
	M+B+C	45.0 a	42.0 a	41.0 a
	M+B+L	36.0 a	41.0 a	47.0 a
	M+B+S	55.0 a	49.0 a	51.0 a
	LSD	**33.4**	**11.2**	**32.1**
Transpiration Rate (mmol H_2O m^{-2} s^{-1})	B	9.9 c	5.1 b	3.9 d
	M+B	9.6 c	4.9 b	4.0 d
	M+B+C	11.8 b	4.9 b	4.7 c
	M+B+L	9.9 c	5.3 b	5.3 b
	M+B+S	13.4 a	7.4 a	6.3 a
	LSD	**0.5**	**0.8**	**0.2**

Treatments with same letter along the columns are not significantly different according to LSD at $p \leq 0.05$. DAT- Days after transplanting of bananas

4.9 Effect of intercropping maize and banana with agroforestry tree species on maize total chlorophyll content (%)

There were significant differences ($p \leq 0.05$) on the chlorophyll content for both seasons among the treatments (Table 4.9). There was a rise in the total chlorophyll content as the number of days after planting increased up to 56 DAP. The highest chlorophyll content was observed at 56 DAP compared to other days of measurement for both season 1 and 2. The lowest chlorophyll content was shown at 84 DAP. There was significant difference in MF at 56 DAP however, it was not significantly different from MBS and MBL. The least chlorophyll content was measured under monocrop maize without fertilizer application treatment. The MBL and MBS treatments performed better than the MBC with MBS posting the highest chlorophyll content throughout among the agroforestry treatments.

Though the maize with fertilizer treatment showed the highest total chlorophyll content, it was not significant to that of MBS treatment at 56 DAP during 2nd season. Maximum chlorophyll content was observed at 56 DAP in all treatments during the two seasons of study. There was a decline on the chlorophyll content at 84 DAP during the two seasons.

Table 4.9. Effect of intercropping maize and banana with agroforestry tree species on maize chlorophyll contents (µmol) during the first and second seasons

Seasons	Treatment	28 DAP	56 DAP	84 DAP
Season 1	M+B	37.1 c	43.5 c	32.9 b
	M+B+C	37.2 c	43.6 bc	32.3 b
	M+B+L	40.4 ab	48.0 abc	34.8 b
	M+B+S	40.3 ab	48.4 ab	35.3 b
	M+F	43.1 a	49.5 a	40.8 a
	M Alone	38.6 bc	46.9 abc	35.4 b
	LSD	**3.0**	**5.0**	**4.6**
Season 2	M+B	41.4 b	42.3 bc	39.4 ab
	M+B+C	37.1 c	40.3 c	34.7 b
	M+B+L	40.5 b	42.8 bc	36.9 b
	M+B+S	41.5 b	45.2 ab	39.4 ab
	M+F	46.8 a	48.0 a	45.5 a
	M Alone	40.2 b	41.5 bc	36.3 b
	LSD	**2.8**	**4.8**	**5.47**

Treatments with same letter along the columns are not significantly different according to LSD at $p \leq 0.05$. DAP- Days after Planting of maize

4.9.1. Effect of intercropping maize and banana with agroforestry tree species on banana total chlorophyll content

The chlorophyll contents in the banana crop showed significant differences ($p \leq 0.05$) under the MBS treatments at 199 DAT for the first season, though not significantly different from all the other treatments except under MB at 199 DAT (Table 4.10). There was minimal differences between the chlorophyll content under the agroforestry treatments. MBS measured higher banana chlorophyll content compared to the other treatments.

Significantly ($p \leq 0.05$), higher banana chlorophyll content were observed only at 416 DAT under MBS treatments in the 2nd season (Table 4.10). However, this was not significantly different from the rest of the treatments except the MB and MBC treatments. Consistently high chlorophyll content were observed in the MBS and the lowest chlorophyll content were under the B treatment during the days of measurement for both seasons. Despite high amount of chlorophyll content under MBS treatment, the difference with other treatments was minimal.

Table 4.10. Effect of intercropping maize and banana with agroforestry tree species on banana chlorophyll contents (µmol) during the first and second seasons

Seasons	Treatment	143 DAT	171 DAT	199 DAT
Season 1	B	53.8 a	49.2 a	52.9 ab
	M+B	53.2 a	54.1 a	51.3 b
	M+B+C	55.1 a	52.6 a	52.1 ab
	M+B+L	53.1 a	49.9 a	51.6 ab
	M+B+S	54.2 a	55.9 a	57.3 a
	LSD	**3.7**	**7.2**	**5.8**
	Treatment	**360 DAT**	**416 DAT**	**488 DAT**
Season 2	B	45.8 a	51.2 a	54.2 a
	M+B	49.8 a	49.5 bc	55.6 a
	M+B+C	48.4 a	48.5 c	53.3 a
	M+B+L	49.1 a	52.1 ab	55.7 a
	M+B+S	48.6 a	54.0 a	58.1 a
	LSD	**5.1**	**3.3**	**5.9**

Treatments with same letter along the columns are not significantly different according to LSD at $p \leq 0.05$. DAT- Days after transplanting of bananas

4.9.2. Effect of intercropping maize and banana with agroforestry tree species on maize cob mineral content

The cob nutrient contents recorded significant ($p \leq 0.05$) differences among the treatments (Table 4.11). The maize plants intercropped with agroforestry trees showed higher cob nutrient content in comparison to other treatments. During 1st season, cob calcium content under MBL and MBS treatments showed significantly higher levels compared to MBC, MB, MF and M treatments. However, cob calcium in MBC was higher than those under MB, MF and M treatments.

Significantly higher ($p \leq 0.05$) cob calcium levels were measured under MBS compared to other treatments in season 2. The least cob calcium content was recorded in MF however; this was not significantly different from those under M, MB, MBC and MF.

The maize cob potassium content showed significant differences among the treatments ($p \leq 0.05$) (Table 4.11). MBL and MBS had significantly higher cob potassium content than the cob potassium content in all treatments, though not significantly different from those of MBS and MBL. The least potassium content was recorded under maize with no fertilizer treatment though not significant to MF and MB. In the second season, maize potassium cob content showed significantly greater content under MBS (Table 4.11). MBL, MBC and MB showed no significant differences in cob potassium with MBL exhibiting higher content than MBC. The least cob potassium content was measured under maize with no fertilizer treatment.

The maize cob magnesium nutrient uptake showed significant difference ($p \leq 0.05$) in MBS and MBL treatments during 1st season (Table 4.11). The highest cob magnesium content was measured under MBS followed by MBL and MBC among those under agroforestry tree species. The least magnesium cob content was shown under MB, MF and M treatments. MBS treatment performed better than the MF, MBL and MBC treatments. In the 2nd season, significantly high ($p \leq 0.05$) cob magnesium content was measured under MBS and it was not significantly different from MF (Table 4.11). Among agroforestry trees treatments, MBL had the second best and it was not significantly different from MBC. The least magnesium content was under maize with no fertilizer treatment which was not significantly different from maize banana (MB) treatment.

The MBS showed high cob nitrogen content, though not significantly different from other treatments apart from in the MBL which reported least cob magnesium content (Table 4.11).

During the 2nd season, highest nitrogen was recorded under MBC which was not significantly different from MB, MBS, MF and M treatment and significantly different from MBL which recorded the least cob nitrogen content.

Significant differences ($p \leq 0.05$) of maize cob phosphorus nutrient uptake was measured in MBS, MBL, MB and MF treatments in the 1st season with MBS recording the highest cob nitrogen content (Table 4.11). Highest maize cob nitrogen content were consistently recorded under agroforestry tree treatments. In the 2nd season, MBS and MF treatments showed significantly higher cob phosphorus. MB and M registered lowest phosphorus content, which was not significantly different from MBL and MBC treatments.

Table 4.11. Effect of intercropping maize and banana with agroforestry tree species on maize cob nutrient contents (mg/kg) during 1st and 2nd season

Season	Treatment	Ca	K	Mg	N	P
Season 1	M+B	0.08 c	6.57 bc	0.02 d	5.1 ab	0.37 ab
	M+B+C	0.11 b	5.83 bc	0.03 bc	5.83 ab	0.38 b
	M+B+L	0.13 a	7.60 ab	0.04 ab	4.97 b	0.37 ab
	M+B+S	0.13 a	9.47 a	0.04 a	5.90 a	0.47 a
	M+F	0.08 c	6.43 bc	0.02 cd	5.60 ab	0.41 ab
	M Alone	0.07 c	4.58 c	0.02 cd	5.17 ab	0.34 b
	LSD	**0.02**	**2.60**	**0.01**	**0.88**	**0.10**
Season 2	M+B	0.08 c	6.37 bc	0.03 cd	5.27 ab	0.33 b
	M+B+C	0.09 bc	6.90 bc	0.03 bc	5.90 a	0.37 b
	M+B+L	0.10 b	7.20 b	0.04 bc	5.10 b	0.34 b
	M+B+S	0.13 a	9.30 a	0.05 a	5.77 ab	0.39 a
	M+F	0.07 c	6.27 c	0.04 ab	5.60 ab	0.42 a
	M Alone	0.08 bc	6.10 c	0.02 cd	5.23 ab	0.33 b
	LSD	**0.02**	**0.90**	**0.01**	**0.74**	**0.09**

Treatments with the same letter along the columns are not significantly different according to LSD at $p \leq 0.05$.

4.9.3 Effect of intercropping maize and banana with agroforestry tree species on maize grain mineral content

There were significant differences ($p \leq 0.05$) on maize grain calcium content under MBS, MF and MBL in the 1st season (Table 4.12). MBS had the highest grain calcium content while the least was under maize without fertilizer treatment (M). Similarly, during the 2nd season MBS and MF showed significantly high grain calcium content than all the treatments with maize without fertilizer treatment posting the least grain calcium content.

The MBS and MF treatments showed significant differences ($p \leq 0.05$) from the rest of the treatments for both 1st and 2nd season (Table 4.12). However, MBS showed highest grain potassium content while maize without fertilizer treatment had the least during the study period. Apart from the maize under fertilizer treatment, the agroforestry tree species treatments recorded the highest grain potassium content than the rest of the treatments for both seasons.

Significantly ($p \leq 0.05$) high grain magnesium content was registered under the MBS treatment only in season 1 (Table 4.12). The least content was recorded under the maize without fertilizer treatment. No significant differences were observed under the following treatments MBL, MBC, MB and MF. During the 2nd season, MBS and MF recorded significantly higher grain magnesium content while maize without fertilizer treatment recorded the least.

The highest nitrogen uptake were registered in MBS treatments in the 1st season; which was not significant to MBL and MF (Table 4.12). The M showed lower grain nitrogen uptake however, it was insignificant to MBC and MB. In the 2nd season, MBS and MF treatments showed significantly high grain nitrogen content (Table 4.12). MBL showed the 2nd highest grain nitrogen but was insignificant to MBC and MB and the least recorded under maize without fertilizer treatment.

There were significant differences ($p \leq 0.05$) on maize grain phosphorus nutrient uptake for both seasons under MBC, MBL, MBS and MF (Table 4.12). Highest maize grain phosphorus content were obtained under MBL in 1st season, MBS and MF during 2nd season. During the 1st season low grain phosphorus content were reported under MB and M. Treatments with agroforestry trees showed higher maize grain phosphorus compared to treatments without agroforestry trees during the days of measurement.

Table 4.12. Effect of intercropping maize and banana with agroforestry tree species on maize grain nutrient contents (mg/kg) during 1st and 2nd season

Season	Treatment	Ca	K	Mg	N	P
Season 1	M+B	0.34 bcd	3.40 c	0.81 bc	13.83 bc	1.87 c
	M+B+C	0.40 abc	3.53 bc	0.92 b	13.90 bc	2.73 a
	M+B+L	0.30 cd	3.97 b	0.90 b	14.53 ab	2.97 a
	M+B+S	0.46 a	4.83 a	1.12 a	15.30 a	2.87 a
	M+F	0.41 ab	4.71 a	0.97 b	15.20 a	2.87 a
	M Alone	0.30 d	2.80 d	0.66 c	13.27 c	2.17 bc
	LSD	**0.10**	**0.54**	**0.13**	**1.12**	**0.35**
Season 2	M+B	0.34 bc	3.40 b	0.79 c	13.77 bc	2.10 cd
	M+B+C	0.38 b	3.57 b	0.96 b	13.87 bc	2.70 a
	M+B+L	0.37 b	3.57 b	0.83 c	14.07 b	2.60 ab
	M+B+S	0.52 a	4.90 a	1.08 a	15.50 a	2.87 a
	M+F	0.57 a	4.23 a	1.08 a	15.63 a	2.87 a
	M Alone	0.29 c	3.07 b	0.73 d	13.47 c	1.93d
	LSD	**0.06**	**0.59**	**0.06**	**0.52**	**0.27**

Treatments with the same letter along the columns are not significantly different according to LSD at $p \leq 0.05$.

4.9.4 Effect of intercropping maize and banana with agroforestry tree species on maize leaves mineral content

There were significant differences ($p \leq 0.05$) in maize leaves calcium nutrient content in MBS, MBC and MF) during 1st season (Table 4.13). The MBS treatment recorded highest leaf nutrient content among all the treatments, however, it was not significantly different from MBC and MF. The least leaf calcium nutrient was measured under maize without fertilizer treatment. In the 2nd

season, MBC and MF recorded highest leaf calcium nutrient content that was not significantly different from MBL and MBS. The lowest leaf calcium content were recorded under M and MB treatments.

There were significant differences ($p \leq 0.05$) in maize leaf potassium nutrient content in MBS, MBC and MF which was significantly different from MB, MBL and M treatments during 1st seasons (Table 4.13). Maize under fertilizer treatment recorded highest potassium content but the difference with MBS treatment was minimal. The M treatment reported the least potassium nutrient content. During 2nd season, MBS and MF showed higher potassium nutrient content but was not significant from MBL and MBC. The MB recorded the least potassium content, which was not significantly different from M treatment.

There were significant differences ($p \leq 0.05$) of maize leaf magnesium nutrient content in maize under MBS, MF and MBC during 1st season with both MBS and MF registering highest levels of the magnesium content (Table 4.13). The lowest potassium content was observed under MBL and maize plants without fertilizer treatment (M) which was not significantly different to MB. There was no significant differences in leaf potassium content among treatments during 2nd season (Table 4.13). MF recorded higher magnesium content however there was no much difference between MF and MBS and MBC.

The maize leaf nitrogen content showed significant differences ($p \leq 0.05$) under MF, MBS and MBC during 1st season (Table 4.13). The highest leaf nitrogen content was recorded in MF which was not significantly different to MBS and MBC. Least leaf nitrogen was observed under maize plants without fertilizer application. In the 2nd season MBS and MF showed significantly higher nitrogen content than the rest of the treatments with the least being reported under maize without fertilizer treatment and maize – banana treatments.

There were significant differences ($p \leq 0.05$) of maize leaf phosphorus nutrient content under MF, MBS and MBC during 1st season (Table 4.13). MF recorded the highest phosphorus content however, the difference with MBS was minimal. Least phosphorus content was registered under maize without fertilizer treatment. During 2nd season MF registered significantly higher phosphorus content, however the difference between MF and MBS was minimal. The lowest phosphorus content was observed under M treatment.

Table 4.13. Effect of intercropping maize and banana with agroforestry tree species on maize leaves nutrient contents (mg/kg) during 1st and 2nd season

Season	Treatment	Ca	K	Mg	N	P
Season 1	M+B	0.51 c	2.67 b	0.53 bc	3.20 c	0.35 c
	M+B+C	0.82 a	3.10 a	0.65 ab	3.97 a	0.48 a
	M+B+L	0.66 b	2.73 b	0.50 c	3.60 b	0.42 b
	M+B+S	0.90 a	3.27 a	0.70 a	4.20 a	0.51 a
	M+F	0.83 a	3.43 a	0.713 a	4.97 a	0.54 a
	M Alone	0.29 d	2.20 d	0.44 c	2.57 d	0.26 d
	LSD	**0.11**	**0.23**	**0.15**	**0.24**	**0.03**
Season 2	M+B	0.51 bc	1.79 c	0.50 a	2.70 d	0.36 c
	M+B+C	0.82 a	2.93 ab	0.60a	3.90 bc	0.47 b
	M+B+L	0.64 ab	2.60abc	0.50a	3.57 c	0.47 b
	M+B+S	0.68 ab	3.43 a	0.60a	4.07 ab	0.50 b
	M+F	0.86 a	3.57 a	0.70a	4.47 a	0.56 a
	M Alone	0.29 c	2.03 bc	0.40a	2.87 d	0.29d
	LSD	**0.25**	**1.06**	**30.21**	**0.49**	**0.03**

Treatments with the same letter along the columns are not significantly different according to LSD at $p \leq 0.05$.

4.9.5 Effect of intercropping maize and banana with agroforestry tree species on maize root mineral content

There were significant differences ($p \leq 0.05$) on maize root calcium nutrient content in MF, MBS, MBL and MB during the 1st season (Table 4.14). The MF recorded highest root calcium but it was not significant to MBS, MBL and MB. MBC treatment showed slightly lower root calcium content and it was not significant compared to that of maize without fertilizer treatment (M). During the 2nd season, significantly high ($p \leq 0.05$) root calcium content was observed in the MF, MBS and MBL. Among agroforestry tree treatments MBC registered lower root calcium content and was not significantly different from MB. The M recorded the lowest root calcium content among all the treatments.

There were significant differences ($p \leq 0.05$) of maize root potassium nutrient content in MBS and MF treatment during the study period (Table 4.14). Maximum potassium uptake was registered in the MBS which is significant from MF. The maize without fertilizer application recorded the least root potassium content.

There were significant differences ($p \leq 0.05$) of maize root magnesium nutrient content in both seasons under MBS and MF (Table 4.14). The highest magnesium content was recorded under MBS followed by MF and was significantly different from other treatments for both seasons. The lowest content was registered in MB and in M treatments.

The maize root nitrogen content showed significant differences ($p \leq 0.05$) in MBS, MBL and MF during 1st season (Table 4.14). The MBS had the highest nitrogen content which was not significantly different from MF and MBL treatments. The maize without fertilizer treatment had the least root nitrogen content. During the 2nd season, maize under fertilizer treatment showed significant differences, however the difference between MF and MBS and MBL was minimal. The least root nitrogen content was under MB treatment.

There were significant differences ($p \leq 0.05$) of maize root phosphorus nutrient content in MBS, MBL, MBC and MF in the 1st season (Table 4.14). The MBS had higher phosphorus concentration which were not significant to MBL, MBC and MF treatments. Similarly, in the 2nd season, the highest content was in maize under fertilizer treatment but it was not significant to MBS. The MB and M treatment recorded the least root phosphorus content.

Table 4.14. Effect of intercropping maize and banana with agroforestry tree species on maize root nutrient contents (mg/kg) during 1st and 2nd season

Season	Treatment	Ca	K	Mg	N	P
Season 1	M+B	0.15 ab	0.37 bc	0.44 d	0.30 c	0.11 bc
	M+B+C	0.14 bc	0.34 cd	0.63 c	0.40 b	0.13 ab
	M+B+L	0.17 a	0.40 b	0.74 b	0.43 ab	0.13 ab
	M+B+S	0.17 a	0.46 a	0.87 a	0.45 a	0.14 a
	M+F	0.19 a	0.45 a	0.81 a	0.46 a	0.14 a
	M Alone	0.13 c	0.31 d	0.38 e	0.21 d	0.08 c
	LSD	**0.02**	**0.04**	**0.04**	**0.04**	**0.03**
Season 2	M+B	0.13 b	0.37 bc	0.44 d	0.30 e	0.09 c
	M+B+C	0.14 b	0.35 bc	0.65 c	0.40 d	0.14 b
	M+B+L	0.17 a	0.40 b	0.76 b	0.44 c	0.13 bc
	M+B+S	0.18 a	0.48 a	0.88 a	0.49 b	0.24 a
	M+F	0.18 a	0.45 a	0.80 a	0.67 a	0.26 a
	M Alone	0.11 c	0.30 c	0.30 e	0.22 f	0.09 c
	LSD	**0.02**	**0.07**	**0.07**	**0.04**	**0.04**

Treatments with the same letter along the columns are not significantly different according to LSD at $p \leq 0.05$.

4.9.6 Effect of intercropping agroforestry tree species on maize stem mineral content

There were significant differences ($p \leq 0.05$) of maize stem calcium nutrient content in maize under MBS and MF (Table 4.15). The highest stem calcium content was under MBS though not significant to that of maize under fertilizer treatment. The least calcium content was measured under MB and M alone. In the 2nd season, MBC recorded significantly higher ($p \leq 0.05$) stem calcium content which was not significantly different from MBS, MB, MF and maize without fertilizer treatment. The MB and M showed least maize stem calcium content and they were not significantly different.

There were significant differences ($p \leq 0.05$) of maize stem potassium nutrient content under MBC, MBL, MBS, MF and M alone during the 1st season (Table 4.15). The highest potassium content was under maize with fertilizer application, however there was minimal difference compared to MBS. The MB treatment had the lowest stem potassium nutrient content. In the 2nd season, MBC had highest content which was not significantly different from that of MF, MBL, MBS and M alone. The lowest content was recorded in the maize-banana treatments during the study period.

There were significant differences ($p \leq 0.05$) of maize stem magnesium nutrient content under MBC, MBL, MBS and MF in both seasons (Table 4.15). However, the highest magnesium content was recorded under MF followed by MBS with minimal difference between them during 1st season. The lowest stem magnesium nutrient content was reported under maize without fertilizer treatment. In the 2nd season MBS reported highest stem magnesium nutrient content than all treatments but it was not significantly different from MF, MBL and MBC. The M treatment recorded the lowest stem magnesium nutrient content though insignificantly to MB treatment.

The maize stem nitrogen content showed significant differences ($p \leq 0.05$) during both seasons under MBC, MBL, MBS and MF (Table 4.15). The MBS reported highest stem nitrogen content though it was not significantly different from all treatments apart from MF and M treatments during 1st season. Similarly, during the 2nd season MBC treatment registered higher content that was not significantly different from all other treatments except MB and M treatments. In both seasons, MB and M had the lowest maize stem nitrogen content.

There were significant differences (p≤0.05) of maize stem phosphorus nutrient content under MBS, MBC and MF during 1st season (Table 4.15). The MBS treatments had the highest phosphorus nutrient content which was not significantly different from MBC and MF. The maize without fertilizer application showed the lowest stem phosphorus among all treatments. Similarly, in the 2nd season the highest content was in the maize under fertilizer treatment but the difference was minimal compared to MBS and not significantly different from that of MBL and MBC treatments. The MF and that MB had the least stem phosphorus content uptake.

Table 4.15. Effect of intercropping maize and banana with agroforestry tree species on maize stem nutrient contents (mg/kg) during the first and second seasons

Season	Treatment	Ca	K	Mg	N	P
Season 1	M+B	0.32 e	2.21 b	0.37 b	2.97 b	0.47 c
	M+B+C	0.74 b	4.00 a	0.57 a	4.53 a	0.59 a
	M+B+L	0.66 c	3.50 a	0.54 a	4.37 a	0.53 b
	M+B+S	0.85 a	4.17 a	0.61 a	4.77 a	0.62 a
	M+F	0.72 a	4.33 a	0.68 a	4.00 a	0.51 a
	M Alone	0.31 e	3.10 ab	0.22 c	2.63 b	0.41 d
	LSD	**0.05**	**1.25**	**0.07**	**0.43**	**0.03**
Season 2	M+B	0.33 b	3.20 b	0.34 bc	2.90 c	0.47 c
	M+B+C	0.71 a	4.07 a	0.56 a	4.80 a	0.60 ab
	M+B+L	0.69 a	3.67 ab	0.53 a	4.27 ab	0.53 abc
	M+B+S	0.66 a	3.80 ab	0.62 a	4.67 a	0.60 a
	M+F	0.68 a	4.02 a	0.59 a	4.53 a	0.61 a
	M Alone	0.55 ab	3.30 ab	0.31 c	3.23 bc	0.47 bc
	LSD	**0.33**	**0.78**	**0.09**	**1.24**	**0.13**

Treatments with same letter along the columns are not significantly different according to LSD at p≤0.05.

4.9.7 Effect of intercropping maize and banana with agroforestry tree species on banana leaf mineral content

There were significant differences (p≤0.05) of banana leaf calcium nutrient content in bananas under MBS and MBL as compared to B, MB and MBL however, there was no significant difference MBL and MBC during 1st season (Table 4.16). During the 1st season MBS registered highest content which was not significantly different from MBL treatments while B treatment registered the lowest banana leaf calcium content among all treatments.

In the 2nd season, MBS recorded highest leaf calcium content which was not significantly different to MBC. The lowest leaf calcium content was registered under monocropped banana treatments in both seasons. The leaf calcium content under MBL was not significantly different that of MBC.

There were significant differences ($p \leq 0.05$) of banana leaf potassium nutrient content under MBC, MBL and MBS treatments during 1st season (Table 4.16). The highest potassium nutrient content was registered under MBC followed closely MBC and MBL. The B treatment registered lowest banana leaf potassium content. In the 2nd season, MBC and MBS treatments reported significantly highest potassium content though insignificantly different from MBC. The monocropped banana recorded the least leaf potassium content.

There were significant differences ($p \leq 0.05$) of banana leaf magnesium nutrient content under MBS and MB for both seasons which was significantly different from MBL, MBC and B (Table 4.16). The highest magnesium content was recorded under MBS followed by MB treatments in the two seasons. The lowest magnesium content was recorded under monocropped banana treatment.

The banana leaf nitrogen content had significant differences ($p \leq 0.05$) in MBC and MBS treatments during both seasons (Table 4.16). *Sesbania sesban* and *Calliandra callothyrsus* treatments reported highest nitrogen content in banana leaves during both seasons which was significantly different from all other treatments. Monocrop banana had the lowest leaf nitrogen content among all treatments during the study period.

There were significant differences (p≤0.05) of maize leaf phosphorus nutrient content under MBC, MBS and MBL which was significantly different from MB and B treatments for both seasons under the three agroforestry trees in season one and in MBS, MBC and MB in season two (Table 4.16). MBS registered the highest phosphorus content in season one which was not significantly different from MBL and MBC with B treatment registering lowest banana leaf nitrogen content. During the 2nd season banana leaf nitrogen content registered significant differences (p≤0.05) under MB, MBC and MBS (Table 4.16). Maize banana treatment recorded highest banana leaf phosphorus but was not significantly different from MBS and MBC treatments. Similarly, in the 2nd season monocropped banana treatment registered lowest leaf phosphorus which was not significantly different from the rest of the treatments.

Table 4.16. Effect of intercropping maize and banana with agroforestry tree species on banana leaves nutrient contents (mg/kg) during the first and second seasons

Season	Treatment	Ca	K	Mg	N	P
Season 1	B	2.93 d	18.40 c	5.03 c	23.23 d	1.13 c
	M+B	3.57 c	22.73 b	6.73 a	27.23 c	1.73 b
	M+B+C	5.20 b	28.53 a	5.13 bc	37.10 ab	2.23 a
	M+B+L	5.47 ab	27.80 a	5.30 bc	36.63 b	2.30 a
	M+B+S	5.67 a	28.33 a	6.90 a	38.80 a	2.40 a
	LSD	**0.40**	**3.39**	**0.82**	**1.75**	**0.27**
Season 2	B	3.00 d	19.37 c	4.67 c	23.50 c	1.47 b
	M+B	3.57 cd	23.47 b	6.97 a	25.40 c	2.37 a
	M+B+C	5.17 ab	27.67 a	6.43 b	36.23 a	2.20 a
	M+B+L	4.30 bc	23.43 b	6.00 b	33.17 b	1.80 b
	M+B+S	5.70 a	27.03 a	7.47 a	36.40 a	2.27 a
	LSD	**0.88**	**1.83**	**0.70**	**2.89**	**0.35**

Treatments with same letter along the columns are not significantly different according to LSD at p ≤ 0.05.

4.10 Effect of intercropping maize and banana with agroforestry tree species on number of maize cobs per plot

The number of maize cobs per plot showed significant differences ($p \leq 0.05$) for both seasons (Fig. 4.1). The maize under fertilizer application showed the highest number of maize cobs compared to the rest of the treatments however, MBS recorded significantly higher number of cobs compared to MBL, MB and M. The MBL had the least number of cobs among the treatments. During the second season, the number of maize cobs in MBS and MF treatment were highest, however they were not significantly different from each other. Maize cobs were lowest under MBL treatment during the first and second seasons among the agroforestry trees while maize banana intercrop and maize without fertilizer application reported least number of maize cobs in the second season. The 2nd season reported significantly higher number of maize cobs compared to season one.

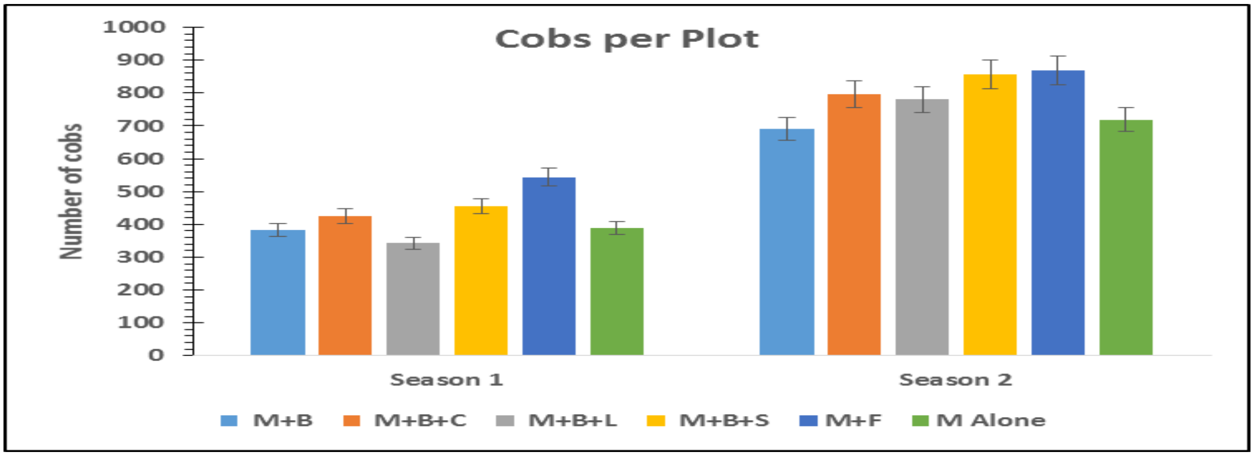

Figure 4.1: Effect of intercropping maize and banana with agroforestry tree species on number of maize cobs per plot during the first and second seasons. Error bars indicate the SE at p≤0.05.

4.10.1 Effect of intercropping maize and banana with agroforestry tree species on maize grain yield parameters

The number of maize rotten cobs, number of maize cobbed plants and maize total biomass did not show significant differences ($p \leq 0.05$) during the study (Table 4.17). In the 1st season, high number of maize rotten cobs were registered under the maize without fertilizer application with *Calliandra carlothyrsus* and *Sesbania sesban* treatments recording the lowest number of rotten cobs. Contrary to the 1st season, the 2nd season recorded the highest number of rotten cobs in with fertilizer application and in *Calliandra carlothyrsus* treatment recording the least number of rotten cobs. In both seasons, MBS and MBC recorded the lowest number of maize with rotten cobs.

The maize under fertilizer application treatment registered high number of cobbed maize plants during both seasons, but not significantly different to MBL and MBS during season 1(Table 4.17). In the second season no significant differences was reported. The agroforestry trees treatments registered high number of cobbed maize plants with *Sesbania sesban* having the highest number and maize without fertilizer application having the least number of cobbed maize plants.

The maize plant total biomass did not show significant differences ($p \leq 0.05$) among the treatments during the period of study (Table 4.17). The MBS treatments and the maize under fertilizer recorded the highest total biomass during the study period. During the 1st season, MB had the least total biomass and the maize without fertilizer application registered the least biomass in the 2nd season.

Table 4.17. Effect of intercropping maize and banana with agroforestry tree species on maize yield parameters during the first and second season

Seasons	Treatment	Rotten Cobs	Cobbed Plants	Total Biomass
Season 1	M+B	6.3 a	88.0 a	1782.0 a
	M+B+C	2.3 a	90.0 a	1796.0 a
	M+B+L	6.3 a	137.7 a	1817.0 a
	M+B+S	3.0 a	138.3 a	2107.0 a
	M+F	4.0 a	170.3 a	2117.0 a
	M Alone	8.0 a	81.0 a	1797.0 a
	LSD	**6.3**	**48.9**	**1069.8**
Season 2	M+B	5.0a	73.0 a	931.0 a
	M+B+C	1.7 a	114.0 a	901.0 a
	M+B+L	3.0 a	106.0 a	847.0 a
	M+B+S	3.3 a	173.0 a	1146.0 a
	M+F	6.0 a	109.0 a	1057.0 a
	M Alone	4.3 a	73.0 a	784.0 a
	LSD	**4.9**	**112.9**	**577.0**

Treatments with same letter along the columns are not significantly different according to LSD at $p \leq 0.05$.

4.10.2 Effect of intercropping maize and banana with agroforestry tree species on maize grain yield parameters

Significant differences ($p \leq 0.05$) were recorded for both seasons, under *Sesbania sesban* and in maize under fertilizer treatments (Fig. 4.2). During season one, maize under MBS treatments and the maize under fertilizer recorded the highest grain yield amongst the treatments. In the second season, MBS and MF recorded significantly high grain yields. The MB, MBC, MBL and M recording the yields that was not significantly different from each other. Among the agroforestry trees, MBS recorded the highest grain yield followed by MBC and the least was under MBL treatments.

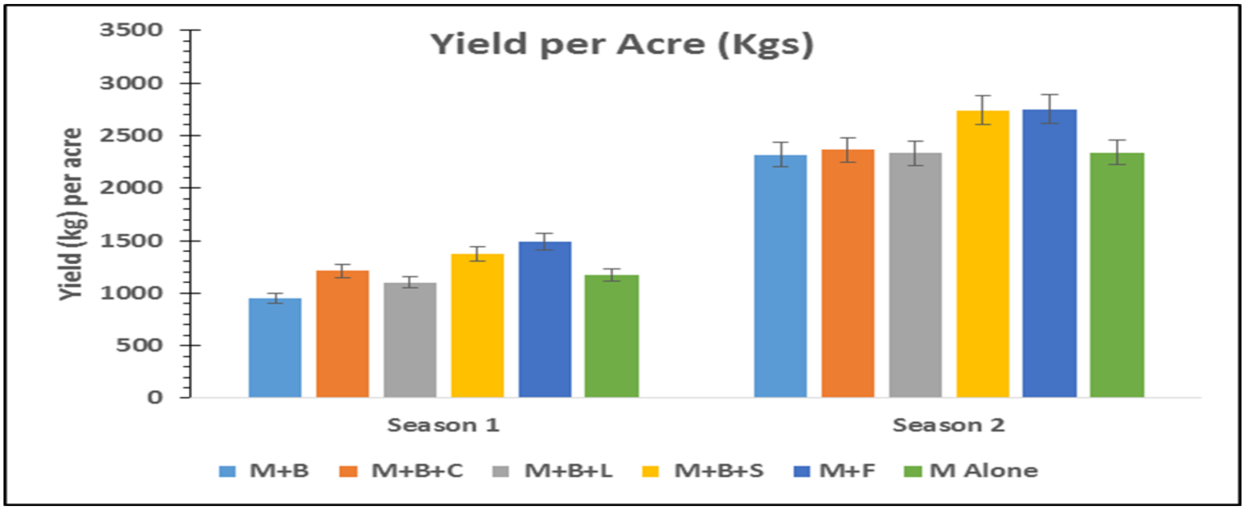

Figure 4.2: Effect of intercropping maize and banana with agroforestry tree species on grain yield of maize per acre during the first and second seasons. Error bars indicate the SE at p≤0.05.

4.10.3 Effect of intercropping maize and banana with agroforestry tree species on banana bunch weight

The MBS reported significantly higher (p≤0.05) bunch weight of bananas than all the treatments (Fig.4.3). The MBS had the heaviest bunch weight. Monocropped banana crop had the least bunch weight however; it was not significant to MB, MBL and MBC treatments. Banana bunch weight was significantly higher under MBS among the treatments.

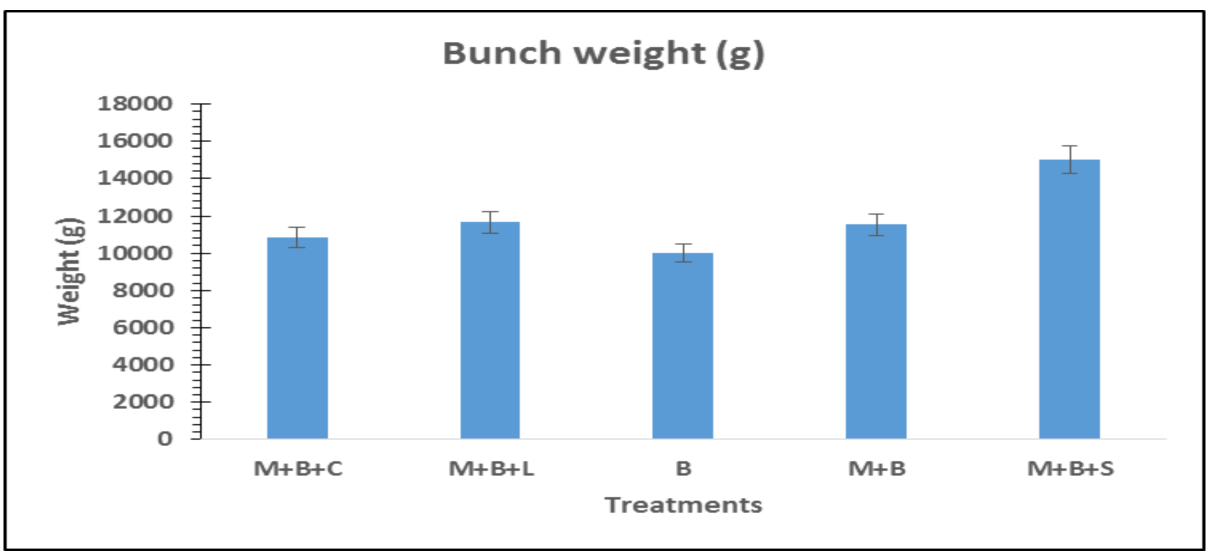

Figure 4.3: Effect of intercropping maize and banana with agroforestry tree species on the bunch weight (g) of bananas at the harvest. Error bars indicate the SE at p≤0.05.

4.10.4 Effect of intercropping maize and banana with agroforestry tree species on banana finger length

Significant differences ($p \leq 0.05$) were observed on the banana finger length in MBS treatment in comparison to the other treatments (Fig. 4.4). Banana crops under MBS treatments produced significantly longest finger length of 20 cm while the B treatment had the shortest at 17 cm. Intercropping of banana crops with agroforestry trees produced longer fingers of bananas as compared to monocropped bananas.

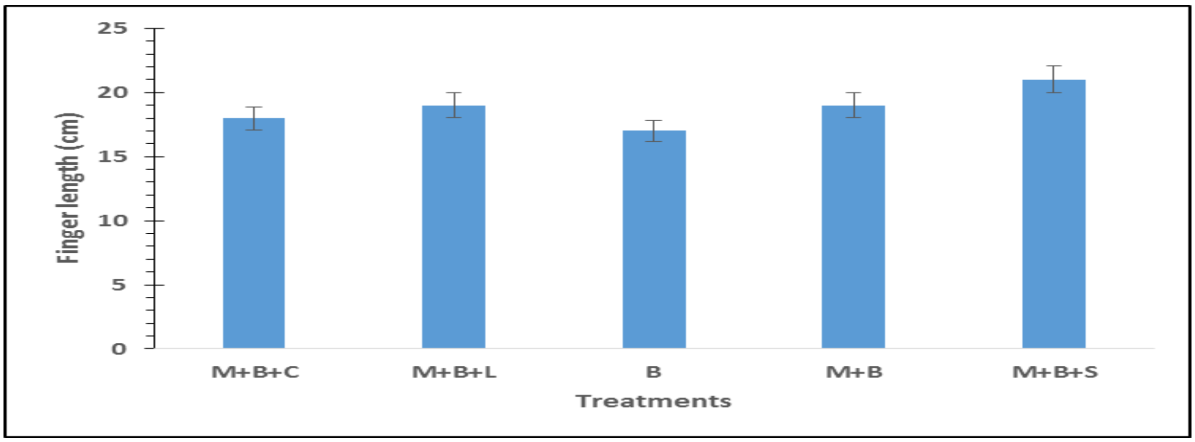

Figure 4.4: Effect of intercropping maize and banana with agroforestry tree species on the finger length (cm) of bananas at harvest. Error bars indicate the SE at p≤0.05.

4.10.5 Effect of intercropping maize and banana with agroforestry tree species on the number of hands and fingers per bunch of banana

There were no significant difference in between the numbers of hands per bunch of the banana plants among the treatments (Fig. 4.5). The number of fingers per bunch showed significant differences ($p \leq 0.05$) where the highest was recorded on the MBS at 105 fingers while the lowest was recorded on the intercrop of MB and in the MBC at 84 fingers respectively (Fig. 4.5).

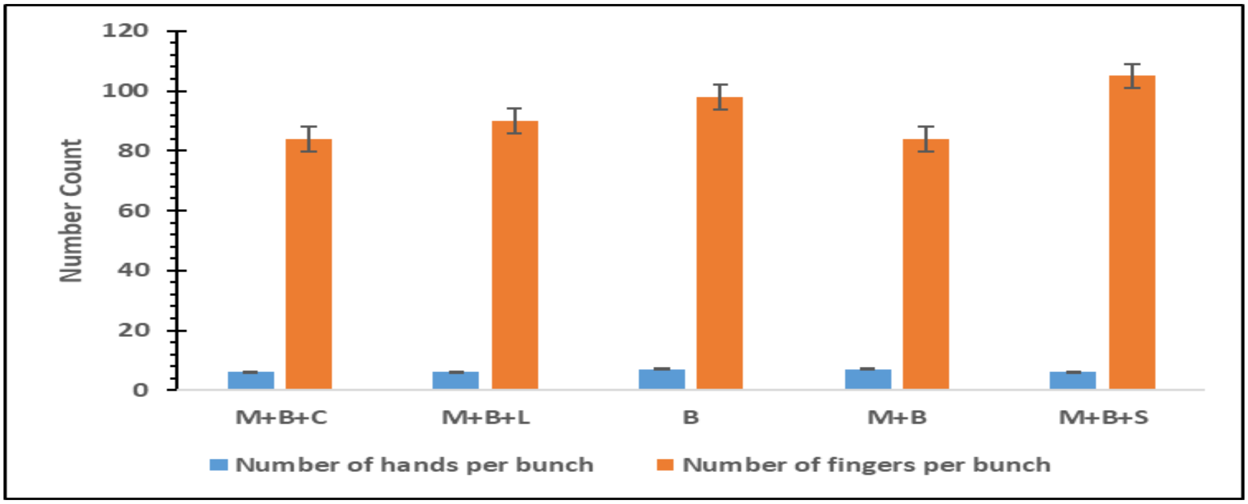

Figure 4.5: Effect of intercropping maize and banana with agroforestry tree species on the number of hands per bunch and number of fingers per bunch of bananas at harvest. Error bars indicate the SE at p≤0.05.

4.11 Correlation Analysis

Intercellular CO_2 concentration was positively and significantly correlated with leaf area and net photosynthesis. More significant and positive correlations were measured under net photosynthesis and transpiration rate, plant height and leaf area and leaf area and net photosynthesis. According to results, there was a negative correlation between transpiration rate with plant height and leaf area (Table 4.18).

Table 4.18: Correlation analysis on maize intercellular CO_2 concentration (C_i), transpiration rate (E), plant height, leaf area and net photosynthesis (A) parameters

Variables	C_i	E	P. height	leaf area	A
C_i					
E	0.1905				
P. height	0.3931	-0.6500			
leaf area	0.7265	-0.4128	0.8163		
A	0.5011	0.5125	0.4066	0.5013	

Values with positive sign have positive correlation and those with negative sign have negative correlation with significance level of p≤0.05

Significant strong correlations was measured under intercellular CO_2 concentration with net photosynthesis and leaf area, and under net photosynthesis with transpiration rate and leaf area (Table 4.19). The weak positive correlations was recorded between transpiration rate and intercellular CO_2 concentration, leaf area and transpiration rate and net photosynthetic rate and plant height. The leaf areas of banana plants were negatively correlated with transpiration rate and plant height. The negative correlations were also observed between transpiration rate and intercellular CO_2 concentration (Table 4.19)

Table 4.19: Correlation analysis on banana intercellular CO_2 concentration (C_i), transpiration rate (E), plant height, leaf area and net photosynthesis (A) parameters

Variables	Ci	E	P. height	leaf area	A
C_i					
E	0.4389				
P. height	-0.7375	-0.8324			
leaf area	0.8596	0.3508	-0.3363		
A	0.9216	0.7166	0.4609	0.5587	

Values with positive sign have positive correlation and those with negative sign have negative correlation with significance level of $p \leq 0.05$

CHAPTER FIVE

DISCUSSION

5.1 Effect of intercropping maize and banana with agroforestry tree species on maize and banana growth parameters

Higher maize plant height was reported under maize in the MBS treatments during the period of study. The highest maize plant height under MBS treatments may be attributed to the increased nutrients being availed by the nitrogen fixation and sesbania prunings which decomposed to provide the required nutrients. This could further be attributed to the enhanced nutrient facilitation by the maize and the *Sesbania sesban* tree plant interaction. The shortest maize were in MBC and this could be credited to slow release and breakdown of the prunings. This reduced available nutrients in turn decreased the activities of the apical meristematic cells resulting to slow plant primary growth. The results obtained are in agreement with that of Ebeid *et al*. (2015) who reported taller lemon grass under the intercrop of *Sesbania sesban* tree species.

In terms of leaf area, the MBS and MF treatments demonstrated larger leaf areas despite not showing significant differences. The high leaf areas may also be due to more moisture within soils as the ground surface evapotranspiration is reduced as the leafy *Sesbania sesban* and other intercrop plants provided mulching effect. This increased soil water and therefore resulted to increased leaf area surface to promote the rate of cuticular transpiration and photosynthetic efficiency. Leaf area is a significant determinant of crop productivity in maize particularly in light sensitive limited environment as experienced in agroforestry intercrop farming system. The leaf area is important factor in the physiological process such as photosynthesis, which is promoted through light harvesting efficiency. The results are in agreement to that of Becham *et al*. (2018) who reported larger leaf areas in maize when intercropped with soya beans. The high leaf areas of maize intercropped with S*esbania sesban* can be attributed to nutrient facilitation resulting from nitrogen fixation and leaf and twig decomposition of the *Sesbania sesban* tree prunings.

Number of maize leaf did not show significant differences among treatments. However, a higher number of leaves were recorded in the MBL treatments which was second to maize under fertilizer treatment. To the contrary, the MBS treatments recorded the least number of leaves in first season and in maize banana during second season. The low number of leaves recorded in maize banana treatment during second season could be as a result of nutrient depletion due to minimal nutrient recycling and nitrogen fixation. The highest number of leaves in maize under fertilizer treatment was due to readily available nutrients that was released to the maize plants. The number of green leaves however did not show any significant change among all the treatments. This aspect could not be explained by this study. The findings are in line with earlier outcomes of Gabatshele *et al*. (2019) and Iderawumi, (2014) who reported increased number of leaves of sorghum and maize when intercropped with cowpeas respectively.

Significant differences were registered in stem diameter among treatments at 28 DAP and 84 DAP with MBS, MBL and MF treatments posting the largest stem diameters. The large stem diameter reported under MBS and MBL treatments can be attributed to the quality of nutrients recycled through twig and leaf pruning decomposition arising from the pruned biomass and through nitrogen fixation (Mucheru *et al*. 2017). Additionally, the increase may also be due to the reduction in competition for soil moisture and resource partitioning that promoted photosynthetic efficiency which channeled photo-assimilates to the growth regions that resulted to stem growth. The high stem diameter registered in maize under fertilizer application was due to faster and ready release of available nutrients from the fertilizer. However, fertilizer application may not be easily accessible to most economically challenged smallholder farmers. Therefore, the good results reported in the MBS and MBL treatments might be a remedy to those farmers who may not afford inorganic chemical fertilizers. The results are similar to the findings of Becham *et al*. (2018) who reported larger maize stem diameters in maize – soya bean intercrops. Similar results were also reported by Muthuri, (2005) who found out increased wheat and maize diameter in the intercrop with P. deltoids.

5.2 Effect of intercropping maize and banana with agroforestry tree species on banana plant growth parameters

The banana plant height did not show significant differences among the treatments. The tallest banana plants were registered under MBL in the first season and in the MBS treatments in the second season. The increased banana height in the MBS and MBL treatments may be attributed to the high amount of nitrogen that was fixed through their nitrogen fixing capacity and the high nutrient quality of their leaf and twig prunings that decomposed releasing the required nutrients for growth. The two-agroforestry trees may also have promoted resources partitioning, facilitation processes and increased complementarity use of the growth resources such as nitrogen, phosphorus, calcium and magnesium. The findings agree with those of Gabatshele *et al*. (2019) who reported taller sorghum plants when intercropped with cowpeas. Similar findings have also been reported by Ashraf *et al*. (2019) and Ebeid *et al*. (2015) who founded taller sweet basil and lemon grass plants when intercropped with aromatic trees and *Sesbania sesban* respectively have also reported similar findings.

Banana leaf area showed insignificant differences during the study period in all treatments. MBS treatments showed largest leaf areas for both seasons and the least leaf area was reported in the B. The large leaf areas in MBS treatments may be due to the high amount of nitrogen nutrient that was fixed through their efficient nitrogen fixing capacity and the high nutrient quality of their leaf and twig prunings that decomposed hence recycling the required nutrients for growth. The mulching and surface covering of the crops in the intercrop could have also facilitated reduction in the soil surface evapotranspiration. This resulted in increased soil water, which might have demanded increased leaf size to enhance excess water loss through the expanded leaf sizes. This adaptation further could result in the increased surface area for light harvesting for primary productivity. These results are in agreement to those of Gabatshele *et al*. (2019) and Ashraf *et al*. (2019) who reported taller sorghum and sweet basil plants under the intercrop with cowpea and aromatic trees respectively.

Significant differences were observed at 171 DAT and slightly at 388 DAT under MBS treatments. The increased number of green leaves under the sesbania treatments may be attributed to the increased nitrogen that was fixed by sesbania sesban trees and the decomposition of leaf biomass from the prunings. There were slight changes in the number of green leaves in bananas and this may be attributed to the succulent nature of the banana pseudo stem which has high ability to store more water making it less susceptible to dangers of water shortages. This ensures reduced rate of leaf withering, thus most leaves are retained to the plant. The rate of new leaf development is also relatively low. The results obtained are in tandem with the earlier findings of Iderawumi (2014) who reported increased number of green leaves in maize plants under the maize - cowpeas intercrop. The results similar to these were also reported by Amos *et al*. (2012) in maize-legume intercrop, where maize plants reported more leaves.

There was no significant differences in the banana stem during the study period, however, higher banana stem diameter was recorded in the intercrop of agroforestry trees with MBS having relatively larger stem diameters than the rest of the treatments. The larger stem diameters in

MBS treatments may be attributed to the added biomass resulting from regular prunings and nitrogen fixed by the nitrogen fixing plants and improved resource partitioning. Towards the end of the study, larger diameters were registered and this could be due to the decomposed maize plant residues from the previous maize harvests. The small stem diameter recorded in the B treatment may be due to limited nutrients recycling such as nitrogen as the sole banana crop relied entirely on the nutrients that were initially in the soils as opposed to other treatments that contained nitrogen-fixing trees. The results agrees with those of Muthuri, (2005) and Chaudhry, (2003) who reported larger wheat and maize diameters under the intercrop with P. deltoids. However, these results contradicts those of Ndlovu *et al*. (2016) who reported suppressed maize plant stem diameter in *Grevillea robusta* intercrop which was credited to competition for water and nutrients as opposed to the findings of this study where nitrogen fixing tree species with high potential of fixing nitrogen in the soils thus resulting in the increased stem diameter.

5.2.1. Effect of intercropping maize and banana with agroforestry tree species on net photosynthesis, intercellular CO_2 concentration and transpiration rate for maize and banana plants

Significant net photosynthetic rate was registered at 56 DAP in first season and 56 DAP in the second season. The net photosynthetic rate for banana showed significant differences only at 360 DAP with MBC treatment being significantly high than the rest of the treatments. High photosynthetic rates were registered under agroforestry tree treatments with MBS and MBC recording the highest net photosynthetic rates than the rest of the treatments for maize and bananas respectively. The high photosynthetic rates observed under *Sesbania sesban* may be due to the increased intercellular CO_2 concentration that was brought about by availability of soil water that facilitated stomatal opening allowing transpiration consequently promoting CO_2 uptake hence increasing the intercellular CO_2 concentration. The net photosynthetic rate of maize significantly reduced at 84 DAP despite even registering higher transpiration rate and intercellular CO_2 concentration. These findings are in line with the results of Sanjeev (2016) who reported increased net photosynthesis in the garlic intercropped with quava, plum and poplar in relation to monocropped garlic. Nissanka and Sangakkara (2008) reported similar results, where increased net photosynthesis in the intercrops compared to the sole crop.

Significant differences were observed under intercellular CO_2 concentration at 28 DAP in the first season and in the entire study period during second season. During first season, the highest intercellular CO_2 concentration were measured under MB treatment while in the second season MBS treatment had the highest intercellular CO_2 concentration. The higher intercellular CO_2 concentration in MBS could be attributed to the *Sesbania sesban* plants providing sufficient ground cover to soils. This reduced soil evaporation and competition for moisture consequently increasing water availability within the soil and to the associated plants. More water in the soil stimulated stomatal opening to dispense excess water through leaf transpiration. The stomatal opening of maize and banana plants resulted to more CO_2 intake hence increasing intercellular CO_2 concentration in the leaves. Higher CO_2 uptake resulted to high rates of photosynthesis producing osmotically active sugars that further enabled the guard cells to bulge and stomata remaining open for water and CO_2 diffusion. Contrary to the rest of the treatments, B and MBL treatments had significantly lower number of leaves between the 388 DAT and 416 DAT. The findings concurs with that of Ghanbari *et al*. (2010) and Mithamo (2013) who reported higher intercellular CO_2 concentration in the leaves of maize and coffee plants when intercropped with cowpea and fruits respectively.

There were no significant differences in transpiration rate among treatments in the first season but significant differences was registered in the second season at 84 DAP. Maize and banana under the agroforestry trees showed higher transpiration rates compared to those in other treatments without agroforestry trees. The MBS had higher transpiration rates followed by MBL and MBC the least among the treatments in the agroforestry trees. The high transpiration rates witnessed among the agroforestry tree treatments may be due to the surface cover of the trees and the mulching effect of the pruned biomass that reduced water loss from the soil via soil evaporation. This increased water in the soil rhizosphere resulting to increased stomatal opening to facilitate rapid leaf transpiration. The outcomes agree to earlier reports of Ghanbari *et al*. (2010) who reported improved conservation of the soil moisture in the maize intercropped with cowpea compared to monocropped maize without fertilizer application.

5.2.2 Effect of intercropping maize and banana with agroforestry tree species on maize and banana total chlorophyll content

Total chlorophyll content showed significant differences among treatments during the study period for maize and for bananas at 199 DAT in season one and 416 DAT in the second season. MBS recorded the highest chlorophyll content than all the treatments in both maize and bananas. The maize under MBS and MF recorded minimal differences in chlorophyll content. The study outcomes are in agreement with those of Ashraf *et al*. (2019) who found increased sweet basil chlorophyll in the intercrop with aromatic tree plants. Similar observations were also registered by Chu *et al*. (2004) in whose findings recorded increased total chlorophyll content of rice leaves under intercropping compared to sole cropped rice. However, the current findings of this study contradicts the earlier findings by Ndlovu (2013) who reported reduced total chlorophyll content on maize in Trans Nzoia, Kenya. Since most smallholder farmers have limited access to mineral fertilizers and the negative environmental effects of the mineral fertilizer, *Sesbania sesban* may be a remedy to such farmers. Therefore, *Sesbania sesban* trees may have significant effect on the maize chlorophyll content and can be recommended to farmers who fail to afford the chemical fertilizers. The increased chlorophyll content recorded under MBS treatments may be attributed to the high amount of nitrogen added to the study soils through nitrogen fixation and decomposition of pruned biomass of the tree twigs and leaves (Mucheru *et al*. (2007). The increased transpiration rate also increased the mineral nutrient uptake by the maize and banana crops. The decomposing prunings added magnesium, calcium and phosphorus which are also key elements in the chlorophyll formation.

5.3 Effect of intercropping maize and banana with agroforestry tree species on banana total chlorophyll content

The banana total chlorophyll content showed significant differences at 199 and 416 DAP in all treatments. The highest total chlorophyll content were reported under MBS treatments. The increased chlorophyll content under MBS treatments could be attributed to the faster decomposition of the *Sesbania sesban* plant materials that added more nutrients into the soil. The findings may also be attributed to the nutrient partitioning between the sesbania trees and the banana plants as the sesbania trees could have developed deep roots to utilize nutrients from the deep surfaces reducing nutrient competition with the banana crops. Since nitrogen is a component for chlorophyll synthesis, being made readily available increases the chlorophyll content. The findings are in agreement with those of Kordi *et al*. (2017) who reported high chlorophyll content in maize under maize-cowpeas-sweet basil intercrop. The results in *Sesbania sesban* can be attributed to its efficiency in the fixing of the nitrogen and the quality of the chemical composition of prunings added to the soil (Mucheru *et al*. 2007). Similar findings were reported Ashraf *et al*. (2019) in sweet basil in the intercropped with aromatic tree plants.

5.4 Effect of intercropping maize and banana with agroforestry tree species on the maize mineral nutrient content

The maize cob nutrient contents showed significant differences among the treatments. MBS treatments consistently recorded the highest nutrient contents in the cob than all other treatments. The maize cob highest potassium and nitrogen mineral nutrient content, followed by phosphorus, calcium and magnesium respectively. The maize under fertilizer treatment had higher tissue nutrients partitioned compared to the sole maize without fertilizer treatment and intercrop of maize with banana treatments. These could be attributed to the less nutrients in the soils as there was limited nutrient recycling and resource partitioning. In terms of nutrient partitioning in the cobs potassium was highest, followed by nitrogen content, phosphorus, calcium and lastly magnesium. Potassium and Nitrogen were found to be extremely higher compared to other nutrients. This could be due to the synergistic effect between the two nutrients. These results correspond with those of Nissanka and Sangakkara (2008) who reported that high nitrogen in maize leaves and grains than those of stems and roots. These results under agroforestry treatments are also in agreement with those of Suvera *et al*. (2015) who found that N, P and K nutrient contents of *Pongamia pinnata* trees were increased when intercropped with *Ocimun basilicum* plants. Similarly, the findings also correspond to those of Bertalot *et al*. (2014). The high maize cob nutrient content recorded under agroforestry trees could be due to decomposition of pruning that increased the micronutrients in the study soils hence promoting their uptake by maize plants. The high content observed under the *Sesbania sesban* trees may be due to its high efficiency in fixing nitrogen and the high quality of leaf biomass (Mucheru *et al*. 2007).

The maize grain, stem and leaf nutrient content showed significant differences among treatments with MBS and MF recording highest nutrient. Highest nutrient partitioned in maize grain under fertilizer treated plots can be attributed to available nutrient release from the maize under fertilizer as opposed to maize without fertilizer application plant that relied on the limited nutrient being recycled in the study soils. The high nutrient content registered in the maize under *Sesbania sesban* treatments may be attributed to the decomposition of the tree prunings and the nitrogen fixation abilities of the *Sesbania sesban* trees in comparison to the other agroforestry trees (Mucheru *et al*. 2007). Even though the fertilizer is producing the above positive results, it is however not readily available to all smallholder farmers in this region and also it has been earlier reported to have significant pollution effects on the environment (Mwangi 1999). These low partitioned nutrients in these treatments may be attributed to the insufficient nutrient in the soils as there was limited nutrient recycling. In terms of nutrient partitioning in the grain, nitrogen was highest, followed by potassium content, phosphorus, magnesium and lastly calcium. Potassium and Nitrogen were highly partitioned compared to other nutrients. These findings are in tandem with those of Chen *et al*. (2010); Nissanka and Sangakkara (2008) who reported increased nitrogen concentrations in maize grains. Similar results were also reported by Ajayi *et al*. (2011) who showed that N, P, K, Ca and Mg uptake are enhanced by deep rooted leguminous trees that enhance pulling up of nutrients from below ground to maize crop rhizosphere. The study outcomes are also in agreement with findings of Mugendi *et al*. (2003) and Giller (2001) who reported that non-legumes accumulate substantial quantities of N, P, K, Mg Ca nutrients in their leaves that are later released for crop use upon soil incorporation and subsequent decomposition. The observed results may be attributed to the increased nitrogen uptake through the nitrogen fixation and decomposition of plant prunings. The essentiality of the nitrogen nutrient in the physiological and metabolic processes of the plant such as chlorophyll pigment formation and enzyme formation could have been the reason for its increased uptake. Within the non-agroforestry tree treatments, the maize with fertilizer application had higher tissue nutrients partitioned especially in the second season compared to the maize without fertilizer application and intercrop of maize with banana treatments. These could be attributed to the limited nutrients in the soils as there was inadequate nutrient recycling. In terms of nutrient partitioning in the leaves, nitrogen was highest, followed by potassium content, calcium, magnesium and lastly phosphorus.

5.5 Effect of intercropping maize and banana with agroforestry tree species on maize yield

The number of maize cobs and maize yield per acre under the MBS and in the MF treatments recorded significant differences. Higher number of maize cobs recorded in the *Sesbania sesban* agroforestry intercrop was possibly due to improved nitrogen fixed by the nitrogen fixing plants and the decomposition of the tree prunings. Furthermore, the high amount of moisture within the MBS treatment could be the cause of increased yield as water availability to the plant is regarded as a key factor to crop productivity (Netondo, 1991). The higher yields could also be attributed to higher nitrogen and phosphorus nutrients in the soils that were added through nitrogen fixation, mineralization and decomposition of the tree prunings (Mucheru *et al*., 2007). The lower number of maize cobs in the monocropped maize without fertilizer and in banana maize intercrop could be due to minimal amount of nitrogen and phosphorus in the soils occasioned by little nutrient recycling. Phosphorus paucity constrained sink meristematic activities resulting to reduced photo-assimilate processing. The low concentration of root nitrogen content is an indicator of reduced uptake thus reduced grain filling and maturity. The results are in line with Phiri *et al*. (1999); Kaizzi *et al*. (2006); Sanchez and Jama (2002); Mucheru-Muna *et al*. (2007); Akinnifesi *et al*. (2007) and Mugendi *et al* (2011) who in their findings reported that, the cereal-legume intercrop or with agroforestry trees resulted to increased harvest.

Significant differences on the maize yield related parameters was only observed in the number of maize plants with cobs during the second season under MBS. The increase in number of maize plants with cobs and total biomass observed under intercropping can be attributed to increased nutrient supply through nitrogen fixation and as a result of twig and pruning decomposition. Generally, there were fewer number of rotten maize cobs under agroforestry treatments which could be attributed to the fact that trees acting as windbreakers which enabled plants to remain upright hence could not retain much moisture thus reducing rotting. The high productivity of maize in terms of fewer rotten maize cobs, high number of maize plants with cobs and high total biomass could also be due to the lower incidences of pests and diseases to maize under agroforestry systems (Akinnifesi *et al*., 2007). The findings are in tandem with those of Staver *et al*. (2001); Akinnifesi *et al*. (2007) and Sileshi *et al*. (2008) who reported higher yields of maize and bananas under the intercrop with *Gliricidia sepium* and legume fallows.

5.6 Effect of intercropping maize and banana with agroforestry tree species on banana yield

The banana yield showed significant differences in the MBS treatment. MBS recorded significantly heavier bunch weight, longer fingers and number of fingers per bunch. The number of hands per bunch showed no significant differences in all the treatments. The yield parameters of bunch weight, finger length and number of fingers per bunch registered under bananas intercropped with *Sesbania sesban* might have been due to the increased nitrogen nutrient uptake resulting from the nitrogen fixation and the biomass added through the leafy biomass decomposition that added humus to soils. The decomposition of the agroforestry tree cuttings may have significantly influenced nitrogen, phosphorus, potassium, calcium and magnesium uptake by banana plants. Phosphorus could have led to increased meristematic tissues, increased photosynthetic rates, banana fruit filling and elongation of the banana fingers. The increased banana yield under agroforestry trees is partly due to reduced disease and pests incidence on bananas (Staver *et al*., 2001). Additionally, leguminous plants produced biomass that increased the fertility status (Ogunnika, 2005). The findings concurs with the previous results of Chibudu, (1998); Phiri *et al*. (1999); Akinnifesi *et al*. (2007) and Frank *et al*. (2005).

5.7 Effect of intercropping maize and banana with agroforestry tree species on correlation analysis of some parameters

Correlation coefficients among most of the traits were statistically significant $P<0.05$). The significantly higher positive correlations observed under leaf area and intercellular CO_2 concentration, net photosynthesis and intercellular CO_2 concentration, net photosynthesis and transpiration rate, net photosynthetic and leaf area in both maize and bananas within the intercrop. Net photosynthesis was positively correlated with intercellular CO_2 concentration, transpiration rate and leaf area. Intercellular CO_2 concentration was also positively correlated with leaf area. This may be due to increased stomatal conductance which could have been contributed by high soil water brought about by the reduced soil evapotranspiration as the agroforestry tree plants provide surface cover. The efficient translocation of photosynthates from source to sink resulting to the growth of larger plant leaves and plant height. These findings are in agreement with the earlier findings by Ali *et al*. (2014) that reported stronger morpho-physiological traits of maize.

CHAPTER SIX

CONCLUSION, RECOMMENDATION AND SUGGESTIONS FOR FURTHER RESEARCH

6.1 Conclusion

The results in this study indicates that *Sesbania sesban*, *Calliandra calothyrsus* and *Leucaena diversifolia* agroforestry tree species when intercropped with maize and banana crops affect plant growth, physiology, gas exchange, biochemistry and ultimately their yield.

Intercropping *Sesbania sesban* trees with maize led to a higher maize plant height and larger leaf areas. However, *Leucaena diversifolia* resulted to increased leaf areas and the stem diameters of the maize plants. On the banana plants, *Sesbania sesban* enhanced leaf area, number of green leaves and stem diameter while *Leucaena diversifolia* promotes banana height. Agroforestry trees increased nutrient recycling and potentially soil moisture and reduced competition for the growth nutrients. The increased soil moisture promoted stomatal conductance that resulted to higher transpiration rates and intercellular CO_2 concentration. Higher photosynthetic rates were realized.

Agroforestry tree species increased the rates of net photosynthesis, intercellular CO_2 concentration and transpiration rates of maize and banana plants. *Sesbania sesban* promoted higher intercellular CO_2 concentration, transpiration rates and net photosynthesis. Therefore, incorporating nitrogen-fixing trees in farming could influence positively on net photosynthesis, increased intercellular CO_2 concentration and transpiration rates.

The agroforestry trees affected the physiological aspects of the maize and banana plants through increased total chlorophyll content. *Sesbania sesban* increased total chlorophyll content in both maize and banana plants in comparison to other agroforestry trees. Agroforestry trees with intense ability to fix nitrogen and recycling of other essential macronutrients may lead to enhanced chlorophyll synthesis.

The trees also significantly affected the biochemical aspects of the plant crops through increased N, P, K, Ca and Mg nutrient uptake in the crops and apportioning. *Sesbania sesban* trees enhanced nutrient uptake and partitioning to various plant parts of maize. More potassium was partitioned in the cobs, high nitrogen contents was partitioned to the leaves, stems and grains and most of the magnesium was partitioned to the roots.

The intercrop of maize, bananas and *Sesbania sesban* trees resulted to higher yields, higher biomass, higher number of maize plants with cobs and fewer number of maize with rotten cobs. The maize and banana plants intercropped with *Sesbania sesban* trees had the highest growth rates, physiological, biochemical and yield parameters.

It is logical to conclude that intercellular CO_2 concentration, net photosynthesis, leaf area and transpiration rate are the major contributors to crop production and these parameters had significantly higher correlation values. Therefore, selection of such parameters should be a major concern for selection in the agroforestry farming system.

6.2 Recommendations

Higher maize and banana growth, biochemical, physiological and yield responses were recorded under *Sesbania sesban* tree species treatment. Therefore, *Sesbania sesban* can be recommended for intercropping with maize and banana for sustainable crop plant height, stem diameter, higher nutrient uptake, increased gas exchange, higher total chlorophyll and ultimately higher yields to farmers.

6.3 Suggestions for further research

1. Future studies should determine the water use efficiency (WUE) of maize and banana plants under similar experimental setting in order to establish the amount of water used up by the intercropped plants in metabolic processes and the amount of water lost by the same crops through transpiration.
2. Future studies should evaluate the below ground and above ground dry matter allocations of maize and banana crops under similar experimental conditions. This may help us understand the nature of interactions occurring between the crops and the agroforestry tree species.
3. Future studies should consider using agroforestry tree species that are atleast older than one year to ensure a provision of large amounts of pruning material for application.
4. Future studies should determine the amount of biological nitrogen fixation which was added into the soil by the three agroforestry tree species.

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APPENDICES

Appendix 1: Plot layout at Maseno University farm in Vihiga site.

R1	R2	R3
1. banana+ maize + *Calliandra calothyrsus*	banana+ maize+ *Leucaena diversifolia*	banana+maize+ *Sesbania sesban*
2. maize without fertilizer	banana+maize	Maize without fertilizer
3. banana+maize+ *Leucaena diversifolia*	Maize with fertilizer	Maize with fertilizer
4. banana	banana+ maize+ *Sesbania sesban*	banana+maize+ *Leucaena diversifolia*
5. banana+maize	Maize without fertilizer	banana
6. maize with fertilizer	banana+maize+ *Calliandra calothyrsus*	banana+maize
7. banana+maize+ *Sesbania sesban*	banana	banana+maize+ *Calliandra calothyrsus*

Modified plot layout at Maseno University farm in Vihiga site

M+B+C	**M**	**M+B+L**	**B**	**M+B**	**Maize + fert**	**M+B+S**	**Replication 1**
1001	1002	1003	1004	1005	1006	1007	
M+B+L	M+B	Maize + fert	M+B+S	Maize	M+B+C	B	**Replication 2**
2001	2002	2003	2004	2005	2006	2007	
M+B+S	Maize	M+fert	M+B+L	B	M+B	M+B+C	**Replication 3**
3001	3002	3003	3004	3005	3006	3007	

Appendix 2. Photo showing maize-banana- Calliandra calothyrsus plot at Vihiga site, Maseno University farm. The agroforestry trees were 194 days old (Photo by researcher).

Appendix 3 Photo showing maize without fertilizer plot at Vihiga site, Maseno University farm. (Photo by researcher).

Appendix 4: Photo showing maize-banana- Sesbania sesban plot at Vihiga site, Maseno University farm, unpruned plot. The agroforestry trees were 194 days old (Photo by researcher).

Appendix 5: Photo showing maize-banana-Sesbania sesban plot at Vihiga site, Maseno University farm, during flowering following prunnings. (Photo by researcher).

Appendix 6: Photo showing banana plot at Vihiga site, Maseno University farm, (Photo by researcher).

Appendix 7 Chemical composition of the cow dung manure used in the study (Source: Author)

pH(H_20)	N (g/kg)	P (g/kg)	K (g/kg)	Ca (g/kg)	Mg (g/kg)
9.6	12.8	1.78	1.14	3.47	1.36

Appendix 8 Nutrient composition of the agroforestry tree species used in the study

	N	P	K	Ca	Mg
Calliandra calothyrsus	3.3	0.2	1.1	0.9	0.4
Leucaena diversifolia	3.8	0.2	1.8	1.4	0.4
Sesbania sesban	3.8	0.18	1.4	2.2	0.6