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Mineral nutrient uptake of maize and banana in an intercrop with agroforestry tree species in Vihiga County, Kenya

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Abstract: Western Kenya faces high population pressure and this has increased demand for food. Smallholder farmers in the region have been forced to practice poor farming practices such as continuous cultivation and clearing of forests to put more land to crop production. This has resulted in severe land degradation, climate change and reduced farm productivity. Agroforestry trees have been reported to improve soil fertility through nitrogen fixation coupled with leaves and twig decomposition. However, this has not been ascertained in maize-banana agroforestry systems in Vihiga County. Understanding the effects of intercropping of maize and banana with *Sesbania sesban*, *Calliandra calothyrsus* and *Leucaena diversifolia* agroforestry trees on nutrient uptake may be a remedy to the challenges. Therefore there is need to fully understand the effects of intercropping selected agroforestry trees with maize and banana on nutrient uptake of maize and banana. The objective of the study was to determine the effect of intercropping agroforestry tree species on maize and banana tissue N, P, K, Mg, Ca uptake and partitioning. The study was conducted at Maseno university farm located in Vihiga County. The Williams varieties of banana of the same age were obtained from KALRO-Thika., Seeds of selected agroforestry trees were purchased from KEFRI – Muguga, planted in a seedbed and the seedlings raised in nurseries. Hybrid maize seed, H513 was purchased from an agrovet. Banana holes were dug 2x2 feet, 20 Kg of decomposed cow dung manure + 20 Kg of top soil + 200g of NPK fertilizer added in each banana hole and banana planted. Randomized complete block design (RCBD) with 3 replications were used with seven treatment levels of i.e. maize, banana, maize + banana + Calliandra, maize + banana + leucaena, maize + banana + sesbania, maize + banana, and fertilized maize. Maize were planted at 0.75 m inter row by 0.3 m spacing. Five maize plants per treatment and per replication were sampled randomly from the eight middle rows at harvest and partitioned in to leaves, shoots, roots, cobs and maize grains. Two banana plants were sampled and its leaves taken for mineral tissue analysis. The maize roots were washed in water to remove soil. The samples were oven dried to a constant weight at 72 ^{0}C. The samples were then ground into powder for determination of nutrient analysis. Procedures by Motsara and Roy (2008) was used to determine the nitrogen, phosphorus, potassium, calcium and magnesium mineral nutrient in various plant tissues. Data was subjected to Analysis of Variance using Genstat statistical package Version 15.2. Maize and bananas that were intercropped with trees recorded highest nutrient uptake and partitioning. *Sesbania sesban* recorded higher nutrient uptake as compared treatments without tree intercrops. These findings can be used to advice smallholder farmers of Vihiga County on the best intercropping system to adopt for maximum maize and banana production.

Keywords: *Sesbania sesban*, *Calliandra callothyrsus*, *Leucaena diversifolia*, intercropping, *nutrient uptake*, agroforestry.

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INTRODUCTION

High Population pressure in agricultural potential areas of Western Kenya has increased demand for food production. Vihiga county is the third most populated county in the republic 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 coupled with declining food production has led to poor farming practices such as clearing forest to put more land under crop production. According to Hansen *et al.*, (2010) the clearing of forests has resulted in global forest cover loss estimated at an average area of 1,011,000 km^2, translating to 3.1% loss per year. According to Ibid, (2008) this has in turn led to reduced soil fertility, severe land degradation, climate change and consequently reduced farm productivity. The high population pressure may lead to more forest land converted to agricultural land further worsening the problem of land degradation and climate change in Sub Saharan Africa. Therefore, this demands a shift in the agricultural system to balance between crop production and environmental management. According to FAO, (2011) Smallholder farmers are the most important food security stakeholders in Sub-Saharan Africa. These farmers practice subsistence agriculture characterized by low crop production due to soil nutrient depletion (Mugwe *et al.*, 2007).

Several studies have been carried out in recent years and proven the beneficial effects of legumes on soil fertility improvements (Sanginga and Woomer, 2009). For instance, in Kenya Mugwe *et al.*, (2009) found that herbaceous legumes improved soil fertility properties, especially cations such as Ca, K and Mg which in turn were taken up by the annual maize crops. In Tanzania Tuaeli and Friesen (2003) reported improved soil fertility after incorporation of *Dolichos* and *Mucuna* to the soil. Leucaena 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 incorporated into the soil at the beginning of a season have been found to increase crop yields and to have a positive effect on soil properties (Delve *et al.*, 2000). However, information about on the effects of agroforestry trees on the mineral nutrient content under maize-banana intercropping system in Vihiga is unknown. When Tithonia is incorporated into the soil, the nutrients contained in tithonia are rapidly released into plant-available forms during decomposition (Gachengo *et al.*, 1999). The N and P concentration of leaves was greater than the critical levels for N and P mineralization meaning that addition of biomass to the soil resulted in net mineralization rather than immobilization (Jama *et al.*, 1998). 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). For this reason, there is need to adopt an intercropping system of banana, maize and agroforestry trees in Vihiga. Nevertheless, there is paucity of information on the effect of trees on the mineral nutrient uptake in maize-banana intercrop.

According to Zaharah (2008), when maize was grown between hedgerows of leguminous trees, *Paraserianthes falcataria* and *Gliricidia sepium* in an alley cropping system and the tree prunings used as a source of nutrients for the maize crops, it was found that leaf prunings contributed up to 15% of the N taken up by the maize while hedgerow trees were found to contribute N to the maize through root decomposition. 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. Zaharah (2008) showed that leaf mulch did not contribute N to corn production in the first season, but contributed some to the subsequent seasons, and the integration of legume prunings with either fertilizer or the hedgerow (or both), resulted in an improvement in the N nutrition of corn. Legumes in alleys and fallows increase N, P, exchangeable bases (Ca, K, Mg) and maintain higher soil pH than natural grass fallows or continuous sole maize cultivation (Bünemann *et al.*, 2004). Phosphorus is the second most important nutrient that is frequently deficient in African soils and more so in western Kenya (Kwabiah *et al.*, 2003). In sub-Saharan Africa, organic materials continue to be a major source of plant nutrients in smallholder farming cropping systems (Baijukya and de Steenhuijsen Piters, 1998). However, traditional crop residues, cattle manure and green manure that would otherwise substitute inorganic P fertilisers are usually not available in sufficient quantities on most farms. If available, these organic materials are very low in nutrients such as P. In addition, there is competition between farming and livestock for the same organic materials (Jama *et al.*, 2000). All these setbacks have let to low nutrient uptake by plants thereby affecting plant growth and development which further results in the dwindling maize and banana production. 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. In Kenya, there are limited studies on the impact of *Sesbania sesban*, *Leucaena diversifolia* and *Calliandra calothyrsus* trees on nutrient uptake under maize and banana intercropping systems especially in Vihiga County.

Banana requires large amounts of nitrogen and potassium followed by phosphorus, calcium and magnesium to maintain high yields (Abdullah *et al.*, 1999). To fulfill the plant demand for nutritional attributes, it is essential to apply those elements in the soil, which mostly comes from inorganic chemical sources. The increased use of chemical fertilizer is undesirable because its production is an energetically costly process and considerable pollution is caused through both the production and use of mineral N-fertilizers. This is exacerbated by the relatively low efficiency of their uptake by plants due to non-extensive root system (Khan *et al.*, 2007). Little is reported on the effect of combining fertilizers trees with banana and maize intercrop in nutrient poor soils of Vihiga County. Nitrogen (N) is a key element in banana nutrition and extra nitrogen must be frequently applied on infertile soils since growth and development are promoted by N (INIBAP, 1998). Nitrogen enhances growth by increasing leaf size and gives the leaves their green colour. Nitrogen therefore enhances fruiting (INIBAP, 1998). Banana plants accumulate the phosphorus (P) they require over a long period and lose relatively little through the fruit (Robinson, 1996). This study aimed at investigating how intercropping of maize and banana with agroforestry tree species in Vihiga County affects the nutrient uptake of maize and banana.

2. MATERIALS AND METHODS

2.1. Site description

The experiments were conducted for two consecutive seasons from August 2018 to September 2019 at Vihiga County (00^o 00'15.5''S; 034^o 35'53.1''E; 1522 masl) in Western Kenya. The soils had very low N, P, K, Ca and Mg hence highly impoverished (Table 1). The site receives an annual mean precipitation of 1750 mm with bimodal pattern of distribution, with long rains occurring from March to July and short rains from August to November. The mean temperature of the study site was 28.7 degrees Celsius with relative humidity of 40%. The preliminary soil chemical characteristic of the study site was determined at the beginning of the experiment. The soils at the study site were acidic with a low mean pH of 4.65 coupled with high exchangeable aluminium (III) ions (Table 1). The soils had low soil nutrient status.

Table 1. Initial soil chemical properties of the experimental site at Maseno University farm in Vihiga County in the months of May, 2018

Component	Amount	Guide Low	Guide high	Status
pH	4.65	6	6.8	Low
N %	0.16	0.2	0.5	Low
P ppm	2.57	30	100	Low
K ppm	46.8	120		Low
Ca ppm	105	261	305	Low
Mg ppm	22.3	80		Low
Al meq/100g	1.88		.< 0.5	High

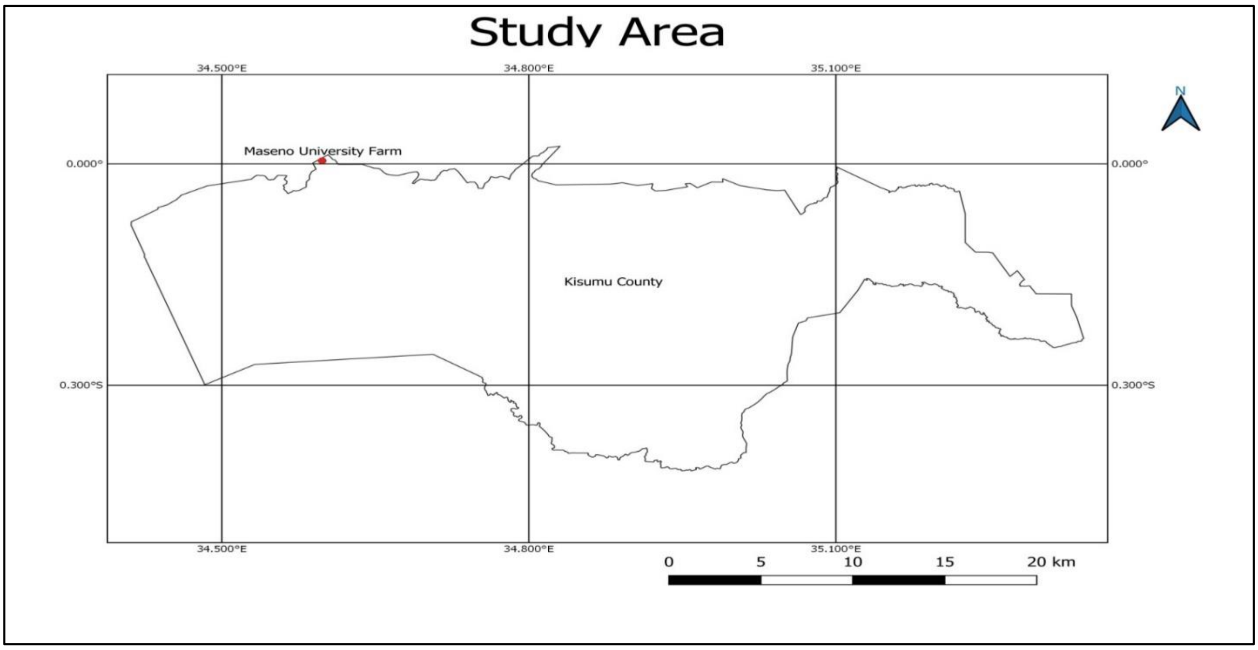

Figure 1: Map showing the Vihiga study site at Maseno University farm. Source, Google maps

2.2 Experimental Treatment and Design

The experiment was laid out at Maseno University farm located in Vihiga County in a Randomized complete block design with seven treatments i.e. unfertilized maize (M), banana (B), maize + banana + calliandra (MBC), maize+ banana+ leucaena (MBL), maize+ banana+ sesbania (MBS), maize + banana (MB), fertilized maize (MF) replicated three times. The treatments were replicated three times. The Williams banana varieties of the same age were obtained from KALRO-Thika and Hybrid maize seed, H513 was purchased from an agrovet. Seeds of agroforestry trees were obtained from KEFRI- Muguga and sown in seedbed after which the seedlings were transplanted in the nursery before being transplanted in the experimental plots at a spacing of 0.5m by 3m. Plot sizes measured 9m by 12 m, Banana holes were dug 2x2 feet, 20 kg of decomposed cow dung manure + 20 kg of top soil + 200g of NPK (N=14%, P=29%,K=6%, S=4%, Zn=0.1%, Cao=4%, B=0.1% and MgO= 1%) fertiliser was compounded in each banana hole before planting the Banana. In agroforestry plots the banana spacing was 3m by 3m, 3m by 2.5m in pure banana, , 6m by 2.5m in maize and banana, 0.75m by 30cm in maize and 2 rows banana x 4 within row in maize + banana+Agroforestry trees. Fully grown agroforestry trees were regularly pruned and the prunings applied in the same plots every fourteen days.

2.3. Determination of plant mineral nutrient content

The plant mineral analysis was done at the time of harvesting. Five maize plants per treatment and per replication were sampled randomly from the eight middle rows at harvest and partitioned in to leaves, shoots, roots, cobs and maize grains. The different plant parts were handled separately. The maize roots were washed in water to remove soil. Two banana plants per treatment and replication were sampled and two youngest leaves taken for mineral tissue analysis. The samples were oven dried to a constant weight at 72 ^{0}C. The samples were then ground into powder for determination of Ca, Mg, N, P and K nutrient content. Procedures by Motsara and Roy (2008) were used to determine the nitrogen, phosphorus, potassium, calcium and magnesium mineral nutrient in various plant tissues.

2.4. Data Analysis

The data collected was subjected to Analysis of Variance (ANOVA) using Genstat statistical package version 15.2. Means were separated using Fischers' protected LSD test at 95% confidence level.

3. RESULTS

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

3.1.1: Cob calcium nutrient content

There were significant differences among the treatments in cob calcium nutrient contents (Table 2). The maize plants intercropped with agroforestry trees showed higher cob nutrient content in comparison to other treatments. During 1st season, cob calcium content under maize+banana+ *Leucaena diversifolia* (MBL) and maize+banana+*Sesbania sesban* (MBS) treatments showed significantly higher levels compared to maize+banana+*Calliandra carlothyrsus* (MBC), maize+banana (MB), fertilized maize (MF) and monocropped maize (M) treatments. However, cob calcium in MBC was higher than those under MB, MF and M treatments. In the 2nd season, MBS recorded significantly higher cob calcium levels compared to other treatments. The least cob calcium content was recorded in MF however, this was not significantly different from cob calcium content of M, MB, MBC and MF.

3.1.2: Cob Potassium nutrient content

There were significant differences among the treatments in potassium content of cob (Table 2). In the 1st season, the cob potassium under MBL and MBS were significantly higher than the cob potassium content of all the other treatments. However, there was no significant difference between MBS and MBL. The lowest potassium content was recorded under unfertilized maize however, it was not significantly different from MF and MB. During the 2nd season maize potassium cob content was significantly higher under MBS compared to the rest of the treatments (Table 2). There was no significant difference in cob potassium content between MBL, MBC and MB however MBL showed higher content than MBC. The least cob potassium content was recorded under unfertilized maize.

3.1.3: Cob Magnesium nutrient content

There were significant differences in the maize cob magnesium nutrient content during 1st season (Table 2). MBS recorded significantly higher cob magnesium content as compared with the other treatments. MBL had the second highest magnesium content however, this was not significantly differently different from MBC, MF and M. The least magnesium cob content was recorded under M+B. *Sesbania sesban* treatment performed better than the fertilized maize and also better than the *Leucaena diversifolia* and *Calliandra carlothyrsus* treatments. In the 2nd season significantly high cob magnesium content was recorded under MBS and it was not significantly different from MF (Table 2). Among agroforestry trees treatments, MBL recorded the second best and it was not significantly different from MBC. The least magnesium content was under maize alone (M) which was not significantly different from maize banana (M+B) treatment.

3.1.4: Cob Nitrogen nutrient content

MBS showed significantly higher cob nitrogen content which was not significantly different from all the other treatments except in the MBL that recorded the least cob nitrogen content during the 1st season (Table 2). During the 2nd season highest nitrogen content was recorded under MBC which was not significantly different from MB, MBS, MF and M treatments and significantly different from MBL which recorded the least cob nitrogen content.

3.1.5: Phosphorus nutrient content

Significant differences of maize cob phosphorus nutrient uptake were observed in MBS, MBL, MB, MF treatments in the 1st season with MBS recording the highest cob nitrogen content (Table 2). Highest maize cob nitrogen content was consistently recorded under agroforestry trees. In the 2nd season, MBS and MF treatments showed high cob phosphorus which was significantly different than the rest of the treatments. MB and M treatments registered lowest phosphorus content which was not significantly different from MBL and MBC treatments.

Table 2. Effect of intercropping maize and banana with agroforestry tree species on the maize cob nutrient contents (mg/kg)

Season	Treatment	Ca	K	Mg	N	P
Season 1	M+B	0.08 c	6.57 bc	0.02 d	5.1 ab	0.367 ab
	M+B+C	0.1067 b	5.83 bc	0.03 bc	5.83 ab	0.38 b
	M+B+L	0.1267 a	7.6 ab	0.0367 ab	4.97 b	0.37 ab
	M+B+S	0.13 a	9.47 a	0.0433 a	5.9 a	0.467 a
	M+F	0.0833 c	6.43 bc	0.0233 cd	5.6 ab	0.407 ab
	M Alone	0.07 c	4.58 c	0.0233 cd	5.17 ab	0.337 b
	LSD	**0.015**	**2.602**	**0.008**	**0.876**	**0.102**
Season 2	M+B	0.08 c	6.37 bc	0.0267 cd	5.267 ab	0.333 b
	M+B+C	0.0867 bc	6.9 bc	0.0333 bc	5.9 a	0.367 b
	M+B+L	0.0967 b	7.2 b	0.0367 bc	5.1 b	0.34 b
	M+B+S	0.1367 a	9.3 a	0.05 a	5.767 ab	0.393 a
	M+F	0.0667 c	6.27 c	0.04 ab	5.6 ab	0.417 a
	M Alone	0.0767 bc	6.1 c	0.02 cd	5.233 ab	0.333 b
	LSD	**0.02269**	**0.898**	**0.01085**	**0.741**	**0.0922**

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

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

3.2.1: Grain calcium nutrient content

Significant differences of maize grain calcium content was registered among the treatments in the 1st season (Table 3). MBS showed the highest grain calcium content however, it was not significantly different from MF and MBC. The least calcium content was recorded under M.

In the 2nd season MBS and MF showed significantly high grain calcium content as compared to the other treatments with M posting the least grain calcium content.

3.2.2: Grain potassium nutrient content

MBS and MF showed significant differences from all the other treatments for both 1st and 2nd season (Table 3). However, MBS showed highest grain potassium content while unfertilized maize had the least during the two seasons. Apart from the fertilized maize treatment, the agroforestry tree species recorded highest grain potassium content than the treatments without the agroforestry trees during both seasons.

3.2.3: Grain magnesium nutrient content

Significantly high grain magnesium content was registered under the MBS treatment in the 1st season (Table 3). The least content was recorded under the unfertilized maize. 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 as compared with the other treatments while unfertilized maize recorded the least.

3.2.4: Grain nitrogen nutrient content

The highest nitrogen uptake was registered in MBS treatments in the 1st season, however it was not significantly different from MBL and MF treatments (Table 3). The unfertilized maize (M) showed lower grain nitrogen uptake however, it was not significantly different from MBC and MB treatments.

In the 2nd season MBS and MF treatments showed significantly high grain nitrogen content (Table 3). MBL showed the 2nd highest grain nitrogen content however it was not significantly different from MBC and MB while the least was recorded under unfertilized maize.

3.2.5: Grain phosphorus nutrient content

There were significant differences of maize grain phosphorus nutrient uptake for both seasons under MBC, MBL, MBS and MF (Table 3). Highest maize grain phosphorus content was achieved under MBL in the 1st season. The low grain phosphorus content was reported under maize-banana (MB) and in unfertilized maize (M) in the 1st season.

During the 2nd season significant differences were observed under MBS, MBL, MBC and MF (Table 3). MBS recorded the highest phosphorus content while least phosphorus content was under MB and M. In the two seasons, treatments with agroforestry trees showed higher maize grain phosphorus content compared to treatments without agroforestry trees.

Table 3. Effect of intercropping maize and banana with agroforestry tree species on the maize grain nutrient contents (mg/kg)

Season	Treatment	Ca	K	Mg	N	P
Season 1	M+B	0.343 bcd	3.4 c	0.813 bc	13.83 bc	1.867 c
	M+B+C	0.4 abc	3.533 bc	0.92 b	13.9 bc	2.733 a
	M+B+L	0.303 cd	3.967 b	0.903 b	14.53 ab	2.967 a
	M+B+S	0.46 a	4.833 a	1.117 a	15.3 a	2.867 a
	M+F	0.41 ab	4.71 a	0.973 b	15.2 a	2.867 a
	M Alone	0.297 d	2.8 d	0.66 c	13.27 c	2.167 bc
	LSD	**0.102**	**0.54**	**0.13**	**1.117**	**0.351**
Season 2	M+B	0.3433 bc	3.4 b	0.787 c	13.77 bc	2.1 cd
	M+B+C	0.38 b	3.567 b	0.96 b	13.87 bc	2.7 a
	M+B+L	0.37 b	3.567 b	0.8267 c	14.07 b	2.6 ab
	M+B+S	0.52 a	4.9 a	1.0833 a	15.5 a	2.867 a
	M+F	0.567 a	4.233 a	1.081 a	15.63 a	2.867 a
	M Alone	0.2933 c	3.067 b	0.7267 d	13.47 c	1.933d
	LSD	**0.06369**	**0.5939**	**0.0592**	**0.521**	**0.2671**

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

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

3.3.1: Leaf calcium nutrient content

There were significant differences of maize leaves calcium nutrient content among the treatments during the 1st season (Table 4). MBS recorded the highest calcium content as compared to MB, MBL and M. However, it was not significantly different from MBC and MF (Table 4). The least leaf calcium nutrient was recorded under M.

In the 2nd season significant differences were recorded under MBC, MBL, MBS and MF with MF and MBC recording the highest leaf calcium nutrient content (Table 4). The MBS and MBL were not significantly different from MB. The lowest leaf calcium content was recorded under M.

3.3.2: Leaf potassium nutrient content

There were no significant differences in maize leaf potassium nutrient in MBS, MBC and MF However, they were significantly different from MB, MBL and M during 1st seasons (Table 4). MF recorded highest potassium content but the difference with MBS treatment was marginal. M reported the least potassium nutrient content. MBL recorded the least potassium content among agroforestry trees.

During 2nd season MBS and MF showed higher significant potassium nutrient content but was not significantly different from MBC (Table 4). MB recorded the least potassium content which was not significantly different from MBL and M.

3.3.3: Leaf magnesium nutrient content

There were no significant differences of maize leaf magnesium nutrient in maize under MBS, MF and MBC during 1st season with both MBS and MF registering highest levels of the magnesium content (Table 4). Lowest magnesium nutrient content was observed under MBL and M which was not significantly different from that of MB.

During 2nd season, there were no significant differences among the treatments (Table 4). MF recorded higher magnesium content however it was not significantly different from the other treatments. The least magnesium content was recorded under M treatment.

3.3.4: Leaf nitrogen nutrient content

The maize leaf nitrogen content showed no significant differences under MF, MBS and MBC during 1st season however the treatments were significantly different from MB, MBL and M (Table 4). The highest leaf nitrogen content was in the MF which was not significantly different from MBS and MBC. The least leaf nitrogen was observed under M treatment.

In the 2nd season MBS and MF recorded significantly higher nitrogen content than the rest of the treatments however, MBS content was not significantly different from MBC. The least nitrogen content was under M and MB treatments.

3.3.5: Leaf phosphorus nutrient content

There was significant differences of maize leaf phosphorus nutrient content under MF, MBS and MBC during 1st season (Table 4). MF recorded the highest phosphorus content however, there was no much difference with MBS. Least phosphorus content was registered under unfertilized maize. 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 unfertilized maize.

Table 4. Effect of intercropping maize and banana with agroforestry tree species on the maize leaves nutrient contents (mg/kg)

Season	Treatment	Ca	K	Mg	N	P
Season 1	M+B	0.513 c	2.667 b	0.53 bc	3.2 c	0.3533 c
	M+B+C	0.817 a	3.1 a	0.653 ab	3.967 a	0.48 a
	M+B+L	0.657 b	2.733 b	0.497 c	3.6 b	0.42 b
	M+B+S	0.903 a	3.267 a	0.703 a	4.2 a	0.51 a
	M+F	0.833 a	3.433 a	0.713 a	4.967 a	0.54 a
	M Alone	0.287 d	2.2 d	0.44 c	2.567 d	0.26 d
	LSD	**0.107**	**0.233**	**0.147**	**0.242**	**0.033**
Season 2	M+B	0.507 bc	1.79 c	0.5 a	2.7 d	0.36 c
	M+B+C	0.817 a	2.93 ab	0.6 a	3.9 bc	0.4667 b
	M+B+L	0.637 ab	2.6 abc	0.5 a	3.567 c	0.4667 b
	M+B+S	0.68 ab	3.43 a	0.6 a	4.067 ab	0.5 b
	M+F	0.863 a	3.57 a	0.7 a	4.467 a	0.56 a
	M Alone	0.29 c	2.03 bc	0.4 a	2.867 d	0.2867d
	LSD	**0.2539**	**1.064**	**30.21**	**0.4934**	**0.03387**

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

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

3.4.1: Root calcium nutrient content

Significantly higher maize root calcium nutrient content was reported in MF, MBS, MBL and MB during the 1st season, however MB was not significantly different MBC (Table 5). The MF recorded highest root calcium content however it was not significantly different from that of MBS, MBL and MB.

During the 2nd season significantly high root calcium content was observed in the MF, MBS and MBL as compared to the other treatments. Among agroforestry tree treatments MBC registered lower root calcium content and was not significantly different from MB. The unfertilized maize (M) recorded the lowest root calcium content among all treatments.

3.4.2: Root potassium nutrient content

There was significant differences of maize root potassium nutrient content in MBS and MF treatment during 1st season (Table 5). The highest potassium uptake was registered in the MBS which was not significant from MF. The fertilized maize (M) recorded the least root potassium content.

During the 2nd season significant differences MBS and MF showed significant differences from other treatments. The trend among treatments were similar to the ones in the 1st season.

3.4.3: Root magnesium nutrient content

There were no significant differences of maize root magnesium nutrient content in the 1st season under MBS and MF, however they were significantly different among the other treatments (Table 5). The highest magnesium content was recorded under MBS followed by MF and was significantly different from those of the other treatments. The lowest magnesium content was registered in the M treatment.

During the 2nd season, the results were similar to those of the 1st season.

3.4.4: Root nitrogen nutrient content

The maize root nitrogen content showed significant differences during 1st season (Table 5). MBS, MBL and MF had significantly higher nitrogen content during 1st season. MBS reported highest nitrogen content from the other treatments however, MBL was not significantly different from MBC. M recorded the least root nitrogen content.

During the 2nd season MF showed significantly higher nitrogen content. MBS recorded the second best nitrogen content among the treatments. The least root nitrogen content was reported MB treatment.

3.4.5: Root phosphorus nutrient content

There were no significant differences of maize root phosphorus nutrient content in MBS, MBL, MBC and MF in the 1st season, however they were significantly different from MB and M treatments (Table 5). The maize under MBS recorded the highest phosphorus content which was not significantly different from MBL, MBC and MF treatments. The least phosphorus was recorded under M.

Similarly, in the 2nd season the highest content was in MF but it was not significantly different from that of MBS. The least maize root phosphorus content was recorded MB and M treatments.

Table 5. Effect of intercropping maize and banana with agroforestry tree species on the maize root nutrient contents (mg/kg)

Season	Treatment	Ca	K	Mg	N	P
Season 1	M+B	0.1533 ab	0.3667 bc	0.4433 d	0.3033 c	0.1067 bc
	M+B+C	0.1433 bc	0.3433 cd	0.6267 c	0.4 b	0.1267 ab
	M+B+L	0.17 a	0.4 b	0.74 b	0.4333 ab	0.1267 ab
	M+B+S	0.1733 a	0.4567 a	0.8667 a	0.4533 a	0.1433 a
	M+F	0.19 a	0.45 a	0.8133 a	0.46 a	0.1367 a
	M Alone	0.1267 c	0.3067 d	0.38 e	0.2133 d	0.0833 c
	LSD	**0.022**	**0.041**	**0.042**	**0.043**	**0.028**
Season 2	M+B	0.1333 b	0.37 bc	0.4433 d	0.3 e	0.0933 c
	M+B+C	0.14 b	0.35 bc	0.6533 c	0.3967 d	0.1367 b
	M+B+L	0.1733 a	0.4033 b	0.7567 b	0.4367 c	0.13 bc
	M+B+S	0.1767 a	0.48 a	0.88 a	0.4933 b	0.24 a
	M+F	0.1783 a	0.45 a	0.7967 a	0.6667 a	0.2567 a
	M Alone	0.1067 c	0.3 c	0.2967 e	0.2167 f	0.0933 c
	LSD	**0.02144**	**0.07114**	**0.06764**	**0.04**	**0.03758**

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

3.5 Effect of intercropping maize and banana with agroforestry tree species on maize stem mineral content

3.5.1: Stem calcium nutrient content

In the 1st season there was no significant differences of maize stem calcium nutrient content in maize under MBS and MF (Table 6). The MBS recorded the highest stem calcium content however it was not significantly different from fertilized maize. The least calcium content was registered under MB and M.

In the 2nd season MBC recorded significantly higher stem calcium content which was not significantly different from MBS, MB, MF and M. The MB and M treatments showed least maize stem calcium content and they were not significantly different from each other.

3.5.2: Stem potassium nutrient content

There were no significant differences of maize stem potassium nutrient content under MBC, MBL, MBS, MF and M during the 1st season (Table 6). The highest potassium uptake was registered in MF and MBS. MB treatment recorded the lowest stem potassium nutrient content compared to the rest of the treatments however, it was not significantly different from M.

In the 2nd season MBL reported highest potassium content but was not significantly different from MF, MBL, MBS and M. The lowest content was recorded in the MB treatments during the study period.

3.5.3: Stem magnesium nutrient content

There were significant differences among treatments in stem magnesium content. MBC, MBL, MBS and MF had significantly higher as compared to the other treatments (Table 6). However, the highest magnesium content was recorded under MF followed by MBS during 1st season. The lowest stem magnesium nutrient content was reported under M 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. Unfertilized maize recorded the lowest stem magnesium nutrient content however it was not significantly different from MB treatment.

3.5.4: Stem nitrogen nutrient content

There were significant differences in the maize stem nitrogen content during both seasons (Table 6). During the 1st season MBS reported highest stem nitrogen content. However, the stem nitrogen content was not significantly different from the other treatments except MB and M treatments.

Similarly, during the 2nd season MBC treatment registered higher nitrogen content that was not significantly different from the other treatments except MB and M treatments. In both seasons MB and M registered the lowest nitrogen content.

3.5.5: Stem phosphorus nutrient content

There were significant differences in maize stem phosphorus nutrient content during the 1st season (Table 6). The MBS treatments recorded the highest phosphorus nutrient content which was not significantly different from MBC and MF. The M recorded the lowest stem phosphorus among all treatments.

In the 2nd season the highest phosphorus content was recorded in MF however it was not significantly different from that of MBS and MBC treatments. The M and MB reported the least stem phosphorus content.

Table 6. Effect of intercropping maize and banana with agroforestry tree species on the maize stem nutrient contents (mg/kg)

Season	Treatment	Ca	K	Mg	N	P
Season 1	M+B	0.32 d	2.21 b	0.3267 b	2.967 b	0.4667 c
	M+B+C	0.74 b	4.0 a	0.5733 a	4.533 a	0.5933 a
	M+B+L	0.66 c	3.5 a	0.54 a	4.367 a	0.53 b
	M+B+S	0.8467 a	4.17 a	0.6133 a	4.767 a	0.6233 a
	M+F	0.7233 a	4.33 a	0.6833 a	4.0 a	0.5133 a
	M Alone	0.31 d	3.1 ab	0.22 c	2.633 b	0.41 d
	LSD	**0.053**	**1.245**	**0.077**	**0.431**	**0.033**
Season 2	M+B	0.327 b	3.2 b	0.343 bc	2.9 c	0.467 c
	M+B+C	0.713 a	4.07 a	0.563 a	4.8 a	0.597 ab
	M+B+L	0.69 a	3.67 ab	0.533 a	4.27 ab	0.53 abc
	M+B+S	0.66 a	3.8 ab	0.617 a	4.67 a	0.6 a
	M+F	0.68 a	4.02 a	0.593 a	4.53 a	0.613 a
	M Alone	0.547 ab	3.3 ab	0.307 c	3.23 bc	0.47 bc
	LSD	**0.3314**	**0.784**	**0.0854**	**1.237**	**0.1269**

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

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

3.6.1: Leaf calcium nutrient content

There were significant differences in banana leaf calcium nutrient content among the treatments. (Table 7). During the 1st season MBS registered significantly higher content however, it was not significantly different from MBL treatments while the 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 from that of the MBC treatments. The lowest leaf calcium content was registered under B treatments in both seasons. The leaf calcium content under MBL was not significantly different that of MBC.

3.6.2: Leaf potassium nutrient content

In the 1st season MBC, MBL and MBS recorded significantly higher potassium content as compared to MB and B treatments (Table 7). There were no significant differences of banana leaf potassium nutrient content under MBC, MBL and MBS treatments during 1st season (Table 7). The highest potassium nutrient content was registered under MBC followed closely by MBS and MBL. The B treatment registered lowest banana leaf potassium content.

In the 2nd season MBC and MBS treatments reported significantly higher potassium content than the rest of the treatments. The lowest potassium content was recorded in the B treatments.

3.6.3: Leaf magnesium nutrient content

There were significant differences of banana leaf magnesium nutrient content among treatments (Table 7). During the 1st season MBS recorded significantly higher magnesium content however, it was not significantly different from MBL and MBC. The B treatment recorded the lowest magnesium content. In the 2nd season, a similar trend as the one in the 1st season was registered.

3.6.4: Leaf nitrogen nutrient content

The banana leaf nitrogen content showed significant differences at MBC and MBS treatments during the 1st season (Table 7). MBS and MBC treatments reported highest nitrogen content which was significantly different from all other treatments. The B treatment registered the lowest leaf nitrogen content. During the 2nd season a similar trend to that of 1st season was registered.

3.6.5: Leaf phosphorus nutrient content

There were significant differences in maize leaf phosphorus nutrient content under MBC, MBS and MBL which was significantly different from that one of MB and B for both seasons (Table 7). The MBS registered the highest phosphorus content in the 1st season which was not significantly different from MBL and MBC. The B treatment registered lowest banana leaf nitrogen content.

During the 2nd season banana leaf nitrogen content registered significant differences under MF, MBC and MBS (Table 7). The MBS recorded highest banana leaf phosphorus but was not significantly different MF and MBC. In the 2nd season, the trend similar to the 1st season was reported.

Table 7. Effect of intercropping maize and bananas with agroforestry tree species on the mineral nutrient contents (mg/kg) of banana leaves 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 the same letter along the columns are not significantly different according to LSD at $p \leq 0.05$.

4.0. DISCUSSION

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

The MBS showed significantly higher maize cob mineral content as compared to the rest of the treatments. The agroforestry trees were found to promote mineral uptake as compared to those treatments without the agroforestry trees except for fertilized maize. The findings on maize and banana cob nutrient content concur with the findings of Nissanka and Sangakkara (2008) who reported that N concentrations of maize leaves and grains were nearly three times higher than those of stems and roots. Furthermore, the results of the study 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. The lowest mineral nutrient content could be attributed to the insufficient nutrient in the soils due to limited nutrient recycling and resource partitioning. The MBS treatments recorded the highest nutrient content among the treatments and this could be attributed to nitrogen fixed by the *Sesbania sesban* trees and the decomposition of the pruned biomass. Nonetheless the fertilizer had produced positive results, it is however not readily available to all small holder farmers in this region. In terms of nutrient partitioning in the cobs potassium was highest, followed by nitrogen, 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.

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

The MBS treatment recorded significantly higher nutrient uptake by the maize grains. In general it was also noted that the three agroforestry tree species had significant effect on the nutrient uptake compared to other treatments except for the fertilized maize. These findings are in tandem with those of Chen *et al*., (2010); Nissanka and Sangakkara (2008) who reported that N concentrations of maize grains in tree intercrops were nearly three times higher than those of the monocropped. These results of increased uptake and partitioning under agroforestry treatments are also in agreement with those of Suvera *et al*., (2015) who reported that N, P and K nutrient contents of *Pongamia pinnata* trees were increased when intercropped with *Ocimun basilicum* plants. Similar results were also reported by Ajayi *et al*., (2011) who found that N, P, K, Ca and Mg uptake are enhanced by deep rooted leguminous that enhances pulling up of nutrients from below ground to maize crop rhizosphere. The high nutrient uptake registered in the *Sesbania sesban* treatments may be attributed to the decomposition of the tree prunings and the nitrogen fixation by the *Sesbania sesban* trees in comparison to the treatments. Even though the fertilizer were seen to produce positive results, it is however not readily available to all small holder farmers in this region and also it has been earlier reported to have significant pollution effects on the environment. The maize intercrop involving agroforestry trees showed high nutrient uptake and this could be due to decomposition of pruning and nitrogen fixation that increased nitrogen nutrient in the study soils hence promoting its uptake.

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

Significantly higher mineral nutrient uptake were registered in both maize and banana leaves under MBS. Maize and banana planted under the three agroforestry tree species were reported to enhance maximum nutrient uptake. These findings concur with the findings of Nissanka and Sangakkara (2008) who reported that nitrogen concentrations of maize leaves and grains were nearly three times higher 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 K nutrient contents of *Pongamia* *pinnata* trees were increased when intercropped with *Ocimun basilicum* plants. 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 MBS and MBC treatments posted significantly highest mineral nutrient content with MBS dominating in comparison to other treatments. These results could be due to nitrogen fixation and pruned biomass decomposition that added nutrients to the soils. 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. 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.

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

Significantly higher mineral nutrient uptake were registered under the MBS treatments. The three agroforestry tree species were reported to promote uptake of nutrients by the maize roots. These findings are in agreement with those of Nissanka and Sangakkara (2008) who reported significant N concentrations of maize leaves and grains. The maize intercrop involving agroforestry trees showed high nutrient uptake and partitioning which can also be attributed to nutrient pulling and resource facilitation from below ground by the deep rooted agroforestry tree species. The findings of this study are in line with those of Ignacio *et al.*, (2013); Oke (2001) and Olujobi *et al.*, (2013) who reported increased N, P, K, Ca and Mg uptake of maize when intercropped with gliricidia trees. These results of increased uptake and partitioning under agroforestry treatments are also in agreement with those of Suvera *et al.*, (2015) who reported that N, P and K nutrient contents of Pongamia pinnata trees were increased when intercropped with *Ocimun basilicum* plants. Similar results were also reported by Ajayi *et al.*, (2011) who found that N, P, K, Ca and Mg uptake are enhanced by deep rooted leguminous that enhances pulling up of nutrients from below ground to maize crop rhizosphere. The MBS treatment reported highest mineral nutrient uptake among all the treatments during the study period. These could be attributed to the nitrogen fixation and decomposition of tree prunings that increased the soil available nutrients. Potassium and Nitrogen were found to be higher to the stem compared to other nutrients. This could be due to the synergistic effect between the two nutrients. Highest nutrients partitioned in maize roots under agroforestry tree intercrop treatments could be attributed to available nutrient released from the decomposition of agroforestry prunings and nitrogen fixation by the nitrogen fixing trees.

4.5. Effect of intercropping maize and banana with agroforestry tree species on maize stem mineral content

The MBS treatment reported significantly higher mineral nutrient uptake than the rest of the treatments among the agroforestry tree treatments. The findings of this study are in line with those of Ignacio *et al.*, (2013); Oke (2001) and Olujobi *et al.*, (2013) who reported increased N, P, K, Ca and Mg uptake of maize when intercropped with gliricidia trees. These results of increased uptake and partitioning under agroforestry treatments are also in agreement with those of Suvera *et al.*, (2015) who reported that N, P and K nutrient contents of *Pongamia pinnata* trees were increased when intercropped with *Ocimun basilicum* plants. Similar results were also reported by Ajayi *et al.*, (2011) who found that N, P, K, Ca and Mg uptake were enhanced by deep rooted leguminous trees that enhanced pulling up of nutrients from below ground to maize crop rhizosphere. The higher nutrient uptake under MBS could be attributed to the nitrogen fixation and decomposition of tree prunings and maize stover that increased the soil available nutrients. Nitrogen and Potassium were highly partitioned compared to other nutrients. High potassium and nitrogen uptake can attributed to the synergistic effect between the two nutrients.

4.2 CONCLUSION

The intercrop system involving agroforestry trees species of *Sesbania sesban*, *Calliandra callothyrsus* and *Leucaena diversifolia* agroforestry tree species with maize and banana crop increased the nutrient uptake which facilitated plant growth and physiology. *Sesbania sesban* trees enhanced higher nutrient uptake and partitioning to various plant body parts among the agroforestry trees used. More potassium was partitioned in the cobs where it is involved in enzyme activation within the plant where it is known to affect protein, starch and ATP production. High nitrogen contents was partitioned to the leaves, stems and grains where it forms a major component of chlorophyll and amino acids. Magnesium was highly partitioned to the roots and this could signify increased uptake from the soil and reduced aluminium effects from the study soils. The higher uptake of nutrients by the stover yield enhances soil available nutrients during their decomposition.

4.3 Recommendations.

Sesbania sesban can be recommended in both maize and banana as it promotes sustainability in crop higher nutrient uptake. *Sesbania sesban* may therefore be recommended for intercropping in the agro-ecological zones of Kenya to promote productivity, climate mitigation and soil fertility improvements.

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Competing interests

The authors have declared that no competing interests exists.

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