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Effect of Intercropping Maize with Selected Agroforestry Species on Maize Yields and Harvest Index in Kisumu and Kisii Counties, Kenya

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Abstract:- Maize is a staple food with a high per capita consumption averaging 125 Kgs per person annually in Kenya. However, its low yields associated with climate change, declining cultivable land and reduced soil fertility posing a serious threat to food security. To ensure increased crop yields, apt intecropping systems and management has to be adopted to meet the ever increasing demands. Field experiments were carried out in Kisii and Kisumu counties over two seasons; to determine the effect of intercropping maize with selected agroforestry species on maize yields and Harvest Index (HI). The treatments consisted of; maize no-fertilizer, maize+banana+*Caliandra* (MBC), maize+banana+ *Leucaena* (MBL), maize+ banana+ *Sesbania* (MBS), maize+ banana (MB) and maize+ fertilizer arranged in a Randomized Complete Block Design (RCBD) with three replications. Agroforestry species were planted six months before maize both in 2018 Short rains (SR) and 2019 Long Rains (LR). Maize-fertilizer treatment was applied with 35 Kgs P/ha and 85 Kgs N/ha. Maize fertilizer had significantly high grain yields in Kisumu LR (3.98 t/ha) which was statistically similar to MBS (3.72 t/ha). In Kisii, Maize fertilizer in SR (4.62 t/ha) and LR (5.0 t/ha) with Maize No fertilizer (5.0 t/ha) had significantly high yields. Maize fertilizer biomass in Kisii SR was 26.4 t/ha and 15.8 t/ha in LR which was significantly similar to Maize No fertilizer (13.9 t/ha) and MBS (13.8 t/ha). Intercropping systems had a significant effect on maize yields and Harvest Index. Maize fertilizer recommended to obtain higher grain and biomass yields in Kisumu and Kisii.

Keywords:- *Intercropping Systems, Agroforestry, Maize Yields, Harvest Index.*

I. INTRODUCTION

Maize (*Zea mays L.*) is one of the most important cereal crops for both human consumption and animal feeds across the globe (Ali *et al*., 2015). In Kenya, it's the staple food with high per capita consumption averaging 125 Kgs per person annually (Byerlee and Eicher, 1997) which provides basic diet to millions of Kenyans. It contributes to more than 25% employment and 20% of the total agricultural production (GoK, 2001; Nyaga, 2018).

Despite the fact that maize plays a key role in food security and income generation in western Kenya and the whole country at large, its production which is done under an estimate of 1.5 million hectares still remains low at about 1.5 tons per hectare against a possible potential of 6.0 tons per hectare (MOA, 2010). Food insecurity is therefore rampant within this region majorly due to low soil fertility levels and unpredictable weather patterns (Sanchez *et al*., 1997, Kitonyo *et al*., 2013, Mbure *et al*., 2015). Thus, of the likely agricultural constraints, nutrient depleted soils are key and major factor affecting maize production in addition to shallow soils and erratic summer rainfall (Robins, 1953, Sadras, 1996, Liu Cheng *et al*., 2017). Various studies have shown the potential of agroforestry cropping system as an approach to an enhanced sustainable agriculture within the tropics (Young, 1997, Mugendi *et al*., 1999, Nyaga, 2018). Agroforestry is a land-use system in which wood perennials like trees and shrubs are cultivated with herbaceous plants (crops, pastures) and livestock in a spatial arrangement or rotation in the same parcel of land (Young, 1997, Stahl, 2005) leading to significant ecological and economical interactions between trees and crops (Nyaga, 2018). Even though agroforestry is a sustainable system towards achieving high crop yields, it comes with few challenges like poor growth and competition which can only be overcome thru good selection of agroforestry species and agronomic management both above and below ground crowns and roots to minimize competition (FAO, 2008, Salau *et al*., 2016). Hence, the addition of agroforestry species to the conventional cropping systems has the capacity to enhance soil fertility through maintenance or improving soil structure and organic matter by the accumulation of above ground litter and root residues in the nutrient depleted soils (Young, 1997, Stahl, 2005, Ahmad *et al*., 2010, Uwizeyimana *et al*., 2018). Agroforestry species like *Sesbania sesban* have been found to have a greater influence on maize yields thru nitrogen fixation and high level of biomass production hence can store up to 10 tons C/ha in 12 months (Nyaga, 2018). *Leucaena diversifolia* and *Calliandra calothyrsus* prunnings incorporated in the soil were found to produce high maize yields after two seasons of planting (Mugendi *et al*., 2007).

The adoption of agroforestry systems by most smallholder farmers has been driven by the multiple beneficial functions like firewood supply, fodder for livestock, green manure (Ojowi *et al.,* 2001, Babu *et al*., 2017), timber, and nitrogen fixation thus supplying nutrients within the soil (Sanchez *et al.*, 1997). However, much work has been done on intercropping and agroforestry cropping systems though they have majorly focused on a single agroforestry tree or cereal-legume cropping systems and nutritional aspects (FAO/IAEA, 2008) over years. In Western Kenya, maize grain yield, biomass and harvest index under selected agroforestry species and cropping systems has not been explored well. Therefore, the present study sought to find out the effects of maize-based agroforestry systems involving different species on maize grain yields, biomass and harvest index in Western Kenya.

II. MATERIALS AND METHODS

➢ *Experimental Site Description*

The study was carried out in two sites, Kisii and Kisumu during the short rains (SR) of September to December 2018 and the long rains (LR) between March to August 2019. The experiments were conducted at the Maseno University Farm, Kisumu County which lies at latitude 0^0 09’’S and longitude 34^o 25-47’’ E and an altitude of approximately 1529m above sea level. The area receives an annual rainfall ranging between 1510-1678 mm with a bimodal distribution. The minimum and maximum annual temperatures range between 9-18^{0}C and 25-35 ^{0}C respectively at the experimental site. The main soil types are Ferralsols which are well drained, deep reddish brown clay-loam with the pH being slightly acidic and ranging between 4.6 and 5.4 (Sikuku *et al.*, 2010).

The Kisii experimental site is located on latitude 0^0 67’ 00’’ N and longitude 34^0 77’ 00’’ E and an altitude of approximately 1700 m above sea level with an average annual temperature of 19.5 ^{0}C. The region receives a significant amount of rainfall throughout the year with an average of 1922mm. The site is within the Kenya Agricultural and Livestock Research Organization (KALRO) farm. The site has a deep, well-drained soil with moderate water holding capacity and are characterized as Nitasols Phaezems (Ojowi *et al*., 2001).

➢ *Experimental Design and Layout*

The experiment comprised of 6 treatments arranged in a Randomized Complete Block Design (RCBD) replicated 3 times giving 18 experimental units. Each experimental unit measured 12 m x 9 m (108 m^2) with pathways of 0.75m between them.

➢ *Treatments*

Sole Maize+ No-fertilizer (M-No Fert.) Maize+ Banana+ *Calliandra* (MBC), Maize+ banana+ *Leucaena* (MBL), Maize+ banana+ *Sesbania* (MBS), Maize and banana (MB) and Sole maize + Fertilizer (M+ Fert.)

➢ *Weather Data*

Daily data for rainfall, temperature, wind and relative humidity was downloaded from the weather station data logger located within the farm (KALRO Kisii and Maseno University). The weather stations are located at the farms, 100m from where the experiments were taking place.

➢ *Crop Establishment and Management*

During the first season, Maize Hybrid 516 was sown on 19th September 2018 and harvested on 10th January 2019. The same maize cultivar was sown on 30th April 2019 and Harvested on 31st August 2019. Maize was planted at the recommended spacing of 0.75 m between rows and 0.30 m within rows, giving a population of 44, 444 plants/ha. The planting depth was 0.05 m and hand weeding done two times in each season. The maize was also sprayed with chlorpyrifos pesticide uniformly to keep them free from fall army worms. The agroforestry species were planted 6 months before the introduction of maize. Pruning of trees was done every four weeks to a height of 0.75m above ground. The pruned materials were chopped into small pieces, weighed and in-cooperated into the soil. The banana intercrop was maintained at four plants per stool.

➢ *Maize Grain Yield and Biomass Determination*

Maize biomass and the grain yields were determined at physiological maturity. Grain yields was obtained from cutting all maize plants in the harvesting area (54 m^2) which were 8 maize rows at the center of each plot leaving out the border rows. All cobs were removed and weighed to get the field weight (FW). Grain moisture content was also measured to at harvest. The formula used to calculate the final grain yield in t/ha is shown in the Equation below (Tandzi and Mutengwa, 2019):

$$Grain\ Yield = \frac{FW * 10{,}000(100\% - \text{Grain Moisture Content})}{Area * 1{,}000 * (100\% - RMC)} * 0.80$$

Where by:

FW- Field Weight (Kgs/plot)
RMC- Required Moisture Content (13%)
AREA- 54 m^2
0.80 – Constant % of maize grain to a whole cob (80%)

Above-ground biomass was determined by sampling 10 maize plants which were cut from the harvesting area 54 m^2 then leaves, shoots and cobs were separated chopped into pieces and placed into size 16 khaki bags separately. Samples of leaves, shoots and cobs of maize plants were taken to the laboratory and oven dried at 70^{0}C to a constant weight to determine the dry weight (Biomass) (Djaman et al., 2013). The above-ground maize biomass yields were computed from kgs within the harvest area then expressed in tons/ha.

➢ *Harvest Index*

This is the plant or crop capacity to allocate resources in terms of assimilates into the formed reproductive parts. According to (Wnuk *et al*., 2013), it’s the proportion of the whole plant biomass which is allocated by the plant into the

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grain or into the economic yield. The plant is more efficient in producing the economic yield when it has a high harvest index. The harvest index (HI) for maize was calculated based upon the dry grain yield and the above ground biomass or dry matter and expressed as a percentage:

$$\text{Harvest Index (\%)} = \frac{Grain\ yield\ t/ha}{Total\ biomass\ weight\ t/ha} \ x\ 100$$

Maize yield (cob weight and grain weight) were assessed by separating the cobs from the stover and weighed. The grain dry weight was determined after shelling the cobs.

➢ *Statistical Analysis*

All parameters were subjected to Analysis of Variance (ANOVA) and the means separated using Least Significance Difference (LSD) at $p < 0.05$ or 95% level of probability to identify significance differences between the treatments for biomass production and grain yield.

III. RESULTS

➢ *Weather During the Experimental*

Maseno, Kisumu site recorded 546 mm of rainfall in 2018 SR between, and 499 mm in 2019 LR between. The precipitation was lowest in November 2018 recording 52.16 mm and 45.76 mm in July 2019 LR. The rainfall reached peak in December 2018 at 238.67 mm in 2018. The annual mean temperature was 20.5 ^{0}C. The month of August 2018 was coolest month of the year with an average of 19.5 ^{O}C. February 2019 was the hottest month with an average temperature of 22.93 ^{0}C.

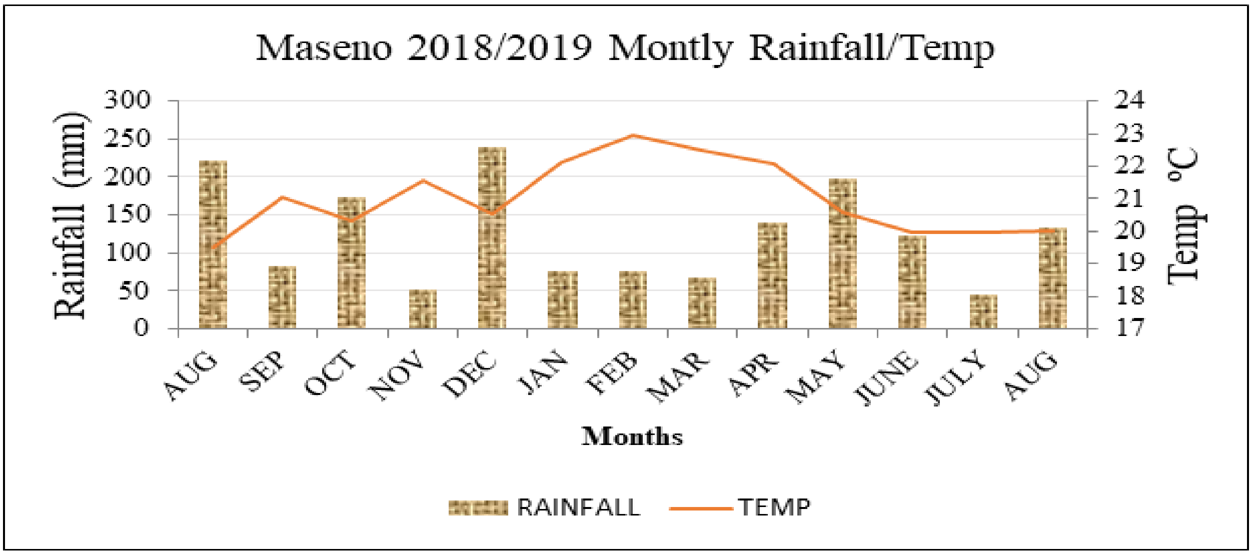

Fig 1 Maseno (Kisumu) Rainfall and Temperature Data 2018/2019

Kisii recorded a total rainfall of 642.5 mm in 2018 SR and 653.2 mm in 2019 LR. The highest amount of rainfall of 238.9 mm was in October and 193.1 mm in June respectively. The annual mean temperature was 19.5 ^{0}C. The month of June 2019 was the coolest with an average temperature of 18.5 ^{0}C while February and March were the hottest months in 2019 with the average of 20.6 ^{0}C.

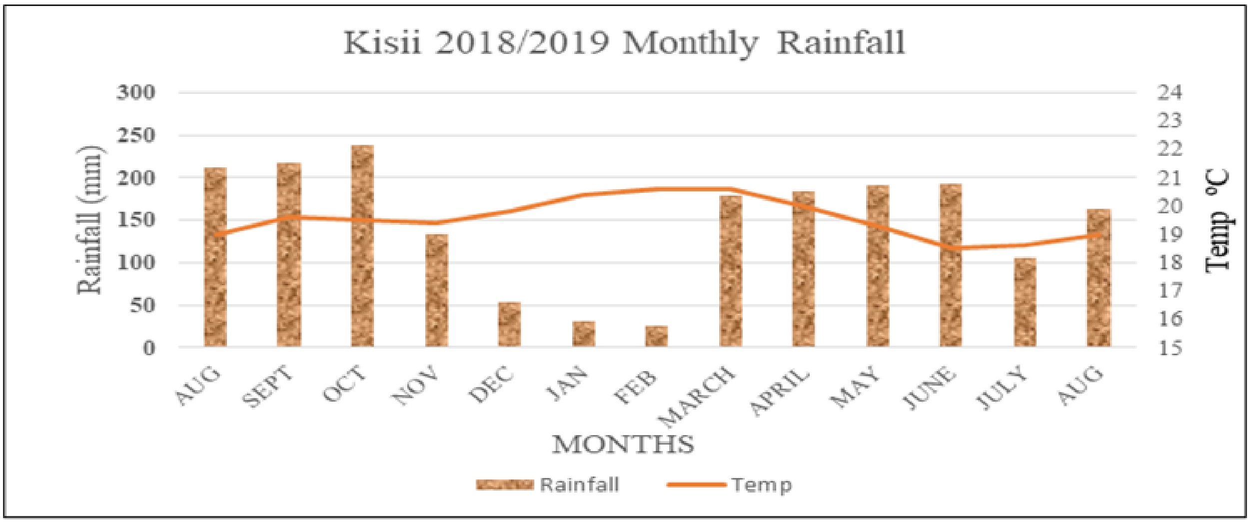

Fig 2 Kisii Rainfall and Temperature Data 2018/2019

➢ *Weather Variations*

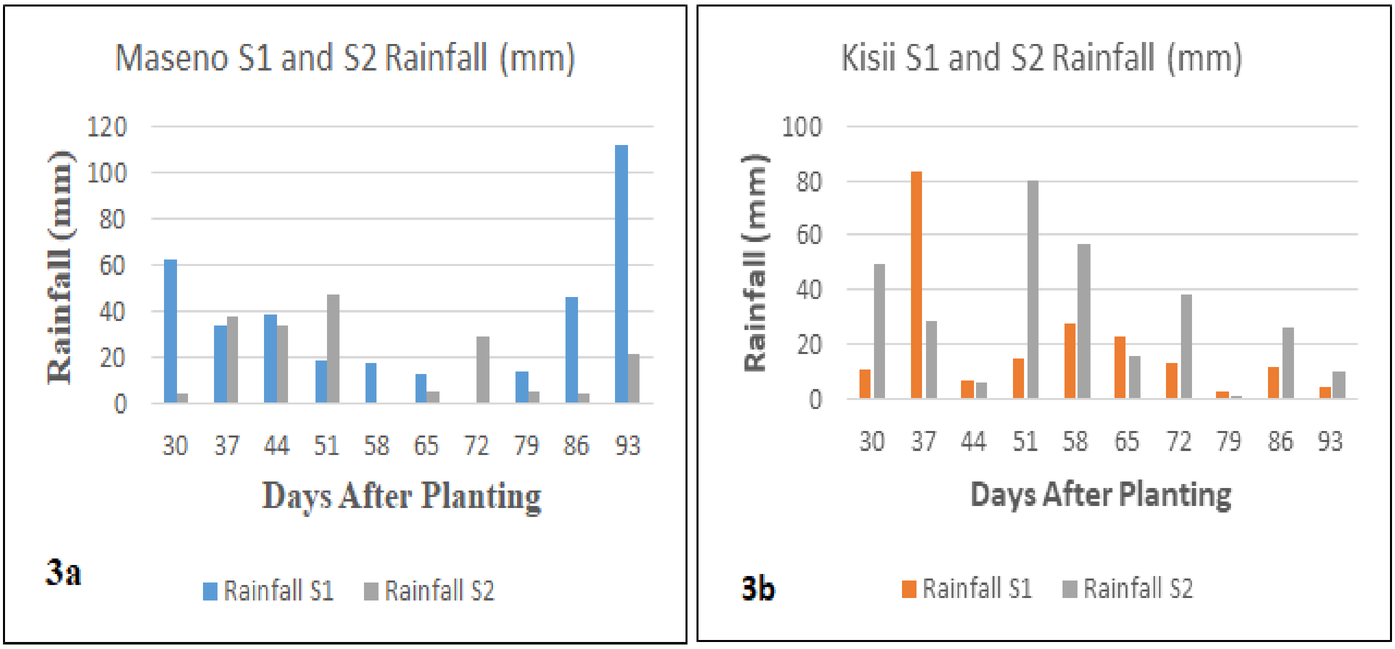

Fig 3 Maseno and Kisii Rainfall Days after Planting

➢ *Maize Grain Yields*

The analyzed data on grain yield for both sites is shown in Table 1 below. There were no significant differences in maize grain yield in Maseno 2018 SR. In 2019 LR, maize fertilizer grain yields were significantly high and statistically similar to sole maize, MBS, MBL but different from MB and MBC which were significantly lower. In Kisii 2018 SR, maize+ fertilizer registered the highest yields of 4.62 t/ha and significantly higher than all other copping systems. MB treatment registered the lowest yields of 3.03 t/ha. In 2019 LR, maize fertilizer registered the high maize grain yields of 5.0 t/ha and this was not statistically different from maize+ no fertilizer which registered 4.77 t/ha while MB registered the low maize grain yield 1.85t/ha.

Table 1 Maize Grain Yield at Maseno and Kisii Sites in 2018 SR and 2019 LR

	Maseno Yield (t/ha)		**Kisii Yield (t/ha)**	
Treatment	**2018 SR**	**2019 LR**	**2018 SR**	**2019 LR**
Maize+ No fertilizer	2.79	2.48	3.473	4.77
Maize+ banana+ *Calliandra*	2.16	2.07	3.124	2.66
Maize+ banana+ *Leucaena*	2.39	2.52	3.247	2.95
Maize+ banana+ *Sesbania*	2.57	3.72	3.109	3.06
Maize+ banana	2.11	2.11	3.032	1.85
Maize+ Fertilizer	2.42	3.98	4.624	5.0
LSD	NS	1.823	0.7245	1.361
Means	2.41	2.81	3.435	3.38
CV%	45.2	35.6	11.6	22.1

T/ha – Tons per hectare, LSD – Least Significance Difference, CV – Coefficient of Variance, Significance difference at $p < 0.05$.

➢ *Maize Biomass Yield*

There were no significant differences in maize biomass yields at Maseno during both seasons. In Kisii 2018 SR, maize+ fertilizer registered the highest maize biomass of 26.4 t/ha which was significantly different from all other cropping systems (*Table 2*). MBS and maize+ no fertilizer with 19.8 t/ha were significantly higher than maize with bananas with 14.0 t/ha. There were no significant differences in maize biomass yields among MBS, MBL and MBC treatments. During 2019 LR, maize+ fertilizer had the highest biomass of 15.8 t/ha which was significantly higher than MBL and MB cropping systems. There were no significant differences in maize biomass yield among MBS, MBL and MBC treatments.

Table 2 Maize Biomass in Maseno and Kisii During 2018 SR and 2019 LR

	Maseno Biomass (t/ha)		**Kisii Biomass (t/ha)**	
Treatment	**2018 SR**	**2019 LR**	**2018 SR**	**2019 LR**
Maize+ No fertilizer	17.9	8.7	19.8	13.9
Maize+ banana+ *Calliandra*	17.8	7.1	15.2	12.9
Maize+ banana+ *Leucaena*	17.3	7.7	16.1	11.5
Maize+ banana+ *Sesbania*	20.2	10.9	19.8	13.8
Maize+ banana	17.4	8.4	14.0	9.7
Maize+ Fertilizer	20.8	10.1	26.4	15.8
LSD	NS	NS	5.2	3.4
Means	18.6	8.8	18.6	12.9
CV%	30.6	32.1	15.2	14.3

T/ha – Tons per hectare, LSD – Least Significance Difference, CV – Coefficient of Variance.

- *Harvest Index*

The analyzed data of harvest index is in shown in *Table 3*. There were no significance differences of HI in Maseno during both seasons. In Kisii 2018 SR, the HI was highest in MB (28.3%) and it was statistically at par with all the other treatments except MBS (20.6%) which was significantly lower. In 2019 LR, the maize+ no fertilizer (32.2%) was significantly higher Maize + Banana (17.5%), MBS (21.1%) and MBC (20.3%), but was statistically at par with MBL and Maize + Fertilizer (30.1%).

Table 3 Harvest Index for Maize

Treatments	**Maseno HI**		**Kisii HI**	
	2018 SR	**2019 LR**	**2018 SR**	**2019 LR**
Maize+ No fertilizer	20.3	29.4	23.1	32.2
Maize+ banana+ *Calliandra*	15.4	31.6	27.2	20.3
Maize+ banana+ *Leucaena*	18.5	30.2	26.8	24.4
Maize+ banana+ *Sesbania*	17.5	31.5	20.6	21.1
Maize+ banana	15.5	24.7	28.3	17.5
Maize+ Fertilizer	15.5	37.0	23	30.1
LSD	NS	NS	6.8	11.8
MEANS	17.1	30.8	24.8	24.3
CV%	20.7	40.0	15.0	26.8

HI – Harvest Index, LSD- Least Significance Difference, CV % - Coefficient of Variance

IV. DISCUSSION

- *Weather Variations at the Sites*

Kisii experienced higher rainfall amounts than Maseno both in 2018 SR and 2019 LR (Figure 1 and 2). However, there was an increased amount of rainfall observed in both sites at the vegetative growth period of maize between 30-51 DAP. But a decline in rainfall was experienced between 58-72 DAP towards the critical stages of maize grain filling stage in both sites (Figure 3a and 3b). Maseno site (Figure 3a) experienced higher rainfall amounts in the 2018 SR with 546 mm than 2019 LR with 499 mm while Kisii site (Figure 3b) had higher rainfall amounts in the 2019 LR with 653.2 mm than 2018 SR with 642.5mm.

- *Maize Grain Yields*

The Kisii 2019 LR low maize grain yields observed in intercrops might be attributed to the high shading effect caused by the tall maturing bananas within the cropping systems (MB, MBC, MBL and MBS) which limited maximum access of light to the maize leaves as compared to maize fertilizer and maize+ no fertilizer treatments (*Table 1*). This observation is different from that in Kisii 2018 SR as same bananas were still young and growing which could not cause shading to the growing maize. A study done in West Africa by Kater *et al*., (1992), found that millet grain yields were often reduced by 50-80% owing to the dense shading by shea butter trees (*Vitellaria paradoxa*) and nere (*Parkiabi globosa*). It is clear that sole maize treatments had increasing grain yield from SR to LR as intercropped maize yields declined (*Table 1*). This could imply that there was competition for available resources from agroforestry species especially bananas as they grew taller in the second season. Similar to these findings, Mugendi *et al*., (1999) and Ndiso *et al*., (2017) found that yields of maize alley-cropped with Calliandra and leucanea were 11-51% lower than those of non-alley cropped treatments which received pruning of *ex situ* agroforestry species. This showed that there was below-ground competition for resources like water and nutrients amongst maize-tree roots (Ouma *et al.*, 2013) and above-ground competition for light which mirrors to the reduced maize grain yields. Competition for nutrients and light might be there in intercrops because sole maize treatments utilized their resources well thus giving significantly higher grain yields in 2019 LR. Even though light competition was minimized by maintaining the tree heights lower than 1 m, the bananas within the cropping systems could have competed with maize for light. In a study by Jones *et al*., (1998) it was found that substantial sorghum yields were only observed in pruned *P. juliflora* cropping system showing that reduced shading enhanced light penetration which led to increased crop growth and thus increased yields.

The low rainfall amounts experienced in Maseno and Kisii 2018 SR influenced the drastic drop of SWC at 72 and 79 DAP which might have affected the initial reproductive stage in maize (*Figure 3*). Liu Cheng *et al.,* (2017) recorded similar findings that soil water depletion and drought stress for 2 days during maize tasseling, silking and pollination could lead to yield losses of up to 22%. Ogola *et* al., (2005) and Mampana (2014) also confirms with the current study that short period water stress may cause poor maize grain filling owing to the negative effects on anthesis and silking causing low yields. In other studies, it has been found that maize grain yields significantly increase by up to 15% with additional irrigation water applied at the critical growth stages of pollination and the grain filling (Jalota *et al*., 2010).

In 2018 SR, maize+ fertilizer had significantly higher grain yields than all other treatments which were significantly similar. This shows that there was minimal competition from agroforestry species in the initial stages of their growth. There was no significant treatment effect on maize grain yields in Kisumu, Maseno 2018 SR due to the observed on-site differences in the crops growth pattern as patches of stunted maize were seen across the experimental site. In 2019 LR, Maize + fertilizer and MBS were observed to have higher grain yields and this could be due to the possibility of the applied fertilizer and the in cooperated pruning's respectively. The applied fertilizer and the high content *Sesbania* residues which decomposes faster than calliandra and leuceana (Stahl, 2005) incorporated in the soil could have improved and enhanced the soil nutrient levels (Khashayar *et al*., 2014). MB in the 2019 LR recorded the lowest maize yields in both sites which might be due to more numbers of bananas which grew tall and large thus shielding the maize under them from receiving enough sunlight. Therefore, in the sense that trees were cut down to less than 1 m, they could not hinder light from reaching maize crops, so the banana shade might have limited the full potential photosynthesis of the crops leading to lower yields.

- *Maize Biomass Yield*

The intercropping systems had no significant effect on maize biomass yields in both seasons in Maseno. In Kisii, different cropping systems had a significant effect on maize biomass where Maize+ fertilizer had significantly higher maize biomass yields in both 2018 SR (26.4 t/ha) and 2019 LR (15.8 t/ha), followed closely by maize+ no fertilizer (*Table 2*). This is attributed to the fact that maize monocrops had no above and below ground competition for resources. Furthermore, sole maize plant population was lower compared to intercrops. Ogola *et* al., (2005) found that reduced maize biomass production was a response of increased plant population density within the cropping systems. These findings are similar to those of Nassary *et al*., (2020) that monocrops in maize-legume cropping systems had higher biomass than intercrops due to absence of competition. This is in contrast with intercrops which had high plant density within the cropping systems which might have reduced the maize total biomass (Uwizeyimana *et al*., 2018). MB had the lowest biomass yields in both 2018 SR and 2019 LR, (14.0 t/ha) and (9.7 t/ha) respectively (*Table 2*). The results in this study corresponds to the findings of Mampana (2014), Nahuel, (2017) and Nassary *et al*., (2020), who found that, treatments intercropped with high and tall growing agroforestry species had low biomass due to resource competition.

The seasonal onset, availability and rainfall distribution during the growth period of a crop has a great impact of the total biomass of maize intercropping system according to Liu Cheng *et al.,* (2017). Ofuyo *et al*., (2020), found that low rainfall amounts during reproductive stages of maize leads to low yields. Furthermore, Huang *et al*., (2015) found that insufficient precipitation during the maize growing season was a major constraint for maximum maize yields. But the cropping systems had no significant difference on the maize total biomass (Nassary *et al*., 2020). The study therefore differs with the current study which indicates that cropping systems had significant effect on the total maize biomass. Therefore, maize crops need optimum amounts of water, light and nutrients during its growth and development stages for optimum biomass yields.

- *Harvest Index*

There were no significance differences in both seasons of Maseno HI. The intercropping systems had a significant effect on the maize harvest index in both seasons of Kisii. During 2018 SR, MB recorded the highest HI of 28.3%. During 2019 LR, maize+ no fertilizer had the highest HI of 32.2% and it was statistically similar to Maize+ fertilizer. Nevertheless, despite maize+ fertilizer being expected to have higher HI, it did not because the applied fertilizer enhanced more vegetative growth than grain in both seasons. These results show low HI in all treatments regardless of the differences because the crop experienced water shortages at critical stages of maize development (from 72- 93 DAP). Djaman *et al*., (2013) found that HI in maize was lower in the rain fed treatment than in the irrigated treatment confirming that water shortage impacts HI negatively. This water shortage affected the grain filling process which led to low grain yields and eventually low HI and these findings are similar to Mampana (2014).

V. CONCLUSION

The intercropping systems had a significant effect on the maize grain and biomass yields with Maize +fertilizer with highest yields both in Maseno and Kisii (*Table 1 and 2*). The readily available nutrients in maize fertilizer treatment enhanced better utilization of soil available water. Bananas are not good intercrops with maize in the second season.

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REFERENCES

[1]. Ali M. R, Rahman M. S, M Asaduzzaman, Hossain M. M, and Mannan M. A (2015). Intercropping maize with different vegetables. Bangladesh Agron. J. 18: 49-52

[2]. Byerlee D. and Eicher C. K (1997). Africa's emerging Maize Revolution. Boulder, CO, Lynne Rienner Publishers.

[3]. Djaman Koffi., Irmak Suat., Rathje William R., Martin Derrel L., and Eisenhauer Dean E., (2013). Maize evapotranspiration, yield production functions, biomass, grain yield, harvest index, and yield response factors under full and limited irrigation. *Biological Systems Engineering.* 56:273-393

[4]. Food and Agriculture/International Atomic Energy Agency (2008). Management of Agroforestry systems for Enhancing resource use efficiency and crop productivity. Soil and water management and crop nutrient section. Rome.

[5]. Government of Kenya (2001). Poverty Reduction Strategy Paper for the Period 2001- 2004. Ministry of Finance and Planning, *Government Printer*, Nairobi. Kenya.

[6]. Huang C., Duiker S. J., Deng L., Fang C and Zeng W (2015). Influence of precipitation on maize yield in the Eastern United States. *Sustainability* 7:5996-6010

[7]. Jalota S. K., Singh S., Chahal G. B. S., Ray S. S., Panigraghy B-S and Singh K. B (2010). Soil texture, climate and management effects on plants growth, grain yield and water use by rainfed maize-wheat cropping system: Field and simulation study. *Agricultural Water Management.* 97: 83-90

[8]. Jones M., Sinclair F. L. and Grime V. L (1998). Effect of trees species and crown pruning on root length and soil water content in semi-arid agroforestry. Plant and soil 201: 197-207

[9]. Kater L.J.M., Kante S., Budelman A (1992). Karite (*Vitellaria paradoxa*) and nere (*Parkia biglobasa*) associated with crops in South Mali. *Agroforestry Syst.* 18:89-105

[10]. Khashayar R., Hamid R. M., Mohammad R. V (2014). Effect of intercropping on resource use, weed management and forage quality. IJPAES. 4:706-713

[11]. Kitonyo O. M., Chemining'wa G. N and Muthomi J. W (2013). Productivity of farmer preferred maize varieties intercropped with beans in semi-arid Kenya. International Journal of Agronomy and Agro-forestry 47:49-66.

[12]. Liu Cheng, Sun Bao-cheng, Tang Huai-jun, Wang Tian-yu, Li Yu, Zhang Deng-feng, Xie Xiaoqing, SHI Yun-su, SONG Yan-chun, YANG Xiao-hong, LI Jian-sheng. (2017). Simple nonlinear model for the relationship between maize yield and cumulative water amount. Journal of Integrative Agriculture 16:858-866.

[13]. Mampana, R. M., (2014). Cropping systems effect on soil water, soil temperature and dryland maize production. University of Pretoria.

[14]. Mbure G. N., Kathuku A. N., Njihia S. N., Saitoti Z., Kaiyare J. M and Ngae G. N (2015). Maize production practices for increased productivity among small holder farmers in central Kenya. KARI, Nairobi.

[15]. Ministry of Agriculture (MOA). (2010). Economic review of Agriculture 2010. Central Planning and Project Monitoring Unit (CPPMU): 27

[16]. Mugendi D. N., Nair P. R. R., Mugwe J. N., O'Neill M. K and Woomer P. L (1999). Alley cropping of maize with Calliandra and leucaena in the subhumid highlands of Kenya. Part 1. Soil-fertility changes and maize yield. Agroforestry systems 45:39-50.

[17]. Muthuri, C.W., Ong, C.K., Craigon, J., Mati, B.M., Ngumi, V.W., Black, C.R. (2009). Gas exchange and water use efficiency of trees and crops in agroforestry systems in semi-arid Kenya. Agriculture Ecosystem Environment 129:497–507.

[18]. Nahuel A. A. P. (2017). A study of water use in Leucaena-grass systems. A Doctor of Philosophy Thesis at The University of Queensland, School of Agriculture and Food Sciences.

[19]. Nassary E. K., Fredrick B and Ndakidemi P. A (2020). Productivity of intercropping with maize and common bean over five cropping seasons on smallholder farms of Tanzania. European Journal of Agronomy. 113:125964

[20]. Ndiso J. B., Chemining'wa G. N., Olubayo F. M and Saha H. M (2017). Effect of cropping system on soil moisture content, canopy temperature, growth and yield performance of maize and cowpea. *International Journal of Agriculture Sciences* 7:1271-1281.

[21]. Nyaga J. M. (2018). Impact of trees on water and nutrients dynamics in small holder maize-based farming systems in Trans-Nzoia, Rift Valley, Kenya. Ph.D. Thesis, Plant Science, Jomo Kenyatta University of Agriculture and Technology.

[22]. Ofuyo D., Opala P., and George O. (2020). Agronomic and economic evaluation of phosphorus fertilizer use in maize-bean cropping systems in Western Kenya. African Journal of Agricultural Research. 16:1364-1371

[23]. Ogola J. B. O., Wheeler T. R., and Harris P. M (2005). Water use of maize in response to planting density and irrigation. S. Afr. J. Plant Soil. 22:2

[24]. Ouma E. N., Rop S., Okoba (2013). Status review of the adopted soil and water management technologies in Kenya as a critical component of the environment. Joint proceedings of the 27th Soil Science Society of East Africa and the 6th African Soil Science Society. 1-7

[25]. Robins J. S. (1953). Some effects of severe soil moisture deficits at specific growth stages in corn. *Agron. J. U.S.* 45:18-21.

[26]. Sadras V. O. (1996) Soil- Water thresholds for the responses of leaf expansion and gas exchange. *Filed crop. U.S*. 47:253-66

[27]. Sanchez, P.A., Buresh, R.J., Leakey, R.R.B. (1997). Trees, soils, and food security. *Philosophical Transactions of the Royal Society B*, 352: 949-960.

ISSN No:-2456-2165

[28]. Sikuku, P. A., Netondo, G. W., Musyimi, D. M., and Onyango J. C. (2010). Effects of water deficit on days to maturity and yield of NERICA rainfed rice varieties. *ARPN Journal of Agriculture and Biological Science*, 5:1-9

[29]. Stahl, L. (2005). Planted tree fallows and their influences on soil fertility and maize production in East Africa. Nitrogen fixation and soil nitrogen dynamics. Doctors dissertation. ISSN 1652-6880, ISBN 91-576-6908-2

[30]. Tandzi L. N and Mutengwa C. S (2019). Estimates of maize (*Zea mays* L.) yield per harvest area: Appropriate methods. *Agronomy* 10:29

[31]. Uwizeyimana D., Mureithi S. M., Karuku G and Kironchi G (2018). Effect of water conservation measures on soil moisture and maize yield under drought prone agro-ecological zones in Rwanda. International soil and water conservation research. 6:214-221

[32]. Waraich E A., Ahmad R., Yaseen M. A., Saifullah and Ahmad M (2011). Improving agricultural water use efficiency by nutrient management in crop plants. *Soil and Plant Science.* 61: 291 – 304.

[33]. Young, A. (1997). Agroforestry for Soil Management. CAB International, Wallingford, UK and ICRAF, Nairobi, Kenya.