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Effect of Cropping Systems and Nitrogen on Maize and Soybean Yields in Western Kenya

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Abstract

Low fertility in highly weathered and degraded soils largely accounts for poor and unsustainable crop yields in most African countries. Studies further reveal negative nutrient balances in major soil elements such as nitrogen (N) ($> 46 \text{ kg ha}^{-1}$) and phosphorus (P) ($> 3 \text{ kg ha}^{-1}$) in most countries in sub-Saharan Africa (SSA), with average mining of the former in some parts of western Kenya estimated at up to 112 kg N ha^{-1} . Productivity of maize and soybean in Kenya, particularly in the western region is generally low, even with application of N, P and potassium (K) fertilizers. The high cost of inorganic fertilizers and decreasing soil productivity demands a reassessment of their use, *vis-a-vis*, other alternative soil nutrient replenishing technologies. An on-farm experiment was laid down in Bungoma-South, Vihiga, and Teso-North Sub Counties of Bungoma, Vihiga and Busia Counties, respectively of western Kenya to assess the effect of selected cropping systems, N fertilizer and manure on maize and soybean yields. The experiment followed a split-plot design with two factors (cropping systems as the main factor and fertilizer interventions as the sub factor) arranged in a randomized complete block design (RCBD) with three replications. The cropping systems consisted of conventional- that is of maize & soybean intercrop of alternate single rows of each crop, MBILI- planted with maize & soybean intercrop of alternate double rows of each crop- and maize and soybean monocrops. The fertilizer interventions comprised of calcium ammonium nitrate (CAN) and farmyard manure (FYM), both applied at two rates of 30 kg N ha^{-1} and 75 kg N ha^{-1} , and without fertilizer (absolute control). The experiment was conducted during two subsequent cropping seasons; short rains between August and December 2011 and long rains occurring between March and August 2012. Results showed that maize yields were significantly larger in both the monocropping (mean yield: 2.0 t ha^{-1}) and MBILI systems (mean yield: 1.8 t ha^{-1}) compared to conventional farming (mean yield: 1.3 t ha^{-1}). For soybeans, significantly larger yields were recorded in the monocropping system (1 t ha^{-1}) compared to the MBILI (0.8 t ha^{-1}) and conventional (0.6 t ha^{-1}) systems. Cropping without fertilizer application resulted to low yields at an average of 1.0 and 0.7 t ha^{-1} for maize and soybean, respectively. Application of CAN at 30 kg ha^{-1} resulted to an average maize yield of 2.5 , 1.4 and 0.7 t ha^{-1} in Bungoma-South, Vihiga and Teso-North Sub Counties, respectively. At least maize yields increased when FYM was applied at 30 kg ha^{-1} by 8 and 14% in Bungoma-South, and Vihiga Sub Counties, respectively, above the yield obtained when CAN was applied at 30 kg ha^{-1} . Application of FYM at 30 kg ha^{-1} resulted to similar maize yield as those observed when CAN was applied at the same rate in Teso-North sub county. For Soybean crop, application of either CAN or FYM at 30 kg ha^{-1} gave very low yields in the entire Sub Counties and in both seasons. Only in Vihiga Sub County where an average of 1.1 t ha^{-1} was obtained while the other two Sub counties had much less yields. On average, application of either CAN or FYM at 75 kg ha^{-1} increased maize yields by 29% above those observed when the two fertilizers were applied at 30 kg ha^{-1} . The same trend was observed with soybeans whose yields increased at an average of 26% when either CAN or FYM was applied 75 kg ha^{-1} . The mean Land Equivalent Ratio (LER) values were greater than 1.0 for the intercropping systems and 1.0 for the monocropping system indicating a yield advantage in intercropping over monocropping.

Keywords: Conventional cropping, CAN, Farmyard manure, Land Equivalent Ratio, MBILI, Monocropping

1. Introduction

Agricultural productivity drives many economies in SSA with the production of cereals and legumes playing a major role both in terms of food and income generation. Ranum (2014), for example, estimated that 50% of the

population in the region and 900 million people worldwide use maize (*Zea mays*) as their preferred food source. In Kenya, more than 2.1 million of the 5.3 million ha arable land is occupied by maize, with the crop accounting for more than 51% of all the staples grown in the country. Soybean (*Glycine max*) has become the most widely cultivated legume in the world because of its richness in protein and lactose (Zander, *et al* 2016). Whereas the demand for these crops is expected to increase two-fold, yields are expected to decline – leading to larger global prices, malnutrition, and poverty (Pagano and Miransari, 2016). This notwithstanding, the productivity of maize and soybean in Kenya is generally low. Although maize productivity varies, currently only 1.8 t ha⁻¹ is realized in Kenya against the potential of 6 t ha⁻¹. Despite efforts to promote productivity-enhancing technologies, output has declined against ever-increasing consumer demand. This has transformed the country into a net grain importer (Njagi *et al.*, 2017). Productivity of soybean in the country is just 0.45 t ha⁻¹, which is about seven times lower compared with Brazil (3.05 t ha⁻¹) and USA (2.92 t ha⁻¹).

It is, therefore, germane to discover new solutions that can increase yields to obtain the estimated attainable and potential harvests of these crops. One way of addressing these is the use of suitable cropping systems and optimizing fertilizer application. The use of mineral fertilizers, for instance, di-ammonium phosphate (DAP) and CAN, have shown to improve crop yields due to their ability to supply crucial nutrients like nitrogen and phosphorus to crops (Odeno *et al.*, 2007). This was observed under field experiments in Sudan (Radma and Dagash, 2013) where nitrogen fertilizer significantly increased maize yield and number of seeds cob⁻¹. Increasing nitrogen fertilizer rates also led to a significant increase in ear length, number of kernels row⁻¹, ear weight and grain yield (Younas, 2002). However, the prohibitive cost of these fertilizers demands a reassessment of their use, *vis-a-vis*, other alternative technologies (Kiani *et al.*, 2005; Billen *et al.*, 2014). Use of organic fertilizers, such as farmyard manure (FYM) could ameliorate some of these deleterious effects. Manure application has been found to provide nitrogen, phosphorus, potassium, etc., and increase soil organic matter and improve soil water holding capacity (Hati *et al.*, 2006; Barbazan, 2004).

The type of cropping system has also been found to be pertinent in determining crop yields. Crops may be planted all alone (monocropping) or together with others (intercropping). The major advantage of intercropping is increased profitability, owing to intensification (Brintha and Seran, 2008), which could be crucial in providing food security in the developing world. Also, other resources such as water, light and nutrients can be utilized more efficiently (Li *et al.*, 2006). Other benefits of intercropping include better soil cover, suppressed weeds by increased soil cover, and reduction of erosion and nutrient leaching (Bilalisa *et al.*, 2010; Seran and Brintha, 2010). Hugar and Palled (2008) observed that in a maize-French bean intercrop, the maize equivalent yield was larger than that obtained from a maize monocrop while kernel yield of maize was unaffected in the intercrop. Studies by Akinnifesi *et al.*, (2006) revealed that without nitrogen fertilizer application, gliricidia-maize intercropping system increased maize yields. The MBILI (an acronym for “Managing Beneficial Interactions in Legume Intercrops) system, developed by a non-governmental organization (NGO) known as SACRED Africa in Bungoma, involves planting double rows of each intercrop. In the MBILI system, two maize rows are spaced at 50 cm pairs that are 100 cm apart (the gap) and two rows of legumes planted within the gap of 33 cm row spacing, giving the maize plant population of 44,000 plants ha⁻¹ and a legume population of about 88,000 plants ha⁻¹ (Tungani *et al.*, 2002). The system is touted to significantly improve the yield of legumes while keeping the maize yield constant, as the staggered row spacing allows for greater light penetration through the maize canopy without changing the plant densities (Tungani *et al.*, 2002). However, the effect of the interplay between various crop systems, different fertilizers, and manure applications on the yield of maize and soybean has not been investigated in the western region of Kenya. The objective of this study was to evaluate the effect of selected cropping systems, nitrogen (N) fertilizer and farmyard manure on maize and soybean crop yields in western Kenya.

2. Materials and Methods

2.1 Study Area

2.1.1 Bungoma-South Sub County, Bungoma County

Bungoma has an altitude that ranges from 2000 m above sea level around Mount Elgon to 1100 m at the minor valleys around the Nzoia river, which drains the major part of the county. The county has a bimodal rainfall pattern, with the first growing season (long rains) extending from March to August, and the second (short rains) from August to December. The rainfall is abundant and well-distributed with an annual average of 1000-1800 mm. The temperature in the county ranges from about 20-22 °C in the southern part of Bungoma to about 15-18 °C on the slopes of Mount Elgon in the northern part of the county. Bungoma County falls under two major agro ecological zones: the transitional upper midland zone UM₄ (referred to as the maize-sunflower zone) and

the Lower Midland zones which cover a greater proportion of the county (LM1-LM3). The soils are developed from volcanic materials mainly the basalt; the soils are well-drained, deep to very deep and vary from dark red Nitisols (Alfisols) and Ferralsols (Oxisols) to dark brown Acrisols (Ultisols) (Jaetzold and Schmidt, 1983). The experiment was laid down on Mr. Francis Wamalwa's farm located at Siritanyi ward in Bungoma-South sub-County. The geographical coordinates of the experimental farm are 0° 33' 54.2" N latitude and 34° 31' 50.6" E longitude, at an altitude of 1424 m above sea level. In reference to Table.1, soils in this study were moderately acidic with low CEC and organic carbon. The two macronutrients; N and P were also low and the soil was of a coarse texture.

2.1.2 Vihiga Sub County, Vihiga County

Vihiga County has an altitude ranging between 1300 and 1800 meters above sea level. The area receives bimodal rainfall that ranges from 1,800 - 2,000 mm per year with the first growing season (long rains) extending from March to August, and the second (short rains) from August to December with an average temperature of 24 °C. It has a high agricultural potential area predominantly (95%) in the upper midland one (UM1) agro-ecological zone and partly lower midland (LM1) well-drained soils that comprise of dystric Acrisols and humic Nitisols with low inherent fertility due to heavy leaching, erosion and poor management (Jaetzold et al., 2006). The experiment was laid down on Mrs. Dorcas Selebwa's farm located at Vokoli Sabatia in Vihiga Sub County. The geographical coordinates of the experimental farm are 0° 07' 9.7" N latitude and 34° 47' 2.8" E longitude, at an altitude of 1632 m above sea level. Soils in this field were slightly acidic, while low in organic carbon and nitrogen. Interestingly, P and Zn in these loamy sands (Table 1) were above the critical values of 10 and 1 mg kg⁻¹ respectively; required for production of most tropical crops.

2.1.3 Teso-North Sub County, Busia County

The county's altitude ranges from 1,300 m to 1500 m above sea level. Most parts of the county receive between 1270 mm and 2000 mm of annual rainfall whose distribution is bimodal with the first growing season (long rains) extending from March to August, and the second (short rains) from August to December. Temperatures for the whole county are more or less homogenous with annual mean maximum temperature ranging between 26 and 30°C while the mean minimum temperature ranges between 14 and 22 °C (Jaetzold and Schmidt, 1983, Jaetzold et al., 2006). The county falls under lower midland agro-ecological zone (LM 1-2, LM3-4). Soils are well-drained Acrisols and Ferralsols and are of a sandier texture than the Bungoma soils (Republic of Kenya, 1997). The experiment was laid down on Mr. Hamu Emeje farm located at Kolanya in Teso-North Sub County. The geographical coordinates of the experimental farm are 0° 42' 52.2" N latitude and 34° 23' 0.83" E longitude, at an altitude of 1413 m above sea level. Soils in this field were moderately acidic with low content of most of the nutrients except P as shown in Table 1.

Table 1. Soils characteristics of the study area

Soil Characteristics	Bungoma-South Sub County	Vihiga Sub County	Teso-North Sub County
Soil pH (1:2.5 H ₂ O)	5.74	5.43	6.41
CEC (cmol _c kg ⁻¹)	5.38	9.88	1.78
Total organic carbon (%)	0.37	1.05	0.25
Total Nitrogen (%)	0.10	0.15	0.06
C:N ratio	3.7:1	7.0:1	4.17:1
Phosphorus (mg kg ⁻¹)	9.35	25.47	23.8
Zinc (mg kg ⁻¹)	0.74	12.21	0.09
Copper (mg kg ⁻¹)	2.17	5.17	0.39
Sand %	69	77	77
Clay %	12	10	10
Silt %	19	13	13
Textural class	Sandy Loam	Loamy Sand	Loamy Sand

Soil sampled at 0-15 cm depth and analyzed for selected parameters at KALRO, Nairobi, Kenya (NARL).

2.2 Description of the On-farm Trial

The on-farm- trials were set up to test the effect of cropping systems and fertilizer interventions on the yield of the crops. The experiment followed a split-plot design with two factors-cropping systems as the main factor and fertilizer interventions as the sub factor- arranged in a randomized complete block design (RCBD) with three

replications. The cropping systems consisted of conventional (maize & soybean intercrop of alternate single rows of each crop), MBILI (maize & soybean intercrop of alternate double rows of each crop) and maize and soybean monocrops. The interrow spacing of the conventional cropping was 37.5 cm while in MBILI, two soybean rows with an interspacing of 33.3cm were planted 50 cm away from two maize rows. In the monocrop, maize and soybean were planted at an interrow spacing of 75 cm and Intra row spacing of 30 cm. Each on-farm trial measured 1428 m² (68 m by 21 m). The farm was divided into 12 main plots where cropping systems were randomly allocated, each measuring 22 m by 4.5 m, and separated from the next plot by a distance of one metre. Each plot was then divided into five subplots where the fertilizer was allocated, each measuring 4.5 m by 4 m, and separated from the nearest subplot by 0.5 m. Within each main plot, five fertilizer treatments were randomly applied at zero N rate (absolute control), calcium ammonium nitrate (CAN) and farmyard manure (FYM) both applied at the rate of 30 kg N ha⁻¹ and 75 kg N ha⁻¹ and hereafter referred to as CAN30N, FYM30N, CAN75N and FYM75N, respectively. During the short rains 2011, FYM of 0.965% N content was sourced from the University of Eldoret farm while in the 2012 long rains; FYM was from the farmer's fields in Bungoma, Vihiga and Teso with N content of 0.85%, 0.73%, and 0.39%, respectively.

2.3 Establishment and maintenance of the field trial

The land was prepared manually using a hand hoe, leveled and pegged. Triple Super Phosphate (TSP) (0-46-0) was applied at a blanket rate of 26 kg P ha⁻¹ during planting to eliminate P deficiency (FURP, 1994). For the FYM and CAN containing 30 kg N ha⁻¹ and 75 kg N ha⁻¹, respectively, was applied to the specified plots during planting.

2.5 Data Collection

Dry matter yields of maize and soybean grain, maize stover and soybean haulm was collected and extrapolated to a hectare basis using plant populations corrected at emergence based on percentage.

2.6 Data Analysis

A mixed-design analysis of variance (ANOVA) was used to analyze the split-plot design arranged in a randomized complete block design (RCBD), with cropping systems and fertilizer application rates as main plots and subplots, respectively. Block was used as the random factor whereas cropping system and fertilizer treatments were the fixed factors. Maize and soybean yields were the dependent variables. Post hoc analysis was conducted using Tukey HSD (Honestly Significant Difference) test. Statistical analysis was carried out based on the model for a split-plot designed as described in Equation (1).

$$Y_{ijkl} = \mu + C_i + F_j + (CF)_{ij} + \varepsilon_{k(i)} + \varepsilon_{ijk} \quad (1)$$

Where,

Y_{ijkl} = Mena crop yield μ = overall mean

C_i = effect of the cropping system (main plot)

F_j = effect of the fertilizer (subplot)

$(CF)_{ij}$ = interaction between cropping system and fertilizer treatments.

$\varepsilon_{k(i)}$ = Error term of the main plot (cropping systems)

ε_{ijk} = experimental error

All statistical tests were performed with the aid of SAS (version 9) statistical package (SAS Institute 2002). All the tests were two-tailed. Significant levels were measured at 95% confidence level with significant differences recorded at $p < .05$.

The Land Equivalent Ratio (LER) was computed to determine yield advantage of either growing maize and/or soybeans. The LER was calculated as by the procedure of Vandermeer (1989), in which the amount of the intercropped yield was divided by the amount of the mono cropped yield for each crop in the field as calculated in equation (2).

$$LER = (Y_{im}/Y_{sm}) + (Y_{ic}/Y_{ss}) \quad (2)$$

Where Y_{im} and Y_{sm} are the yields of intercropped and monocropped maize while Y_{ic} and Y_{ss} are the yields from the intercropped and monocropping soybean, respectively. Partial LERs were added together to find the total LER. The LER is calculated by dividing the amount of the intercropped yield by the amount of the mono cropped yield for each crop in the field Willey (1985). Where LER is more than 1.0, it indicates a positive intercropping advantage.

3. Results

3.1 Maize and Soybean Yields in 2011 Short Rains Season

In the short rain season of 2011, maize yields were generally larger in the monocropping system, followed by MBILI and lastly, in conventional farming (Table 2). The yields were also larger in CAN75N and FYM75N treatments, followed by FYM30N, CAN30N, and lowest in the control treatment. Yields were significantly larger in both mono (3.2 t ha⁻¹) and MBILI (2.7 t ha⁻¹) compared to conventional farming (1.7 t ha⁻¹). In Bungoma-South, monocropping and MBILI farming increased maize yields by about 88% and 58%, respectively relative to conventional farming. Maize yields were found to be the larger when planted with CAN75N (3.5 t ha⁻¹), followed by planting with CAN30N (2.9 t ha⁻¹), FYM30N (2.4 t ha⁻¹) and FYM75N (2.8 t ha⁻¹), while it was the lowest in the control (1.09 t ha⁻¹). In Vihiga, the largest maize yield (Table 2) was obtained, with FYM75N (2.4 t ha⁻¹), followed by CAN75N (2.0 t ha⁻¹), and then, by both FYM30N (1.7 t ha⁻¹) and CAN30N (1.3 t ha⁻¹). The lowest yield was recorded in the control (0.7 t ha⁻¹). In Teso-North, both crop system and fertilizer treatments had significant effects on maize yield in the 2011 short rains. The largest maize yield was found with FYM75N (1.9 t ha⁻¹), followed by CAN75N (1.6 t ha⁻¹), FYM30N (1.6 t ha⁻¹) and CAN30N (1.3 t ha⁻¹). Both MBILI and monocrop systems produced the largest maize yields (1.6 and 1.4 t ha⁻¹, respectively) compared with conventional farming (1.2 t ha⁻¹).

Table 2. Maize yields (t ha⁻¹) in different crop systems and fertilizer treatments in 2011 short rain seasons

	Bungoma-South Sub County				Vihiga Sub County				Teso-North Sub County			
	Mono	MBILI	Conv	Mean	Mono	MBILI	Conv	Mean	Mono	MBILI	Conv	Mean
CAN30N	3.7	3.2	1.6	2.9^a	2.2	0.5	1.2	1.3^a	1.5	1.5	1.1	1.3^a
CAN75N	4.6	3.9	2.1	3.5^b	2.5	2.1	1.4	2.0^b	1.5	1.6	1.7	1.6^a
FYM30N	3.1	2.5	1.5	2.4^a	1.4	1.9	1.7	1.7^a	1.5	1.6	1.3	1.5^a
FYM75N	3.6	2.7	2.2	2.8^a	2.2	2.5	2.4	2.4^c	1.6	2.6	1.6	1.9^b
Control	1.0	1.3	1.0	1.1^c	0.7	0.9	0.4	0.7^d	0.7	0.5	0.5	0.6^c
Mean	3.2 ^a	2.7 ^a	1.7 ^b	2.5	1.8 ^a	1.6 ^a	1.4 ^a	1.6	1.4 ^a	1.6 ^a	1.2 ^b	1.4
SED _{system}	0.44				ns				0.69			
SED _{fert}	0.19				0.18				0.20			
SED _{system *fert}	0.34				0.37				0.20			

CAN = calcium ammonium nitrate; FYM = Farmyard manure; SED = Standard errors of the Difference; Conv. = conventional. Yield means with the same letter in a row (for crop system) or column (for fertilizer treatment) are not significantly different at p<0.05.

In the short rain season of 2011, soya bean yields were largest in the monocropping system, compared to both MBILI and conventional farming. Soya bean yields were found to be significantly larger with both FYM75N (0.52 t ha⁻¹) and FYM30N (0.46 t ha⁻¹) compared with the CAN treatments. However, no significant differences in soya bean yields were found between CAN30N (0.28 t ha⁻¹), CAN75N (0.32 t ha⁻¹) and the control (0.23 t ha⁻¹) (Table 3). In all the subcounties of Bungoma-South, Vihiga and Teso North, yields were significantly larger in the monocropping system than in the other crop systems. However, soybean yields in both the MBILI and conventional systems were found not to be significantly different.

Table 3. Soybean grain yields (t ha⁻¹) in the 2011 short rain seasons

	Bungoma-South Sub County				Vihiga Sub County				Teso-North Sub County			
	Mono	MBILI	Conv	Mean	Mono	MBILI	Conv	Mean	Mono	MBILI	Conv	Mean
CAN30N	0.38	0.19	0.14	0.24^a	1.75	0.82	0.70	1.09^a	0.23	0.34	0.25	0.28^a
CAN75N	0.54	0.29	0.22	0.35^a	1.74	0.63	0.50	0.96^a	0.45	0.25	0.25	0.32^a
FYM30N	0.37	0.10	0.12	0.20^a	1.72	0.72	0.81	1.08^a	0.57	0.47	0.33	0.46^b
FYM75N	0.52	0.16	0.11	0.27^a	1.47	0.75	1.12	1.12^a	0.87	0.35	0.33	0.52^b
Control	0.42	0.14	0.12	0.23^a	1.15	0.71	0.70	0.85^a	0.41	0.09	0.18	0.23^a
Mean	0.45 ^a	0.18 ^b	0.14 ^b	0.26	1.56 ^a	0.73 ^b	0.77 ^b	1.02	0.51 ^a	0.30 ^b	0.27 ^b	0.36
SED _{system}	0.05				0.2				0.05			
SED _{fert}	ns				ns				0.06			
SED _{system *fert}	ns				ns				0.11			

CAN = calcium ammonium nitrate; FYM = Farmyard manure; SED = Standard errors of the Difference; Conv. = conventional. Yield means with the same letter in a row (for crop system) or column (for fertilizer treatment) are

not significantly different at $p < 0.05$.

3.2 Maize and Soybeans Yields in 2012 Long Rains Season

In Bungoma-South, yields were largest in the monocrop (3.76 t ha^{-1}), followed by MBILI (3.03 t ha^{-1}), and were lowest in conventional farming (9 t ha^{-1}). Also planting with FYM at 75 kg N ha^{-1} produced the largest yield of maize (4.27 t ha^{-1}), followed by CAN75N (3.82 t ha^{-1}) in this site (Table 4). This was unlike the 2011 season, where the largest yield was produced by CAN75N. This conclusion is bolstered by the significantly larger yield given by FYM30N (3.03 t ha^{-1}) compared to CAN30N (2.14 t ha^{-1}), unlike in the 2011 season [CAN30N (2.85 t ha^{-1}) and FYM30N (2.36 t ha^{-1})]. The lowest yield in 2012 was found in the control (1.83 t ha^{-1}). An ANOVA revealed significant main effects of cropping system, $F(2, 30) = 504.01$, $p < 0.0001$ and fertilizer treatments, $F(4, 30) = 589.23$, $p < 0.0001$ on the yield of maize in Bungoma-South. Yields were largest in the monocrop (3.8 t ha^{-1}), followed by MBILI (3.0 t ha^{-1}), and were lowest in conventional farming (2.3 t ha^{-1}). Application of FYM at 75 kg N ha^{-1} produced the largest yield of maize (4.3 t ha^{-1}), followed by CAN75N (3.8 t ha^{-1}). No significant differences in maize yield were found between CAN30N (0.15 t ha^{-1}), FYM30N and FYM75N (both had 0.16 t ha^{-1}). The significant interaction between crop system and fertilizer indicated that when FYM was very high (75N), maize yields in mono and MBILI systems were not significantly different from each other. In Vihiga, significant main effects of both the cropping system, $F(2, 30) = 9724.51$, $p < 0.0001$ and fertilizer treatments, $F(4, 30) = 3399.01$, $p < 0.0001$ were found on the yields of maize. Yields were largest in the monocropping system (2.4 t ha^{-1}), followed by MBILI (1.3 t ha^{-1}), and were lowest in conventional farming (1.1 t ha^{-1}). The largest yield produced by fertilizer treatments was in CAN75N (2.4 t ha^{-1}), followed by FYM75N (1.8 t ha^{-1}), CAN30N (1.5 t ha^{-1}), FYM30N (1.4 t ha^{-1}), while it was the lowest in the control (0.90 t ha^{-1}). In Teso North, there were no significant main effects of both the cropping system, $F(2, 30) = 0.38$, $p = 0.6890$ but there were significant effects of fertilizer treatments, $F(4, 30) = 14.96$, $p < 0.0001$ on the yields of maize. The largest maize yield was recorded in FYM75N (1.91 t ha^{-1}), followed by CAN75N (1.61 t ha^{-1}), FYM30N (1.61 t ha^{-1}) and CAN30N (1.34 t ha^{-1}). The lowest yield was recorded in the control (0.56 t ha^{-1}). Both MBILI and mono crop systems produced the largest maize yields (1.58 and 1.35 t ha^{-1} , respectively) compared with conventional farming (1.20 t ha^{-1}).

Table 4. Maize yields (t ha^{-1}) in 2012 long rain season

	Bungoma-South Sub County				Vihiga Sub County				Teso-North Sub County			
	Mono	MBILI	Conv	Mean	Mono	MBILI	Conv	Mean	Mono	MBILI	Conv	Mean
CAN30N	2.8	2.1	1.2	2.1^a	2.1	1.4	1.1	1.5^a	0.2	0.1	0.2	0.15^a
CAN75N	4.3	3.9	3.4	3.8^b	4.7	1.4	1.0	2.4^b	0.2	0.2	0.2	0.17^b
FYM30N	4.0	2.7	2.4	3.0^c	1.8	1.2	1.3	1.4^c	0.2	0.2	0.2	0.20^d
FYM75N	5.0	4.9	2.9	4.3^d	2.0	1.8	1.5	1.8^d	0.2	0.1	0.2	0.16^a
Control	2.7	1.6	1.2	1.8^e	1.4	0.6	0.6	0.9^e	0.1	0.1	0.1	0.13^c
Mean	3.8 ^a	3.0 ^b	2.3 ^c	3.0	2.4 ^a	1.3 ^b	1.1 ^c	1.6	0.2 ^a	0.2 ^a	0.2 ^a	0.2
SED _{system}	0.05				0.01				Ns			
SED _{fert}	0.06				0.01				0.0			
SED _{system*fert}	0.11				0.022				0.01			

CAN = calcium ammonium nitrate; FYM = Farmyard manure; SED = Standard errors of the Difference; Conv. = conventional. Yield means with the same letter in a row (for crop system) or column (for fertilizer treatment) are not significantly different at $p < 0.05$

Soybean yields in the 2012 long rains season are presented in Table 5. The results in Bungoma-South showed that the largest soybean yield was found in the monocrop (1.27 t ha^{-1}), followed by MBILI (0.96 t ha^{-1}), and were lowest in conventional farming (0.82 t ha^{-1}). FYM, applied at 75 kg N ha^{-1} produced the largest yield of soybean (1.37 t ha^{-1}). Analysis of the interaction between crop system and fertilizer treatments showed that whereas the monocropping system in contrast with other systems produced superior yields when CAN was used, MBILI produced the largest yields with FYM75N compared to other crop systems. Yields in Vihiga were similar to those in Bungoma. Soybean yields were significantly larger in mono cropping system (1.36 t ha^{-1}), followed by MBILI (1.12 t ha^{-1}) and were lowest in conventional system (0.91 t ha^{-1}). CAN75N produced the largest yield of the crop (1.53 t ha^{-1}), followed similarly by CAN30N (1.17 t ha^{-1}), FYM30N (1.23 t ha^{-1}) and FYM75N (1.26 t ha^{-1}). The control produced the lowest yield (0.51 t ha^{-1}). In Teso, the largest soybean yields were produced with FYM75N (1.26 t ha^{-1}), followed by both CAN75N (1.04 t ha^{-1}) and FYM30N (0.97 t ha^{-1}), and then by, CAN30N (0.81 t ha^{-1}). Mono produced the largest yields (1.15 t ha^{-1}), followed by MBILI (0.95 t ha^{-1}) and

conventional (0.61 t ha^{-1}).

Table 5. Soybean yields (t ha^{-1}) in the 2012 long rain season

	Bungoma-South Sub County				Vihiga Sub County				Teso-North Sub County			
	Mono	MBILI	Conv	Mean	Mono	MBILI	Conv	Mean	Mono	MBILI	Conv	Mean
CAN30N	1.36	0.53	0.72	0.87^a	1.41	1.08	1.02	1.17^a	1.12	0.84	0.47	0.81^a
CAN75N	1.32	1.12	0.82	1.08^b	1.62	1.72	1.09	1.53^b	1.23	1.21	0.68	1.04^b
FYM30N	1.40	1.02	0.93	1.12^b	1.37	1.21	1.10	1.23^a	1.26	1.03	0.64	0.97^b
FYM75N	1.37	1.68	1.05	1.37^c	1.56	1.26	0.95	1.26^a	1.50	1.26	1.02	1.26^c
Control	0.93	0.47	0.62	0.68^d	0.82	0.43	0.18	0.51^c	0.66	0.39	0.24	0.43^d
Mean	1.27 ^a	0.96 ^b	0.82 ^c	1.02	1.36 ^a	1.14 ^b	0.91 ^c	1.14	1.15 ^a	0.95 ^b	0.61 ^c	0.43
SED _{system}	0.047				0.033				0.027			
SED _{fert}	0.061				0.044				0.035			
SED _{system *fert}	0.105				0.073				0.061			

CAN = calcium ammonium nitrate; FYM = Farmyard manure; SED = Standard errors of the Difference; Conv. = conventional. Yield means with the same letter in a row (for crop system) or column (for fertilizer treatment) are not significantly different at $p < 0.05$.

3.3 Land Equivalent Ratio (LER)

Table 6 presents the total LER for the two growing seasons in the study. The LERs were 1.56 and 1.25 for MBILI and conventional farming, respectively in the short rains of 2011 whereas they were 1.58 and 1.40, respectively for the two systems in the 2012 long rains. The LER for the monocrop was 1.00 in both the seasons. An ANOVA was conducted to test whether the type of cropping system could influence the LER in 2011 and was found to be significant at, $F(2, 24) = 5.563$, $p = 0.01$. The total LERs for MBILI and conventional intercropping systems were significantly greater than one with values of 1.56 and 1.25, respectively in the sites during SR2011. Similarly, in 2012, both the LER for MBILI (1.58) and Conventional (1.40) systems were significantly greater than for the monocrop (1.00), $F(2, 24) = 26.93$, $p < 0.0001$ (Table 6). This was an indication that the two systems had an advantage over sole cropping in land use. The results show that in 2011, there were 56% and 25% greater yield advantage in MBILI and conventional systems, respectively, compared to the monocrop system. In the 2012 long rains, the yield advantage of the intercrop was 58% and 40% for MBILI and conventional, respectively, over and above the monocrop.

Table 6. Effect of cropping system on land equivalent ratio for maize and soybean

2011 Short Rains Season				
Variable	LER	S.D	F-value	p
Mono cropping	1.00	-		
MBILI	1.56	0.43	5.56	0.01
Conventional	1.25	0.44		
2012 Long Rains Season				
Variable	LER	S.D	F-value	p
Mono cropping	1.00	-		
MBILI	1.58	0.32	26.93	$p < 0.0001$
Conventional	1.40	0.19		

LER=Land equivalent ratio; SD=Standard deviation; Means with the same letter down a column are not significantly different at $p < 0.05$.

An ANOVA was conducted to test the effect of season on the LER and was found not to be significant at $p < 0.05$. LER for grain and stover were 1.22 and 1.21, respectively, in the short rains of the year 2011 while in the long rains of 2012, they were 1.23 and 1.27, respectively (Table 7). This indicated that there were 22% and 21% greater yield advantage of grain and stover, respectively, of the intercrop over the component sole crop in 2011 short rain season. In the 2012 long rains, the yield advantage of the intercrop was 23% and 27% grain and stover, respectively, over and above the monocrop. However, the LER for both grain and stover was similar in both the 2011 short rains and long rains seasons (Table 7).

Table 7. Effect of season, on land equivalent ratio of maize and soybean

Season	Grain	Stover
2011 (Short rains)	1.22a	1.21a
2012 (Long rains)	1.23a	1.27a
LSD	0.1272	0.899

Key: Means with the same letter down a column are not significantly different at $p < 0.05$

4. Discussion

Generally, maize yields were found to be significantly larger in both the monocropping (mean yield: 2.00 t ha^{-1}) and MBILI systems (mean yield: 1.77 t ha^{-1}) compared to the conventional farming (mean yield: 1.27 t ha^{-1}). Maize yield in Teso-North was abnormally low (mean = 0.2 t ha^{-1}) because the crop was infected with Maize Lethal Necrosis Disease (MLND) in the 2012 long rains season. On one hand, soybean yields were found, overall, to be significantly larger in the monocropping (mean: 1.00 t ha^{-1}) compared to both MBILI (mean: 0.75 t ha^{-1}) and conventional systems (mean: 0.59 t ha^{-1}). Unlike maize, soybean is a crop that is capable of utilizing both soil N (mostly in the form of nitrate) and atmospheric N (through symbiotic nitrogen fixation) (Vera et al., 2002). Larger maize yields in the monocropping system could be explained by the fact that the maize obtained optimum nutrients and other resources from fertilizers/manures applied or those inherent in the soils, as there was little competition from other crops. Maize growing in the MBILI system could benefit from the nitrogen fixed by legume crop, explaining the larger maize yields. Maize yields in the conventional system could be lower than in the MBILI system because the latter system allows more light penetration for the under-story plant component, without changing the plant densities, improves root distribution and reduces belowground competition (Woomer, 2007; Woomer et al., 2004). Woomer et al., (2004) demonstrated that more than 50% larger light penetration in MBILI cropping system and also suggested that superior crop yields were related to additional advantages in root distribution and reduced below-ground competition. Studies have indicated that the MBILI system, when combined with adjusted nutrient inputs, resulted in superior and robust improvements in crop yields and economic benefits, relative to the conventional intercropping system (Mucheru-Muna et al., 2010).

Soybean yields were largest in the monocropping system because growing, solely; the crop faced no competition for resources such as mineral nutrients from applied fertilizers/manures. The yields for soybean were lower in both the MBILI and conventional system possibly because although the crop expended resources to fix nitrogen for the maize crop, it could have received little in compensation, reducing its yield. The soybean haulm yield reflected a similar trend, suggesting that the same explanation could be applied.

For maize crop, planting with CAN75N and FYM75N were found to significantly increase yields, compared to either planting with CAN30N or planting with FYM30N. Each of these treatments was significantly greater relative to the control. Patel et al., (2006), Kostandi and Soliman (2008) and Younas et al., (2002) reported that increasing nitrogen levels increased grain yield and dry matter production, which were related to differences in size of photosynthetic surface and the relative efficiency of total sink activity. According to them, the larger yields were due to a larger number of grains per cob and a larger weight of the grains. Thus, larger crop yields in the study could result from more availability of nitrogen to plants. Given the prohibitive costs of fertilizers and the possibility of decreasing soil productivity in the long run due to soil mining and environmental pollution Kiani et al., (2005); Billen et al., (2014), the results suggest that where farmers could access cheap sources of FYM, they should consider using them instead of top dressing with nitrogenous fertilizers.

An analysis of various interactions between the main factors showed that CAN generally produce larger yields with monocropping whereas the MBILI system was superior when FYM is used. FYM can increase crop production through a variety of ways: provision of additional nitrogen, provision of phosphorus, provision of potassium, etc. increased soil organic matter, and improved soil water holding capacity (McAndrews et al., (2006); Barbazan, 2004; Hati et al., (2006). This suggests that using the MBILI system with organic fertilizers could be a better option than opting for mineral fertilizers, because of the latter's high costs and environmental pollution.

The mean LER values were always greater than 1.0 in both MBILI and conventional systems showing that although monocropping had larger yields, intercropping was advantageous over sole cropping. This is in agreement with Li et al., (2006) who reported that resources such as water, light and nutrients were better utilized in intercropped than in the respective sole cropping systems. An LER greater than 1.0 has been reported

with bean maize intercropping (Odendo *et al.*, 2011; Saban *et al.*, 2007).

5. Conclusions

The study investigated the effects of different cropping systems, N fertilizer and manure applications on the yield of maize and soybean in the western region of Kenya. Though sole cropping system leads to larger yields in grains, intercropping has more yield advantages compared to monocropping. MBILI system is superior in yields compared to the conventional intercropping system. The greater LER of the intercrops was mainly due to greater resource use and complementarity than when the species were grown together. This shows that intercropping system can significantly benefit the smallholder by increasing yield on a limited amount of land and reducing risk of total crop failure, such as, from prolonged drought.

This study recommends that the most optimal system for growing soya bean and maize that maximizes yield in an economically and environmentally beneficent way is the MBILI system with an organic source of N.

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