International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 12, No. 2, p. 86-99, 2018

INNSPUB

RESEARCH PAPER

OPEN ACCESS

Effect of intercroping maize and soybean on soil fertility

Habineza M. Jean Pierre*[1,2], Josiah M. Kinama[2], Florence M. Olubayo[2], Susan W. Wanderi[3], James W. Muthomi[2], Felister M. Nzuve[2]

[1] *University of Goma (UNIGOM), Goma, Democratic Republic of Congo (DRC)*

[2] *Department of Plant Science and Crop Protection, University of Nairobi, Nairobi, Kenya*

[3] *Kenya Agricultural and Livestock Research Organisation (KARLO), Kenya*

Article published on February 28, 2018

Key words: Maize, Intercropping, Soybean, Nodulation, Soil fertility.

Abstract

This study was carried out to determine the effect of intercropping maize with soybean on soil fertility. The study was conducted at two sites and evaluated three soybean varieties (hybrid SB19, GAZELLE - a local variety, hybrid TGX1990-5F) as sole crop and intercropped with maize, with maize pure stand as control. In the intercropped plots, one row of soybean was planted after every alternate row of maize. Data collected included soil nutrient status before planting and at harvest and nodulation in soybean. Variety TGX1990-5F had significantly more nodules followed by GAZELLE and SB19 was the last in sole crop and in intercrop at Embu during long rains and short rains ($p \leq 0.05$). Mwea produced more nodules compared to Embu. Intercropping maize and soybean had no effect on the number of nodules per plant both seasons.However, TGX1990-5F fixed higher N of 0.39% compared to 0.29% for SB19 in sole crop respectively between sites for the first season after harvesting. TGX1990-5F showed higher N compared to GAZELLE in intercrops between sites for the second season after harvesting. Depending on the requirement of the plants nutrients, TGX1990-5F fixed moderate N for feeding plant. However, GAZELLE showed high Organic Carbon, Potassium and Phosphorus after harvesting than other varieties in both sites and rains seasons. Thus, variety TGX1990-5F can be recomended to smallscale farmers for intercropping with maize because it produced higher nodules and fixed higher N, hence reducing the cost for N fertilizers.

* **Corresponding Author:** Habineza M. Jean Pierre ✉ ir.jphaby@gmail.com

Introduction

Low soil fertility is a important constraint in agricultural production in Sub Saharan Africa. Legume promise of being a cheap alternative soil fertility owing to their ability of fixing atmospheric nitrogen (Phiri *et al.*, 2013). However, soil characteristics can be affected positively or negatively by growth conditions of crops. Intercropping is an agricultural practice of cultivating two or more crops in the same space at the same time (Lithourgidis *et al.,* 2011). The authors also define intercropping as an old and commonly cropping system used which targets to match efficiently crop demands to the available growth resources and labor. Yield and nutrients acquisition advantages are frequently found in intercropping systems. However, there are few published reports on soil fertility in intercropping relative to monocropping (Wang *et al.*, 2014). The stability under intercropping can be attributed to the partial restoration of diversity that is missed under sole crops. According to this statement, intercropping allows high insurance against crop failure, notably in environments known for heavy weather conditions like frost, flood, drought, and overall provides hight financial stability for farmers (Lithourgidis *et al.*, 2011). Moreover, legumes enrich soil by fixing the atmospheric nitrogen transforming it and other mineral from an inorganic form to forms that are avaible for uptake by crops (Li *et al.*, 2012). Biological fixation of atmospheric nitrogen can replace nitrogen fertilization fully or partially. When nitrogen fertilizer is limited, biological nitrogen fixation is the important source of nitrogen in intercropping systems (Fujita *et al.*, 1992). In addition, because inorganic fertilizers contributed to ecosystem damage such as nitrate pollution, legumes grown in intercropping are taken as an alternative and sustainable path of bringing nitrogen in the soil into little input cost and without damage (Fustec *et al.*, 2010). Furthermore, the green parts and roots of the legume component can decompose and provide nitrogen into the soil where it may be made available to subsequent crops. Specially, under low soil nitrogen conditions the advantages of legumes in an intercrop are greater (Fabio *et al.*, 2017). Legumes broadly are more powerful in increasing the productivity of succeeding cereals. The carryover of nitrogen for succeeding crops may be 60-120kg in berseem (*Trifolum alexadrium*), 75kg in cluster bean (*Cyamopsis tetragonolobus*), 68kg in chickpea (*Cicer arietinum*), 54-58 kg in groundnut (*Arachis hypogea*) and 50-51kg in soybean (*Glycina max*) (Bandyopadhyay *et al.*, 2007). In addition, apart from nitrogen, intercropping legume-cereal can allow acquisition of other nutrients such as phosphorus, potassium, sulphur and micro nutrients. Zhang *et al.*, (2015) reported that, maize-soybean intercropping reduced use of N fertilizer per unit of area and enhanced relative biomass of intercropped maize, due to promoteded photosynthetic efficiency of bodder rows and N utilisation during symbiotic period. In addition, Ali *at al.*, (2015) found that, maize-soybean intercropping increased soil organic carbon content, CEC, N, Ca, Mg and P level after harvesting than sole crops. Wang *et al.*, (2014) reported that, globally, soil organic matter did not differ significantly from monocropping but did increase in maize-chickpea intercropping in two years. Soil total N did not differ between intercropping and monocropping in either year, except in maize-fababean intercropping in 2011. Intercropping reduced significantly soil Olsen-P, soil exchangeable K in both years, soil cation exchangeable capacity (CEC) in 2012 and soil p H in 2012. In the majority of cases soil enzyme activities did not differ across all the cropping systems at different P application rates compared to monocrops. However, Owusu & Sadick (2016) reported that before maize-soybean intercropping system, the soil was moderaterly slightly acid (p H=5.6), while the nitrogen was low (0.1%). They said also that, the available phosphorus was very low (4.95mg/kg). After the experiment the results showed that, some soil nutrients increased for exemple organic carbon (0.15%), phosphorus (5.25mg/kg), calcium (0.54cmol (+)/kg), sodium (0.06cmol(+)/kg) while others soil nutrients decreased like the total nitrogen (0.02%), magnesium (0.54 cmol (+)/kg) and potatium (0.12 cmol (+)/kg). In addition the same autors reported that, correlation analysis showed that, organic carbon and available phosphorus correlated positively with all parameters while nitrogen correlated positively with calcium, potassium, magnesium, organic carbon, and phosphorus. Regehr (2014) reported that, soil quality improved significantly in maize-soybean intercropping than monocropping system. Intercropping resulted in higher rates of gross N mineralization than the sole crops, and the 2:3 intecrop resulted in higher rates of gross N immobilization than other treatments. Hence the research in this study for assessing the effect of intercropping maize- soybean on soil fertility at Embu and Mwea sites in Kenya.

Materials and methods

Description of the study sites

The experiments were conducted in Embu and Mwea during two rain seasons of (2016 and 2017). KALRO-Embu is located between latitudes 0˚ 08'35''S and a longitude 37°27′02″ E while KALRO-Mwea is located at a latitude of 00º37'S and a longitude of 37º20'E in Kenya (kirinyaga county, 2014 and Embu county, 2014). During the experiment period the rainfall was 3.21 mm and 0.007 mm at Embu and Mwea, respectively. The mean temperature and relative humidity were respectively 21.42°C and 63.54% at Mwea and 20.3°c and 64.43% at Embu (KARLO Embu and Mwea agromet services). Land preparation was done by ploughing using ox-drawn equipment.

Experimental treatment and design

The treatments consisted of three soybean varieties planted as monocrop or intercropped with maize as follows: l.SB19 (Hybrid), GAZELLE (Local), TGX1990-5F (Hybrid), SB19 intercropped with maize, GAZELLE intercropped with MAIZE, TGX1990-5F intercropped with MAIZE, and maize sole crop as control. Maize variety used for intercropping was DUMA 43. The spacing used was: The monocrop soybean was planted at a spacing of 40cm x 15cm, Soybean intercropped with maize: (80cm x 15cm), Monocrop maize: (80cm x 25cm), Maize intercropped with soybean: (80cm x 25cm). The arrangement of intercropping was 1:1 with one row of maize intercepted by one row of soybean. The experiment was laid out as a randomized complete block design (RCBD) replicated three times The experiments received a basal application of DAP at the rate of 250kg ha^{-1} , (Roy *et al.*, 2006). Because of insufficient rain fall, the trials received supplement by irrigation but the situation of rain fall was drastic and so bad in the second season.

Soil sampling and nutrients analysis

Soil samples were collected with auger tool using zigzag method at a depth of 0-30cm and then mix different samples of the same site in order to get one sample which is homogeneous in each site and taken for analysis at Soil Chemestry laboratory, University of Nairobi for macronutrients, micronutrients and some oligo elements like Zinc, Mn, cobalt and pH. Before planting and after harvesting soil analysis for each treatment was done also in order to ensure the amount of nutrient fixed after harvesting in each plot. The soil pH was measured by using pH meter as showed Van Reeuwijk (2002). Organic carbon was assessed following the model for Walkely and Black (1934).

$$\text{Total organic carbon} = \frac{(\text{Vblank} - \text{V sample}) \times 0.3 \times \text{N} \times 100}{\text{Weight}} \times \frac{100}{77}$$

V blank = Volume of blank, V sample = Volume of sample, 0.3 = Factor, N = Normality for $FeSO_4$.

The total nitrogen was measured using kjedal method as said by (Roberts *et al.,* 1971).

$$\%\text{N total} = \frac{\text{Titre x 14 x Normality of acid used x volume extracted x 100}}{\text{Weight of sample x 1000 x Aliquote taken in (ml)}}$$

However, the available phosphorus in the soil was quantified colorimetrically using spectrophotometer as said by (Roberts *et al.,* 1971).

$$\text{P ppm} = \frac{\text{GR x volume extracted}}{\text{Weight}} \times \frac{50}{3}$$

GR: Absorption, 50: Volume developed, 3: Volume extracted. The quantity of potassium in the soil samples was evaluated by flame photometer as shown by (Roberts *et al.,* 1971). Extractable micronutrients (Fe, Mn, Zn and Cu) were extracted with ethylene-diamaine-tetra-acetic acid (EDTA) method as described by (Roberts *et al.,* 1971). The amounts of the micronutrients in the extract was assessed by atomic absorption spectrophotometer at 279.5nm, 248.3nm, 324.7nm, and 213.9nm wave lengths for Mn, Fe, Cu, and Zn, respectively.

Determination of nodulation

Nodule assessment was done one month after sowing in both sites. The crops were dug up, deposed carefully in the basin and after that, nodules were counted pouring water on the roots of each plant exposed in the basin in order to see carefully all the nodules (Mosanto, 2014).

Table 1. Soil nutrients interpretation according to J. Landon (1991).

Nutrient	*Low*	*Moderate*	*High*
Nitrogen (%)	<0.2	0.2-0.4	>0.5
Phosphorus (ppm)	<10	10-25	>35
Potassium cmol/kg	<0.5	0.5-0.8	>2.0
Calcium cmol/kg	<1.	1-3.0	>5.0
Magnesium cmol/kg	0.5	0.5-1.5	>1.5
Organic carbon (%)		>3.5	
pH	5.5-7.5	(suitable for most crops)	

According to Table 1 for those two sites, only phosphorus is adequate for the soybean and maize, following the soil scale of Lando, 1991 on the interpretation of the soil nutrients, where phosphorus is sufficient it is above 35ppm.

Results

Effect of intercropping on soil fertility

Nodulation per plant

Soybean number of nodules showed significant difference ($P \leq 0.05$) between sites but the seasons were not significantly different. The number of nodules ranged from 33 to 47 at Mwea while Embu ranged from 29 to 43. TGX1990-5F recorded the highest number of nodules of 47 in intercropping followed by SB19 with 35.53 numbers of nodules while GAZELLE recorded the lowest number of nodules of 33.90 at Mwea in long rains. TGX1990-5F presented the highest number of nodules followed by GAZELLE while SB19 recorded the lowest number of nodules in the sole crops in both sites during the long rains. Variety TGX1990-5F showed the highest number of nodules of 43.40 in intercrops followed by SB19 with 33.07 compared to GAZELLE with the lowest number of nodules of 29.87 in long rains at Embu. The number of nodules ranged from 33 to 46 at Mwea contrary to Embu where the number of nodules ranged from 28.07 to 43 in short rains. Variety TGX1990-5F recorded the highest number of nodules of 46.8 followed by GAZELLE with 36.4 compared to SB19 with the lowest number of nodules of 35.3 in sole crops at Mwea. In intercrops, TGX1990-F recorded the highest number of nodules of 46.8 followed by GAZELLE with 35.1 while SB19 presented the lowest number of nodules of 33.9 at Mwea. However, TGX1990-5F showed the highest number of nodules of 43.7 followed by GAZELLE with 32.33 number of nodules compared to SB19 with 29.80 in sole crop at Embu. TGX1990-5F presented highest number of nodules of 43.40 followed by GAZELLE with 33.67 compared to SB19 with 28.07 in intercrops. Intercropping did not reduce the number of nodules per plant in both sites and both seasons. Mwea had the highest number of nodules compared to Embu both seasons. TGX1990-5F showed the highest number of nodules followed by GAZELLE and the last was SB19 giving the lowest number of nodules both sites and both rainy seasons (Table 2).

Table 2. Nodulation per plant for saybean at Mwea and Embu for two rainy seasons.

	Long rains 2016		
	NODP		
Treatment	Embu	Mwea	Mean
SB19	30.4a	34.87b	32.6b
GAZELLE	32.9a	36.60b	34.8b
TGX1990-5F	43.6b	46.87a	42.24a
SB19+MAIZE	33.07a	35.53b	34.3b
GAZELLE+MAIZE	29.87a	33.90b	31.8b
TGX1990-5F+MAIZE	43.40b	47.47a	45.44a
Mean	35.54	39.20	36.87
LSD0.05	5.59	3.33	4.03
CV%	8.7	4.7	6.6
Short rains 2016-2017			
	NODP		
Treatment	Embu	Mwea	Mean
SB19	29.80b	35.3b	32.55b
GAZELLE	32.33b	36.4b	34.36b

TGX1990-5F	43.73a	46.8a	45.26a
SB19+MAIZE	28.07b	33.9b	30.98b
GAZELLE+MAIZE	33.67b	35.1b	34.39b
TGX1990-5F+MAIZE	43.40a	46.8a	45.1a
Mean	35.16	39.5	37.3
LSD0.05	5.66	2.71	4.03
CV%	8.9	3.8	6.6

NODP : Nodulation per plant, LSD : Least sinificant difference, CV : Coeffient of variation, Means bearing the same letter are in the same group.

Soil pH

After harvesting (AH), soil pH showed significant difference between sites and seasons ($p \leq 0.05$) in intercopping and in sole crop. In addition, after harvesting, the pH increased the acidity at Embu and TGX1990-5F showed higher pH (5.18) compared to pH 5.88 less acidic obtained BP followed by GAZELLE (4.83) recorded AH more acidic compared to 6.03 which is less acidic recorded BP and SB19 showed pH more acidic of 4.73 AH than pH 5.95 obtained BP in sole crop. The variety of GAZELLE recorded the higher acidic pH of 4.45 AH compared to 6 less acidic recorded BP followed by SB19 with higher acidic pH of 4.55 AH compared to 5.88 btained BP and the last was TGX1990-5F with 4.6 AH pH more acidic than 6.06 in intercrop at Embu in the first season. However, at Mwea the pH did not change AH compared to pH recorded BP and it remained acidic (5) in sole crops and in intercrops. During the short rains soil pH decreased slightly at Embu AH compared to soil pH BP.

The variety of SB19 decreased soil pH with 6.11 AH compared to 5 obtained BP. TGX1990-5F and GAZELLE had the same pH of 5.8 AH less acidic than 5 for those varieties BP in the sole crop. GAZELLE reduced soil pH acidity to 6.5 AH compared to pH 5 recorded BP, followed by SB19 with 5.8 AH compared to pH 5 recorded BP and the last was TGX1990-5F with 5.58 recorded AH and less acidic than 5 obtained BP in intercrop at Embu. At Mwea all varieties decreased soil pH acidity with pH 6 AH while BP it was more acidic with pH 4 in sole crop and in intercrop in short rains (Table 3).

Table 4. Soil nutrients long rains 2016 and short rains 2016-2017 before planting and after harvesting soybean.

Long rains 2016												
	K Cmol/kg (BP)			K Cmol/kg (AH)			P ppm (BP)			P ppm (AH)		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	1.56a	1.26a	1.41a	1.06c	1.07b	1.06c	21.5a	138.3a	79.9a	12.06e	188.58c	100.33c
GAZELLE	1.46a	1.20ab	1.33a	1.0c	0.92c	0.96d	21.4a	140a	80.7a	15.34d	177.87d	96.61d
TGX1990-5F	1.18a	0.90b	1.04a	1.80a	0.72e	1.26a	21.8a	143a	82.4a	23.03c	188.73b	105.88b
SB19+MAIZE	1.47a	0.95b	1.21a	1.24b	0.85cd	1.05c	23.7a	127.3a	75.5a	24b	144.86g	84.43g
GAZELLE+MAIZE	1.29a	1.10ab	1.19a	1.03c	0.85cd	0.94d	22.1a	138.7a	80.4a	12.07e	165.35e	88.71f
TGX1990-5F+MAIZE	1.53a	1.0ab	1.27a	1.05c	1.23a	1.14b	22.2a	145.3a	83.8a	27.34a	194.87a	111.11a
MAIZE	1.41a	1.17ab	1.29a	1.06c	0.82d	0.93d	21.1a	138.7a	79.9a	15.37d	164.73f	90.05e
Mean	1.42	1.1	1.29	1.17	0.92	1.05	22.0	138.8	80.4	18.46	174.99	96.73
LSD0.05	0.55	0.27	0.30	0.06	0.09	0.07	2.67	17.7	22.09	0.14	0.027	0.092
CV%	22	14.4	18.3	3.0	5.5	4.2	6.8	7.2	18.5	0.4	0.0	0.1
Short rains 2016-2017												
	K Cmol/kg (BP)			K Cmol/kg (AH)			P ppm (BP)			P ppm (AH)		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	1.15a	0.36a	0.75a	0.85c	1.57a	1.21b	148.1a	5.7a	76.9a	27.17f	164.13	95.65b
GAZELLE	1.04b	0.43a	0.74a	0.90c	1.15d	1.03c	127.5ab	6.4a	66.9a	71.74d	88.94	80.34d
TGX1990-5F	1.09ab	0.37a	0.73a	0.85c	1.35c	1.10c	127.7ab	7.7a	67.7a	11.96g	100.52	56.24g
SB19+MAIZE	1.15a	0.49a	0.82a	0.70c	1.34c	1.02c	124.4ab	4.6a	64.5a	76.39c	64.82	70.60f
GAZELLE+MAIZE	1.09ab	0.37a	0.73a	1.50a	1.55ab	1.52a	117.7ab	4.5a	61.1a	123.18a	128.69	125.93a
TGX1990-5F+MAIZE	1.14a	0.29a	0.72a	0.90c	1.15d	1.03c	109.7b	6.6a	58.1a	88.28b	91.326	89.80c
MAIZE	1.05ab	0.49a	0.78a	1.06b	1.45bc	1.26b	124.1ab	6.4a	65.3a	30.87e	120.05	75.46e
Mean	1.10	0.40	0.75	0.96	1.36	1.16	125.6	6.0	65.3	61.37	108.35	84.86
LSD0.05	0.09	0.27	0.30	0.07	0.11	0.07	29.74	2.87	22.09	0.11	0.09	0.092
CV%	5	37.9	18.3	4.5	4.4	4.2	13.3	26.9	18.5	0.1	0.0	0.1

BP: Before planting; AH: After harvesting.

Organic carbon

The results for Organic carbon (OC) didn't give significant difference before planting long rains 2016 and short rains 2017 between sites and seasons, but significant difference was shown after harvesting long rains 2016 and short rains 2016-2017 among treatments and sites ($p \le 0.05$). Organic carbon ranged from 1.24% to 2.8% at both sites and seasons before planting. OC increased in the soil after harvesting than before planting, in the long rains seasons at Embu. TGX1990-5F gave higher OC of 3.77% after harvesting compared to the same variety with 2.82% before planting at Embu followed by GAZELLE (3.19%) recorded after harvesting compared to the same variety with 2.82% obtained before planting. SB19 was last recording 2.68% after harvesting compared to 2.79% obtained before planting in sole crops. GAZELLE showed higher OC (3.18%) after harvesting compared to 2.78 % recorded before planting. TGX1990-5F (2.95 %) followed after harvesting compared to 2.82% before planting. SB19 gave the lowest OC (1.69%) after harvesting than 2.82% obtained before planting in intercropping at Embu for the long rains. Intercropping reduced only OC for SB19 after harvesting than other varieties. Mwea showed the lowest amount of OC in the first season before planting and after harvesting than Embu. SB19 showed the highest OC (1.96%) after harvesting compared to 1.88 % obtained before planting followed by TGX1990-5F (1.53%) obtained after harvesting compared to 1.83% before planting. GAZELLE was the last with (1.39) after harvesting compared to 1.9% before planting in sole crop at Mwea. TGX1990-5F gave higher OC (1.89%) before planting compared to (1.52%) after harvesting. SB19 followed with 1.82 % before planting compared with (1.44%) after harvesting. GAZELLE had the lowest amount of OC (1.78%) before planting compared with 0.82% after harvesting in intercrop at Mwea. During the short seasons, OC increased at both sites after harvesting (AH) than before planting (BP). It ranged from 2.6% to 3% at Embu while it ranged from 2.1% to 3% at Mwea in sole crop as in intercrop. SB19 and GAZELLE gave the same amount of OC (3%) AH compared to 1.26% and 1.28% respectively for SB19 and GAZELLE BP. TGX1990-5F followed with (2.99%) AH more than 1.25% BP. Sole maize gave the lowest amount of OC (1.3%) BP less than (2.83%) AH for maize alone in sole crop. However, in intercrop, TGX1990-5F recorded higher OC (2.90%) AH more than OC (1.24 %) BP followed by GAZELLE with 2.88 % AH greater than OC (1.25 %) BP. SB19 was the last with OC (2.66%) AH higher than 1.28% BP at Embu. For Mwea site, SB19 recorded the biggest OC (2.96%) AH compared to 2.51% BP followed by GAZELLE (2.30%)AH more than 2.19% obtained BP. TGX1990-5F recorded the lowest OC (2.14%) AH less than 2.48%recorded BP in the sole crop. However, TGX1990-5F showed the highest OC (3.39%) AH more than 2.21% BP. SB19 followed with OC (2 .52%) AH compared to 2.41 % BP. GAZELLE was last giving (2.3%) BP and AH in intercrop. Organic carbon in the soil increased according to the results obtained after harvesting at Embu during long rains 2016 and short rains 2016 - 2017 compared to the value obtained before planting, but organic carbon in the soil didn't increase after harvesting at Mwea during long rains 2016 and short rains 2016-2017compared to the value obtained before planting at Embu (Table 3). Intercropping affected negatively the amount of organic carbon in the soil slightlyl.

Total nitrogen

Total nitrogen did not give significant differences between sites and seasons before planting (BP) but N showed significant differences between sites and seasons after harvesting (AH) ($p \le 0.05$). Soil N increased AH than BP at both sites in the first season. However, in the second season, soil N increased only at Embu and decreased at Mwea. It ranged from 0.25% to 0. 29% at Embu while N ranged from 0.17% to 0.20% at Mwea for the first season BP in sole crop as in intercrop. In addition, N ranged from 0. 29% to 0.58% at Embu and from 0.19% to 0.28% at Mwea in intercrop as in sole crop AH. TGX1990-5F gave the highest amount of 0.58% N AH campared to the same variety with 0.27% BP followed by GAZELLE (36%) AH higher than 0.28% obtained BP. Sole maize gave 30% AH more than 0.27% BP. SB19 gave the lowest soil N of 0.29% BP and AH in sole crop. TGX1990-5F showed the highest amount of soil N of 36% AH compared to 0.28% recorded BP followed by GAZELLE (32%) AH more than 0.25% BP.

SB19 gave the lowest soil N of 0.23% AH less than 0.29% obtained BP in intercrop at Embu. At Mwea, all varieties gave the same amount of soil N of 20% AH. It ranged from 0.17% to 0.20% BP in sole crop as in intercrop. SB19 had however higher soil N (0.28%) AH compared to 0.18 % obtained BP in soybean crop and sole maize which had soil N (0.19%) AH more than 0.18% got BP for the long rains at Mwea. For the short rains, TGX1990-5F had higher soil N (0.29 %) AH compared to 0.13 % BP followed by GAZELLE with 0.27% AH more than 0.14% BP. SB19 was the last with 0.24% AH more than 0.12 % BP in sole crop at Mwea. TGX1990-5F recorded (0.29%) N AH compared to 0.13% BP. This was followed by SB19 (0.25 %) AH more than 0.15 % BP. GAZELLE was the last with 0.18% AH compared to 0.14% BP in intercrop at Embu. At Mwea, GAZELLE recorded the biggest soil N (0.28 %) AH compared to 0.27% BP while TGX1990-5F presented the lowest soil N (0.14%) AH less than 0.20% BP with SB19 the second recording 0.23% AH less than 0.27 % obtained BP in sole crop. However, TGX1990-5F showed higher soil N (0.32%) AH compared to 0.26% BP. SB19 followed with (0.18%) AH less than (0.23%) obtained BP. GAZELLE had the lowest amount soil N (0.13%) AH less than 0.22 % found BP in intercrop at Mwea.

TGX1990-5F was the first variety to fix bigger amount of total nitrogen than other varieties in sole crop compared to intercropping. The amount fixed in sole crop is not the same as the amount fixed in intercropping. This means that, intercropping affected negatively the amount of total nitrogen fixed by varieties. From the results of soil analysis long rains 2016 BP, Mwea did not increase total nitrogen fixed by varieties , except SB19 in sole crop (Table 4.5). Comparatively results from soil analysis BP, Mwea site slighly increased total nitrogen except TGX1990-5F in intercropping which gave higher amount than other treatments in intercropping. Nevertheless, TGX1990-5F showed good permance in total nitrogen fixation in sole crop compared to intercropping (Table 3). However, during short rains of 2016-2017, the results obtained after harvesting were lower for some varieties compared to the results obtained before planting.

Potassium and Phosphorus soil nutrients

Potassiun did not show significant difference between sites and seasons before planting (BP) and after harvesting during the long rains while significant difference was shown in the short rains after harvesting (AH) ($p \leq 0.05$) between sites. However, K decreased in the sites AH compared to the value obtained BP in the long rains and short rains except Mwea in the short rains where it increased. The means of K ranged from 1.18 Cmol/kg to 1.56 Cmol/kg at Embu while K ranged from 0.9 Cmol/kg to 1.26 Cmol/kg at Mwea in intercropping as in sole crop for long rains BP. K ranged from 1 Cmol/kg to 1.80 Cmol/kg at Embu compared to Mwea where K ranged from 0.72 Cmol/kg to 1.23 Cmol/kg in sole crop and in intercrop for the short rains AH. However, TGX1990-5F showed higher K of (1.80 Cmol/kg) AH compared to 1.18 Cmol/kg BP followed by SB19 (1.06 Cmol/kg) recorded AH less than 1.56 Cmol/kg obtained BP and GAZELLE showed the lowest K (1 Cmol/kg) AH less than 1.46 Cmol/kg in sole crop. Variety SB19 presented the biggest amount of K (1.24 Cmol/kg) AH but less 1.47 Cmol/kg obtained BP compared to other varieties AH in intercrop. Maize had 1 Cmol/kg in intercrop AH less than 1.54 Cmol/kg, 1.41 Cmol/kg and 1.29 Cmol/kg respectively for TGX1990-5F in intercrop, sole maize and GAZELLE in intercrop too at Embu. At Mwea, SB19 gave higher K (1.07 Cmol/kg) AH less than 1.26 Cmol/kg BP followed by GAZELLE (0.92 Cmol/kg) AH lower than 1.20 Cmol/kg BP followed by sole Maize (0.82 Cmol/kg) AH less than 1.42 Cmol/kg BP while TGX1990-5F was the last giving (0.72 Cmol/kg) AH less than 0.90 Cmol/kg in sole crop. TGX1990-5F had the biggest K (1.23 Cmol/kg) AH compared to 1 Cmol/kg obtained BP and other varieties had the same K of 0.85 Cmol/kg compared to 1.10 Cmol/kg and 0.95 Cmol/kg respectively for GAZELLE and SB19 BP in intercrop in the long rains at Mwea. For the short rains, all varieties had the same amount of K (0.85 Cmol/kg) AH less than 1 Cmol/kg for all varieties obtained BP in sole crop at Embu. GAZELLE showed the highest K (1.50 Cmol/kg) AH more than 1.09 Cmol/kg BP followed by TGX1990-5F (0.90 Cmol/kg) AH less than 1.14 Cmol/kg recorded BP.

SB19 was the last with (0.70 Cmol/kg) AH less than 1.15 Cmol/kg obtained BP in intercrop at Embu. At Mwea, SB19 showed the highest amount of K (1.57 Cmol/kg) more than 0.36 Cmol/kg BP followed by TGX1990-5F (1.35 Cmol/kg) AH more than 0.37 Cmol/kg recorded BP while GAZELLE was the last with (1.15 Cmol/kg) AH compared to 0.43 Cmol/kg obtained BP in sole crop at Mwea. In addition, GAZELLE showed the highest K (1.55 Cmol/kg) AH more than 0.34 Cmol/kg BP followed by SB19 (1.34 Cmol/kg) AH compared to 0.49 Cmol/kg BP and TGX1990-5F recorded the lowest K (1.15 Cmol/kg) AH compared to 0.29 Cmol/kg recorded BP in intercrop at Mwea (Table 4).

The results for phosphorus (P) did not give significant diference between sites and seasons before planting (BP) but significant difference was shown after harvesting (AH) between sites and seasons ($p \leq 0.05$). The P decreased at Embu AH compared to the results obtained BP in both seasons while Mwea increased P AH than BP for both seasons. The P ranged from 21 ppm to 23 ppm in sole crop and in intercrop at Embu while it ranged from 127 ppm to 145 ppm at Mwea in sole crop as in intercrop in the long rains. For the short rains P ranged from 109 ppm to 148 ppm at Embu compared to Mwea where it ranged from 4 ppm to 8 ppm in sole crop as in intercrop before planting. TGX1990-5F showed higher P of 23 ppm AH compared to 21.08 ppm BP followed by sole maize and GAZELLE with 15.34 ppm AH compared to 21 ppm for sole maize and GAZELLE BP while the lowest was SB19 with 12 ppm AH compared to 21 ppm BP for the same variety BP in sole crop. TGX1990-5F showed the highest amount P (27. 34 ppm) AH more than 22 ppm BP followed by SB19 (24 ppm) AH more than 23.7 ppm and GAZELLE showed the lowest amount of P of 12 ppm AH less than 22 ppm BP in intercrop at Embu. At Mwea site, TGX1990-5F with SB19 recorded the highest amount of P (188 ppm) AH compared to 143 ppm and 138.3 ppm respectively for TGX1990-5F and SB19 BP followed by GAZELLE (177.87 ppm) recorded AH more than 140 ppm BP and sole maize recorded the lowest P (164.73 ppm) AH compared to 138.7 ppm BP in sole crop at Mwea. However, TGX1990-5F recorded the highest amount of P (194.87 ppm) AH compared to 145.3 ppm BP followed by GAZELLE (165.35 ppm) recorded AH more than 138.7 ppm obtained BP and the last was SB19 with lower P of 144.86 ppm AH compared to 127.3 ppm recorded BP in intercrop for the long rains. During the short rains GAZELLE recorded the biggest amount of P (71.74 ppm) AH less than 127.5 ppm BP followed by sole maize (30.87 ppm) recorded AH less than 124 ppm obtained BP followed by SB19 (27.17 ppm) AH compared to 148 ppm for the same variety obtained BP and TGX190-5F recorded the lowest amount of (11.96 ppm) AH compared to 127 ppm obtained BP in sole crop at Embu. Intercropping showed higher amount of P compared to the sole crop where GAZELLE recorded the biggest amount of 123.18 ppm AH compared to 117.7 ppm BP followed by TGX1990-5F (88.28 ppm) AH less than 109.7 ppm BP and SB19 showed the lowest amount of P (76.39 ppm) AH less than 124.4 ppm obtained BP at Embu. Mwea showed the highest P than Embu and SB19 recorded the biggest amount of 164.13 ppm AH more than 5.7 ppm BP. SB19 was followed by sole maize with (120.05 ppm) AH less than 6.4 ppm BP. Sole maize was followed by TGX1990-5F (100.52 ppm) obtained AH more than 7.7 ppm BP while GAZELLE presented the lowest P (88.94 ppm) AH compared to 6.4 ppm BP in sole crop at Mwea. GAZELLE recorded the highest amount of P (128.68 ppm) AH higher than 4.5 ppm BP followed by TGX1990-5F (91.32 ppm) AH more than 6.6 ppm BP while SB19 was the last recording (64.82 ppm) AH compared to 4.6 ppm got BP at Mwea in intercrop. From the long rains before planting, the results showed that, all treatments fixed high amount of phosphorus in sole crop as in intercrop (Table 4).

Discussions

Nodulation per plant

Soybean number of nodules showed significant difference ($P \leq 0.05$) between sites but the seasons were not significantly different. The number of nodules ranged from 33 to 47 at Mwea while in Embu the number of nodules ranged from 29 to 43. TGX1990-5F recorded the highest number of nodules of 47 in intercropping while GAZELLE recorded the lowest number of nodules at Mwea in intercropping too.

TGX1990-5F presented the highest number of nodules for 43.6 in sole crop while GAZELLE recorded the lowest number of nodules 29.87 in intercropping at Embu long rains 2016. During the short rains, the number of nodules per plant was almost the same as in the first season. The number of nodules ranged from 33 to 46 at Mwea compared to Embu where the number of nodules ranged from 29 to 43. The high number of nodules produced in both sites could be due to the adaptation of those varieties on the soil sites. These results agree with Madimba *et al.* (1994) who recorded the number of nodules ranging from 21 to 51 with diverse strains. In contrary Habineza *et al.* (2016) recorded the number of nodules ranging from 1 to 3 when the seeds were not inoculated and inoculated respectively with *Bradyrhyzobium japonicum*. TGX1990-5F recorded the highest number of nodules with 46.8 in sole crop as in intercropping compared to SB19 with the smallest number of nodules of 33 at Mwea in intercropping too. TGX1990-5F showed the highest number of nodules of 43.7 in sole crop while SB19 recorded the smallest number of nodules for 29.8 at Embu in sole crop too. Intercropping did not reduce the number of nodules per plant both sites and both seasons. Mwea had the highest number of nodules compared to Embu which produced lowest number of nodules in both seasons. This could be because of good soil conditions previously at Mwea compared to Embu. Mwea received regularly water from irrigation to supplement of rain fall and this condition could promote good development of microorganisms which could permit good nodulation at Mwea than Embu. This agrees with Mosanto (2014) who said that, the first step in nodulation is the presence of soil rhizobia bacteria and the good penetration of the bacteria into the root hair of soybean seedling and the formation of an infection thread while the following conditions (fields with poor soil rhizobia bacteria populations or fields with previous forage legume , low quality inoculants due to inappropriate storage and conditions, dry conditions, excessive moisture or flooding for several days, soil pH below 6.0 and above 8.0) are most likely to cause the failure of nodulation and reduce N fixation. The high production number of nodules for TGX1990 – 5F can justify the high biomass production because of the high biological nitrogen fixation (Fujita, 1992) and (Sloger, 1969). GAZELLE produced the lowest amount of nodules per plant in intercropping. This was due to the low amount of biomass produced by that variety in intercropping in both seasons and both seasons. On the contrary, Issahaku (2010) reported that, intercropping maize-soybean reduced the soybean nodulation. Exotics varieties (SB19 and TGX1990-5F) recorded highest number of nodules than the local variety (GAZELLE). This could be due to their genetic makeup.

Soil Nitrogen

Soil N showed significant differences between sites and seasons after harvesting (AH) ($p \leq 0.05$). However, in the second season, soil N increased only at Embu and decreased at Mwea. This could be justified by the adaption of the varieties used which could fix more nodules, hence, nitrogen fixation at Embu compared to Mwea. This agrees with Garg *et al.* (2004) who reported that, legumes in good conditions must use a lot of amount of carbohydrate to produce more nodules, hence, nitrogen fixation. TGX1990-5F showed the highest amount of soil N of 36% AH compared to 0.28% recorded BP and SB19 gave the lowest soil N of 0.23% AH less than 0.29% obtained BP in intercrop at Embu in long rain. However, during the short rain, TGX1990-5F showed higher soil N of 0.32% AH compared to 0.26% BP while GAZELLE had the lowest amount of soil N of 0.13% AH less than 0.22 % for the same variety found BP in intercrop at Mwea. Only TGX1990-5F achieved the high amount of N (0.58%) while other varieties produced moderate soil N depeding to the scale for Landon (1991). Differences in amounts of N fixed could be due to varietal differences. From this results, Stagnari *et al.* (2017), reported that, most recent research has focalized on potential of intercropping in sustainable productions and in particular on grain legumes that can fix N_2 through biological mechanisms (BNF). In addition, Ndusha (2011) said that, SB24 and SB19 produced no significant differences in shoots weight, but this adviced that as both of them are promiscuous, they nodulated freely with different isolates as the nodulation reflet soil nitrogen fixation.

Soil Phosphorus

Soil phosphorus (P) after harvesting (AH) showed significant difference between sites and seasons ($p \leq 0.05$). The P decreased at Embu AH compared to the results obtained BP both seasons while Mwea P (AH) increased both seasons. However, some soybean varieties increased amount of phosphorus in the soil for both sites and both rainy seasons in intercropping compared to sole crop, but some others varieties did not. This might be due to some nutrients in the soil which could play the role of complexation, and some time produced by maize or soybean cultuvated, hence reduction of soil P at Embu than Mwea. In contrary, at Mwea the increae of P in both rainy seasons can be explained by the varieties (soybean and maize) makeup to produce some nutrients which could play the role for solubilisation of insolubale P, hence, high phosphorus production. This agrees with the results found by Phiri *et al.* (2013) who reported that, some legumes have the capacity to enhance the availability and efficient utilisation of residual phosphorus which is otherwise not available to cereals.

TGX1990-5F showed higher P of 23 ppm AH compared to 21.08 ppm BP while SB19 produced the lowest P of 12 ppm AH compared to 21 ppm BP in sole crop in the long rain at Embu. GAZELLE recorded the highest amount of P (128.68 ppm) AH higher than 4.5 ppm BP while SB19 was the last recording (64.82 ppm) AH compared to 4.6 ppm obtained BP at Mwea in intercrops. The differences in P fixed could be due to differences in varieties for P utilization. Bandyopadhyay *et al.* (2007), found that, legume is a natural small-nitrogen manufacturing factory in the field and farmers by growing these crops can have an important role in increasing indigenous nitrogen production. Legumes help in solubilizing insoluble phosphorus in soil, enhancing the soil physical area, improving soil microbial activity and restoring organic matter. In addition, the results found at Embu agree with Matusso (2014), who reported that, at Embu site, the available phosphorus values did not show any significant differences among treatments. However, phosphorus decreased from the long rains to short rains. That may be caused by the drougth which was pronounced in the short rain than the long rain.

Soil Potassium

Soil potassium showed significant difference in the short rains after harvesting (AH) ($p \leq 0.05$) between sites. However, K decreased in the sites AH compared to the value obtained BP in the long rains and short rains except Mwea in the short rains where it increased. This increase of K for Mwea could be explained by the availability of the water for irrigation at Mwea compared to Embu. The decrease of K for Embu could be explained by the insufficient of water for irrigation some time which could allow the compaction of the soil due to the drought, hence, soil defficiency in K could occur. This finding agrees with Terry and Ulrich (1973) Murrell (1980); Wolkowski and Lowery (2008) who reported that soil compaction due to machine or other environmental factors could reduce K avaibility in the soil. However Ciećko *et al.* (2004) reported that, the soil defficient in K could caused by the presence of some minerals in the soil like cadminium. SB19 presented the highest amount of K (1.24 Cmol/kg) AH less than 1.47 Cmol/kg obtained BP compared to 1.29 Cmol/kg recorded BP compared to 1 Cmol/kg of K recorded AH for GAZELLE in intercrop at Embu in the the long rains. This agrees with Matusso (2014) who said that, potassium decreased from the long rains to short rains at Embu. The similar situation was observed at kamujine site. At Mwea SB19 showed the highest amount of K (1.57 Cmol/kg) more than 0.36 Cmol/kg BP while GAZELLE was the last with (1.15 Cmol/kg) AH compared to 0.43 Cmol/kg obtained BP in sole crop at Mwea in the short rain. That may be caused by the varieties makeup to fix some nutrients in the soil during the experiment duration.

Organic Carbon

Organic Carbon increased in the soil after harvesting in the long rains seasons at Embu. TGX1990-5F gave higher OC of 3.77% after harvesting compared 2.82% recorded before planting at Embu. This might be due to organic matter decomposed which could increase OC after. SB19 recorded the lowest OC of 2.68 % after harvesting compared to 2.79% obtained before planting in sole crops at Embu in long rain. Mwea site for the long rain did not increase OC AH compared to the results recorded BP.

This could be attributed to high temperature which could speed decomposition, hence, rapid mineralisation and this could result to lower organic matter OC. In the short rain season, at Mwea, TGX1990-5F showed the highest amount of OC of 3.39 % AH more than 2.21 % BP while GAZELLE recorded 2.3 % of OC BP and AH in intercrop. During the short season, OC increased both sites after harvesting (AH). This could be justified by water brought by irrigation both sites which could increase decomposition of organic matter, resulting to high production of OC. Following the key for Landon (1990) on soil nutrients interpretation, Only TGX1990-5F fixed the amounts required for feeding the plants. SB19 and GAZELLE fixed moderate OC for feeding plant. However, intercropping reduced sighltly OC compared sole crop. This could be due to competition among component crops which did not allow high biomass production which could result to high OC production. This was not in agreement with Akinnifesi *et al.* (2007); Sebetha (2015); Nagar *et al.* (2016) who reported that, the soil organic carbon increase in the legume-cereal intercropping, while in monocropping cereal there was a small decrease. Differences in OC could also be depended on varietal genetic make ups.

Matusso *et al.* (2012) oberverd higher soil organic carbon in intercropping than in sole crop. Naresh *et al.* (2014) reported that, sole maize-wheat rotation showed a decline in soil organic carbon by 3.7%, while black gram and cowpea intercropping with corn followed by wheat increased organic carbon.

Soil pH

Soil pH showed significant difference between sites and seasons ($p \leq 0.05$) in intercropping and in sole crop after harvesting (AH). After harvesting in long rain season, the pH increased the acidity at Embu and TGX1990-5F increased acidity (5.18) compared to pH 5.88 less acidic obtained BP while SB19 gave the pH of 4.73 AH more acidic than pH of 5.95 obtained BP in sole crop. The enhancement of the acidity by each variety could be due to its capacity to release some chemicals in the soil for acidification. However, the increasing of soil acidity of pH at Embu could be due to the drought which decreased the soil microorganism activity for decomposition of organic matter which could decrease acidity. In addition, it could be attributed to roots of the varieties cultivated which could produce proton and acidify the soil. This grees with,Ahmad *et al.* (2013) who reported that, some plants species e.g. *Vicia faba* when grown in phosphorus poor conditions, acidifies its rhizosphere with malate and citrate, substantially lowering the pH of the environment.However, at Mwea the pH did not change AH compared to pH BP and it remained acidic (5) in sole crop and in intercrop in long rain. This could be explained by little decomposition of organic matter caused by water from irrigation as suppliment of rain fall allowing soil pH stability at Mwea than Embu in long rain seasons. In the short rains soil pH decreased slightly at Embu AH compared to soil pH BP. SB19 decreased soil pH with 6.11 AH compared to 5 obtained BP. At Mwea all varieties decreased soil pH acidity with pH 6 AH while BP it was more acidic with pH 4 in sole crop as in intercrop in short rains. This might be attributed to good mocroorganism activity in the soil at both sites caused by water from irrigation which could allow good decomposition of organic matter from the crops, hence, soil neutrality. This findings agrees with Bandyopadhyay *et al.* (2007); Nagar *et al.* (2016) who said that, the enhanced organic production in green manure amended soils buffers the soil against pH changes. In addition, Matusso *et al.* (2012); Owusu and Sadick (2016) argued that, increasing soil pH values in intercropping compared to sole crop at kamujine site, means that intercropping lead to decrease soil acidity compared to monocropping, due to higher organic material production. Depending to Lando (1991), all varieties released moderate pH which could alow good growth of nex plant.

Conclusion

The study on intercropping maize-soybean on soil fertility showed that , TGX1990-5F had higher nodules per plant and fixed higher N and increase in other nutrients (OC, K and P), TGX1990-5F was in the middle both sites and in both rainy seasons compared to other varieties after harvesting. The pH released in the soil after harvesting was moderate to support next plants.

In some cases, the variety which produced the higher number of nodules, fixed higher N after harvesting. For example TGX1990-5F produced higher amount of nodules and and it coincided with high fixation of N after harvesting. This was not the case for SB19 and GAZELLE. Hence, TGX1990-5F can be recommended to smallcale farmers for intercropping with maize because it can reduce the cost for N fertilizer fixing N biologicaly freely.

Acknowledgements

This publication was made possible through support provided by Alliance for a Green Revolution in Africa (AGRA) Grant No. 2015 PASS 011. The opinions expressed here in are those of the author(s) and do not necessarily reflect the views of AGRA

References

Ahmad I, Cheng Z, Meng H, Liu T, Wang M, Ejaz M, Wasila H. 2013. Effect of pepper-garlic intercropping system on soil microbial and bio-chemical properties, Pakistan Journal of Botanic **45(2)**, 695-702.

Akinnifesi FK, Makumba W, Sileshi G, Ajayi OC, Mweta D. 2007. Synergistic effect of inorganic N and P fertilizers and organic inputs from Gliricidia sepium on productivity of intercropped maize in Southern Malawi. Plant and Soil **294(1–2)**, 203–217.

Ali A, Ijoyah MO, Usman M. 2015. Intercropped Maize and Soybean under Tillage Practices and Fertilizer Rates in Makurdi , Southern Guinea Savanna Zone of Nigeria, Novelty journals **2(2)**, 12-22.

Bandyopadhyay, Monoranjan Mohanty, Madhab Manna ASR. 2007. Legume Effect for Enhancing Productivity and Nutrient Use-Efficiency in Major Cropping Systems – An Indian Perspective : A. Legume Effect for Enhancing Productivity and Nutrient Use-Efficiency in Major Cropping Systems – An Indian Perspective : A Revie. Journal of Sustanaible Agriculture **30(1),** 59-86.

Black A, Walkley A. 1934. An examination of the digestion method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil science, Rothomsted Experimental Station **(1),** 1-10.

Ciećko Z, Kalembasa S, Wyszkowski M, Rolka E. 2004. Effect of Soil Contamination by Cadmium on Potassium Uptake by Plants, Polish Journal of Environmental Studies **13(3)**, 333–337.

County E. 2014. Office of the Controller of Budget , Embu County, Budget Implementation Review report first quarter FY 2013-2014, Kenya, 1-11.

County K. 2014. Kirinyaga county transition implementation plan, Office of the Governor, Kirinyaga county, KUTUS, Kenya, P.O. Box 260-10034, 1-64.

Fujita K. 1992. Biological nitrogen fixation in mixed legume- cereal cropping systems, Plant and Soil **(141),** 1-32.

Garg N, IRS. 2004. Nitrogen fixation and carbon metabolism in legume nodules, International Journal of Experimental Biology **42**, 138–142.

Habineza M, Alice C, Gakuru S, Dushimimana C. 2016. Effet de l'innoculation au rhizobium et de la fertilisation au triple superphosphate sur le comportement de s varietés du soja, Annales de l'UNIGOM , Goma, DRC **2(6),** 99–110.

Issahaku AR. 2010. Spatial arrangements and time of introduction an intercrop on the productivity of component crops in Maize- soybean intercropping systems, Master of Science in Agronomy Thesis, Kwame Nkrumah University of Science and Technology , Ghana, Accra 1-116.

Joëlle F, Fabien L, Stéphanie M, Jean-bernard C. 2010. Nitrogen rhizodeposition of legumes, Agronomy Sustainable Developpment **30,** 57–66.

Fujita K, GOB, SO. 1992. Biological nitrogen fixation in mixed legume-cereal cropping systems, International Rice Research Institute Manila **141**, 81-202.

Li X, Mu Y, Cheng Y. 2012. Effects of intercropping sugarcane and soybean on growth , rhizosphere soil microbes, nitrogen and phosphorus availability, Polish Academy of Science **10,** 1-7.

Lithourgidis AS, Dordas CA, Damalas CA, Vlachostergios DN. 2011. Annual intercrops: An alternative pathway for sustainable agriculture. Australian Journal of Crop Science **5(4)**, 396–410.

Madimba, Makela MP. 1994. Nodulation et redement du soja Glycine max L. MERRILL inoculé par Bradyrhizobium japonicum dans differents systèmes de culture à Kombé-Brazzaville, congo, Journal tropicultura **5,** 6-10.

Matusso JM, Mugwe J, Macheru-Muna M. 2012. Potential role of cereal-legume intercropping systems in integrated soil fertility management in smallholder farming systems of sub-Saharan Africa,Research Application Summary **00100,** 1815–1843.

Matusso JMM. 2014. Effects of Maize - Soybean intercropping patterns on yields and soil properrties in two contrasting sites Embu and Meru counties, kenya, Master of Science in integrated Soil Fertility Management Thesis, Kenyatta University, Nairobi, Kenya 1-123.

Mosanto. 2014. Soybean Nodulation : Process and Failure How Nodules Are Formed ? Soybean Nodulation : Process and Failure When Inoculants Are Needed Technology Development and Agronomy **1,** 5-6.

Murrell TS, Plant I. 1980. Why are Soil Test Potassium Levels so Variable over Time in the Corn Belt 2 . Time of Year 3 . Nutrient Uptake and Removal by Crops **2,** 1–17.

Nagar RK, Goud VV, Kumar R, Kumar R. 2016. Effect of organic manures and crop residue management on physical , chemical and biological properties of soil under pigeonpea based intercropping system **6(1)**, 101–113.

Naresh RK, Tomar SS, Shahi UP, Singh SP, Singh B. 2014. Sustainability of maize-wheat cropping system by different legume intercropping and nitrogen level treatments on light distribution, soil temperature and crop productivity **8**, 204–213.

Ndusha B. 2011. Effectivess of rhizobia strains isolated from South Kivu soils on growth of Soybeans. University of Nairobi, Department of Land Resource Management, Nairobi, Kenya, Msc. Thesis 1-111.

Owusu A, Sadick A. 2016. Assessment of Soil Nutrients under Maize Intercropping System Involving Soybean, International Research Journal of Agriculture and Food Sciences **1(3)**, 33-43.

Phiri AT, Njoloma JP, Kanyama-phiri GY, Lowole MW. 2013. Effects of intercropping systems and the application of Tundulu Rock phosphate on groundnut grain yield in Central Malawi, International Journal of Plant and Animal Sciences **1(1)**, 11–20.

Regehr A. 2014. Evaluation of maize and soybean intercropping on soil quality and nitrogen transformations in the Argentine Pampa,Master of Science in Environmental Studies Thesis, University of Waterloo, Antario, Canada 1-103.

Roy R, Finck A, Blair G, Tandon H. 2006. Nutrient management guidelines for some major field crops. Plant Nutrition for Food Security **8,** 235- 349.

Roberts S, Vodraska RV, Kauffman MD, EHG. 1971. Methods of Soil, Analysis Used in â€™ the Soil Testing Laboratory at Oregon State University, Agricultural Experiment Station Oregon State University Corvallis **55(321),** 1-41.

Sebetha E. 2015. The effect of maize- legume cropping system and nitrogen fertilisation on yield, soil organic carbon and moisture, Doctor of Philosophy in crop Science Thesis, University of Kwa Zulu-Natal, Scottsville, South Africa 1-271.

Sloger C. 1969. Symbiotic Effectiveness and N2 Fixation in Nodulated Soybean **577**, 1666–1668.

Stagnari F, Maggio A, Galieni A, Pisante M. 2017. Multiple benefits of legumes for agriculture sustainability. Chemical and Biological Technologies in Agriculture **4(2),** 1–13.

Terry N, Ulrich A. 1973. Effects of Potassium Deficiency on the Photosynthesis and Respiration of Leaves of Sugar Beet, Plant Pysiology **1(51),** 783-786.

Van Reeuwijk L. 2002. Procedure for Soil Analysis. 6th Edition. International Soil Reference Center Wageningen. The Netherlands.: (ISRIC) Technical Paper **9,** 1-120.

Wang ZG, Jin X, Bao XG, Li XF, Zhao JH, Sun JH, Li L. 2014. Intercropping enhances productivity and maintains the most soil fertility properties relative to sole cropping, journal pone **9(12),** 1–24.

Wolkowski R, Lowery B. 2008. Soil compaction : Causes, concerns, and cures. Produced by Cooperative Extension Publishing of Wisconsin-Extension, University of Wisconsin-Extension, Madison, Rm. 231, WI 53706, **(432),** 1-8.

Zhang Y, Liu J, Zhang J, Liu H, Liu S, Zhai L, Yin C. 2015. Row ratios of intercropping maize and soybean can affect agronomic efficiency of the system and subsequent wheat. ournal. pone **10(6)**, 1–16.