EVALUATION OF PROMISCUOUS SOYBEAN VARIETIES FOR AGRONOMIC AND GRAIN QUALITY TRAITS IN MAIZE/SOYBEAN INTERCROPPING SYSTEMS IN KENYA

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DECLARATION

This thesis is my original work has not been published earlier in any other higher institution.

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DEDICATION

To my lovely wife Asifiwe Ntasi Brigitte, my children Atukuzwe Mpunga Ornella, Uwase Mpunga Odile and my parents Mpunga Damien and Esperance Mukabutera.

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LIST OF ABREVIATION AND ACRONYMS

ANOVA	Analysis os Variance
AH	After Harvesting
BIOM	Biomass
BP	Before Planting
Cm	Centimeter
Cmol	Centimoler
CV	Coefficient of Variation
D50PF	Days to 50 Percent to Flowering
D75PM	Days to 75 Percent to Maturity
df	degree of freedom
GRM	Germination
HI	Harvest Index
100GW	Hundred Grain Weight
K	Potassium
Kg	Kilogram
LER	Land Equivalent Ratio
LSD	Least Significant diference
mm	millimeter
MLN	Maize Leaf Necrotic
N	Nitrogen
NODP	Nodulation per Plant
NUPOP	Number of Pods per Plant
OC	Organic Carbon
P	Phosphorus

pH	potential of Hydrogen
PHt	Plant Height
ppm	part per million
RCBD	Rendomize Complete Block Design
RH	Relative Humidity
SEEDP	Seeds per Pod
SHAT	Shattering
T HA	Tone per Hectar
YTHA	Yield in Tone per Hectar

ABSTRACT

Soybeans which nodulate effectively with diverse indigenous rhizobia are considered as promiscuous. As such, determination of their suitability in the intercrop system is important. Three varieties namely ; GAZELLE, SB19 and TGX1990 – 5F were used in this study to identify the most suitable promiscuous variety for intercropping with maize at KALRO Embu and KALRO Mwea, Kenya in the long rains of 2016 and short rains of 2016-2017. In addition, the varieties were used to determine the effects of intercropping maize-soybean on soil fertility and grain quality traits. The experimental design was laid out in randomised complete block design replicated three times with seven treatments where T1= SB19, T2 = GAZELLE, T3 = TGX1990 – 5F, T4 = SB19 + MAIZE, T5 = GAZELLE + MAIZE, T6 = TGX1990-5F + MAIZE, T7 = MAIZE (Duma 43). The spacing used was 80cm between rows of maize and 25cm within rows. Soybean was planted between 2 rows of maize at a spacing of 15cm within rows. The arrangement of intercropping was 1:1 which means, one row of maize intercepted with one row of soybean. Data collection was done on germination %, plant height (cm), days to 50% flowering, days to 75% maturity, yield biomass per plant, 100 grain weight, grain yield, harvest index and Land Equivalent Ratio for both crops. In addition, number of nodules per plant, shattering score (1-5), number of pods per plant, number of seeds per pod were collected for soybean only. Data were subjected to ANOVA and means separated using $LSD_{0.05}$. The results showed that growth and production parameters were significantly different ($p \leq 0.05$). The sole crops showed the highest plant height (PHt) compared to the intercropping indicating that intercropping reduced soybean plant height in both rainy seasons. Mwea recorded taller plants compared to Embu in both rainy seasons. TGX1990-5F showed taller PHt followed by SB19 while GAZELLE recorded the lowest PHt in both sites in both rainy seasons. The early variety to 50 % flowering and 75 % maturity was SB19 followed by GAZELLE and the late flowering and maturing variety was TGX1990-5F. Intercropping did not affect days to 50 % flowering and days to 75% maturity. Variety TGX1990-5F was resistant to pod shattering while SB19 and GAZELLE were moderately resistant. Intercropping did not affect pod shattering score. The number of nodules differed with varieties ($p \leq 0.05$) with TGX1990-5F recording the highest number of nodules of 43.7 followed by GAZELLE with 32.33 and SB19 with 29.80 in sole crop at Embu. In intercrop, TGX1990-5F presented higher number of nodules of 43.40 followed by GAZELLE with 33.67 compared to SB19 with 28.07. Soybean in Mwea presented the highest number of nodules compared to Embu in both seasons. Intercropping had no effect on the number of nodules per plant at both sites and both seasons. Variety TGX1990-5F recorded the highest number of pods followed by SB19 while GAZELLE presented the lowest number of pods in sole crop and in intercropping. Intercropping reduced the number of pods per plant in both seasons. Mwea site presented the highest number of pods compared to Embu in both seasons. The number of seeds per pod was not reduced by intercropping and they ranged from (1-3) for all varieties. TGX1990-5F produced higher biomass followed by SB19 while GAZELLE recorded the lowest biomass at both sites and rain seasons. Intercropping reduced soybean yield biomass at both sites and both rain seasons. Mwea produced higher biomass compared to Embu for both seasons. TGX1990-5F recorded the

highest yields between sites during the long rains (1.07 t ha^{-1}) and short rains (0.62 t ha^{-1}) compared to SB19 with lower yields between sites (0.95 t ha^{-1} and 0.23 t ha^{-1}) during long rains and short rains respectively. There were significant differences in the intercropping systems in both sites and seasons, the variety TGX1990-5F indicating its suitability in the intercrops with maize. GAZELLE showed higher HI followed by SB19 while TGX190-5F recorded the lowest HI for both sites and seasons. Intercropping reduced HI in both sites and seasons. TGX1990-5F showed higher LER (1.7) compared to (1.51) for GAZELLE between sites in the long rains while in short season LER was 1.83 for TGX1990-5F compared to 1.19 for SB19 two sites. LER showed advantage between component crops in both sites and seasons. Finally TGX1990-5F was taken as suitable promisuous soybean variety for intercropping with maize. On the effects of intercropping maize-soybean on soil fertility and grain quality traits; results showed that, TGX1990-5F had significant difference ($p \leq 0.05$) fixing high amount of 0. 39 % N compared to 0.29 % for SB19 in sole crop respectively between sites for the first season after harvesting. Variety TGX1990-5F showed significant difference ($p \leq 0.05$) for 0.30 % N compared to 0.15 % of N for GAZELLE in intercrops between sites for the second season after harvesting. Depending on the requirement of the plants nutrients, TGX1990-5F fixed N which was moderate for feeding plant. However, for Organic Carbon (OC), Potassium (K) and phosphorus (P), TGX1990-5F occupied the second position at both sites and in both rain seasons compared to other varieties. TGX1990-5F variety presented high amount of protein content in sole crop and in intercropping of 42.96 % and 38.4 % ($p \leq 0.05$) between sites in the first season compared to GAZELLE with the same amount of protein content of 39 % in sole crops and in intercrops. In addition, TGX1990-5F showed significant difference ($p \leq 0.05$) of 40.84 % compared to 31.98 % GAZELLE in intercropping between sites in the second season. For the oil content, GAZELLE recorded the highest amount of 22 % and 21 % in the first season and second season respectively, in sole crop ($p \leq 0.05$). Variety SB19 recorded the lowest oil content of 13.98 % between sites. Thus, variety TGX1990-5F can be recommended to smallscale farmers for intercropping with maize because it recorded the highest LER and fixed more N , hence reducing the cost for N fertilizers and GAZELLE can be also recomended to farmers who want to produce oil because it produced higher amount of oil content than other varieties and it has big size which could justifty the highest amount of oil content produced.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background

Insufficient crop production is a common issue which many farmers are facing in Africa (Chianu *et al*., 2009). The problem is more pronounced in legume production and combined with soil infertility and reduction of the amount of nitrogen fixed biologically and other ecosystems parameters. Previous studies indicate that, in the beginning of agriculture leguminous plants were important for the human consumption and many leguminous plants provide unique proteins for human beings. The protein content in leguminous plants is a supplement to grain crops forming good mixture for balanced nutrient supply, especially in developing nations (Burstin *et al.*, 2011). Among those legumes, soybean (*Glycina max*) is known for its supply of high quality protein (40%) which is higher compared to other leguminous crops. Current findings discovered that, although soybean proteins can be low in certain amino acids than animal proteins like those set up in eggs or cow's milk; it provides comparable protein value grade as egg or cow's milk protein (Iván *et al.*, 2011). Thus, with the increase of population of Kenya today, it will be better to find an agronomic system which will help us have sustainable agriculture to increase productivity of soybean. Intercropping system is among the systems which are used by many small scale farmers in Kenya. Cereals and legumes are known to be grown in association by growers. The may be because of the legumes capacity to improve soil fertility and reduce soil erosion (Matusso *et al.*, 2012). Flexibility, growth of income, reduction of threat, soil development fertility and maintenance, are major reasons of intercropping for many farmers (Thyamini *et al*., 2010). Intercropping has the capacity to produce more than mono-cropping, giving higher yield permanency and nutrients use efficiency (Amanullah *et al.*, 2016). In addition, intercropping cereal-legume have good capacity to reduce weeds development, while cereals in sole crop needs more space to produce the same yield as in intercrop (Ijoyah, 2012). Soybean is among main legumes which are more produced in the world. The major countries that produce the crop are led by USA with (46%), followed by Brazil with (20%), Argentina (13.5%) and China (9%); other countries producing soybean include India, Paraguay, Canada and Indonesia. Africa contributes only 1% of soybean production (Masuda and Goldsmith, 2009). The percentage of soybean production held by each Africa's country including Kenya is quite low. Annual demand for soybean in Kenya can surpass 100,000 MT which is among the biggest in the East African area. Soybean production is less than 5,000 MT annually, giving a shortage of more than 95% (Abuli, 2016). This shortage is coved by importation. Nevertheless, two regions in Kenya are contributing to soybean production which are: Kakamega, Siaya, Bungoma, Vihiga, Busia, Trans Nzoia, Homa Bay, Migori, Kisii and Nyamira counties (western area) and Kirinyaga, Embu, Meru and Tharaka Nithi Counties (Central highlands region). Western area is producing more than central region highlands. Kenya imports soybean from Uganda, Malawi, Zambia, Zimbabwe, Argentina , India and recently Brazil (Abuli, 2016). In this case, improving intercropping system of cereals and legumes in Kenya would be necessary in order to help small scale farmers increase their yield per unit area.

1.2 Problem statement and Justification of the study

The millions of small-scale farmers in the world are facing major problems, like insufficient food, soil infertility, drought and incapacity to find chemical fertilisers. Population of Sub-Saharan Africa (SSA) is growing up while agricultural yield is decreasing and small scale farmers cannot access agricultural input easily, because of the high cost of input (Sei, 2014). The status of nutrition of rural households in Kenya is very critical. In 2011, 2.5 million persons undernourished in Kenya were found by Kenya Food Security Steering Group (KFSSG) in which 1.5 million were found in primary school in the dry land regions (Sei, 2014). In 2003 Kenya Demographic and Health Survey demonstrated anthropometric indicators for insufficient food between children with five years as: 20.2% of kids were malnourished, 4% were severely malnourished, 33% of male and 28% of female kids were underdeveloped, and 6.1 % died (Tom, 2013). During 2007, almost 56% of Kenyans could not acess food to accomplish 2250 kilocalories for mature people per day (Tom, 2013). The Food Insecurity Multidimensional Index (FIMI) can be synthesized in four dimensions of food security, availability, access, utilization and stability of food (Marion, 2011). It is well known that malnutrition leads to learning impairments, stunted growth, and low adult productivity in the long term, and causes low immunity leading to high child mortality rate. In order to overcome the impasse, the persistence of protracted food security crises must be addressed. That is why Government of Kenya enhances activities which are aiming to improve agricultural productivity by raising new technologies in different sectors. In addition, the Kenya Government cares about cereals stocks and other food prices maintenance in the market in order to give access to food by poor people. Even if these approaches were used to reduce food insecurity, food insecurity is still visible notably in periods affected by long drought and floods. However, the service which is controlling food insecurity has not assured people the obtainability (Romano, 2009). Furthermore, a big proportion of the population of undernourished people in Kenya are in dry land, semi-arid areas and constitute a big area of the country (USAID, 2013). In Kenya, agriculture provides livelihoods for the vast majority of the poor populations. Farming systems and livelihood activities in central Kenya are relatively similar, with some small variations in terms of crop preference (FAO, 2001). Among those crops, soybean could be encouraged because of its financial, dietary and useful importance securities because of care in Kenya where more of 30% of children are undernourished, joblessness rate is over 40% and small utilisation of fertiliser (Abuli, 2016). Considering the economic importance of soybean grain in nutritional side, and maize as major cereal plant, small scale farmers choose to growth those crops together than separate in many countries (Muoneke *et al.,* 2007). Soybean have higher nutritional value where, it possess 20 % oil, 40 % high protein, as compared to 7 % rice, 10 % maize ,12 % wheat, 20 to 25 % other pulses (Raji, 2007). Its protein is rich in the valuable amino acid lysine (5 %) in which more cereals are deficient. It also have a high quantity of minerals, salts, and vitamins (Matusso *et al.*, 2012) . Soybean can fix N 6 times greater than common bean (ONE ACRE FUND, 2015). The soybean is variable, in terms of its both usage and agronomical attributes. Soybean can be grown in different enviroments, transformable to many products e.g. tofu, soy beverages, soymilk soy seasonings and soy meal and can be used as input in the production of bread, cakes and breakfast cereals. In its accomplish value chain, soybean can form a high industrial base for such a developing country as Kenya and generally in Sub Sahara Africa (SSA) where the malnutrition is a big issue with the need of the urgent solution (Abuli, 2016). However, its low production is incapable of satisfying the needs of the increasing population. Hence, increasing soybean yields is one of the strategies to fight food insecurity in Kenya. That assumption can be achieved correctly after finding solutions to many research's gaps of soybean which are composed of breeding for biotic constraints (diseases and pests), a biotic stresses (drought, water logging), quality improvement (high oil and protein content), as well as other agronomic traits such as keeping green grains and reduced pod shattering (Puji *et al.*, 2014). As such, this study aims to improve soybeans cropping systems in particular intercropping systems. Planting two or more crops in the same season in the field is known as intercropping which is a sustainable agricultural technic and it uses nutrients better than monocrop (Matusso *et al.,* 2012). However, this technique has been demonstrated as system which can be highly effective compared to monocrop, also improving the ecosystem (Remison, 1978). Intercropping maize-soybean is taken as a good substitute for supplying nitrogen and raising maize production and increases productivity per unit area and time. In addition, traditional growers appear to have purposely scheduled their planting system with the aim of maintaining the soil fertility, because intercropping gives a persistent and effective agro ecosystem. Some studies reported that, the choice of plant association is the major point for effective intercropping (Ijoyah and Jimba, 2012). Non compatibility aspects like planting density, root system and nutrient need to be considered (Ijoyah and Jimba, 2012). Small scale famers prefer intercropping mixing many crops together without worrying about the species, but considering compatible plants is a major point in intercropping in terms of growth pattern, land, light, water use efficiency and fertilizer usage (Thyamini *et al*., 2010). Intercropping is playing vital role in subsistence food supply in advanced and developing nations (Belel *et al.,* 2014). Leguminous crops are able to fixe N and that N fixed in intercropping is an important resource for the cereals in growing time (Bhagat *et al.,* 2006). This led to development of promiscuous soybeans varieties that fix N without Rhizobia. However, there are no studies that have been done to assess the suitability of these varieties in the intercrop system. In addition, the effect of intercropping maize and promiscuous soybean varieties on several agronomic and seed quality traits is not well understood. There is need, therefore, to evaluate promiscuous soybean varieties for agronomic and seed quality traits in maize/soybean intercropping systems.

1.3 Objectives

1.3.1 Broad objective

The broad objective was to increase productivity of maize and soybean through intercropping system using promiscuous soybean varieties.

1.3.2 Specific objectives

The specific objectives are to:

1. Determine the most suitable promiscuous soybean variety for intercropping with maize.
2. Determine the effect of intercropping maize - soybean on soil fertility and grain quality traits.

1.3.3 Hypothesis

1. One of promiscuous soybean varieties chosen is more suitable for intercropping with maize than others.
2. Intercropping of maize and soybeans affects soil fertility and grain quality traits.

CHAPTER TWO

2.0 LITTERATURE REVIEW

2.1 Production of soybean in Sub-Saharan Africa (SSA) and in Kenya

Soybean is among the major legumes planted in Sub-Saharan Africa (SSA) because of its good nutritional value. It prefers sandy and heavy textured soils with pH ranging between 5.5 – 8.5. Soybean yield in rain fed ranged between 1.5 to 2.5 t /ha in monoculture, and the low average production is between 0.15 to 1.6 t/ ha in many countries in Africa, while Brazil, production can reach upto 4 t /ha (Nekesa *et al.,* 2011). Abuli (2016) also reported that the annual demand for soybean in Kenya can surpass 100,000 MT which is among the highest in the East African area. Yet, soybean production does not reach 5,000 MT annually, giving a shortage of more than 95%. This shortage is coved by importation. Compared to the production in Brazil, that production is very low and needs to be raised to achieve production which can meet the demand.

2.2 General overview on intercropping system

Cropping system involves plants and plant-arrangements and the organization method utilised on a specific farm during a given period. That word isn't novel. It has been utilized more frequently in recent years, debating about sustainable agriculture. Growing two or more crops (i.e. intercrop or association) is necessary in agriculture in terms of better usage of resources, increasing yields, productivity and raising soil fertility than sole cropping (Li *et al.,* 2013). Intercropping system comprises four technics which are: Mixed arrangement, where plants are grown simultaneously in association; row arrangement, where plants component are grown simultaneously in diverse rows; strip arrangement, where plants are grown simultaneously in diverse strips; and relay arrangement , where plant are grown in relay so that growth cycles overlap (Li *et al*., 2013). Productivity and profitability are among the reason which allow preference of cereal- legume cropping system used to day by many farmers in order to achieve food and nutritional security and sustainability. Yield benefit, high use efficiency of light and water, and pest and disease reduction are major causes of intercropping preference. Legumes-cereals are intercropped aiming that, cereals will profit from the N fixed by legumes (Mohammed *et al.,* 2008). Plant legumes are also important in increasing production, as well as N and P nourishment of cereals. In intercropping, the level of reserve of nutrient, total yield and yield between intra and interspecific can be influenced by competition or the presence of ecosystem resources (Nwaogu and Muogbo, 2015). In addition, a lot of mechanisms explain how intercropping use water, light, nutrients proficiently than mono-cropping (Andersen, 2005). That situation can happen when the component crops are not competing for the same nutrients (Trenbath, 1993).

2.3 Intercropping system profits

Intercropping system is known by many scientists as valuable to farmers in the for small-input/high-risk environment of the tropics. Intercropping legumes-cereals is suitable small-scale farmers because of the capacity of cereals to reduce soil erosion and increasing of soil fertility by legumes. Flexibility, profit maximisation, risk minimization are also causes of intercropping preference by small-scale farmers in addition increasing soil fertility, ecosystem conservation, weeds control and stable nutrition (Dwivedi *et al*., 2015). Cereals require the same space in sole crop as in intercrop to produce the same yield(Ijoyah, 2012).That is why intercropping is better for maximization of the land for production in this time where population is increasing exponentially while production is increasing arithmetically (Ijoyah, 2012). However, good intercropping achieve on best benefits due to positive interaction between the component crops (Lithourgidis *et al.,* 2011).

2.4 Weed control

Most scientists believe that, traditional intercrop systems are better in weeds control, than sole crop (Willey *et al.*,1983), but also that can depend on weed growth and its competition habits and the behaviour of crop components during intercropping (Willey *et al.*,1983). It has been reported that cereals and cowpea intercrop decreased striga propagation on the high level (Khan *et al*., 2002). Mashingaidze (2004) also reported that maize-bean intercrop decrease weed biomass by 50-66 % when the bean density is 222,000 plants ha^{-1} equivalent to 33 % of the maize density (37,000 plants ha^{-1}).

2.5 Pest and diseases control

In terms of pests and diseases, the most recognized effect is that, one crop can offer protection to the spread of a pest or disease of the other crop (Willy *et al.*,1983). Sekamatte *et al.*, (2003) also reported that termite which attack common bean can be controlled by soybean and groundnut intercropping. In addition, maize stalk borer infestation was higher in sole (70 %) than in the intercrop of maize/soybean (Martin, 1990).

2.6 Soil erosion control

Plant cover in intercropping plays an important role in stopping energy from rain fall and prevent runoff which could cause soil erosion. Its known that, cereals have the capacity to stop erosion and legumes can fertilize soil by fixing biological N and together they play complemententary role (Thyamini, 2010). Kariaga (2004) showed that in maize-cowpea cropping system, cowpea acts as a good cover and decreases run off than maize-bean system. Rana and Rana (2011) found that taller crops act as wind barrier for short crops, in intercrops of taller cereals with short legume crops. However, sorghum-cowpea cropping system decreases erosion by 20-30 % than sorghum mono crop by 45-55 % compared to cowpea monocrop.

2.7 Biological Nitrogen Fixation (BNF) in cereal-legume intercropping system

BNF, which allows legumes to rely on atmospheric nitrogen (N), is better especially where fertilizer N is insufficient (Fujita *et al.,* 1992). That situation is more pronounced in Sub Saharan Africa (SSA) where annual N reduction was taken at all levels at rates of 22 kg ha^{-1}

(Smaling *et al.,* 1997) and mineral-N fertilizer is sometimes not accessible to growers (Jama *et al.,* 2000). Under different environment and soil situations, BNF for legumes contributes to N for growth and grain yield production for component crops. However, after disintegration of legume residues, the soil can restock N which can be used later by cereals. Legumes which can produce grain and green manure have a potential to fix 100 to 300 kg N ha^{-1} from atmosphere (Table 2.1). Studies which quantify legumes which fix N are insufficient. However, the one available demonstrated technical problems in that situation (Jama *et al.,* 2000). For instance Fujita *et al.,* (1992) found that, 30-60 kg N ha^{-1} $year^{-1}$ are fixed by legumes in the soil.

Table 2.1: A summary of N2 fixation potential from different categories of tropical legumes

Legume system	% N derived from fixation	Amount fixed (kg N ha^{-1})	Time (days)
Grain	60-100	105-206	60-120
Green manure	50-90	110-280	45-200
Trees	56-89	162-1,063	180-820

Source: Fujita *et al.,* 1992

Osunde *et al.,* (2004) has shown that, 40 % of N can be fixed by legumes biologically without nitrogen fertilizer in intercropping system of soybean with cereals and 30 % in the monocrop. Sanginga *et al.,* (1996) found that Mucuna amassed in 12 weeks about 160 kg N ha^{-1} when intercropped with maize. Eaglesham, *et al.,* (1981) recorded that cowpea fixed about 41 kg N ha^{-1}, in intercropping with maize. According to Ofori and stern, (1987) the quantity of N fixed by legume in cereal- legume intercrop, depends on numerous factors, like plant species , plant morphology, density of crops component , technics aspect, and growth habit of the component crops. Fujita *et al.,* (1992) found that, zero use of N-fertilizer and shading didn't affect N2-fixation by the component groundnut crop. However, when 50 kg N ha^{-1} was used, BNF was reduced to 55 %. This means that, heavy use of combined N reduces BNF, which was verified by Ofori and stern (1987) who assessed the N economy of a maize-cowpea in intercrop. Furthermore, according to Fujita *et al.,* (1992) plant population contributes to amount of N resulting from dinitrogen fixation. Even if the annual potential fixation rates of N can be 300 kg N ha^{-1}, the quantity measured on field of the small-scale farmers is still very little (6 kg N ha^{-1} to 80 kgN ha^{-1}), excluding soybean whose range of fixation comprises 100 and 260 kg N ha^{-1} in a period which cannot exceed three months (Li *et al.*, 2004). In addition, some scientists have shown that grains obtained from the component plants are the main contributors of N loss from the intercropping system and can range from 50 to 150 kg N ha^{-1}. Denitrification, leaching and volatilization are the mechanism in which nitrogen can be lost or the material harvested, especially in the grains (Stern, 1993). Osunde *et al.,* (2003) reported that, BNF by promiscuous varieties of soybeans in cereal-legume intercropping offers a potential for reducing the speculation made by scale farmers on nitrogen fertilizers.

2.8 Transfer of nitrogen in cereal intercropped with legume

Previous studies have reported that intercropping non-legumes and legumes supply nitrogen to non-legumes through nitrogen from legumes (Fujita *et al.,* 1992). Eaglesham, *et al.,* (1981), reported that in SSA nitrogen fixed by the leguminous plants component in current growing season are available to the associated cereal. Eaglesham, *et al.,* (1981) revealed that during association of maize and cowpea, maize crops had used 24.9 % of fixed nitrogen by cowpea. Fujita *et al.,* (1992), reported that, the benefits of associating crops with legumes could be affected by crop densities and legume growth stages. Nitrogen is found by succeeding crops due to nodule senescence, root and fallen leaves (Giller and Mapfumo, 2006).

2.9 Residual effects of cereal-legume cropping system

Legumes in intercropping accumulate N in the soil and that N can be available for feeding the next plant which can be in rotation, sole crop or in intercropping during next season (Ofori and Stern, 1987). However, Yusuf *et al.* (2009) reported maize productivity was 46%

greater when grown after soybean than when grown after other maize. Wortmann et al., (1994) found that Tephrosia (Tephrosia vogelii), velvet bean (Mucuna pruriens), sunhemp (Crotalaria juncea), organic matter increased maize production from 3-6 T ha^{-1} without mineral N fertilizer. In addition, Whitbread and Pengelly, (2004) reported that production of maize was improved by 25 % and 88 % after intercropping of mucuna-maize and cowpea-maize respectively. Phiri *et al*., (1999) reported that maize production was enhanced 24.4 % after Sesbania sesban -maize cropping system. Kureh *et al*., (2006) obtained that, production of maize was 28% greater one year after soybean application and 21% greater one year after cowpea application than successive maize planting. However, they found also that, maize production was 85% greater two years after soybean and 62% greater two years after cowpea than planting maize successively. Nevertheless, Recous *et al.*, (2008) reported maize improved productivity of 34.0% after 4 successive intercropping of maize and gliricidia than sole maize. Franzluebbers *et al.*, (2016) found that 30% efficient productivity of millet was increased in millet-cowpea cropping system than sole millet planting. Akinnifesi et al., (2007) reported that maximizing the input of legume N to the next plant, is essential to exploit total quantity of N in legume plant, the amount of N given from N_2 fixation, the quantity of legume N mineralized and the effectiveness of use of this mineral N. Nevertheless, it is not always easy to improve these aspects. However, recent studies on nodulation of promiscuous soybean varieties and non promiscuous soybean showed that, non-promiscuous soybean varieties produced high amount of nodules after inoculation with *Bradyrhizobium japonicum* and fertilizer application than promiscuous soybean varieties non innoculated (Njeru *et al*., 2013; Klogo *et al.*, 2016). This might improve the amount of nitrogen fixation for non promiscuous soybean compared to promuscuous soybean varieties (Njeru *et al*., 2013; Klogo *et al.*, 2016). Thus, selection and breeding for promuscuous varieties which could produce high amount of nodules and enhance biological nitrogen fixation gains in smallholder systems are needed.

2.10 Maturity of the crops

When component crops for intercropping have different growing times for each stage, competition can be reduced because each plant would need nutrients in its specific time which can be different for another component plant, so, fertility in the soil cannot be finished and production advantage can be greater than in the sole crop (Ofori and Stern, 1987). Thus, plants which can present their maturity in different times are very important because they can equilibrate their needs in terms of water, light, and nutrients during their different maturity time and these plants are very useful for intercropping (Seran and Jeyakumaran, 2009). In this case Rana and Rana, (2011) found that green gram matured at 60 days after planting while maize peak sunlight was fitting demand in maize-green gram intercropping.

2.11 Compatible crops

Compatible crops in intercropping are very important because they can easily diminish competition by their arrangement in the field and by exploiting the soil nutrients (Gebru, 2015). Cereals-legumes cropping system is the most used in small scale farmers in SSA because it is compatible and component plants can use N from the soil from different origins (Lithourgidis *et al.*, 2011). Competition for soil water, light and nutrients is greater for cereals than legumes in cereals–legumes intercropping (Thobatsi, 2009).

2.12 Plant density

Planting density for each crop is adapted under its normal rate. However, in the intercrop plant density is adjusted below its full rate density. Furthermore, if full density of each crop could be applied the way it is, any yield could be found because of excess population of plants (Thyamini *et al.*, 2010). Morgado and Willey, (2003) obtained that bean plant population can decrease dry matter yield for maize and bean for each plant separately. Muoneke et al., (2007) also reported that soybean yield decreases by 21 and 23 percent by enhancing maize plant population at 44,440 and 53,330 plants/ha, successively. Another study conducted by Bulson *et al.,* (1997) found that wheat grain and all the biomass can increase nitrogen content when the population of bean is increased in wheat-bean intercropping system; and it increased also the grain protein harvested. Egbe, (2010) reported that increasing density of soybean increases the value of soybean by (0.76 - 1.15) in the intercrop with sorghum, showing greater effectiveness at the biggest population densities than the sorghum component, while the effectiveness ratio of sorghum increased negatively (1.23 - 0.76). Prasad and Brook, (2005) found that increasing maize population can increase maize dry matter but also decreasing quantity of light which could reach the soybean in intercropping. N_2 fixation can be influenced also by plant density. In this case, Kessel and Roskoski, (1988) said that biological nitrogen fixed in cowpea at 30 to 50% depends on the spacing used considering the light interception ability of each legume species.

2.13 Time of planting

Planting time is among the major factors determining the loss or the gain of the yield in intercropping system and it has been highlighted by previous studies. However, Mongi *et al.,* (1976) found that growing cowpea-maize instantaneously provided efficient production. Barbosa *et al.,* (2008) also showed that planting cowpea with maize together increases the yield per unit area, and at the same time cowpea controls bad herbs at certain levels. In addition, Addo-Quaye *et al.* (2011) reported that maize-soybean grown instantaneously or earlier soybean presented greater values of leaf area index (LAI), crop growth rate (CGR) and net assimilation rate (NAR), than to when it was late planted.

2.14 Promiscuous soybeans and its importance

Soybeans which can produce effective nodules with diverse native rhizobia are referred to as promiscuous soybeans (Kueneman *et al.,* 1998). Promiscuous soybean allows smallholder farmers to get seeds which can produce high yield, maintaining cropping system, increasing soil fertility, producing more protein and oil content, while soybean which need artificial inoculant increase input decreasing productivity per unit of area (Mpepereki *et al.*, 2000).

2.15 Nodulation formation

Atmospheric N fixation can be effective if suitable populations of soil N-fixing bacteria (*Bradyrhizobium japonicum* in the genus Rhizobium) are either available in the soil or applied to soybean grains so nodules can form on roots. The first step in nodulation is the good penetration of the bacteria into the root hair of soybean seedling and the formation of an infection thread. Nodules from the root can result from many infection threads or double infection from the single thread. A round 10 to 14 days, the N fixation begin to happen in the nodule. Rhizobium bacteria convert atmospheric N to ammonium (NH_4) which is a form of N available to the crops, and in turn the crops provide carbohydrates to the bacteria to survive. The following conditions are most likely to cause the failure of nodulation and reduce N fixation: 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. Nodules can be viable and available with 8 to 20 nodules at the flowering stage (Mosanto, 2014). Madimba *et al*., (1994) reported that, nodulation can be effective depending on differents strains of Rhizobia and environmental conditions so their study showed that the soybean strain (FN_3) gave 27 to 51 nodules per plant while the soybean strain (IRAT274) gave 19 to 45 nodules per plant. The control gave 3 to 40 nodules per plant.

2.16 Effect of intercropping on productivity and Land Equivalent Ratio (LER)

Enhancing the productivity of the component plant per unit of surface is among the major aims for intercropping system (Sullivan, 2003). On the other hand, utilizing Land Equivalent Ratio (LER) in cereal-legume cropping system, Khan *et al*., (1988) found cooperation among crops and higher yield than monocrop. Muoneke et al., (2007) obtained yield advantage from intercropping productivity of 2-63 % as presented by LER 0f 1.02-1.63 showing effective utilization of land resource in intercropping system than in sole crop. Raji, (2007) found great effective production in intercropping systems of maize-soybean. Addo-Quaye *et al.*, (2011); Dariush, Ahad, and Meysam (2006) reported that LER gave efficient productivity in maize-soybean intercropping than sole crop. They also demonstrated, LER of 1.22 and 1.10 for maize-soybean intercrop in two successive years. Matusso, *et al.*, (2012) reported higher productivity among pearl millet-cowpea cropping system than in their monocrops where LER was 1.2. Dariush *et al*., (2006) found LER alternated from 1.15 to 1.42 showing land use efficacy of maize and great efficiency of climbing bean in intercrop per unit area than sole crop.

2.17 Effect of intercropping on grain quality

Ayu *et al.*, (2004) found that, sorghum gave maximum protein yield intercropped with soybean than sorghum monocrop. In many cereal- legumes intercropping systems, there is emanation of favourable exudates from the component legume to the associated cereal and this is suspected to have effects on the quality of the cereal in terms of protein yield. However, William (2012) reported that varieties with early maturity give poor seed quality especially for those varieties whose maturity are not uniform. Wet conditions, shading by component crops, pressures of some diseases, poor conditions between pysisological maturity and harvest can enhance the decrease of seed quality.

2.18 Disadvantage of intercropping

The roots of crops in association compete for growth factors such as nutrients, light and moisture which may affect the associated crop negatively (Rana and Rana, 2011). Sarkodie and Kahaman (2012) reported that legumes could become pest in an intercropping system by shading the components crop(s) and thereby reducing yield. The main issue of intercropping is that, the component in that cropping system cannot be harvested by machine because the machine cannot separate the crops associated. So, farmers must separate those component crops by hand and arrange it by hand. In addition, some association systems permit harvest at differents dates and that save crop species divided (Rana and Rana, 2011)

CHAPTER THREE

3.0 SELECTION OF THE MOST SUITABLE PROMISCUOUS SOYBEAN VARIETY FOR INTERCROPPING WITH MAIZE

3. 1 Abstract

This study was conducted in two sites (Mwea and Embu) in kenya to determine the suitability of three promiscuous soybean varieties namely; GAZELLE, SB19 and TGX1990 – 5F in intercropping with maize. A randomised complete block design (RCBD) was used and seven treatments namely T1 = SB19, T2 = GAZELLE, T3 = TGX1990 – 5F, T4 = SB19 + MAIZE, T5 = GAZELLE + MAIZE, T6 = TGX1990 - 5F + MAIZE, T7 = MAIZE (Duma 43) were replicated three times. The spacing was 80cm between rows of maize and 25cm within rows. Soybean was planted between 2 rows of maize at a spacing of 15cm within rows. The arrangement of intercropping was 1:1 which means, one row of maize intercepted by one row of soybean. Data collection was done on germination rate, plant height, days to 50 % to flowering, days to 75 % to maturity, biomass per plant, 100 grain weight, grain yield, harvest index for soybean and maize and nodulation per plant, shattering score, number of pods per plant, number of seeds per pod were collected on soybean only. All data were subjected to ANOVA and means separated using $LSD_{0.05}$. The results showed that variety TGX1990 - 5F recorded the highest yields compared to GAZELLE between sites (Embu and Mwea) during the long (1.07) and short rains (0.62) season of 2016. LER was 1.83 for TGX1990-5F and was the highest LER (1.83) in intercropping compared to 1.19 for SB19 between the sites an indication of its suitability compared to other varieties. LER showed advantage between component crops for the first season and the second season though the first season at Mwea the experiment did’nt give maize grain due to MLN desease. Maize biomass was used to assess LER and it showed advantage. In conclusion, variety TGX1990-

5F was the most suitable promusuous soybean for intercropping with maize in small scale farming systems

Key words: *Promiscuous soybeans, intercropping maize and soybeans, LER*

3.2 Introduction

The demand for soybean products for both animal and human consumption in many tropical countries is high. This is due to low soybean productivity in Sub Saharan African (Chianu *et al*., 2009). The successful production of soybean in the tropics is dependent upon the cost of production and processing compared to imported processed products. So, it is essential that the N required for high yielding soybeans be obtained from biological N fixation and not expensive nitrogenous fertilizers (Kueneman *et al.,* 1998). Alot of studies, in temperate and tropical environments, have demonstrated that improved high – yielding soybean varieties require inoculation with *Rhizobium japonicum* to give their yield potential when grown in soils where inoculum has not been applied (Hunt *et al.,* 1985). This presents a challenge in the tropics, due to the fact that there is inadequate capacity for inoculants production and quality maintenance. Imported Inoculum may resolve the production problem, but storage, distribution and education of the small-scall farmer present big issue (Kueneman *et al.,* 1998). Another practical alternative to the use of inoculums that comprise *R. japonicum* strains may be the development of soybean varieties that are capable of forming an effective symbiosis with indigenous rhizobia (Mpepereki *et al.*, 2000). Those varieties could be very important for intercropping with maize, for increasing diverse productivity per unit area compared to sole cropping (Sullivan, 2003). For instance, using Land Equivalent Ratio (LER) in a maize soybean intercropping system, Khan *et al*. (1988) reported that it was greater than one under sole crop. Most researchers believe that the intercropping system is especially beneficial to the smallholder farmers in the low-input/high-risk environment of the tropics (Dwivedi *et al*., 2015). The intercropping of cereal and legumes is widespread among smallholder farmers due to the ability of the legume to cope with soil erosion and with declining levels of soil fertility. The principal reasons for smallholder farmers to intercrop are flexibility, profit maximization, risk minimization against total crop failure, soil conservation improvement of soil fertility, weed control and balanced nutrition (Dwivedi *et al*., 2015). Other advantages of intercropping include potential for increased profitability and low fixed costs for land as a result of a second crop in the same field (Thobatsi, 2009). The objective of this study was to identify the most suitable promiscuous soybean variety for intercropping with maize in Kenya.

3.3 Materials and Methods

3.3.1 Study area description

The experiment was carried out in two sites, KALRO Embu and KALRO Mwea. KALRO-Embu is located in Embu County in the Eastern part of Kenya. It lies between latitudes 0 ˚ 08’ 35’’S and a longitude 37°27′02″ E. (Abuli, 2016). Embu occupies among the most main fertile lands in the Kenyan highlands, with its weather favorable for a variety of agricultural activities (Embu County, 2014). KALRO-Mwea is in Kirinyaga county, situated in the Central Region of Kenya at a latitude of 00^0 37’S and a longitude of 37^o 20’E (Fig 3.1) (Kirinyaga County, 2014).

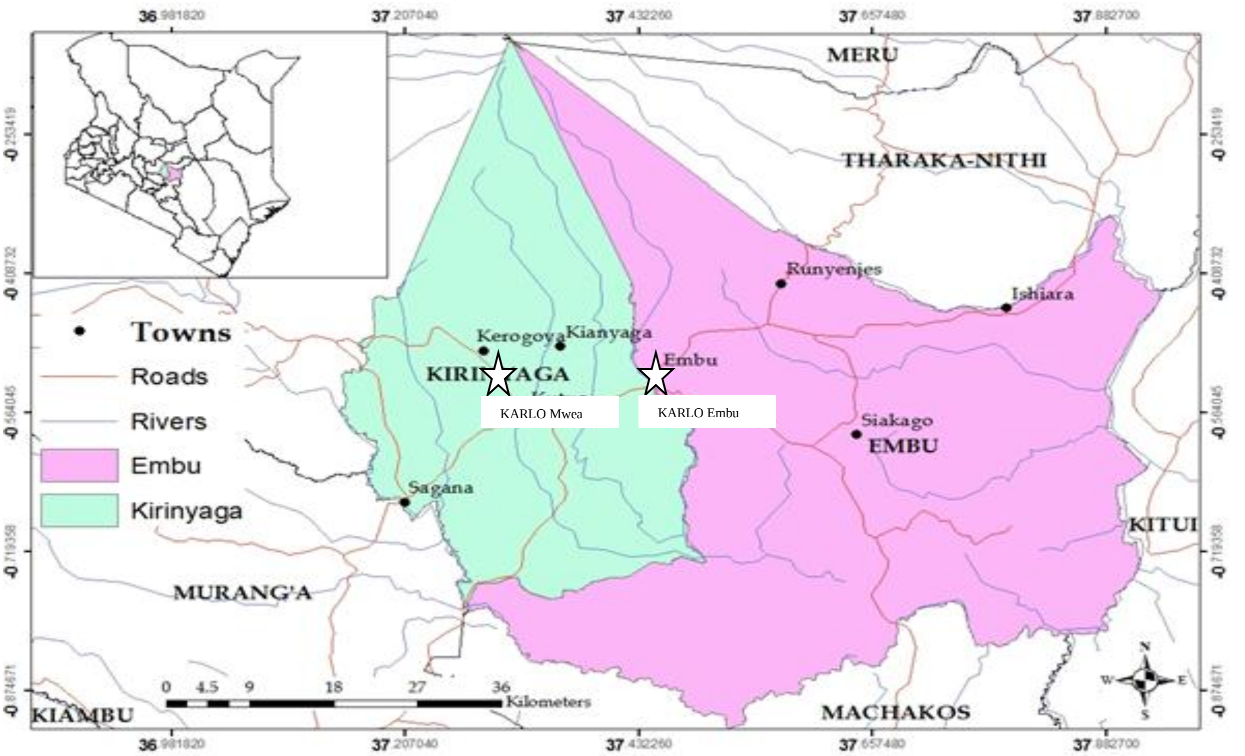


Figure 3.1 : Geographic maps of Kirinyaga and Embu Counties

3.3.2 Climate

Embu and Kirinyaga Counties rely on bimodal rainfall where the long rain season is usually from mid-March to June and the short rain season is from August to November. The short dry season between the rain seasons begin from mid June to mid July. The seasonal mean precipitation is 1500mm and the temperature range between 18°-28°C for Embu county (Embu County, 2014), while the seasonal mean precipitation for Kirinyaga county is 1679 mm and the temperature range between 8.1°-30.3°C (Kirinyaga County, 2014).

3.3.3 Soil

Embu soils are mainly acidic humic nitisols (Benvindo *et al.*, 2014). The prevalence of soil acidity is responsible for the lower soil microbial community which results in the low organic matter as a consequence of reduced turnover of organic residues. The low soil organic matter also contributes to low levels of nitrogen (N), phtosphorus (P), carbon (C) and other nutrients. These disadvantageous conditions contribute to poor soil fertility and crop performance (Benvindo *et al.*, 2014). For Kirinyaga County, vertisols is the most dominant in the area. Also, the soil is characterised by low water holding capacity and low organic matter levels which intensify the water deficit challenge. Accordingly the nutrients, N, P, K and C are low. For this reason, fertility is generally low for that county for optimum growth of the crops, manures and fertilizers should be added (Kanake, 1986). The initial soil analysis was done before start of experiment.

3.3.4 Experiment design and layout

In this study, the land preparation was done by ploughing using ox- draw equipment in that area. The experiment was laid out as a randomized complete block design

(RCBD). There were treatments replicated three times. Each experimental unit was 4m x 3 m separated by 1m for the path (Fig 3.2).

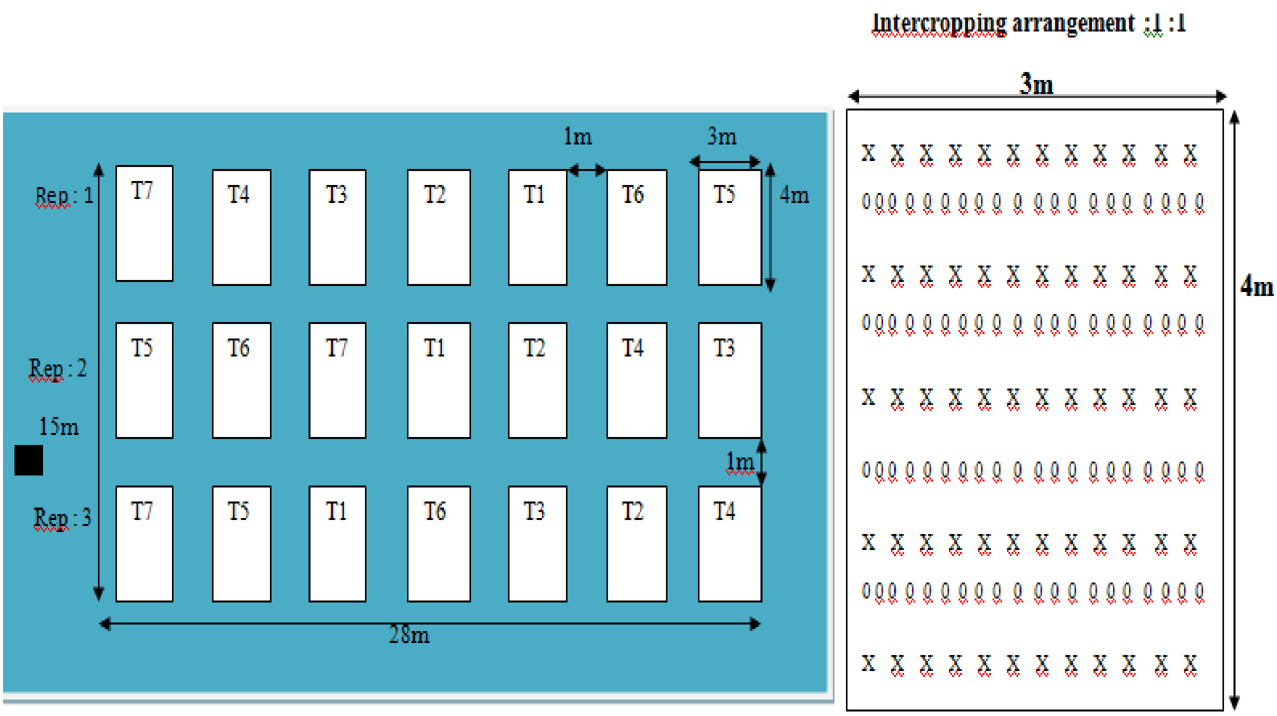


Figure 3.2 : Experimental design

Where T1 = SB19, T2 = GAZELLE, T3 = TGX1990-5F, T4 = SB19+MAIZE T5 = GAZELLE+MAIZE, T6 = TGX1990-5F+MAIZE, T7 = MAIZE (DUMA 43)

The population densities and spacing used were as follows: In sobean monocrop: The population density was 166,666.66 plants ha^{-1} (40 cm x 15 cm) while in the intercrop with maize was 83,333.33 plants ha^{-1} (80 cm x 15 cm). Population in the maize monocrop was 50,000 plants ha^{-1} (80 cm x 25 cm) while in the intercrop it was 50,000 plants ha^{-1} (80 cm x 25 cm). The total area of the experiment was 420 m^2. In total, the experiment had 2700 plants of soybean in which 900 plants were in intercrop with maize while1800 plants were in sole crops. The total density in whole experiment for maize was 720 plants in sole crops as in intercrop. The arrangement of intercropping was 1:1 which means, one row of maize intercepted by one row of soybean. This partten has been adopted from Democratic Republic of Congo, where the varieties were obtained. This partten is the popular practice in that area.

3.3.3 Management of the experiment

The experiment was conducted in two growing seasons (short rain season and long rain season). Basal fertilizer of DAP was applied at 10.5 kg per site at the rate of 250kg ha^{-1} , meaning that each plot received 300 g of fertilizer and the application was done by row as explained by (Roy *et al*., 2006). The first planting was done on 9th June 2016 at Embu and 10th June at Mwea during the long rain season. The second planting was done on 8th November 2016 and on 9th November 2016 at Mwea and Embu respectively. In both sites the first and second weeding were carried out manually to keep the plots free from weeds. During the cropping seasons the rain fall was insufficient, and the trials received the supplement of irrigation. The situation of rain fall was severe in the second season. Five plants were taken as sample for all parameters except for the yield where all the plants from the middle of the plot were taken.

3.3.4 Data collection

The data were collected for both soybean and maize on germination percentage, plant height, biomass per plant, number of pod per plant, nodulation per plant, number of seed per pod, shattering score, 50% days to flowering, 75% to maturity, 100 grains weight, grain yield and LER. Maize was also scored for MLN that attacked the crop during the experimental period.

3.3.4.1 Germination percentage

The data for germination percentage was collected considering germinated plants multiplied by 100 divided by the total number of grains sown. The germination unit was in percentage as follows;

$$\text{Germination } \% = \frac{\textit{Germinated seed}}{\textit{Seed sown}}\ x\ 100$$ (Equation 1) on germination %

3.3.4.2 Plant height

Plant height was taken using tape measure, from the bottom of the plant till the end of the plant hight for maize and soybean. Five plants were taken as sample per plot in the middle now to avoid influence of others plots. After measuring height of five plants, the average was computed in order to get the plant height for one plant (Naim *et al*., 2012).

3.3.4.3 Days to 50% flowering and days to 75% maturity

This parameter was estimated by counting the number of days taken for each variety in the field after 50 percentages of soybeans or maize flowered since the sowing date. The same procedure was repeated also when estimating days to 75 percentage maturity for soybean and maize.

3.3.4.4 Plant biomass

Plant biomass was done using the electronic balance, measuring the weight of five plants and the total biomass obtained was divided by five in order to get the average biomass of one plant (Naim *et al*., 2012). Biomass data was collected during the harvesting time. The biomass in t ha^{-1} was obtained by taking the quantity of biomass per plot and extrapolating it per ha.

3.3.4.5 Shattering score

This parameter was assessed at maturity by taking 30 dried pods and putting them in khaki envelope and exposing them on sun for 7 days counting the number of shattered pods per day and converting it in percentage as shown below.

$$\text{Shattered pods \%} = \frac{\text{Number of pods shattered}}{\text{Number of pods taken as sample}} \times 100$$

(Equation 2) Shattering score

The scoring rate of pod shattering was as follows: 1 = No pod shattering (Very Resistant); 2 = < 25% pod shattering (Resistant); 3 = 25-50% pod shattering (Moderately Resistant); 4 = 51-75% pod shattering (Highly susceptible); 5 = > 75% pod shattering (Very Highly susceptible) (Haruna, 2010; Krisnawati & Adie, 2017).

3.3.4.6 Number of pods per plant

The number of pods per plant was taken by counting all pods which were on the five plants taken as sample size, divided by five to get the pods average per plant at harvest time.

3.3.4.7 Number of seed per pod

The number of seeds per pod was taken counting all seeds which were in the five pods taken randomly on five plants as sample size, divided by five to get the seeds average per pod.

3.3.4.8 Nodulation assessment and time

The nodule viability assessment was done by digging up five soybean plants, without pulling to avoid nodules stripping off the roots. That operation was realized after the second and the third trifoliate leaf had emerged. In the absence of nodules, resampling was done after one week in the same field (Mosanto, 2014). The first nodules are formed within one week after seedling emergence and become visible as they increase in size. After ten to fourteen days, the nodule bacteria can supply most of the plant's nitrogen requirements. The nodules permit fixation of atmospheric nitrogen but are energetically expensive to develop and maintain (Shantharam and Mattoo, 2017). For our case, that operation 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.

3.3.4.9 Soybean and maize yield

The harvesting of soybean and maize were done taking all the plants from the middle of the plot for each component crop at the maturity time. Soybean plants for each plot were threshed on the mat then winnowing and put in paper bag. The weight for soybean grains was obtained using electronic balance. After getting yield for each plot in grams, it was extrapolated in tonne per hectare. The maize ears from each plot were removed on stems at maturity time and grains were shelled from the stalk and conserved in paper bag. The weight for maize grains was obtained using electronic balance. After getting yield for each plot in grams, it was extrapolated in tonnes per hectare.

3.3.4.10 Performance of the intercropping Maize – Soybean systems estimated by LER

To evaluate the intercrop's performance, land equivalent ratio was calculated using formula provided by Amanullah *et al.* (2016) as follows:

$$LER = \frac{Y_{SB}\ \text{in mixed stand}}{Y_{SB}\ \text{in pure stand}} + \frac{Y_{MZ}\ \text{in mixed stand}}{Y_{MZ}\ \text{in pure stand}}$$ (Equation 3) Land Equivalent Ratio

Where

LER = Land equivalent ratio

Y_{SB} = Yield of soybean crop

Y_{MZ} = Yield of maize crop.

When LER ratio is more than (1.0), it indicates the advantage in associated crops than the sole crop (Adam & Mohammed, 2012). For example, a LER of 1.15 means that a surface planted as a pure crop, would need 15% more land to produce the same yield as the same surface planted in intercropping. LER of 2.0 means the intercropped surface would provide twice as much as the sole crop (Sylvia, 1999). Nevertheless, LER of 1.0 or less shows that no difference in yield between the intercropping and sole crop (Adam & Mohammed, 2012).

3.3.4.11 Harvest index

In many crops, the main progress in breeding for higher yields is obtained principally between man-made selection forces for the harvest index (HI), that is, an increased plant capacity to allocate biomass (assimilates) into the formed reproductive parts**.** The relationships of harvest index with biomass and grain yield follow the multiplicative yield component model, in which grain yield is a product of harvest index and biomass yield (Wnuk *et al.*, 2013)**.** The model formula used to compute HI was**:**

$$HI = \frac{Grain\ yield\ T/ha}{Biomass\ yield\ T/ha}\ x\ 100$$ (Equation 4) Harvest index

3.3.4.12 One hundred grains weight

100 grains weight was measured using electronic balance taking 100 grains from harvested soybean and maize grains. 100 grains are used for the biggest grains size (eg: Maize) while 1000 grains are used for the smallest grains size (eg: sun flower) as outlined by Aziz *et al*., (2012).

3.3. 5 Data analysis

The data were analyzed using Gen stat program fourth edition and means were compared using (LSD) on threshold of ($p \leq 0.05$) (ILRI-ICRAF, 2007).

3.4 Results

The combined analysis of variance of soybean in sole crop and in the intercrop showed that, interaction among treatments x sites x seasons did not show significant difference in all parameters ($p \leq 0.05$) (Table 3.1 page 29). The combination of seasons x sites showed significant difference on days to 50 % flowering, days to 75 % maturity ($p \leq 0.05$). Treatments x sites did not show significant difference in all parameters. Interaction between treatments x seasons did not show significant difference in all parameters too. The sites showed significant difference on plant height, days to 50 % flowering, days to 75 % maturity, except for germination rate. Germination rate, plant height, days to 75 % maturity, showed significant difference between seasons but significant difference was not shown on days to 50% flowering. The treatments were significantly different for plant height, days to 50% flowering, days to 75% maturity, $p \leq 0.05$ except for germination % ($p \leq 0.05$) (Table 3.1).

Table 3.1: Mean square of soybean germination %, plant height, days to 50 % to flowering, days to 75 % maturity at Embu and Mwea in sole crop and in intercrop, long rains of 2016 and short rains of 2016-2017

Source of variation	Df	GRM	PH	D50PF	D75PM
Replications	2	285.99	104.54	0.875	0.514
Treatments	5	141.77^{NS}	813.98*	726.3*	1057.1*
Seasons	1	9414.21*	1144.81*	0.50^{NS}	2.72*
Sites	2	15.40^{NS}	5517.75*	7280.2*	2.73*
Treatments x Seasons	5	88.40^{NS}	69.42^{NS}	0.100^{NS}	0.356^{NS}
Treatments x Sites	5	15.56^{NS}	17.44^{NS}	0.36^{NS}	79.26^{NS}
Seasons x Sites	1	102.01^{NS}	69.42^{NS}	0.22*	4.50*
Treatments x Seasons x sites	5	39.45^{NS}	45.54^{NS}	0.289^{NS}	0.60^{NS}
Residual	46	77.90^{NS}	50.71	0.599	0.369
Total	71				

*Significant on $p \leq 0.05$, NS: Non Significant difference on $p \leq 0.05$, df: Degree of freedom, GRM: Germination %, PHt: Plant height, D50PF: Days to fifty percent flowering, D75PM: Days to seventy percent maturity.

Table 3.2 on page 30 for the combination of treatments x sites showed significant difference on shattering score, yield in t ha^{-1}, harvest index and land equivalent ratio. Interaction between treatments x seasons showed significant difference on shattering score, number of pods per plant, 100 grains weight, yield in t ha^{-1} ($p \leq 0.05$). The sites showed significant difference on nodulation per plant, number of pod per plant, number seeds per pod and biomass in t ha^{-1}. Shattering score, number of pods per plant, number of seed per pod, 100 grains weight, yield in t ha^{-1}, biomass in t ha^{-1}and land equivalent ratio, showed significant difference between seasons (Table 3.2 on page 30). The treatments were significantly different in shattering scores , nodulation per plant, number of pod per plant, 100 grain weight, yield in t ha $^{-1}$, harvest index and land equivalent ratio ($p \leq 0.05$) except for, number of seeds per pod and biomass per plant ($p \leq 0.05$). The combination of seasons x sites showed significant difference on number of pods per plant, number of seeds per pod, 100 grains weight and significant difference was not shown on shattering score, nodulation per plant, biomass in t ha^{-1}, yield in t ha^{-1}, harvest index and land equivalent ratio ($p \leq 0.05$). The combined analysis of variance of soybean in sole crop and in the intercrop showed that, interaction among treatments x sites x seasons did not show significant difference in all parameters ($p \leq 0.05$) (Table 3.2 on page 30).

Table 3.2: Mean square of soybean shattering score, nodules per plant, number of pods per plant, seeds per pods, 100 grains weight, biomass in t ha^{-1}, yield in t ha^{-1}, harvest index, and land equivalent ratio at Embu and Mwea in sole crop and in intercrop, long rains 2016 and short rains 2016-2017

Source of variation	Df	SHAT	NODP	NUPOP	SEEDP	100GW	BIO T HA^{-1}	YTHA	HI	LER
Replications	2	17.38	7.14	85.9	0.149	2.73	7.788	17.38	0.04	1.17
Treatments	5	733.49*	469.22*	3379.4*	0.142	52.94*	96.18^{NS}	733.49*	0.08*	0.38*
Seasons	1	887.26*	1.25^{NS}	13755.9*	2.56*	764.21*	189.19*	887.26*	0.03^{NS}	0.60*
Sites	2	35.94^{NS}	256.51*	12012.5*	1.17*	8.40^{NS}	56.901*	35.94^{NS}	0.015^{NS}	0.001^{NS}
Treatments x Seasons	5	324.51*	10.27^{NS}	1145.6*	0.19^{NS}	80.61*	16.055^{NS}	324.51*	0.014^{NS}	0.19^{NS}
Treatments x Sites	5	278.90*	1.88^{NS}	554.5^{NS}	0.113^{NS}	9.06^{NS}	2.333^{NS}	278.90*	0.03*	0.45*
Seasons x Sites	1	95.38^{NS}	0.19^{NS}	2244.5*	1.07*	22.68*	4.503^{NS}	95.38^{NS}	0.001^{NS}	0.12^{NS}
Treatments x Seasons x sites	5	59.43^{NS}	2.93^{NS}	115.2^{NS}	0.15^{NS}	1.97^{NS}	9.260^{NS}	59.43^{NS}	0.06^{NS}	0.049^{NS}
Residual	46	25.18	6.01	250.6	0.087	5.18	7.695	25.18	0.013	0.082
Total	71									

*Significant on $p \leq 0.05$, NS: Non Significant difference on $p \leq 0.05$, df: Degree of freedom, SHAT: Shattering score, NODP: Nodulation per plant, NUPOP: Number of pod per plant, SEEDP: Seed per plant, GW: Grain weight, BIOT HA^{-1} : Biomass in tonne per ha, YTHA: Yield in tonne per ha, HI: Harvest index, LER: Land equivalent ratio.

3.4.1 Soybean germination

During the short rains, significant differences were observed in the sole crops and the intercrops between the sites. During the long rains of 2016, germination % for soybeans did not give significant different in the sole and the intercrop between the sites. However, Germination % was higher during the long rains recording 90 % compared to the short rains recording between 67 and 79% (Table 3.3, page 33).

3.4.2 Soybean plant height

Soybean plant height (PHt) showed significant difference ($p \leq 0.05$) between sites and seasons (Table 3.3, page 33). Soybean PHt ranged from 40.83 cm to 61.80 cm between sites in the long rains while it ranged from 46.63 cm to 67.50 cm in the short rain season between sites too. Mwea recording the tallest soybean PHt ranging from 47.1 to 67.7 cm while Embu presented the shortest plant height ranged between 30.4cm and 55.87cm in sole crop and intercrop in the long rain season. During the short rain season, soybean PHt ranged from 55.40cm to 71.53cm at Mwea while it ranged from 37.87cm to 54cm at Embu in sole crop and intercrop. Sole crops showed the highest PHt compared to intercropping indicating that intercropping reduced soybean plant height for both rain seasons (Table 3.3, page 33). Varieties differed in terms of PHt. TGX1990 – 5F recorded (Figure 3.3 (c)) the tallest plants height of 55.87 cm and 44.27cm in sole crop and in intercrop in Embu in the long rain. This was followed by SB19 with 43.2cm and 33.9 cm while Gazelle recorded the shortest PHt of 30.40 cm and 34.9 cm respectively in sole crops and intercrop at Embu in long rains. At Mwea, variety TGX1990-5F recorded the tallest PHt followed by SB19 while GAZELLE as the shortest (47.13 cm) in sole crops and intercrop both rainy seasons. Varieties differed in tems of plant height in short rains (Table 3.3, page 33).Variety TGX1990-5F showed the tallest PHt of 54 cm and 52.53cm followed by SB19 (Figure (3.3(b)) with 47.40 cm and 42.07cm compared to GAZELLE(Figure (3.3(a)) with the smallest PHt of 44.67 cm and 37.87cm in sole crop and intercrop respectively at Embu. However, at Mwea, TGX1990-5F showed the highest PHt of 81 cm and 67.40cm followed by SB19 with 71.53 cm and 63.20 cm compared to GAZELLE with the shortest PHt of 56.83 cm and 55.40 cm in sole crop and intercrop respectively in the short rainy seasons. Intercropping affected negatively the PHt compared to the results obtained in sole crop (Table 3.3, page 33).

Figure 3.3 : (a) Intercropping at Embu. (b) Intercropping at Mwea. (c) sole crop

3.4.3 Days to 50 % flowering and 75 % maturity for soybean

Days to 50 % flowering and 75 % maturity in the sole crops and the intercrops systems differed between the sites ($p \leq 0.05$) (Table 3.3, page 33). However, the trend for flowering and maturity was similar for the 2 seasons at Mwea. Days to 50 % flowering ranged from 69 days to 84 days at Embu while at Mwea it ranged from 48 days to 64 days among varieties in both seasons (Table 3.3, page 34). In addition, days to 75 % maturity ranged from 95 days to 121 days at Embu and 80 days to 95 days at Mwea in both seasons. For days to 50 % flowering, variety SB19 took 49 and 69 days to flower while the last variety to flower was TGX1990-5F which took 64 days and 84 days at Embu and Mwea respectively. The same trend was observed in days to 75 % maturity where variety SB19 (Figure 3.4 (a)) took 80 and 95 days to mature and GAZELLE was the second variety mature ((Figure 3.4 (b)). Variety TGX1990-5F (Figure 3.4 (C)) took 95 and 121 days to mature at Mwea and Embu respectively. Nevertheless, intercropping did not reduce days to 50 % to flowering and 75 % to maturity both sites and both seasons (Table 3.3, page 34).

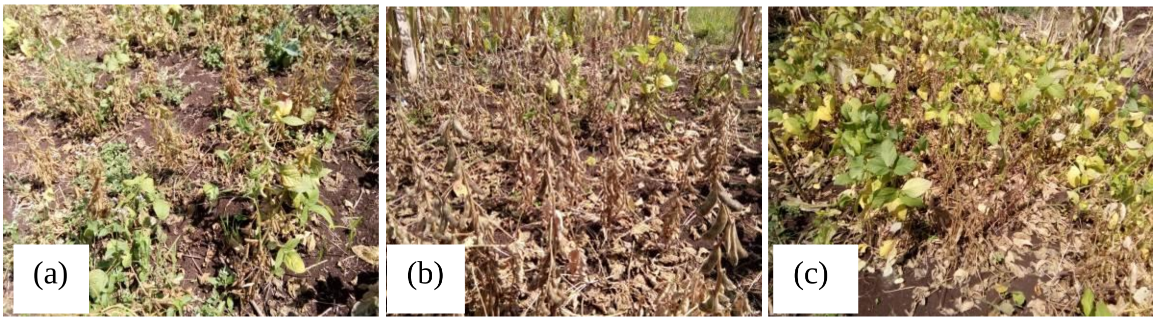


Figure 3.4 : Soybean in the field at maturity time, sole crop. (a) SB19, (b) Gazelle,(c)TGX1990 – 5F.

Table 3.3: Soybean germination percentage, plant height, days to 50% flowering and days to 75% maturity both rainy seasons at Embu and Mwea during long rain of 2016 and short rain of 2016-2017

						Long rains 2016						
	GRM			PH			D50PF			D75PM		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	96.0a	97.5a	96.75a	43.2b	59.13ab	51.17b	69.3b	49b	59.15b	95.3d	80c	87.5c
GAZELLE	98.3a	98.7a	98.5a	30.4c	47.13b	38.77c	68.3b	49.3b	58.8b	100c	84.6b	92.5b
TGX1990-5F	98.0a	95.6a	96.8a	55.87a	67.73a	61.80a	84.6a	64a	74.3a	121a	95.3a	107.5a
SB19+MAIZE	98.0a	95.6a	96.8a	33.9ab	50.53b	42.20c	69.6b	49.3b	59.45b	96.3d	80c	87.5c
GAZELLE+MAIZE	98.0a	94.9a	96.5a	34.9ab	46.80b	40.83c	69.3b	48.6b	58.95b	102b	84.3b	92.5b
TGX1990-5F+MAIZE	96.3a	93.7a	95.0a	44.27b	64.40a	54.33b	84.3a	64a	74.15a	121a	95a	107.5a
Mean	97.43	96.0	96.7	40.41	55.95	48.18	74.23	54.03	64.13	105	86.67	95.83
LSD0.05	4.65	3.07	4.19	10.52	11.5	3.37	1.6	0.802	1.27	1.24	0.0802	0.99
CV%	2.6	1.8	10.3	14.3	11.68	13.6	1.7	1.2	1.2	0.9	1.2	0.6
						Short rains 2016-2017						
	GRM			PH			D50PF			D75PM		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	83.0a	76.5a	79.8a	47.40ab	71.53a	59.47a	69.33b	49b	59b	95c	80.66c	87.8c
GAZELLE	77.5a	80.3a	78.9a	44.67ab	56.83b	50.75a	69.33b	49.33b	59b	100.3b	85b	92.6b
TGX1990-5F	75.3a	71.7a	79.4a	54.00a	81.00a	67.50a	84.67a	64.67a	74a	121a	95.33a	108.2a
SB19+MAIZE	67.3a	71.7a	69.5b	42.07ab	63.20b	52.63a	69b	49.33b	59.17b	95c	80.33c	87.6c
GAZELLE+MAIZE	67.7a	69.0a	68.3b	37.87b	55.40c	46.63b	69b	48.6b	58.8b	100b	85b	92.5b
TGX1990-5F+MAIZE	62.3a	72.0a	67.2b	52.53a	67.40b	59.97a	84a	64a	74a	120.3a	95a	107.5a
Mean	72.18	73.5	73.85	46.41	65.89	56.15	74.22	53.98	63.99	105.15	86.6	95.83
LSD0.05	20.76	17.51	4.19	8.86	11.5	3.37	1.6	1.2	1.27	0.802	0.40	0.99
CV%	15.8	12.8	10.3	10	12.8	13.6	1.7	0.9	1.2	0.7	0.6	0.6

LSD: Least significant difference, GRM: Germination, PHt: Plant height (cm) and D50PF: Days to fifty percent to flowering. Means bearing the same letter are in the same group

3.4.4 Soybean shattering score

Table 3.4 on page 36 on shattering score (SH) showed significant difference between sites and seasons ($p \leq 0.05$). The shattering score ranged from 11 % to 36 % at Mwea while at Embu it ranged from 8 % and 30 % in the long rains. GAZELLE recorded the highest SH of 23.3 % and 30% followed by SB19 with 20 % and 25% while TGX1990-5F recorded the lowest SH of 11% and 8% in sole crops and intercrop respectively at Embu in the long rains. At Mwea, GAZELLE recorded the highest of SH of 23 % and 36.67%compared to SB19 (20.7 % and 16.3%) and TGX1990-5F (11% and 15%) in sole crops and intercrops during the long rain seasons. During the short rains, SH was ranged between 16 % and about 30 % at Mwea, while in Embu SH ranged from 16 % to about 52 %. GAZELLE presented the highest SH of 46.63% followed by SB19 with SH of 25.56 % and TGX1990-5F with the lowest amount of SH of 16.64 % in sole crop at Embu in long rainy season (Table 3.4 on page 36). However, SB19 presented higher amount of SH of 52.22 % in intercrops followed by GAZELLE with 18.89 % compared to TGX1990-5F with the lowest amount of SH of 13.33 % at Embu. At Mwea, GAZELLE showed the highest SH of 30.66 % followed by 18.33% compared to TGX1990-5F with lower SH of 16.66 % in sole crops. In intercrops, SB19 gave the highest SH of 30.33 % followed by GAZELLE with 30 % compared to TGX1990-5F with 25 % in short rains (Table 3.4 on page 36). Thus, following the shattering score scale, TGX1990 – 5F variety was the most resistant to pod shattering because it's score shattering scale was 2, while GAZELLE with and SB19 were moderately resistant to pod shattering considering the scale shattering score (Table 3.5 page 37). Intercropping did not affect soybean pod shattering.

3.4.5 Nodulation of soybean per plant

Soybean number of nodules showed significant difference ($P \leq 0.05$) between sites but the seasons were not significantly different (Table 3.4, page 36). The number of nodules ranged from 33 to about 47 at Mwea while Embu ranged from 29 to about 43. TGX1990-5F recorded the highest number of nodules of 47 in intercropping followed by SB19 with 35.53 number of nodules while GAZELLE recorded the lowest number of nodules of 33.90 at Mwea in long rains. Variety 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 (Table 3.4, page 36).

In the short rains, the number of nodules ranged from 33 to about 46 at Mwea in contrast of Embu where the number of nodules ranged from 28.07 to about 43. 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, the variety 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 higher 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 both sites and both seasons. Mwea site presented the highest number of nodules compared to Embu in 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 3.4, page 36).

3.4.6 Number of pods per plant for soybean

The number of pods per plant presented significant difference between sites in the sole crop and in intercrops in the long rains (Table 3.4, page 36). The short rains did not show significant difference between sites. The number of pods ranged from 46 to about 107 at Mwea, while it ranged from 13 to about 82 at Embu in both sole crop and intercrop. During the long rain season, variety TGX1990-5F presented the highest number of pods followed by SB19 in sole crop in both sites. GAZELLE recorded the lowest number of pods in intercropping at Mwea and Embu sites. During the short rains the number of pods was reduced at both sites compared to the long rains of 2016. The number of pods per plant ranged from 11 to about 57 at Mwea and from 10 to about 33 at Embu in sole crop and in the intercrop. TGX1990-5F recorded the highest number of pods and GAZELLE had the lowest number of pods. Intercropping affected negatively the number of pods per plant both seasons. Mwea site had the highest number of pods compared to Embu in both seasons (Table 3.4, page 36). However, the long rains 2016 did not show significant difference of seeds per pod between sites.

3.4.7 Number of seeds per pod for soybean

The seeds per pod ranged from 2 to 2.7 at Mwea while they ranged from 1.6 to 2 at Embu (Table 3.4, page 36). The number of seeds per pod differed significantly during the short rains between sites and ranged from 2 to 3 at Mwea and from 2 to 2.7 at Embu. SB19 presented the highest number of seeds per pods of 3 followed by GAZELLE with 2.5 and the last was TGX199-5F with 2.07 at Mwea. Intercropping did not have bad influence on number of seeds per plant. Mwea site presented the biggest number of seeds per pod compared to Embu both seasons (Table 3.5, page 37).

Table 3.4: Soybean shattering score, nodulation per plant, number of pod per plant, seed per pod for soybean during long rain of 2016 and short rain of 2016-2017

	Long rains 2016											
	SH			NODP			NPODP			SEEDPP		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	20abc	20.7ab	20.33b	30.4a	34.87b	32.6b	42.1a	81.3ab	61.7b	1.93a	2.3a	2.1a
GAZELLE	23.3ab	23ab	23.17b	32.9a	36.60b	34.8b	24.4a	61.3a	42.85b	2a	2.2a	2.1a
TGX1990-5F	11cd	11cd	11.00c	43.6b	46.87a	42.24a	82.7a	107.2a	94.95a	1.93a	2.7a	2.3a
SB19+MAIZE	25ab	16.3ab	20.67b	33.07a	35.53b	34.3b	13.0a	49.3b	31.15c	1.6a	2.3a	1.95a
GAZELLE+MAIZE	30a	36.67a	33.33a	29.87a	33.90b	31.8b	23.8a	46.7b	35.25c	1.8a	2.3a	2.05a
TGX1990-5F+MAIZE	8d	15ab	11.50c	43.40b	47.47a	45.44a	44.5a	106.8a	75.65b	1.7a	2.5a	2.1a
Mean	19.56	20.45	20.00	35.54	39.20	36.87	38.4	75.4	56.86	1.8	2.4	2.1
LSD0.05	5.26	12.76	8.25	5.59	3.33	4.03	32.79	34.78	26.02	0.52	0.49	0.48
CV%	14.8	34.3	21.3	8.7	4.7	6.6	46.9	25.3	36.7	15.6	11.5	13
	Short rains 2016-2017											
	SH			NODP			NPODP			SEEDPP		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	25.56b	18.33c	21.9c	29.80b	35.3b	32.55b	22.5ab	57.7a	40.1a	2.6a	3b	2.8a
GAZELLE	46.63a	30.66a	38.64a	32.33b	36.4b	34.36b	33.3a	36.5ab	34.9a	2.7a	2.5ab	2.6b
TGX1990-5F	16.64b	16.66d	16.65c	43.73a	46.8a	45.26a	33.7b	48.4b	41.05a	2.4a	2.07a	2.2b
SB19+MAIZE	52.22a	30.33a	41.28a	28.07b	33.9b	30.98b	14.6b	24.3ab	19.45a	2.6a	2.4ab	2.5b
GAZELLE+MAIZE	18.89b	30.00a	24.45b	33.67b	35.1b	34.39b	17.1b	11.7a	14.4a	2.2a	2.7ab	2.45b
TGX1990-5F+MAIZE	13.33b	25.00b	19.17c	43.40a	46.8a	45.1a	10.6b	41.1ab	25.85a	2.08a	2.1ab	2.09b
Mean	28.87	25.16	27.02b	35.16	39.5	37.3	21.96	36.6	32.5	2.4	2.5	2.4
LSD0.05	13.43	0.94	8.25	5.66	2.71	4.03	14.12	33.04	26.02	0.45	0.52	0.48
CV%	25.6	2.3	21.3	8.9	3.8	6.6	35.4	49.6	36.7	10	11.6	13

LSD: Least significant difference, CV: Coefficient of variation, D70PM: Days to seventy percent to maturity, SH: Shattering score, NODP: Nodulation per plant. Means bearing the same letter are in the same group.

Table 3.5 : Soybean pod shattering and shattering scores at Mwea and Embu for long rains 2016 and short rains 2017

	Long rains 2016			Short rains 2016-2017		
Sites/Treatment	Mean shattering %	Shattering scores	Shattering reaction classification	Mean shattering %	Shattering scores	Shattering reaction classification
EMBU						
SB19	20abc	2	R	25.56 b	3	MR
GAZELLE	23.33ab	2	R	46.63 a	3	MR
TGX1990-5F	11cd	2	R	16.64d	2	R
SB19+MAIZE	25ab	3	MR	52.22a	4	HS
GAZELLE+MAIZE	30a	3	MR	18.89b	2	R
TGX1990-5F+MAIZE	8d	2	R	13.33b	2	R
CV%	14.8	-		25.6	-	
$LSD_{0.05}$	5.26	-		13.42	-	
MWEA						
SB19	20.67ab	2	R	18.33^{c}	2	R
GAZELLE	23ab	2	R	30.66^{a}	3	MR
TGX1990-5F	11cd	2	R	16.66^{d}	2	R
SB19+MAIZE	16.33ab	2	R	30.33^{a}	3	MR
GAZELLE+MAIZE	36.65a	3	MR	30.00^{a}	3	MR
TGX1990-5F+MAIZE	15 ab	2	R	25.00^{b}	3	MR
CV%	34.3	-		0.94	-	
$LSD_{0.05}$	12.76	-		23.35	-	

CV: Coefficient of variation, LSD: Last significant difference. The scoring rate was as follows: 1 = No pod shattering (Very Resistant); 2 = < 25% pod shattering (Resistant); 3 = 25-50% pod shattering (Moderately Resistant); 4 = 51-75% pod shattering (Highly susceptible); 5 = > 75% pod shattering (Very Highly susceptible).

3.4.8 One hundred grain weight for soybean

During the long rains of 2016, 100 grain weight (100 GW) showed significant difference ($p \leq 0.05$) between (Table 3.6, page 39). It ranged from 14 g to 27 g at Mwea while at Embu ranged from 14 g to about 24 g. There were varietal differences among the varieties in the sole and intercrop system. In the sole crop GAZELLE presented the highest GW of 24.33g followed byTGX1990-5F with 18.33g while SB19 had the lowest GW of 16.67 g in sole crops at Mwea. In the same site, variety SB19 recorded the highest GW of 27 g followed by TGX1990-5F with 20.33 g while GAZELLE recorded the lowest GW of 14.67 g in the intercrop(Table 3.6, page 39). In Embu during the long rains GAZELLE recorded GW of 24.71 g higher than 16.47 g for SB19 and TGX1990-5F 16.10 g in sole crops while in intercrop SB19 recorded the highest compared to GAZELLE and TGX1990-5F. However, 100 GW did not have significant difference between sites in the short rains but significant differences were observed among treatments both sites. 100 GW ranged between 11 g to about 14 g at Mwea and from 10g to about 14g at Embu. TGX1990-5F showed the highest 100 GW of 14.62 g in intercrops followed by GAZELLE with 12.79 g 100 GW while SB19 gave the lowest 100 GW of 11.24 g at Mwea. GAZELLE showed the highest 100 GW of 12.98 g in sole crop followed by 12.43 g of 100 GW for TGX1990-5F compared to SB19 with the lowest 100 GW of 11.24g at Mwea (Table 3.6, page 39). However, at Embu GAZELLE produced 14.27 g of 100 GW higher than 13.09 g of 100 GW for SB19 compared to 11.95 g 100 GW for TGX1990-5F in sole crops. In addition, variety GAZELLE showed higher 100 GW of 14.35 g followed by TGX1990-5F with 14.24 g compared to SB19 with 10.23 g of 100 GW in intercrops at Embu (Table 3.6). Mwea presented the highest 100 GW compared to Embu in both seasons. Depending on the results obtained in the sole crop and in intercropping, intercropping affected negatively 100 grain weight and the long rains 2016 had higher amount of 100 grain weight compared to the short season (Table 3.6, page 39).

3.4.9 Soybean biomass

Soybean biomass showed significant difference ($p \leq 0.05$) between sites and seasons(Table 3.6, page 39). The biomass from Mwea ranged from 3 t ha^{-1} to about 12 t ha^{-1} while biomass from Embu was 2 t ha^{-1} to 14 t ha^{-1} (Table 3.6). TGX1990-F had the highest biomass of 12.9 t ha^{-1} and 10.6 t ha^{-1} followed by SB19 with 8.23 t ha^{-1} and 4.48 t ha^{-1} and the variety which presented the lowest biomass was GAZELLE with 7.89 t ha^{-1} and 3.54 t ha^{-1} respectively in sole crops and in intercrop at Mwea. Variety TGX1990-5F showed the highest biomass of 14.7 t ha^{-1} followed by SB19 with 7.29 t ha^{-1} and of biomass while GAZELLE recorded the lowest biomass of 5.38 g in sole crops at Embu in long rains. Variety TGX1990-5F showed the highest biomass followed by SB19 while GAZELLE recorded the lowest biomass as sole crop and in intercrop at Embu in the long rains. The short rains produced the lowest biomass compared to the long rains(Table 3.6, page 39). Plant biomass of Mwea ranged from 2 t ha^{-1} to about 10 t ha^{-1} while at Embu plant biomass ranged from 1 t ha^{-1} to 4 about ha^{-1}. TGX1990-

5F showed the highest biomass followed by SB19 while GAZELLE presented the lowest biomass at Mwea both in sole crops and intercrops. GAZELLE showed the highest amount of biomass of 4.3 t ha^{-1} followed by TGX1990-5F with 3.98 t ha^{-1} while SB19 showed the lowest amount of biomass of 2.57 t ha^{-1} in sole crops at Embu in short rains. Variety TGX1990-5F recorded the highest biomass of 2.98 t ha^{-1} followed by GAZELLE with 2.09 t ha^{-1} of biomass while SB19 recorded the lowest biomass of 1.63 t ha^{-1} in intercrops at Embu. Intercropping reduced plant biomass both seasons and both rains seasons (Table 3.6, page 39).

Table 3.6 : Soybean 100 grain weight, biomass at Embu and Mwea during long rain of 2016 and short rain of 2016-2017

	Long rains 2016					
	100GW			BIOM		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	16.47b	16.67c	16.57b	7.29b	8.23c	7.72c
GAZELLE	24.71a	24.33ab	24.52a	5.38b	7.89c	6.6c
TGX1990-5F	16.10b	18.33bc	17.22b	14.7a	12.9a	13.8a
SB19+MAIZE	24.05a	27.00a	25.52a	2.23b	4.48d	3.35c
GAZELLE+MAIZE	14.69b	14.67c	14.68b	2.92b	3.54d	3.23c
TGX1990-5F+MAIZE	14.49b	20.33abc	17.41b	7.51b	10.6ab	9.05b
Mean	18.42	20.22	19.32	6.67	7.9	7.3
LSD0.05	2.256	6.557	3.741	6.85	2.51	4.56
CV%	6.7	17.8	14.2	56.4	17.4	48.8
	Short rains seasons					
	100GW			BIOM		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	13.09ab	11.24b	12.17a	2.57bc	4.92a	3.7b
GAZELLE	14.27a	12.98ab	13.63a	4.30a	4.84a	4.5b
TGX1990-5F	11.95ab	12.43ab	12.19a	3.98ab	10.06a	7.02a
SB19+MAIZE	10.23b	11.45b	10.84a	1.63c	3.43a	2.53b
GAZELLE+MAIZE	14.35a	12.79ab	13.57a	2.09c	2.11a	2.1b
TGX1990-5F+MAIZE	14.24a	14.62a	14.43a	2.98abc	5.86a	4.42b
Mean	13.02	12.58	12.80	2.9	5.2	4.04
LSD0.05	3.130	2.671	3.741	9.39	41.35	4.56
CV%	13.2	11.7	14.2	29.4	72.4	48.8

100GW: 100 Grain weight (g)**, BIO: Biomass** (T ha^{-1})

3.4.10 Soybean yield

Soybean yield showed significant difference ($p \leq 0.05$) between sites in the long rains 2016 (Table 3.7, page 42). Soybean yield ranged from 0.6 t ha^{-1} to 3.7 t ha^{-1} at Mwea recording higher yields than Embu where soybean yield ranged from 0.44 t ha^{-1} to 2.17 t ha^{-1} in sole crop and intercrop in the long rain seasons. However, in the short rains, soybean yield ranged from 0.3 t ha^{-1} to 1.4 t ha^{-1} at Mwea recording lower yields than Embu where soybean yield ranged from 0.15 t ha^{-1} to 1.75 t ha^{-1} in sole crop and intercrop. In long rain season, TGX1990-5F presented the highest yield followed by SB19 while GAZELLE showed the lowest yield in the sole crop and intercrop at Mwea(Table 3.7, page 42). However, at Embu, variety GAZELLE presented higher grain yield of 2. 17 t ha^{-1} followed by SB19 with 1.44 t ha^{-1} compared to TGX1990-5F which recorded the lowest yield of 0.91 t ha^{-1} in sole crop. In the intercrop, variety SB19 recorded higher grain yield of 1.08 t ha^{-1} followed by GAZELLE with 0.75 t ha^{-1} compared to TGX1990-5F with the lowest grain yield of 0.44 t ha^{-1} in long rain season. GAZELLE recorded higher grain yield of 1.4 t ha^{-1} followed by SB19 with 1.3 t ha^{-1} in sole crop compared to TGX1990-5F with lower grain yield of 0.7 t ha^{-1} at Mwea (Table 3.7, page 42). At Embu, in short rains, GAZELLE showed the highest grain yield of 1.75 t ha^{-1} followed by 0.98 t ha^{-1} for TGX1990-5F compared to SB19 with the lowest grain yield of 0.92 t ha^{-1} in sole crops. However, TGX1990-5F recorded the highest grain yield of 0.43 t ha^{-1} followed by 0.39 t ha^{-1} for GAZELLE while SB19 recorded the lowest grain yield of 0.15 t ha^{-1} in intercrops at Embu. Mwea produced higher yield compared to Embu both seasons. Intercropping reduced soybean grain yield in both sites and seasons (Table 3.7, page 42).

3.4.11 Soybean harvest index

Harvest index (HI) showed significant difference between sites and seasons ($p \leq 0.05$) (Table 3.7, page 42). HI ranged from 0.17 to 0.42 at Mwea while Embu HI ranged from 0.10 to 0.54. SB19 variety presented the highest HI of 0.42 and 0.18 followed by 0.33 and 0.17 for GAZELLE while TGX1990-5F recorded the lowest HI of 0.29 and 0.17 in sole crops and in intercrops respectively at Mwea in long rainy seasons. However, GAZELLE presented higher HI of 0.48 followed by SB19 with 0.21 HI compared to TGX1990-5F with the lowest HI of 0.06 in sole crops at Embu long rain season. At Mwea, SB19 showed the highest HI of 0.42 followed by GAZELLE with 0.33 and TGX1990-5F recorded the lowest HI of 0.29 in the long rain season in the sole crop. The short rains showed lower HI than the long rains. In the short rain, Mwea site did not give significant difference among treatments and HI ranged from 0.1 to 0.3 while Embu HI differed and ranged among 0.1 to 0.39 (Table 3.7, page 42). GAZELLE and SB19 showed higher HI of 0.3 and 0.2 compared to TGX1990-5F with the lowest HI of 0.1 and 0.2 at Mwea in sole crops and intercrop respectively. However, variety GAZELLE showed the highest HI of 0.39 and 0.20 followed by SB19 with HI of 0.36 and 0.10 compared to TGX1990-5F with the lowest HI of 0.26 and 0.17 respectively in sole crop and intercrop at Embu in shotrt rain season. Intercropping reduced HI both sites and both seasons. Mwea produced the highest HI in both season compared to Embu (Table 3.7, page 42).

3.4.12 Land Equivalent Ratio

LER did not give significant difference between sites in the long rains 2016. LER differed among treatments at Mwea where it ranged from 1.3 to 1.9 (Table 3.7, page 42). At Embu, LER did not give significant difference among treatments and it ranged from 1.5 to 1.8. TGX1990-5F showed the highest LER of 1.9 followed by SB19 with LER of 1.5, while GAZELLE presented the lowest LER of 1.3 at Mwea in long rain seasons. At Embu, variety SB19 showed the highest LER of 1.8 followed by GAZELLE with LER of 1.7 while TGX1990-5F produced the lowest LER of 1.5 in the long rains of 2016 (Table 3.7, page 42). During the short rains LER showed significant difference between sites ($p \leq 0.05$). LER ranged from 1.10 to 2 at Mwea while at Embu LER was among 1 .06 to 1.62. Variety TGX1990-5F showed the highest LER of 2.04 followed by SB19 with 1.31 while the variety of GAZELLE presented the lowest LER of 1.10 at Mwea (Table 3.7, page 42). Embu did not give significant difference among treatments but TGX1990-5F showed higher LER of 1.62 followed by GAZELLE with LER of 1.53 while SB19 showed the lowest LER of 1.07 in the short rains. LER showed advantage between maize-soybean intercropped because it recorded higher value than 1. TGX1990-5F was taken as the best promiscious soybean for intercropping with maize because it showed land equivalent ratio higher than other varieties (Table 3.7, page 42).

Table 3.7: Soybean yield in, Harvest index and Land equivalent ratio in long rain at Embu and Mwea during long rain of 2016 and short rain of 2016-2017

	Long rain 2016								
	YTHA			HI			LER		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	1.44b	3.1bc	2.27a	0.21c	0.42a	0.32a	1.8a	1.5b	1.66a
GAZELLE	2.17c	2.6b	2.38a	0.48ab	0.33ab	0.41a	1.7a	1.3b	1.51a
TGX1990-5F	0.91ab	3.7c	2.31a	0.06c	0.29ab	0.18b	1.5a	1.9a	1.7a
SB19+MAIZE	1.08b	0.8a	0.94b	0.54a	0.18b	0.36a	1.7a	1.5b	1.61a
GAZELLE+MAIZE	0.75ab	0.6a	0.68b	0.28c	0.17b	0.11b	1.8a	1.3b	1.56a
TGX1990-5F+MAIZE	0.44a	1.7ab	1.07b	0.10c	0.17b	0.14b	1.5a	1.9a	1.7a
Mean	1.13	2.08	1.61	0.28	0.26	0.25	1.66	1.6	1.63
LSD0.05	0.06	0.86	0.64	0.24	0.86	0.18	0.40	0.27	0.47
CV%	3.2	22.3	32	46.6	22.3	45.1	13.3	9.5	18.8
	Short rain 2016-2017								
			YTHA			HI			LER
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	0.92a	1.3a	1.11b	0.36ab	0.3a	0.33ab	1.07a	1.31ab	1.19b
GAZELLE	1.75a	1.4a	1.58a	0.39a	0.3a	0.35a	1.53a	1.10a	1.31b
TGX1990-5F	0.98a	0.7bc	0.84b	0.26abc	0.1a	0.18ab	1.62a	2.04b	1.83a
SB19+MAIZE	0.15a	0.3c	0.23b	0.10c	0.2a	0.15b	1.07a	1.31ab	1.19b
GAZELLE+MAIZE	0.39a	0.3c	0.35b	0.20abc	0.2a	0.2ab	1.53a	1.10a	1.32b
TGX1990-5F+MAIZE	0.43a	0.8b	0.62b	0.17bc	0.2a	0.19ab	1.62a	2.04b	1.83a
Mean	0.77	0.8	0.85	0.25	0.22	0.24	1.40	1.48	1.45
LSD0.05	1.09	0.39	0.64	0.19	0.23	0.18	0.69	0.43	0.47
CV%	77.2	26	32	43.6	61.8	45.1	24.9	16	18.8

YTHA: Yield in tone per ha, HI: Harvest index, LER: Land Equivalent Ratio, LSD: Least significant difference, CV: Coefficient of variation

Table 3.8 on page 43 shows that the sites showed significant difference on days to 50 % flowering and days to 75 % maturity. The combined analysis of variance of maize in sole crop and in intercrop showed that, interaction among treatments x sites x seasons did not show significant difference in all parameters ($P \leq 0.05$). The combination of season x site showed significant difference on 75 % maturity, 100 grain weight and land equivalent ratio and did not show significant difference on other parameters. Interaction between treatment x site did not give significant difference on all parameters (Table 3.8, page 43). The interaction between treatments x seasons did not show significant difference on all parameters also. The seasons showed significant difference in all parameters while treatments did not show significant difference in all parameters.

Table 3.8: Mean square of Maize germination rate, plant height, days to 50 % flowering, days to 75 % maturity at Embu and Mwea in sole crop and in intercrop during long rain of 2016 and short rain of 2016-2017

Source of variation	Df	GRM	PH	D50PF	D75PM
Replications	2	6.80	167.3	133.33	133.33
Treatments	3	33.10^{NS}	17.3^{NS}	0.00^{NS}	0.00^{NS}
Seasons	1	149.81*	35795.8*	133.33*	133.33*
Sites	1	60.75^{NS}	432.0^{NS}	3333.33*	3333.33*
Treatments x Seasons	3	49.48^{NS}	404.0^{NS}	0.00^{NS}	0.00^{NS}
Treatments x Sites	3	38.77^{NS}	111.6^{NS}	0.00^{NS}	0.00^{NS}
Seasons x Sites	1	75.00^{NS}	514.8^{NS}	133.33^{NS}	133.33*
Treatments x Seasons x sites	3	38.73^{NS}	98.6^{NS}	0.00^{NS}	0.00^{NS}
Residual	30	28.46	407.1	19.05	19.05
Total	47				

*Significant on $p \leq 0.05$, DF: Degree of freedom, GRM: Germination %, PHt: Plant height, D50PF: Days to 50 % flowering, D75PM: Days to 75% maturity.

Table 3.9 on page 44 for combined analysis of variance of Maize in sole crop and in intercrop showed that, interaction among treatments x sites x seasons did not show significant difference in all parameters ($P \leq 0.05$). The combination of season x site showed significant difference on 100 grain weight and land equivalent ratio and did not show significant difference on other parameters (Table 3.9 on page 44). Interaction between treatment x site gave significant difference only on LER. The interaction between treatment x season showed significant difference on LER also. The sites showed significant difference on 100 grain weight, biomass t ha $^{-1}$, yield t ha $^{-1}$ and LER. The seasons showed significant difference in all parameters while treatments did not show significant difference in all parameters (Table 3.9 on page 44).

Table 3.9: Mean square on one hundred grains weight, biomass in t ha^{-1}, yield in t ha^{-1}, harvest index, and land equivalent ratio of Maize at Embu and Mwea in two rain seasons in sole crop and in intercrop

Source of variation	Df	100GW	BIO T HA-1	YTHA	HI	LER
Replications	2	3.06	54.03	4.875	0.1750	0.16292
Treatments	3	0.96^{NS}	9.31^{NS}	0.391^{NS}	0.1884^{NS}	0.13606
Seasons	1	1870.75*	1139.21*	135.946*	0.7009^{NS}	4.63142*
Sites	1	4667.72*	767.70*	334.963*	0.3018^{NS}	5.92910*
Treatments x Seasons	3	2.23^{NS}	6.69^{NS}	1.013^{NS}	0.2425^{NS}	0.35712*
Treatments x Sites	3	5.67^{NS}	3.80^{NS}	1.803^{NS}	0.2176^{NS}	0.25947*
Seasons x Sites	1	733.67*	29.26^{NS}	0.517^{NS}	0.5239^{NS}	11.57385*
Treatments x Seasons x sites	3	4.35^{NS}	9.77^{NS}	1.977^{NS}	0.1657^{NS}	0.21964
Residual	30	14.44	12.10	1.150	0.2027^{NS}	0.07367
Total	47					

* Significant on $p \leq 0.05$, df: Degree of freedom, SHAT: Shattering score, 100GW: 100Grain weight, BIOT HA^{-1} : Biomass in tonne per ha, YTHA: Yield in tonne per ha, HI: Harvest index, LER: Land equivalent ratio.

3.4.13 Germination rate, plant height, days to 50 % flowering and Days to 75% to maturity for Maize

Table 3.10 on page 45 showed that germination % of maize (DUMA 43) intercropped with soybeans and sole crops did not show significant difference at both sites and both rain seasons. In addition, maize plant height did not also give significant difference among treatments and sites in intercropping and in sole crops ($P \leq 0.05$). However, the days to 50 % flowering for maize were between 83-85 at Embu and 63-64 at Mwea for the long rains 2016 while it took 77 days at Embu, and 63-64 days at Mwea for the short rains of 2016-2017 (Table 3.10, page 45). The days to 75% maturity were between 120-121 at Embu while at Mwea maize crops did not produce ears because of MLN which attacked the maize crops (Table 3.10, page 45) for the long rains 2016, but for the shot rains of 2016-2017, MLN did not appear in the field. Days to 75% to maturity did not show signicant difference between sites and seasons.

Table 3.10: Germination %, plant height, days to 50 % flowering, days to 75 % maturity at Embu and Mwea of Maize during long rain of 2016 and short rain of 2016-2017

Long rains 2016												
	GRM			PH			D50PF			D75PM		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
Sole Maize	99.33a	99a	99.17a	112.1a	112.1a	112.1a	83.7b	64a	73.83a	120a	100a	110a
SB19 + Maize	99.33a	100a	99.67a	127.8a	127.7a	127.8a	84.7b	63.7a	74.16a	120.33a	101.67a	111a
Gazelle + Maize	99.67a	98.33a	99a	119.4a	119.5a	119.5a	83b	64a	73.5a	120a	100.33a	110.17a
TGX1990-5F+ Maize	100a	100a	100a	121.1a	118.9a	120a	85.33a	64.3a	74.83a	121a	101.33a	105.67a
Mean	99.58	99.33	99.33	120.1	119.55	119.83	84.16	64	74.08	120.33	100.83	110.58
LSD	20.34	6.66	8.9	32.25	31.44	33.4	2.13	1.37	8.97	1.91	1.97	5.16
CV%	10.9	3.4	5.5	13.4	13.2	13.6	1.3	1.1	7.4	0.8	1.0	4.0
Short rains 2016-2017												
	GRM			PH			D50PF			D75PM		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
Sole Maize	94.67a	100a	97.34a	164a	193.7a	178.9a	77.33a	63.67a	70.5a	113.3a	100a	106.7a
SB19 + Maize	98.67a	96.67a	97.67a	161.3a	172a	166.7a	77.67a	63.67a	70.67a	113.67a	100a	106.8a
Gazelle + Maize	97.67a	98.87a	98.27a	175.3a	178.8a	177.1a	77.33a	64a	70.67a	114.33a	100.67a	107.5a
TGX1990-5F+ Maize	83.20a	97.67a	90.44a	172a	178.4a	175.2a	77.33a	64a	70.67a	113.3a	100.33a	106.7a
Mean	93.55	98.30	95.93	168.15	180.73	174.44	77.42	63.84	70.63	113.65	100.25	106.9
LSD	20.34	6.66	8.9	20.16	33.75	33.4	1.52	1.37	8.97	1.91	1.49	5.16
CV%	10.9	3.4	5.5	6.0	11.5	13.6	1.0	1.1	7.4	0.8	0.7	4.0

GRM: Germination, PHt: Plant height (cm) and D50PF: Days to 50 percent flowering, D75PM: Days to 75 percent maturity, LSD: Least significant difference. Means bearing the same letter are in the same group.

3.4.14 One hundred grain weight, biomass per plant and yield for Maize

Table 3.11 on page 46 on one hundred grain weight for maize did not give significant difference between sites for the long rains of 2016. Mwea did not produce maize grains because of MLN which destroyed maize plant. Mwea showed 100 GW ranging from 26 g to 28 g. The significant difference for 100 GW occured in the short rains 2016-2017 at Mwea, where it ranged from 19 g to 21 g. 100 GW from Embu ranged from 31 g to 34 g. Embu produced higher amount of 100 GW for both seasons compared to Mwea in sole crop and in intercropping (Table 3.11 on page 46). However, plant biomass showed significant difference between sites and seasons. The biomass ranged from 5 t ha^{-1} to 17 t ha^{-1} in sole crop and in intercropping at Mwea while plant biomass was among 12 t ha^{-1} to 15 t ha^{-1} at Embu. During the short rains of 2016-2017, plant biomass ranged from 3. 66 t ha^{-1} to 17 t ha^{1} at Mwea and 12 t ha^{-1} to 23 t ha^{-1} at Embu in sole crop and in intercropping. Embu produced the highest plant biomass both seasons. Intercropping did not affect plant biomass at both sites and seasons (Table 3.11 on page 46). Maize grain yield did not give significant difference between sites and seasons. Mwea site did not produce maize grain yield beause of MLN which attacked crops in the long rains season 2016 but the experiment produced biomass which helped us to calculate LER. Maize grain yield ranged from 4.45 t ha^{-1} to 5.67 t ha^{-1} at Embu. During the short rains 2016-2017, maize grain yield ranged among 2.63 t ha^{-1} to 3.53 t ha^{-1} at Mwea while Embu maize grain yield was among 7.49 t ha^{-1} 9.62 t ha^{-1} in intercropping and in sole crop. Mwea produced the lowest amount of maize grain yield compared to Embu. Embu produced the highest amount of maize yield during the short rains 2016-2017 than the long rains 2016. Intercropping did not reduce maize grain yield both sites and seasons (Table 3.11, page 47).

Table 3.11: One hundred grains weight, biomass, and maize grain yield at Embu and Mwea of Maize during long rain of 2016 and short rain of 2016-2017

	Long rains 2016								
	100GW			BIOM			GY		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
Sole Maize	28.32a	0.00	14.16a	12.7a	3.66b	8.15b	4.53a	0.00	4.53a
SB19 + Maize	26.92a	0.00	13.46a	15.32a	17.68a	16.51a	5.67a	0.00	5.67a
Gazelle + Maize	28.45a	0.00	14.23a	13.55a	17.35a	15.45a	5.65a	0.00	5.65a
TGX1990-5F+ Maize	26.48a	0.00	26.48a	13.78a	5.15b	9.47b	4.45a	0.00	4.45a
Mean	27.54	0.00	13.77	13.84	10.96	12.4	5.08	0.00	5.08
LSD	9.12	-	6.337	5.01	1.41	5.8	1.93	-	1.79
CV%	16.6	0.00	19.0	18.1	16.4	25	19	0.00	25.4
	Short rains 2016-2017								
	100GW			BIOM			GY		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
Sole Maize	30.32a	20.62ab	25.47a	12.7b	3.66b	8.2b	8.18a	3.53a	5.86
SB19 + Maize	31.58a	21.22a	26.40a	15.3b	4.46b	9.89b	7.40a	3.47a	5.43
Gazelle + Maize	34.12a	19.15b	26.64a	23.12a	17.35a	20.23a	9.62a	2.63a	6.12
TGX1990-5F+ Maize	32.81a	20.23ab	26.52a	22.67a	12.1b	17.36a	9.40a	3.00a	6.2
Mean	32.21	20.30	26.26	18.46	9.38	13.92	8.65	3.15	5.9
LSD	12.46	1.893	6.337	6.64	9.74	5.8	3.17	17.9	1.79
CV%	19.4	4.7	19.0	15.1	31.3	25	18.3	28.3	25.4

100GW: 100 grain weight, BIOM: Biomass in T ha-1, GY: Grain Yield in T ha^{-1}, LSD: Least significant difference, CV: Coeffient of variation. Means bearing the same letter are in the same group.

3.4.15 Maize harvest index

Maize HI did not show significant difference between sites and seasons ($p \leq 0.05$). Mwea site did not produce HI because of maize which were destroyed by MLN that is why they did not produce maize grain yield which could help for computing HI. Embu HI for long rains of 2016 recording among 0.32 to 0.42. In addition, in the short rains Mwea HI ranged from 0.1 to 1.23 while in Embu HI ranged from 0.33 to 0.43. Intercropping did not reduce maize HI at both sites and seasons (Table 3.12, page 47).

3.4.16 Land Equivalent Ratio

During the short rains 2016-2017, LER differed among treatements at Mwea and ranged from 1.31 to 2.04 while Embu site did not show significant difference among treatments and ranged from 1.07 to 1.62. LER did not show significant difference between sites for the long rains of 2016 ($p \leq 0.05$). Mwea showed significant between treatments and LER ranged from 1.3 to 1.9. Embu recorded LER ranging from 1.5 to 1.8. Intercropping did not reduce LER for the components crops. LER showed advantage between component crops because it was higher than 1. Maize plant biomass helped in computing LER in the long rain of 2016 because maize did not produce grain yield due to MLN (Table 3.12).

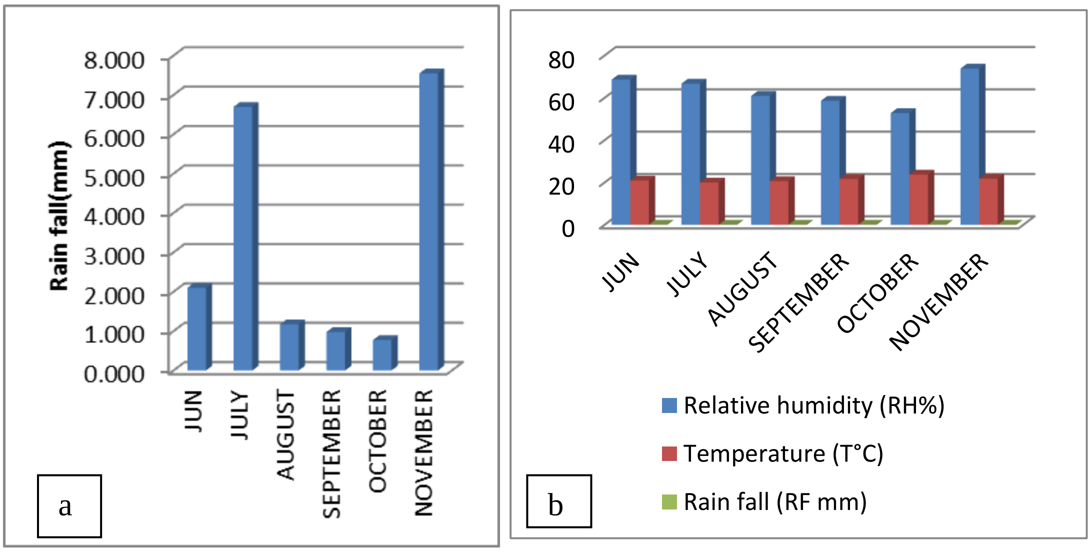
Table 3.12 : Maize harvest index, Land Equivalent Ratio at Embu and Mwea during long rain of 2016 and short rain 2016-2017

	Long rains 2016					
	HI			LER		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean
Sole Maize	0.35a	0	0.35a	1.7a	1.5b	1.6a
SB19 + Maize	0.38a	0	0.38a	1.8a	1.5b	1.7a
Gazelle + Maize	0.42a	0	0.42a	1.7a	1.3b	1.5a
TGX1990-5F+ Maize	0.32a	0	0.32a	1.5a	1.9a	1.7a
Mean	0.37	0	0.37	1.68	1.56	1.62
LSD	0.15	-	0.75	13.1	0.30	0.47
CV%	20.8	-	147.8	0.44	9.6	23.5
	Short rain s 2016-2017					
	HI			LER		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean
Sole Maize	0.43a	0.23a	0.33a	1.07a	1.98ab	1.53ab
SB19 + Maize	0.33a	0.20a	0.27a	1.07a	1.31b	1.19b
Gazelle + Maize	0.42a	0.15a	0.29a	1.62a	2.04a	1.83a
TGX1990-5F+ Maize	0.42a	1.23a	0.83a	1.6a	2.04a	1.82a
Mean	0.4	0.45	0.43	1.34	1.84	1.58
LSD	0.14	1.78	0.75	0.70	0.60	0.45
CV%	17.6	197.7	147.8	26.5	18.9	23.5

Harvest index, LER: Land equivalent ratio, LSD: Least significant difference, CV: Coeffient of variation. Means bearing the same letter are in the same group.

3.4.2 Weather data during the experiment duration Long rain 2016

The mean rain falls (mm) during the experiment duration were 3.21 mm and 0.007 mm at Embu and Mwea respectively. Rain fall from Mwea were very negligible. However, the mean for temperature and relative humidity were respectively 21.42°C and 63.54 % at Mwea (Figure 3.5).



: (a)

Figure 3.5 : Weather data at EMBU site, (b) Weather data at MWEA site.

3.5 Discussion

3.5.1 Growth paramaters

3.5.1.1 Germination rate in percentage (%)

During the long rains of 2016, germination % for soybeans was not different in the sole crop and the intercrops between the sites (Table 3.3 page 33). However, during the short rains significant difference was observed in the sole crops and the intercrops between the sites. Germination % was higher during the long rains recorded 90 % compared to the short rains that recorded between 67 to 79%. The good prefomance in germination % during the long rains could be justified by the water for irrigation as supplement to rain fall at both sites which was more available in the long rains than in the short rains. Germination % of Maize did not show significant difference between sites both seasons ($p \leq 0.05$). Germination % of maize ranged from 98 % to 100 % at Mwea, while it ranged from 99 % to 100 % at Embu in the long rain of 2016 in intercropping and in sole crops. This can be attributed to the soil conditions at Embu, which was lighter than Mwea soil which was heavy because of the clay. In addition, the cooler and wetter conditions for the first season may have increased germination % in both sites. The short rains presented the lowest germination % than the long rain of 2016. Mwea germination % ranged from 96.67 % to 100 % and 83.20 to 98.67 % at Embu. Intercropping did not reduce the germination % of maize and soybean at both sites and seasons. Mwea site presented higher amount of maize germination % than Embu in both seasons (Table 3.10, page 45). This could be due to the presence of water for irrigation on time at Mwea while at Embu some time the water was not available in time. The poor germination % for the short rain seasons can be justified by the drought which was pronounced during critical growth phase of crops, hence, the high temperature could have reduced germination %. This agrees with Wang, (2005) who reported that, high temperatures

(>15°C) and insufficient soil water reduced germination % in his experiment on different crops grown by farmers .

3.5.1.2 Plant height (cm)

Soybean plant height showed significant difference ($p \leq 0.05$) between sites and seasons. Mwea recording the tallest plant height ranging from 47 to 67 cm while Embu presented the shortest plant height ranging between 40 to 55 cm in the long rains. Plant heights ranged form 46 to 67 cm between sites. GAZELLE variety had the lowest plant height compared to other varieties with 44.67cm and 56.83cm at Embu and Mwea respectively in sole crop. TGX1990 – 5F recorded the highest PHt of 54 cm and 81 cm for Embu and Mwea respectively in sole crop too. The tallest PHt at Mwea could have been induced by the water for irrigation which was available on time compared to Embu where crops got irrigation water after long time of struggle with the drought. On the other hand, this could be due to genetic makeup of each variety. However, the presence of water at Mwea allowed nutrients uptake for the crops compared to Embu. These results confirm results for Hermanson (2015) who said that insufficient water supply can limit efficient nitrogen uptake for good growth condition of plant while Rezaei *et al.* (2009) reported that water stress reduces plant nutrients uptake and reduces photosynthesis. Maize PHt did not show significant difference in both sites and in two seasons. Maize plant height ranged from 112 cm to 119 cm at Mwea compared to Embu where it ranged from 112 cm to 120 cm. The short PHt for maize at Mwea in long rain could be justified by MLN incidence and severity which were more pronounced at Mwea than Embu. During the short rains, Mwea registered maize PHt of 172 cm to 193 cm while Embu recorded maize PHt ranging from 161 cm to 175 cm. The tallest maize PHt recorded for the short rains at both sites can be attributed to the absence of MLN which would have reduced growth conditions for the maize. Also, the tallest soybean at Mwea for the long rains can be justified by the poor developpment of maize leaves attacked by MLN, thus the shading effect and competition from maize was minimal. However, all soybean varieties recorded the tallestPHt in sole crops compared to the intercrops both rain seasons. For instance, TGX1990-5F recorded 54cm in sole and 52.2 cm in intercrop at Embu while it recorded 81 cm in sole and 67.40 cm in intercrop at Mwea. This could be attributed to the effect of shading where taller crops compete with shorter crops for sunlight, water, nutrients and air. These results confirm Simpson's (1999) results, that; soybean is susceptible to moisture competition, probably a result of relatively small root system and inherently low water use efficiency. While Ijoyah (2012) reported that, light interception in intercropping had negative impact on plant height for short crops than taller crops compared to sole cropping. In addition, maizePHt was not affected by intercropping in both sites and seasons. This agrees with Muoneke *et al*. (2007), who reported that,PHt did not show significant difference among sole maize and intercropped maize while Thobatsi (2009), also found that maize in intercropping with cowpea did not have any effect on maize plant height.

3.5.1.3 Days to 50 % flowering and Days to 75 % maturity

Days to 50 % flowering and 75 % maturity for soybean in the sole and the intercrop systems differed between the sites ($p \leq 0.05$). However the trend for days to 50 % flowering and days to 75 % maturity was similar for the 2 seasons at Mwea. Days to 50 % to flowering ranged from 69 days to 84 days at Embu while at Mwea it ranged from 48 days to 64 days among varieties in both seasons. In addition, days to 75 % to maturity ranged from 95 days to 121 days at Embu and 80 days to 95 days at Mwea in both seasons. Days to 50 % flowering and 75 % maturity were low at Mwea compared to Embu. This might be due to the fact that, Mwea is in low altitude compared to Embu which is high altitude. Higher altitude could increase days to 50 % flowering and 75 % maturity while lower altitude could narrow 50 % flowering and 75 % maturity. For days to 50 % flowering, the early variety to flowering

SB19 took 49 days while the late variety to flowering TGX1990-5F took 64 days at Mwea in both seasons. The early variety to flower SB19, took 69 days while the late variety to 50 % flowering TGX1990 – 5F took 84 days at Embu. However, the early variety to 75 % to maturity SB19 took 80 days while the late variety TGX1990-5F took 95 days at Mwea. The early variety to 75 % to maturity SB19 took 95 days while the late variety TGX1990-5F took 121 days both seasons. This variation could be justified by genetic makeup of different varieties. The variation in flowering and maturity could also be attributed to the climatic conditions in which the experiments were conducted. Mwea site is low altitude which resulted to the early crop maturity, while Embu high altitude enhanced the late crops maturity. This has also been reported by Sileshi (2013) who said that, soybean varieties can be early maturing because of some genetic characteristics or environment. Nevertheless, intercropping did not reduce soybean and maize days to 50 % flowering and 75 % maturity at both sites and both seasons. This agrees with Abubaker (2008) who reported that, intercropping of maize and beans had no effect on days to 50 % flowering and 75 % maturity of both component crops.

3.5.1.4 Biomass yield (t ha^{-1})

Soybean biomass showed significant difference ($p \leq 0.05$) between sites and seasons. TGX1990-F had the highest biomass of 12.9 t ha^{-1} followed by SB19 with 8.23 t ha^{-1} in sole crop and GAZELLE presented the lowest amount of biomass with 3.54 t ha^{-1} in intercropping at Mwea. Variety TGX1990-5F presented the highest biomas of 14.7 t ha^{-1} compared to SB19 with the lowest biomass of 7.29 t ha^{-1} in sole crop at Embu. The highest biomass production by TGX1990-5F compared to other varieties could be justified by its high plant height, vigour and yield. This agrees with Sileshi (2013) who reported that, high biomass production for soybean varieties could be due to their agronomic perfomances. SB19 produced the lowest amount of biomass in intercropping in the long rain of 2016. The short rains showed the lowest amount of biomass compared to the long rains. TGX1990-5F showed the highest biomass of 10 t ha^{-1} in sole crop and GAZELLE presented the lowest amount of biomass of 2.11 t ha^{-1} at Mwea in intercropping. At Embu, GAZELLE showed the highest amount of biomass of 4.3 t ha^{-1} in sole crops while SB19 showed the lowest amount of biomass of 1.63 t ha^{-1} in intercropping. Intercropping reduced plant biomass in both seasons. Mwea produced higher soybean biomass compared to Embu in both seasons. The highest soybean biomass produced at Mwea compared to Embu could be attributed to the availability of water from irrigation as supplement for rainfall at Mwea than Embu. Also it could be explained by the DAP fertilizer applied before planting both sites. This finding agrees with Mugendi *et al*. (2010) who said that, application of fertilizer which contain nitrogen would be also the base of high biomass production. However, Geren *et al*. (2008) reported that, intercropping of climbing bean, cowpea with corn improved total fresh yield biomass of the component crops. In addition, intercropping system increases not only yield stability but also contribute to mixed crops yielding more biomass than monocrops (Karpenstein-machan and Stuelpnagel, 2000). In the contrast, Sarkodie & Kahaman, (2012) and Fujita, (1992) reported that, intercropping system reduced soybean biomass production than the monocrop when the component crops are compiting for moisture, sunlight and nutrients. However, maize biomass showed significant difference between sites and seasons. The biomass ranged from 5 t ha^{-1} to 17 t ha^{-1} in sole crop as in intercropping at Mwea while plant biomass was from 12 t ha^{-1} to 15 t ha^{-1} at Embu. During the short rains of 2016-2017, maize biomass ranged from 3. 66 t ha^{-1} to 17 t ha^{-1} at Mwea and 12 t ha^{-1} to 23 t ha^{-1} at Embu in sole crop as in intercropping. Embu produced the highest amount of maize biomass at both seasons. The higher maize biomass produced at Embu than at Mwea in long rains could be justified by the minimal incidence and severity of MLN at Embu compared to Mwea where MLN presented maximal incidence and severity on maize which could result to reduction of maize biomass production. For the short rains, the high maize biomass produced could be due to the good adaptation of the variety Duma 43 at Embu than at Mwea. It can also be explained by the climatic conditions, because Embu is in high altitude which increased the number of days of vegetation growth, hence the biomass increased while the low altitude for Mwea reduced the number of days of vegetation hence the reduction of biomass. Intercropping did not affect maize biomass at both sites and seasons. These results agrees with Presad and Brook (2005) who reported that intercopping of cereal-legumes did not affect maize biomass.

3.5.1.5 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 at Embu the of 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. Variety TGX1990-5F presented the highest number of nodules 43.6 in sole crop and GAZELLE recorded the lowest number of nodules 29.87 in intercropping at Embu long rain of 2016. During the short rain, 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. These results agrees with the one of 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*. The variety which recorded the highest number of nodules was TGX1990-5F with 46.8 in sole crop as in intercropping compared to SB19 which presented the smallest number of nodules of 33 at Mwea in intercropping. TGX1990-5F showed the highest number of nodules of 43.7 in sole crop while

SB19 recorded the smallest number of nodules of 29.8 at Embu in sole crop. Intercropping did not reduce the number of nodules per plant at both sites and both seasons. Mwea site presented the highest number of nodules compared to Embu which produced lowest number of nodules both seasons. This could be justified by the good soil moisture conditions at Mwea compared to Embu. The soil at Mwea received regular water from irrigation as supplement to rainfall and this condition could allow good development of microorganisms particulary the strains rhizobia which could permit good nodulation at Mwea than at 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. However, 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 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. That situation can justify the low amount of biomass produced by that variety in intercropping in both seasons and both sites in agreement with Issahaku (2010) who reported that, intercropping maize-soybean reduced the soybean nodulation.

3.5.2 Production parameters

3.5.2.1 Number of pods per plant and seeds per pod

During the long rains of 2016, the number of pods per plant presented significant differences between sites in the sole crop as in the intercrop. The short rains did not show significant differences between the sites. TGX1990-5F presented the highest number of pods of 107 followed by SB19 with 81 pods per plant in sole crop. GAZELLE showed the lowest number of pods of 46 in intercropping at Mwea. TGX1990-5F recorded the highest number of pods of 82.7 in sole crop while GAZELLE recorded the lowest number of pods of 13 in intercropping at Embu in the long rain of 2016. The difference between varieties in pod production could be justified by genetic caracteristics for each variety. During the short rains the number of pods was reduced in both sites compared to the long rain of 2016. TGX1990-5F recorded the highest number of pods and GAZELLE presented the lowest number of pods in sole crops and in intercropping. The reduction of the number of pods per plant in the short rains could be explained by the climatic conditions which were not good like insufficient rainfall which reduced the growth of the plant. Intercropping reduced the number of pods per plant both seasons. These findings concur with (Sloger, 1969) who reported that, the number of pods per plant can be reduced by intercropping when the component crop has capacity to develop large leaves which causes shading hence photosynthesis is reduced as key point of pod formation. Mwea site presented the highest number of pods compared to Embu in both seasons. The highest number of pods presented by Mwea site is explained by the unhealthy conditions of maize associated with MLN which developed small quantities of leaves and which could not intercept the light and compete more efficiently on nutrients uptake with soybean (Kinama *et al*., 2011) in the first season, while in the second season, the highest amount of pods per plant can be explained by the quantity of water which was given to the plants as supplement of rainfall by irrigation. This might be combined also to the high temperature from Mwea ranged between 8.1-30.3°C which could allow the quick decomposition of organic matter. This decomposition could allow the availability of nutrients to increase the growth of the plant, producing high number of pods than Embu where the temperature is ranging between 18-28°C.

In addition, the long rains in 2016 did not show significant difference in seeds per pod between sites. The seeds per pod ranged from 2 to 2.7 at Mwea while they ranged from 1.6 to 2 at Embu. GAZELLE showed the highest number of seeds per pod of 2 at Embu while it received the lowest amount of seed per pod of 2.2 at Mwea in sole crop than other varieties. SB19 showed the lowest amount of seeds per pods of 1.6 at Embu in sole crop. The number of seeds per pod differed significantly during the short rains between sites and ranged from 2 to 3 at Mwea and from 2 to 2.7 at Embu in sole crop and in intercrop respectively. SB19 pesented the highest number of seeds per pods of 3 followed by GAZELLE with 2.5 and the last was TGX199-5F with 2.07 in sole crop at Mwea. Intercropping reduced the number of pods per plant. Mwea site presented the highest number of seeds per pod compared to Embu both seasons. This can be attributed to the unhealthy conditions of maize infected by MLN which developed small quantities of leaves that could not intercept the light and compete more efficiently on nutrients uptake with soybean (Kinama *et al.*, 2011). The situation was not good for the short rain of 2016-2017 where the number of seeds per pod was reduced by 43.82% at Mwea for TGX1990-5F and 23.80% of the same variety at Embu. That could be attributed to unreliable rainfall that was received in the short rains season in both sites, hence the crops were unable to achieve good formation of pods and seeds (Shadreck, 1999). Intercropping did not reduce the number of seeds per pod at both sites and in two seasons. This agrees with Legwaila *et al.* (2012) who said that, the number of flowers for cowpea per plant were decreased by intercropping but that cropping system didn’t decrease significantly the number of seeds per pods and weight of seeds.

3.5.2.2 Shattering score

Shattering score showed significant difference between sites and seasons ($p \leq 0.05$). The shattering score ranged from 11 % to 36 % at Mwea while shattering score trend for Embu ranged from 8 % to 30 % in sole crop as in intercropping. The high number of pods shattering at Mwea compared to Embu can be justified by the low altitude of Mwea which could increase temperature, hence increasing the stattering score (36.67) compared to Embu with high altitude and low temperature, hence reducing the shattering score (30) for GAZELLE in intercropping for the long rain of 2016. This agrees with Haruna (2010); Krisnawati and Adie (2017) who reported that, soybean varieties possessing resistance to pods shattering resistance is most important in improvement of soybean in the tropics where the temperature can lead to the loss of yield through pods shattering. GAZELLE presented the highest shattering score for 36.67 % in intercropping, followed by SB19 (20.7 %) in sole crop while TGX1990-5F showed the lowest shattering score for 11 % in the sole crop at Mwea. The variety for TGX1990-5F presented the lowest shattering score of 8 % at Embu in intercropping in compared to GAZELLE which showed the highest shattering score of 30 % followed by SB19 (25 %) in intercropping too in the long rains 2016. The high shattering score for GAZELLE could be justified by its genetic characteristic to pod shattering compared to other varieties. During the short rains, shattering score ranged between 16 % and 30 % at Mwea, while Embu presented shattering score ranging from 16 % to 52 %. The highest shattering score at Embu could be explained by the drought which occurred during the harvesting period and insufficient water for irrigation at Embu than Mwea. These results are corroborated by Zhang & Bellaloui (2012) who reported that, different weather patterns, especially temperature and rainfall in each year might be essential factors affecting pods shattering patterns. However, GAZELLE presented the highest amount of shattering score of 30.66 % compared to TGX1990-5F which had the lowest shattering score of 16.66 % in sole crops at Mwea. SB19 showed the highest shattering score for 52.22 % while TGX1990-5F showed the lowest shattering score of 13.33 % in intercropping. Thus, following the shattering score scale, TGX1990 – 5F was among varieties which were resistant to pod shattering because it’s score shattering scale was 2, and GAZELLE with SB19 were among varieties which were moderately resistant to pod shattering concidering it’s scale shattering score which was many times 3 than 2 in two rains seasons (Haruna, 2010; Krisnawati & Adie, 2017). Intercropping did not increase pod shattering.

3.5.2.3 Hundred grain weight

100 grain weight showed significant difference ($p \leq 0.05$) between sites in the sole crop as in intercropping. SB19 recorded the highest 100 grain weight of 27 g compared to GAZELLE which recorded the lowest 100 grain weight of 14.67 g in intercropping at Mwea. GAZELLE presented the highest 100 grain weight of 24.71 g in sole crop while it showed the lowest 100 grain weight in intercropping at Embu. However, 100 grain weight did not have significant difference between sites in the short rains but significant difference was observed among treatments in both sites. TGX1990-5F showed the highest 100 grain weight of 14.62 g in intercropping while SB19 presented the lowest 100 grain weight of 11.24 g in sole crop at Mwea. GAZELLE showed the highest 100 grain weight of 14.27 g in sole crop compared to SB19 which had the lowest 100 grain weight of 10.23g at Embu. Mwea presented the highest 100 grain weight than Embu both seasons. The higher 100 grain weight for Mwea compared to Embu could be justified by the good adaptation of varieties at Mwea compared to Embu. This could also result from the availability of the water for irrigation at Mwea compared to Embu in two rainy seasons. However, on the results obtained in the sole crop and in intercropping, showed that, intercropping reduced soybean 100 grain weight. This might be due to competition for water, nutrients and sun light between components crops. Similar results were obtained by Undie *at al.* (2012) who reported that maize-soybean intercropping reduced 100 grain weight for soybean during two years (2007) and (2008). In addition, Li *et al.* (2013) found that, 100 grain weight was significantly reduced by intercropping of

soybean-sugacane, by 16.12 to 9.53 % respectively in sole crop compared to intercrop. For Mbah *et al*. (2007), maize-soybean intercropping affected negatively 100 grain weight in intercropping than in sole crop in one season (2002). The long rain of 2016 had higher 100 grain weight compared to the short season. These results could be justified by the sufficient water which was available during the first season than the second which allowed good formation of grain. However, 100 grain weight for maize did not give significant difference between sites for the long rains of 2016. Mwea did not produce maize grains because of MLN which destroyed plant. Mwea showed 100 GW ranged from 26 g to 28 g .The significant difference for 100 GW was visible in the short rains 2016-2017 at Mwea, where it was among 19 g to 21 g. 100 GW from Embu ranged from 31 g to 34 g. Embu produced higher amount of 100 GW both seasons compared to Mwea in sole crop and in intercropping. The high 100 grain weigh from Embu compared to Mwea can be explained by the good adaptation of the variety of maize Duma 43 used at Mwea compared to Embu.

3.5.2.4 Soybean yield in tonne per ha

Soybean yield showed significant difference ($p \leq 0.05$) between sites in the long rain of 2016. Soybean yield ranged from 0.6 t ha^{-1} to 3.7 t ha^{-1} at Mwea compared to Embu where soybean yield ranged from 0.44 t ha^{-1} to 2.17 t ha^{-1}. TGX1990-5F presented the highest yield of 3.7 t ha^{-1} in sole scrop while GAZELLE showed the lowest yield of 0.6 t ha^{-1} in intercropping at Mwea. At Embu, GAZELLE presented the highest yield of 2. 17 t ha^{-1} in sole crops compared to TGX1990-5F which recorded the lowest yield of 0.44 t ha^{-1} in intercropping. The short rains recorded the lowest yield compared to the long rains of 2016. Mwea yield ranged from 0.3 t ha^{-1} to 1.4 t ha^{-1} and Embu yield ranged from 0.15 t ha^{-1} to 1.75 t ha^{-1}. GAZELLE recorded higher yield of 1.4 t ha^{-1} in sole crops than SB19 with 0.3 t ha^{-1} at Mwea in intercropping. GAZELLE recorded the highest yield of 1.7 t ha^{-1} compared to SB19 with the lowest yield of 0.15 t ha^{-1} in intercropping. Mwea produced higher yield compared to Embu both seasons. The higher soybean yield from Mwea than Embu in both seasons could be explained by the adaptation of the genotypes cultivated which could be adapted at Mwea than Embu. In addition, the irrigation on time as supplement for rainfall for Mwea compared to Embu put those genotypes in favorable condition to produce good yield. Intercropping system reduced soybean yield both sites and seasons. That could be explained by the competition between soybean and maize for water, nutrients, air and light compared to the sole crops (Sloger, 1969 and Amanullah *et al.*, 2016). However, Issahaku (2010) reported that the yield of soybean decreased in intercropping with maize than sole crops and maize benefits more from intercropping than soybean. In addition, Rana and Rana (2011) reported that, the roots of crops in intercropping compete for growth factors such as nutrients, light and moisture which may reduce legumes yield in cereal-legumes intercropping . For Sarkodie and Kahaman (2012) legumes could become pest in an intercropping system by shading the components crop(s) and thereby reducing yield. However maize grain yield did not give significant difference in the sole and intercrop at Embu ($p \leq 0.05$). Mwea maize production was infested by MLN disease especially in the long rains seasons of 2016 but the experiment produced biomass which was used to calculate LER. Maize yield ranged from 4.45 t ha^{-1} to 5.67 t ha^{-1} at Embu. During the short rains of 2016-2017, yield ranged among 2.63 t ha^{-1} to 3.53 t ha^{-1} at Mwea while at Embu maize the yield was 7.49 t ha^{-1} 9.62 t ha^{-1} in intercropping as in sole crop. Mwea produced the lowest amount of maize yield compared to Embu. Embu produced the highest amount of maize yield during the short rains of 2016-2017 compared to the long rains of 2016. The higher maize yield production for Embu compared to Mwea could be justified by adaptation of the variety (Duma 43) at Embu compared to Mwea. Intercropping did reduce maize yield both sites and seasons. MLN incidence and severity was significantly different between sites ($p \leq 0.05$). The highest MLN scoring (5) was recorded at

Mwea. Embu had low incidence and severity. This situation could be due to environmental differences in the two sites. Mwea site is in low altitude with high temperature while Embu site is in high altitude with low temperature. The high temperature of Mwea could have accelerated the development of MLN incidence and severity compared to Embu. This agrees with Nelson *et al*. (2011) who reported that, the incidence and severity of MLN varies with plant age, time of infection, genotype and environment. However, Mwea lost total maize grain yield through MLN attack, and only the biomass was harvested. This results are corroborated by Miano (2010) who reported that, the losses of maize production due to MLN is between 50% and 90% depending on varieties.

3.5.2.5 Harvest index

Soybean Harvest Index (HI) showed significant difference between sites and seasons ($p \leq 0.05$). HI was 0.17 to 0.42 at Mwea while Embu showed HI of 0.10 to 0.54 in sole crop as in intercropping. SB19 variety presented the highest HI of 0.42 and TGX1990-5F showed the lowest HI of 0.17 at Mwea. However, SB19 showed the highest HI of 0.54 while TGX1990-5F showed the lowest HI of 0.10 in intercropping at Embu in the long rains of 2016. The short rains showed the lowest HI compared to the long rains. Mwea site did not show significant difference among treatments and HI ranged from 0.1 to 0.33 while Embu HI differed and ranged from 0.1 to 0.39 in sole crop. GAZELLE gave the highest HI of 0.3 in sole crop and TGX1990-5F presented the lowest HI of 0.1 at Mwea in sole crop. GAZELLE showed the highest HI of 0.39 in sole crop compared to SB19 which showed the lowest HI of 0.10 in intercropping at Embu. Intercropping reduced HI in both sites and both seasons. This might be due to shading of maize on soybean which could allow the the decrease ofsoybean yeald, hence, the decrease of HI. This agrees with Naim *et al*. (2012), who said that, the higher plant population in intercrops decrease HI while lower plant population in sole crops tend to increase HI. Mwea produced the highest HI both seasons than Embu. The highest HI produced at Mwea compared to Embu could confirm the highest soybean yield recorded as results to sufficient water which was provided by rainfall and irrigation to supplement rainfall at Mwea. During the long rains at Embu SB19 produced low yield of 1.08 t ha^{-1} with high HI of 0.54 in intercrops. This finding agrees with Ayaz (1994) who reported that, grain yield and harvest index of grain legumes are highly variable and even plant with good health sometimes give poor yields. The cause of that variability in grain yield and low HI are under research until now. In addition Wnuk *et al*. (2013) reported that, for wheat or cereals, the main progress in breeding for higher yields is obtained principally between man-made selection forces for the harvest index (HI), that is, an increased plant capacity to allocate biomass (assimilates) into the formed reproductive parts**.** The relationships of harvest index with biomass and grain yield follow the multiplicative yield component model, in which grain yield is a product of harvest index and biomass yield**.** However, morpho-physiological assessment done by researchers in a modern wheat collection says that the increased partitioning of the dry matter into grains already attained its physiological justified limit (HI value of around 0.6). In addition, GAZELLE showed higher yield of 2.17 t ha^{-1} at Embu with higher HI of 0.48 in the long rains seasons in sole crops. This agrees with Wnuk *et al*. (2013)**,** who reported that, the higher HI exibited the higher grain yield in his experiment on cereals- legumes. This could be due to assimilation of the biomass in grain yield by GAZELLE compared to other varieties. This was in greement with Scott (1977) who reported that, low biomass production yield allowed higher HI production hence higher grain yield production. Maize HI did not show significant difference between sites and seasons ($p \leq 0.05$). HI for Mwea was not calculated because of MLN which attacked Maize and the grain yield was lost completely in the long rain season. Embu HI for long rains 2016 ranged from 0.32 to 0.42. For the short rains Mwea HI ranged from 0.1 to 1.23 while Embu HI was between 0.33 to 0.43. Intercropping did not reduce maize HI both sites and seasons. This results agrees with Sadras *et al.* (2001); Stoltz and Nadeau (2014) who reported that, maize HI was stable in sole crops and in intercrops when it was intercropped with sunflower and soybean.

3.5.2.6 Yield advantage assessed by Land equivalent ratio

LER did not give significant difference between sites in the long rains of 2016. LER differed among treatments at Mwea where it ranged from 1.3 to 1.9. Embu did not show significant difference and LER ranged from 1.5 to 1.8. TGX1990-5F showed the highest LER of 1.9 at Mwea while GAZELLE presented the lowest LER of 1.3. However, TGX1990-5F showed the lowest LER of 1.5 at Embu compared to SB19 which presented the highest LER of 1.8 in the long rains 2016. During the short rains LER showed significant difference between sites ($p \leq 0.05$). LER ranged from 1.10 to 2 at Mwea while at Embu LER was 1 .06 to 1.62. TGX1990-5F showed the highest LER of 2.04 and GAZELLE variety presented the lowest LER of 1.10 at Mwea. Embu did not give significant difference among treatments but TGX1990-5F showed the highest LER of 1.62 while SB19 showed the lowest LER of 1.06. TGX1990-5F was taken as the best promiscious soybean for intercropping with maize because it showed land equivalent ratio with advantage for the components crops. The Land Equivalent ratio showed the advantage between component crops because it was higher than 1. This finding agrees with Sullivan (2003) Hugar and Palled (2008); Addo-Quaye (2011); Yusuf *et al.* (2012) who recorded LER greater than 1.00 in cereals-legumes cropping system. Variety TGX1990-5F recorded the highest LER of 1.62 at Embu. Sylvia (1999) and Dariush *et al*. (2006), confirmed that, land equivalent ratio of 1.62 means that an area shown as sole crops, need 62% more land to produce the same yield as the same area planted in an intrecrops combination. In addition, Khan Zada *et al.* (1988) reported that, the use of N increased LER and showed efficient utilisation of land in different planting pattens. Adam and Mohammed (2012) also reported that, cropping system improved total yield which was accompanied by greater land equivalent ratio.

3.6 Conclusion

The study revealed that growth parameters and production paramaters for soybean decreased in intercropping than in the sole crop. Maize was not affected significantly by intercropping. GAZELLE gave the highest yields followed by TGX1990-5F and SB19 showed the lowest yields in sole crop between sites in the long rains 2016. The short rains showed significant difference between sites. This season showed the lowest yields between sites compared to the long rains of 2016. Variety TGX1990-5F recorded the highest yields in the intercrop followed by GAZELLE and SB19 was the last. LER for TGX1990-5F was 1.7 followed by SB19 (1.66) and SB19 recorded the lowest LER of (1.51) between sites in the long rains 2016. However, LER for TGX1990-5F was 1.83 followed by GAZELLE (1.31) and SB19 recorded the lowest LER of (1.19) between sites in the short rains. Based on the yield and yield component performance both in the sole and the intercrop as well as LER, variety TGX1990-5F was considered as the most suitable promisuous soybean for intercropping with maize.

CHAPTER FOUR

4.0 EFFECT OF INTERCROPING MAIZE - SOYBEAN ON SOIL FERTILITY AND GRAIN QUALITY TRAITS

4.1 Abstract

Maize-soybean intercropping system may give positive or negative responses on soil proprieties and seed quality traits through environmental factors and physiological attributes as compared to their performance in sole crops. There is therefore need for information in order to confirm this hypothesis. The objective of this study was to determine the effects of intercropping maize-soybean on soil fertility and grain quality traits. This study was conducted in two sites (Embu and Mwea) in two rainy seasons. The experiment was laid out in randomized complete block design (RCBD) replicated three times with seven treatments which are : T1= SB19, T2 = GAZELLE, T3 = TGX1990 – 5F, T4 = SB19 + MAIZE, T5 = GAZELLE + MAIZE, T6 = TGX1990-5F + MAIZE, T7 = MAIZE (Duma 43). The data were collected on soil nutrient before planting and after harvesting and on protein and oil content and grain size. The results showed that TGX1990-5F recorded higher N (0. 39 %) compared to 0.29 % for SB19 and 0.28 % for GAZELLE in sole crop between sites after harvesting the first season crop. In addition, TGX1990-5F gave significant differrence ($p \leq 0.05$) for 0.30 % of N compared to 0.15 % of N for GAZELLE and 0.22 % of N for SB19 in intercrops between sites after harvesting the second season crops. Intercropping reduced N fixation for SB19 and GAZELLE compared to TGX1990-5F in the second rainy season crop than the first rainy season crop. However, there was an increase of soil fertility for N in both sole crops and intercrops after harvesting compared to before planting. In addition, Organic Carbon (OC), Potassium (K) and photosphorus (P) after harvesting were very high where GAZELLE took the first place than other varieties in both sites and rain seasons compared to other varieties. Furthermore (OC, K and P) were almost the same as in intercrops and in sole crops in both sites and both rainy seasons and there was an increase in those nutrients after harvesting. Thus, the protein ranged from 36.57 % to 42.96 % in the long rainy season crop while in the short rainy season crop it ranged from 31.98 % to 40.84 % in sole crop and in intercrops between sites. TGX1990-5F presented high amount of protein in sole crops and in intercropping 42.96 % and 38.4 % respectively, between sites in the first season. In addition, variety TGX1990-5F showed significant difference for protein content of 40.84 % compared to 31.98 % for GAZELLE in intercropping between sites in the second season. For the oil content, GAZELLE recorded the higher amount of oil content of 22 % and 21 % for the first season and second season respectively in sole crops while SB19 recorded the lowest with 13.98 % between sites. Hence, TGX1990-5F can be recommended to smallscale farmers for intercropping with maize because it can provide protein and reduce the cost for N fertilizer fixing N biologicaly freely. In terms of grain size GAZELLE local variety had greater size of 6.5 mm than SB19 which had 6 mm ($p \leq 0.05$). Intercropping reduced grain size for SB19 compared to other varieties because for example, the highest amount of grain size was recorded for the grains from intercroping compared to sole crops. This was not the same case for maize because maize grain was not affected by intercropping system.

Keywords: *Intercropping system, soil fertility, protein content, oil content, grain size, soybean and Maize*

4.2 Introduction

Soil characteristics, grain quality traits, protein and oil content can be affected positively or negatively by growth conditions of crops. Intercropping, the agricultural practice of cultivating two or more crops in the same space at the same time, is an old and common cropping system used which targets to match efficiently the crop demands to the available growth resources and labor (Lithourgidis *et al*., 2011). The stability under intercropping can be attributed to the partial restoration of diversity that is missed under sole crops. According to this view, intercropping allows high insurance against crop failure, notably in environments known to have weather conditions like frost, flood, drought, and overall provides high financial stability for farmers (Lithourgidis *et al*., 2011). Moreover, legumes enrich soil by fixing the atmospheric nitrogen transforming it from an inorganic form to forms that are avaible for uptake by crops. 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, inorganic fertilizers contribute to ecosystem damage such as nitrate pollution, when over applied. Legumes grown in intercropping are taken as an alternative and sustainable path of bringing nitrogen in the soil and reducing input cost (Fustec *et al*., 2010). Futhermore, 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. In addition, 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 has been shown to be 60-120 kg in berseem (*Trifolum alexadrium*), 75 kg in cluster bean (*Cyamopsis tetragonolobus*), 68kg in chickpea (*Cicer arietinum*), 54-58 kg in groundnut (*Arachis hypogea*) and 50-51 kg in soybean (*Glycina max*) (Bandyopadhyay *et al*., 2007). In addition, apart from nitrogen, intercropping legume-cereal can allow acquisition of other nutrients such asPHtosphorus, potassium and sulphur (Erik , 2005). However, more interaction mechanisms that happen between plant species when intercropped as well as the effect of intercrop on the following crop in the fallow might have effects on grain quality. This has been shown determining the effect of intercropping on a series of quality factors, such as physical grain quality, ratio of nitrogen and sulphur concentrations, protein quality for wheat and fababean (Erik , 2005). Musa *et al*., (2011) reported that intercropping increased chemical composition as dry matter, ash, protein, fiber content and tannin content of cowpea in maize-cowpea intercropping. Eskandari & Ghanbari (2009) and Yucel & Avci (2009) showed that, intercropping legume-cereal increased crude protein than monocropping, while Jayanta *et al*., (2015) found that, intercropping maize-soybean increased protein and nitrogen content in both seeds, nitrogen content in stover and total nitrogen uptake with 75-100% of recommended nitrogen. In addition, Abdel *et al*., (2016) revealed that intercropping soybean-sunflower spaced at 20 cm (soybean) had the highest seed oil yields per ha compared to other spacing. However, effect of intercropping maize- soybean on soil fertility and seed quality traits is not well understood. As such, this study was designed to assess the effect of intercropping maize-soybean on soil fertility and seed quality traits at Embu and Mwea sites in Kenya.

4.3 Materials and Methods

4.3.1 Sites characteristics

The trials were conducted in two sites. The first site was KALRO-Embu**,** located in Embu County in the Eastern part of Kenya. It lies between latitudes 0 ˚ 08’ 35’’S and a longitude 37°27′02″ E with two distinct rain seasons. **KALRO-Mwea** is in Kirinyaga county**,** situated in the Central Region of Kenya at a latitude of 00^{0} 37’S and a longitude of 37^{o} 20’E. The sites are described in detail in chapter three section three. The seasonal mean precipitation is 1500mm and the temperature range from between 18°-28°C for Embu couty (Embu County, 2014), while the seasonal mean precipitation for Kirinyaga county is 1679 mm and the temperature range between 8.1°-30.3°C (Kirinyaga County, 2014).

4.3.2 Soil collection and analysis

Soil samples were collected using zigzag method at a depth of 0-30 cm and then mixed the different samples of the same site in order to get one sample which is homogeneous in each site and taken for analysis at the University of Nairobi laboratory analysis for macronutrients, micronutrients (S, Na, Ca) and some oligo elements like Zinc, Mn, cobalt and pH.

4.3.2.1 pH analysis

The soil pH was assessed in H_2O using a 1:2.5 soil to water ratio using a digital pH -meter. This was done by taking 6 gms for soil of 2 mm and putting it in plastic bottle. The soil sample was later mixed with 15 ml of distilled water and the solution shaken with the shaker. After shaking in 30 minutes, the solution was let to stand on the table for 15 minutes, and then the pH was read (Figure 4.1) (Van Reeuwijk, 2002).

Figure 4.1: pH meter used for computing pH

4.3.2.2 Organic carbon

Organic carbon was evaluated using 0.5 mm and 0.5 g of soil put in flat bottomed flask. 10 ml ascorbic acid and was added and mixed with 15 ml of sulphuric acid and let settle on table for 15 minutes (Figure 4.2.a). After that, cool water was added till to it attained 100 ml. 1 mlPHtenolphthalein indicator was added to change the colour. Titration was done with $FeSO_4$

(Figure 4. 2.b). Reading the initial point and the final point, the actual point was assessed taking the final point minus the initial point. The actual point was assessed by inserting the final point in the formula in order to get the concentration of the organic carbon in the soil in percentage as illustrated by (Walkely and Black, 1934).

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

(Equation 5) Organic carbon

Where V blank = Volume of blank, V sample = Volume of sample, 0.3 = Factor, N = Normality for $FeSO_4$, $\text{Total oxidized organic carbon} = \frac{100}{77}$

The method need ensures says that the soil recovers 77 % and permit to convert it in percentage.

Figure 4.2: (a) Preparation of solution for organic carbon. (b) Titration of organic carbon with $FeSO_4$ analysis

4.3.2.3 Total nitrogen analysis

The total N of the soil was assessed by taking 1g of soil sample of 0.5 mm and putting it in kjeldal flask; adding 8 ml of sulphuric acid and 1 packet of catalyst in each sample for the activation of the reaction. The kjeldal with soil sample was later placed in the digester for 1 hour digestion. The sample from the digester was mixed with distilled water in plastic battle and 10 ml was taken to the flat bottomed flask and mixed with 3 drops ofPHtenolphthalein indicator. 20 ml of boric acid was added in that solution and the bottomed flask was placed in the distiller for distillation in 5 minutes. 5 ml of sodium hydroxide was put in kjeldal flask and placed in the distiller to help the distillation. The titration was done by the sulphuric acid reading the initial point, final point and actual point was computed by subtraction of the final point by the initial (Roberts *et al.,* 1971). The actual point was used to calculate the total nitrogen as showed in the formula below:

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

(Equation 6) Total nitrogen

4.3.3.4 Phosphorus analysis

Phosphorus analysis was done by taking 2.5 gms of 2 mm and putting it in plastic bottle. 25 ml of double acid (Hcl + H_2S0_4) diluted was added in that soil sample. The solution was taken to the shaker for homogenization in 30 minutes, and then the distillation could follow. After distillation, 3 ml from the sample distilled were added in flat bottomed flask of 50 ml then some quantity of distilled water was added in that solution. 5 ml of ascorbic acid was later added then topped up with distilled water and available phosphorus was quantified colorimetrically using spectrophotometer (Roberts *et al.,* 1971). The absorption on the spectrophotometer was calculated using the formula below:

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

(Equation 7) Phosphorus

GR: Absorption, 50: Volume developed, 3: Volume extracted

4.3.3.5 Potassium, Mn, Fe, Cu, and Zn analysis

The quantity of potassium in the soil samples was evaluated by flame photometer following by the extraction of the soil samples by 1 N ammonium acetate atPHt 7.0 (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 279.5 nm, 248.3 nm, 324.7 nm, and 213.9 nm wave lengths for Mn, Fe, Cu, and Zn, respectively.

4.3.3 Grain size

The grain size was measured by a stack of sieves with hole-diameter ranging from (5.5 mm to 10 mm) for maize and (4 mm to 8 mm) for soybean and seven size bins were generated from 100 grains taken as sample for maize and soybean each and grain size were assessed in %. The operation was done in the lab of department of Food Science , University of Nairobi (Shahin & Symons, 2005) (Figure 4.3).

Figure 4.3 : Sieves used for seeds size generation

4.3.4. Crude protein determination

After drying samples of soybean in an air oven, and grinding it, crude protein was determined weighing accurately about 0.5g of soybean sample and putting it in a nitrogen-free paper. One catalyst tablet was added in each one kjedhal flask and 20 ml of conc. H_2SO_4. The mixture in kjedhal flasks were heated slowly and carefully in the digestion system, until a clear solution is obtained in almost 8 hours (Figure 4.4(a)). After digestion, add distilled water of ¾ in the flask and three drops of phenolphthalein. 400 ml conical flask containing 50 ml of 0.1NHcl solution and some drops of methyl orange indicator under the outlet of distillation unit was done and connect the kjeldhal flask to the distillation unit. After that, 40% NaOH solution was added into the kjeldhal flask to change the colour of the solution. The distillation was done until a drop of distillate does not react with nessler's reagent placed in a test tube (Figure 4.4(b)). After distillation, the titrations were done with 0.1 N NaOH solutions and calculate the crude protein content of the sample, carrying out a blank determination for the correction of the acid titre (Figure 4.4 (c)) (Katerine, 2012).

$$\% \text{ Protein} = \frac{14 \text{ x } 6.25 \text{ x } 100 \text{ x } 0.1(\text{NaoH})}{\text{weight x } 1000} \text{ x Titre}$$

(Equation 8) Protein determination

Where 14= Molecule weight of nitrogen, 625= Convention factor to protein, 0.1= Normality for NaoH

Figure 4.4 : Digestion of protein in the digester, (b) Distillation of protein, (c) Protein after distillation

4.3.5. Crude oil determination

After drying samples of soybean in air oven and grinding it, the crude fat was assessed weighing accurately about 5g of sample and put it into an extraction thimble. The samples were covered with the cotton wool and each extraction thimble was placed into the sohxlet extractor. The tarred flat bottomed flask with 200 ml of petroleum was placed on a heating mantle and connected to the soxhlet extractor (Figure 4.4 (a)). The extraction was done for about 8 hours (Figure 4.4 (b)). Evaporation of the solvent was done in a rotary evaporator and dried the residue in an air-oven at 105°C for 1 hour (Figure 4.4 (C)). Calculation of the crude fat content of the sample was done at the end (Figure 4.4(d)) (CSIRO and the victorian goverment, 2006).

$$\%\ \text{Oil determination} = \frac{(\text{Flask} + \text{oil})}{\text{Sample weight}} \text{ x } 100$$

(Equation 9) Oil determination

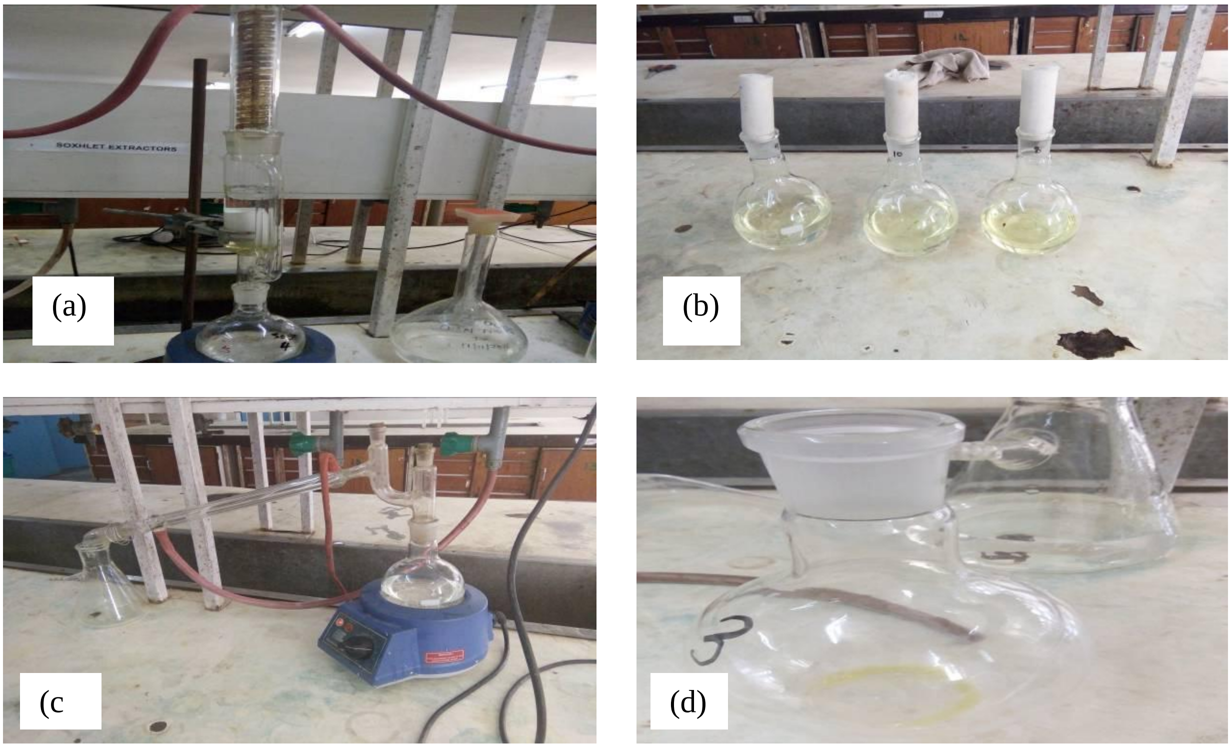


Figure 4.5: (a) Extraction of the soybean oil with soxhelt method, (b) Soybean oil after extraction, (c) Separation of petrolium with soybean oil with evaporation, (d) Soybean oil after evaporation.

4.3 Results

4.4.1 Soil analysis before planting

Table 4.1 shows soil analysis before planting in the long rains. The pH was 5.70 to 6.01 respectively for Mwea and Embu. Embu presented higher N of 0.29 % compared to Mwea with 0.19 %. For organic carbon Embu also recorded higher amount of 2.84 % than Mwea with 1.89 %. However, Mwea showed higher amount of P of 145 ppm compared to Embu with 22.1 ppm for the long rains (2016-2017). Table 4.2 shows soil analysis before planting in the short rains. The pH was 5.28 compared to 5.06 respectively for Mwea and Embu. The nitrogen was 0.23 % compared to 0.14 % respectively for Mwea and Embu. Mwea recorded higher amount of OC of 2.45 % while Embu showed the lowest amount of 1.37 %. K presented higher amount of 1.15 Cmol/kg at Embu than 0.4 Cmol/kg for Mwea. However the highest amount of 151.7ppm for P was recorded at Embu while Mwea recorded the lowest amount of 5.83 ppm. According to Table 4.3, page 77, for the two sites, only phosphorus was adequate for the soybean and maize, following the soil scale of Lando (1991) on the interpretation of the soil nutrients, where phosphorus is sufficient when it is above 35ppm.

Table 4.1: Soil chemical characteristics at the experimental sites before sowing (Long rains 2016-2017)

		%	**%**	**Cmol/kg**				**P ppm**				
Sites	pH	N	0C	K	Na	Ca	Mg	P	Mn	Zn	Fe	Cu
MWEA	5.70	0.19	1.89	1.10	0.60	1.43	0.95	145.0	65.20	0.85	60.34	1.64
EMBU	6.01	0.29	2.84	1.40	0.45	0.68	0.66	22.1	32.50	2.40	19.66	1.50

Table 4.2: Soil chemical characteristics for experimental sites before sowing (Short rains 2016)

		%	**%**	**Cmol/kg**				**P ppm**				
Sites	pH	N	0C	K	Na	Ca	Mg	P	Mn	Zn	Fe	Cu
MWEA	4.28	0.23	2.45	0.4	0.61	4.20	1.87	5.83	76.50	7.60	103.50	2.10
EMBU	5.06	0.14	1.37	1.15	0.45	4.50	1.45	151.7	72.30	6.50	115.20	1.50

Table 4.3: Soil nutrients interpretation according to 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	
P^H		5.5-7.5 suitable for most crops	

4.4.2 Effects of intercropping maize – soybean on soil fertility

After combined analysis of variance for soil nutrients done before planting for the long rains of 2016 and short rains of 2016-2017, the results did not show significant difference in interaction among treatments x seasons x sites for pH, OC, N, K and P ($p \leq 0.05$) (Table 4.4, page 79). However, these parameters showed significant difference among seasons x sites. The pH, OC, N, K and P did not show significant difference between treatments x sites and between treatments x seasons. In addition, the sites showed significant difference only for pH and K and not for other parameters while all parameters showed significant difference between seasons. The treatments did not show significant difference in all parameters. However, the combined analysis of variance for soil nutrients done after soybean and maize harvesting both seasons, showed significant difference in all parameters for all source of variation except sites which did not show significant difference for organic carbon (Table 4.4, page 78).

Table 4.4: Mean square of soil nutrients before and after planting long rains of 2016 and short rains of 2016-2017

		Soil nutrient before plating					Soil nutrient after harvesting				
Source of variation	df	pH	%OC	%N	K Cmol/kg	P ppm	pH	%OC	%N	K Cmol/kg	P ppm
Replication	2	0.030	0.048	0.0027	0.015	1546.3	0.0129	0.0025	0.0011	0.008	8.544
Treatments	6	0.041^{NS}	0.010^{NS}	0.0013^{NS}	0.048^{NS}	104.6^{NS}	0.195*	0.588*	0.017*	0.08*	1.519*
Seasons	1	20.296*	6.085*	0.0490*	5.195*	4453.9*	28.037*	6.619*	0.049*	0.28*	2.957*
Sites	1	10.255*	0.064^{NS}	0.0002^{NS}	5.611*	41.2^{NS}	0.195*	16.669^{NS}	0.180*	0.11*	2.175*
Treatments. Seasons	6	0.056^{NS}	0.017^{NS}	0.0008^{NS}	0.042^{NS}	146.3^{NS}	0.089*	0.413*	0.014*	0.20*	2.004*
Treatments. Sites	6	0.031^{NS}	0.019^{NS}	0.079^{NS}	0.031^{NS}	159.2^{NS}	0.203*	0.898*	0.020*	0.12*	3.553*
Seasons. Sites	1	0.217*	21.492*	0.178*	0.715*	293405.5*	0.001^{NS}	6.242*	0.046*	2.21*	6.301*
Treatments.Seasons. sites	6	0.027^{NS}	0.016^{NS}	0.002^{NS}	0.014^{NS}	108.9^{NS}	0.411*	0.325*	0.008*	0.20*	1.834*
Residual	54	0.031	0.01912	0.0010	0.033	182.2	0.010	0.0021	0.0002	0.0021	3.218
Total	83										

Sv: Source of variation, df: degree of freedom, * Significant at $p \leq 0.05$, NS : Non significant

4.4.2.1 Soil pH before planting and after harvesting

Soil pH did not give significant difference before planting (BP) between sites and seasons (Table 4.5, page 84). However, 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 acidity at pH 5.18 compared to pH 5.88 (less acidic) obtained BP in the long rains followed by GAZELLE at pH 4.83 recorded AH (more acidic) compared to pH 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 intercrop of GAZELLE recorded 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 obtained 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 (Table 4.5, page 84). During the short rains soil pH decreased slightly at Embu AH compared to soil pH BP. The variety of SB19 decreased soil pH to 6.11 AH compared to 5.1 obtained BP. TGX1990-5F and GAZELLE had the same pH of 5.8 AH less acidic than 5.1 for those varieties BP in the sole crop. The intercrop of GAZELLE reduced soil pH acidity to 6.5 AH compared to pH 5.1 recorded BP, followed by SB19 in intercrop with 5.8 AH compared to p H 5 recorded BP and the last was TGX1990-5F with 5.58 recorded AH and less acidic than 5.1 obtained BP in intercrop at Embu. At Mwea all varieties decreased soil pH acidity to pH about 6 AH while BP it was more acidic with pH slightly above 4 in sole crop and in intercrop in short rains.

4.4.1.2 Organic carbon before planting and after harvesting

The results for Organic carbon (OC) didn’t give significant difference before planting long rains of 2016 and short rains of 2017 between sites and seasons, but significant difference was shown after harvesting long rains of 2016 and short rains of 2016-2017 between treatments and sites ($p \leq 0.05$) (Table 4.5, page 84). Organic carbon ranged from 1.24 % to 2.82 % at both sites and seasons before planting in long rains. Organic Carbon increased in the soil after harvesting during 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 and the last variety was SB19 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 % for the same variety recorded before planting followed by TGX1990-5F (2.95 %) after harvesting compared to 2.82 % for the same variety before planting and SB19 gave the lowest OC (1.69 %) after harvesting than 2.82 % obtained before planting in intercropping at Embu for the long rains. After harvesting SB19 did not increase organic carbon compared to 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 % for the same variety before planting and GAZELLE was the last with (1.39) after harvesting compared to the same variety with 1.9 % before planting in sole crop at Mwea (Table 4.5, page 84). TGX1990-5F had a higher OC (1.89 %) before planting compared to the same variety with (1.52 %) after harvesting followed by SB19 with 1.82 % before planting compared with the same variety with (1.44 %) after harvesting and GAZELLE had the lowest amount of OC of 1.78 % before planting compared by it self with 0.82 % after harvesting in intercrop at Mwea. During the short season, OC increased at both sites after harvesting (AH). It ranged from 2.6 % to 3 % at Embu while it ranged among 2.1 % to 3.4 % at Mwea in sole crop as in intercrop. SB19 and GAZELLE showed the same amount of OC (3 %) AH compared to 1.26 % and 1.28 % respectively for SB19 and GAZELLE BP, followed by TGX1990-5F with (2.99 %) AH more than 1.25 % for the same variety BP (Table 4.5 , page 84). The sole maize showed the lowest OC of 1.3 % BP less than 2.83 % AH for maize alone in sole crop. However, in intercrop, TGX1990-5F recorded higher OC of 2.90 % AH more than 1.24 % for the same variety obtained BP. TGX1990-5F was followed by GAZELLE with 2.88 % AH greater than 1.25 % for the same variety BP and SB19 was the last with 2.66 % AH higher than 1.28 % BP at Embu. For Mwea site SB19 recorded the highest OC (2.96 %) AH compared to 2.51 % for the same variety BP. SB19 was followed by GAZELLE (2.30 %) AH more than 2.19 % obtained BP and TGX1990-5F recorded the lowest OC of 2.14 % AH less than 2.48 % for the same variety recorded BP in the sole crop. However, TGX1990-5F showed the highest amount of OC of 3.39 % AH more than 2.21 % BP for the same variety. TGX1990-5F was followed by SB19 with 2 .52 % AH compared by 2.41 % for the same variety BP and GAZELLE was the 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 of 2016 and short rains of 2016 - 2017 compared to the value obtained before planting. Organic carbon for the soil didin’t increase after harvesting at Mwea during long rains of 2016 and short rains of 2016-2017compared to the value obtained before planting at Embu before planting (Table 4.5 , page 84). Intercropping affected negatively slightly organic carbon for the soil after harvesting.

4.4.1.3 Total nitrogen before planting and after harvesting

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) ($p \leq 0.05$) (Table 4.5, page 84). Soil N increased AH at both sites in the first season. However, in the second season, soil N increased only at Embu and decreased at Mwea (Table 4.5). 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 (0.36 %) AH higher than 0.28 % for the same variety obtained BP. Sole maize gave 0.3 % AH more than 0.27 % BP and 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 0.36 % AH compared to 0.28 % recorded BP followed by GAZELLE (0.32 %) AH more than 0.25 % BP and 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 0.2 % AH while BP those varieties ranged from 0.17 % to 0.20 % in sole crop as in intercrop, except SB19 which had higher soil N of 0.28 % AH compared to 0.18 % obtained BP in sole crop and sole maize which had soil N of 0.19 % AH more than 0.18 % obtained BP for the long rains at Mwea. For the short rains, the same variety TGX1990-5F presented higher soil N of 0.29 % AH compared to 0.13 % BP followed by GAZELLE with 0.27 % AH more than 0.14 % BP and SB19 was the last with 0.24 % AH more than 0.12 % BP in sole crop at Mwea. Variety TGX1990-5F recorded 0.29 % of N AH compared to 0.13 % for the same variety BP followed by SB19 (0.25 %) AH more than 0.15 % BP for the same variety and GAZELLE was the last with 0.18 % AH compared to 0.14 % for the same variety BP in intercrop at Embu. At Mwea, variety GAZELLE recorded a slightly higher soil N of 0.28 %

AH compared to 0.27 % for the same variety BP while TGX1990-5F presented the lowest soil N of 0.14 % AH less than 0.20 % BP and SB19 was the second recording 0.23 % AH less than 0.27 % obtained BP in sole crop. TGX1990-5F showed higher soil N of 0.32 % AH compared to 0.26 % BP followed by SB19 with 0.18 % AH less than 0.23 % for the same variety obtained BP and GAZELLE had the lowest amount soil N of 0.13% AH less than 0.22 % for the same variety found BP in intercrop at Mwea. Compared to the amount found after soil analysis before planting long rains of 2016, TGX1990-5F fixed higher 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 for soil analysis long rains of 2016 before planting, Mwea did not increase total nitrogen fixed by varieties, except SB19 in sole crop (Table 4.5, page 84). In contrast, at results from soil analysis before planting, Mwea site increased slighly 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 4.5, page 84). During short rains of 2016-2017, the results obtained after harvesting were lower for some varieties compared to the results obtained before planting.

Table 4.5: Soil nutrients long rains of 2016 and short rains of 2016-2017 before planting and after harvesting soybean

	Long rains 2016																	
	pH (BP)			pH (AH)			%OC (BP)			%OC (AH)			%N (BP)			%N (AH)		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	5.95a	5.5a	5.74a	4.73 c	5.01d	4.92b	2.79a	1.88a	2.34a	2.68e	1.96a	2.32b	0.29a	0.18ab	0.24a	0.29d	0.28a	0.29b
GAZELLE	6.03a	5.3a	5.66a	4.83b	5.15c	4.99b	2.82a	1.9a	2.36a	3.19b	1.39d	2.29b	0.28a	0.17b	0.23a	0.36b	0.20b	0.28b
TGX1990-5F	5.88a	5.3a	5.59a	5.18a	5.39ab	5.29a	2.82a	1.83a	2.33a	3.77a	1.53b	2.65a	0.27a	0.19ab	0.24a	0.58a	0.20b	0.39a
SB19+MAIZE	5.88a	5.3a	5.59a	4.55d	5.3b	4.93b	2.82a	1.82a	2.32a	1.69f	1.44c	1.56d	0.29a	0.18ab	0.24a	0.23e	0.20b	0.21d
GAZELLE+MAIZE	6.00a	5.5a	5.75a	4.45e	5.1cd	4.78c	2.78a	1.78a	2.33a	3.18b	0.82c	2.00c	0.25a	0.20a	0.23a	0.32c	0.20b	0.26b
TGX1990-5F+MAIZE	6.06a	5.6a	5.83a	4.6d	5.4a	5ab	2.82a	1.89a	2.35a	2.95c	1.52b	2.23b	0.28a	0.19ab	0.24a	0.36b	0.20b	0.28b
MAIZE	6.02a	5.2a	5.61a	4.84b	4.83e	4.84c	2.85a	1.81a	2.34a	2.78d	1.52b	2.15b	0.27a	0.18ab	0.23a	0.30d	0.19b	0.24c
Mean	5.83	5.39	5.68	4.74	5.17	4.95	2.81	1.86	2.34	2.89	1.45	2.17	0.28	0.19	0.24	0.35	0.21	0.28b
LSD0.05	0.29	0.44	0.29	0.06	0.10	0.167	0.12	0.14	0.23	0.06	0.01	0.075	0.04	0.02	0.053	0.016	0.039	0.023
CV%	2.8	4.6	3.4	0.8	1.1	1.8	2.3	4.5	6.7	1.3	0.4	1.9	4.2	6.1	15.7	2.7	10.5	5.6
	Short rains 2016-2017																	
	pH (BP)			pH(AH)			%OC (BP)			%OC (AH)			%N(BP)			%N(AH)		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	5.1a	4.3a	4.7a	6.11b	6.1cd	6.10b	1.26a	2.51a	1.9a	3.03a	2.96b	2.99b	0.12a	0.27a	0.19a	0.24c	0.23c	0.24b
GAZELLE	5.1a	4.2a	4.65a	5.8cd	6.4bc	6.08b	1.28a	2.19a	1.75a	3.05a	2.30d	2.67c	0.14a	0.27a	0.21a	0.27b	0.28b	0.28a
TGX1990-5F	5.15a	4.5a	4.83a	5.8de	6.9a	6.35a	1.25a	2.48a	1.9a	2.99ab	2.14e	2.56d	0.13a	0.20a	0.17a	0.29a	0.14e	0.22c
SB19+MAIZE	5.11a	4.2a	4.66a	5.8c	6.3bcd	6.04b	1.28a	2.41a	1.85a	2.66bc	2.52a	2.59d	0.15a	0.23a	0.19a	0.25c	0.18d	0.22c
GAZELLE+MAIZE	5.13a	4.3a	4.72a	6.5a	5.9d	6.18b	1.25a	2.32a	1.8a	2.88bc	2.33d	2.61c	0.14a	0.22a	0.18a	0.18d	0.13e	0.15d
TGX1990-5F+MAIZE	5.10a	4.3a	4.7a	5.58f	6.19bcd	5.88c	1.24a	2.21a	1.7a	2.90bc	3.39a	3.15a	0.13a	0.26a	0.19a	0.29a	0.32a	0.30a
MAIZE	5.05a	4.3a	4.68a	5.75e	6.5b	6.14b	1.3a	2.19a	1.75a	2.83c	2.29d	2.56d	0.14a	0.17a	0.16a	0.25c	0.21d	0.23b
Mean	5.11	4.3	4.71	5.9	6.3	6.1	1.27	2.32	1.80	2.90	2.56	2.73	0.14	0.23	0.19	0.21	0.21	0.21
LSD0.05	0.15	0.34	0.29	0.05	0.35	0.17	0.16	0.40	0.23	0.11	0.11	0.075	0.027	0.10	0.053	0.11	0.027	0.023
CV%	1.7	4.5	3.4	0.5	3.2	1.8	7	9.8	6.7	2.1	2.4	1.9	11.3	24.9	15.7	2.5	7.4	5.6

Harvesting ; BP : Before Planting

4.4.1.4 Potassium and phosphorus soil nutrients before planting and after harvesting

Potassiun (K) 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 (Table 4.6, page 88). 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. Potassium 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, variety TGX1990-5F showed higher K AH compared other varieties in sole crop. Variety SB19 presented the highest amount of K (1.24 Cmol/kg) AH but less than 1.47 Cmol/kg obtained BP for the same variety 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 at Embu. At Mwea SB19 gave higher K (1.07 Cmol/kg) AH less than 1.26 Cmol/kg BP. SB19 was followed by GAZELLE (0.92 Cmol/kg) AH lower than 1.20 Cmol/kg recorded BP. GAZELLE was followed by sole Maize (0.82 Cmol/kg) recorded AH less than 1.42 Cmol/kg BP and TGX1990-5F was the last giving (0.72 Cmol/kg) AH less than 0.90 Cmol/kg recorded BP in sole crop. However, the variety of TGX1990-5F showed 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. Variety 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 for the same variety recorded BP and 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. 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, variety GAZELLE showed the highest K (1.55 Cmol/kg) AH more than 0.34 Cmol/kg for the same variety 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 4.6, page 88)

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 at Mwea P increased AH 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 and in intercrop before planting. Variety 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. Variety 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. GAZELLE showed the lowest amount of P of 12 ppm AH less than 22 ppm BP in intercrop at Embu (Table 4.6, page 88). At Mwea site, TGX1990-5F and 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. TGX1990-5F and SB19 was followed by GAZELLE with 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. GAZELLE was followed by with SB19 27.17 ppm recorded AH compared to 148 ppm for the same variety 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 highest 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 highest 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. The sole maize was followed also by TGX1990-5F (100.52 ppm) obtained AH more than 7.7 ppm BP and GAZELLE presented the lowest P (88.94 ppm) AH compared to 6.4 ppm BP in sole crop at Mwea. Variety 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 recorded BP at Mwea in intercrop. (Table 4.6, page 88).

Table 4.6: Soil nutrients long rains of 2016 and short rains of 2016-2017 before planting and after harvesting soybean at Embu and Mwea

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

4.4.2 Effects of intercropping maize – soybean on grain size

4.4.2.1 Soybean and Maize grain size during long rains 2016 and short rains 2016-2017

According to the combined analysis of variance of soybean grain size, all parameters did not show significant difference in treatments x seasons x sites ($p \leq 0.05$) (Table 4.7). However, seasons x sites did not give significant difference also for all parameters. The treatments x sites gave significant difference only for soybean with 5.6 mm while the treatments x seasons did not give significant difference ($p \leq 0.05$) for all parameters. The sites gave significant difference only for soybean with 5.6 mm and did not in other parameters. The seasons did not show significant difference in all parameters. Treatments showed significant difference in Soybean with 5.6mm, soybean with 6mm, Soybean with 6.5mm and Soybean with 7mm except for soybean with 4mm and 8 mm (Table 4.7, page 89).

Table 4.7: Mean square of soybean grain size (mm) during long rains 2016 and short rains 2016-2017 at Embu and Mwea.

Source of variation	df	4 mm	5 .6 mm	6 mm	6.5 mm	7 mm	8 mm
Replication	2	10.181	1685.4	3504.0	3725.0	306.8	0.055
Treatment	5	0.014^{NS}	749.9*	8423.0*	9447.0*	1380.4*	0.055^{NS}
Season	1	0.014^{NS}	0.7^{NS}	0.00^{NS}	78.0^{NS}	53.4^{NS}	0.00^{NS}
Site	1	5.014^{NS}	1275.1*	2628.0^{NS}	136.0^{NS}	3.6^{NS}	0.055^{NS}
Treatment. Season	5	0.014^{NS}	0.9^{NS}	3.0^{NS}	48.0^{NS}	49.8^{NS}	0.00^{NS}
Treatment. Site	5	1.681^{NS}	499.1^{NS}	4363.0*	2029.0^{NS}	244.7^{NS}	0.055^{NS}
Season. Site	1	0.014^{NS}	0.7^{NS}	0.0^{NS}	39.0^{NS}	50.0^{NS}	0.00^{NS}
Treatment. Season. Site	5	0.014^{NS}	0.9^{NS}	3.0^{NS}	55.0^{NS}	50.0^{NS}	0.00^{NS}
Residual	46	2.123	297.3	1004.0^{NS}	1340.0	228.8	0.026
Total	71						

df : degree of freedom, 4mm : soybean with 4mm, 5.6mm : Soybean with 5.6mm, 6mm : soybean with 6mm, 6.5mm : Soybean with 6.5mm, 7mm : Soybean with 7mm, 8mm : Soybean with 8mm.

The combined analysis of variance of maize grain size showed that treatments x seasons x sites did not give significant difference on maize size with 6mm, maize size with 7mm, maize size with 8mm, maize size with 9.5mm, maize size with 10mm ($p \leq 0.05$) (Table 4.8). Similaly the seasons x sites, treatments x sites and the treatments x seasons did not show significant difference on maize size with 6mm, maize size with 7mm, maize size with 8mm, maize size with 9.5mm, maize size with 10mm. However, the significant difference have been shown in sites for all parameters. The seasons and treatments did not show signifficant difference in all parameters except for grain with 8mm in treatments (Table 4.8 page 90).

Table 4.8: Mean square of maize grain size (mm) during long rains 2016 and short rains 2016-2017 at Embu and Mwea

Source of variation	df	6 mm	7 mm	8 mm	9.5 mm	10 mm
Replications	2	100.40	242.8	109.6	256.65	48.56
Treatments	3	46.19^{NS}	174.4^{NS}	315.2*	122.30^{NS}	38.52^{NS}
Seasons	1	0.19^{NS}	0.8^{NS}	0.0^{NS}	0.02^{NS}	1.69^{NS}
Sites	1	397.52*	59080.3*	6371.0*	28665.19*	981.02*
Treatments x Seasons	3	0.19^{NS}	1.6^{NS}	0.0^{NS}	0.30^{NS}	1.69^{NS}
Treatments x Sites	3	17.30^{NS}	213.0^{NS}	315.2^{NS}	22.02^{NS}	54.02^{NS}
Seasons x Site	1	0.19^{NS}	2.1^{NS}	0.0^{NS}	0.19^{NS}	1.69^{NS}
Treatments x Seasons x sites	3	0.19^{NS}	1.2^{NS}	0.0^{NS}	0.24^{NS}	1.69^{NS}
Residual	30	56.04	121.4	107.5	93.76	31.85
Total	47					

df: degree of freedom, 6mm : Maize size with 6mm, 7mm : Maize size with 7mm, 8mm : Maize size with 8mm, 9.5mm : Maize size with 9.5mm, 10mm : Maize size with 10mm.

Grains with 4mm did not show significant difference between sites and seasons ($p \leq 0.05$). Their means ranged from 0 % to 2.67 % at Mwea in sole crop and in intercrop while grains with 4mm were ranged from 0 % to 3 % at Embu in the long rain and short rains (Table 4.9). Grain with 5.6 mm did not show significant difference between sites and seasons ($p \leq 0.05$). They ranged from 0 % to 30 % at Embu while at Mwea they ranged from 0 % to 6 % in sole crop and in intercrop in the long rains. The same case occured in the second season. SB19 variety recorded the highest percentages of grain size in sole crop and in intercrop followed by TGX1990-5F. However, grain with 6 mm showed significant difference between sites and seasons ($p \leq 0.05$). Variety SB19 recorded a higher amount of 35.3 % more than 23.3 % for GAZELLE and TGX1990-5 recorded the lowest amount of 2.7 % in sole crop. TGX1990-showed higher value of 58 % followed by SB19 (35.7 %) and the last was GAZELLE with 6.3 % in intercrop in the first season at Embu. The percentage of grain size obtained in short rains was the same as the first season. Grain with 6.5 mm did not show significant difference between sites and seasons. This parameter received higher amount grain size than other parameters. TGX1990-5F recorded 89.7 % more than 60.3 % for GAZELLE while SB19 recorded 34 % in sole crop at Embu. In addition, GAZELLE recorded biggest amount of 58 % followed by TGX1990-5F (33.7 %) and the last was SB19 with 31 % in intercop at Embu in long rains. In the same season, TGX1990-5F presented higher amount of 68.3 % followed by 67.3 % for GAZELLE and SB19 presented 0 % in sole crop at Mwea. GAZELLE showed 79.3 % bigger than 65.7 % for TGX1990-5F compared to SB19 with 0.7 % in intercrop for the long rains. Soyean grain size with 7 mm showed significant difference between sites and seasons ($p \leq 0.05$). GAZELLE showed 16.3 % more than 6.7 % for TGX1990-5F and the last was SB19 with 1.7 % in sole crops. Variety GAZELLE presented 35.7 % more than 10.7 % and SB19 showed the lowest amount of 0.3 % in intercrop at Embu in the long rains. Variety GAZELLE showed 32% bigger than 8.3% for SB19 and TGX1990-5F showed the lowest amount of 6 % in sole crop. GAZELLE presented 23 % bigger than 8.7% for TGX1990-5F and SB19 showed the lowest amount of 0.7 % in intercrop at Mwea in the long rains. Soybean with 8mm did not show significant difference between sites and seasons ($p \leq 0.05$). GAZELLE was the variety only which showed with 0.3 % at Mwea. Embu had not been represented by one of these varieties because it did not increase soybean grain size compared to Mwea. Intercropping affected negatively the grain size according to the results found during long rains of 2016 at Mwea than Embu, because Mwea site gave significant difference with 2.67 % and 0.00 % respectively means for SB19 and GAZELLE for soybean size with 4 mm. However, Mwea site produced better grain size compared to Embu. GAZELLE had higher grain size (7 mm) compared to other varieties. SB19 had smaller grain size (6 mm) where the % of grain size was 96% at Mwea in intercropping compared to GAZELLE with 1% in intercropping too (Table 4.9, page 93).

Grain size for maize in intercropping and in sole crop did not give significant difference between sites and seasons ($p \leq 0.05$). Nevertheless, The biggest grain size was found at Embu site compared to Mwea (9 .5 mm) against (7 mm) respectively (Table 4 .10, page 94). Thus, Embu produced better grain size compared to Mwea in both rains seasons. Intercropping did not reduce maize grain size in both sites and both rains seasons. The means for both sites didn't give significant difference for maize grain size

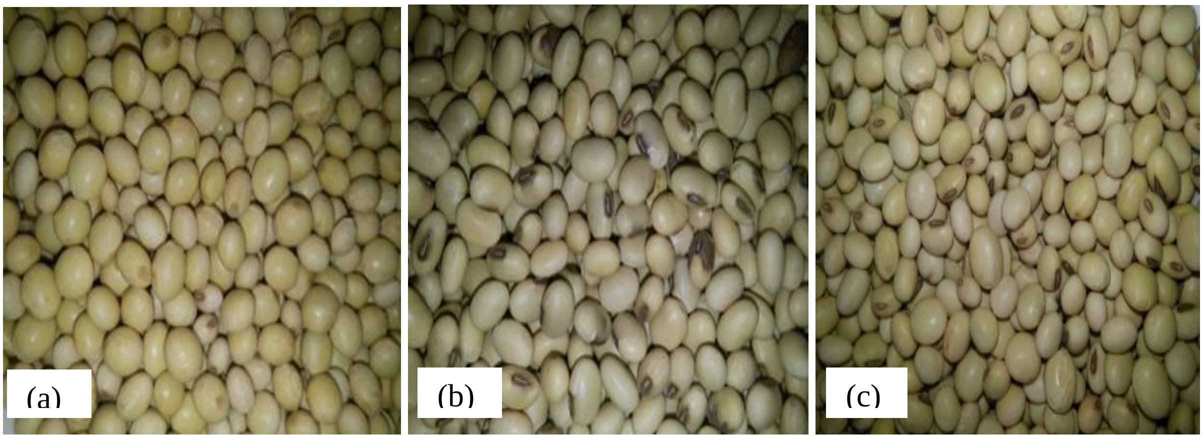


Figure 4.6: Grain of soybean varieties after harvesting ; (a) GAZELLE, (b) TGX1990-5F, (c) SB19

Table 4.9: Soybean grain size (mm) long rains of 2016 and short rains of 2016-2017 at Embu and Mwea

	Long rains 2016																	
	4 mm			5.6 mm			6 mm			6.5 mm			7 mm			8 mm		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	2.33a	0.67ab	1.50a	26.7a	6.0a	16.3a	35.3ab	85.0a	60.2a	34.0a	0.0b	17.0a	1.7ab	8.3bc	5.0b	0.0	0.0a	0.0a
GAZELLE	0.00a	0.00b	0.00a	0.0a	0.0a	0.0a	23.3ab	0.0b	11.7ab	60.3a	67.3a	63.8a	16.3ab	32.3a	24.3ab	0.0	0.3a	0.16a
TGX1990-5F	0.00a	0.00b	0.00a	1.0a	0.0a	0.5a	2.7b	25.7b	14.2ab	89.7a	68.3a	79.0a	6.7ab	6.0bc	6.3b	0.0	0.0a	0.0a
SB19+MAIZE	3.00a	2.67a	2.83a	30.0a	0.0a	15.0a	35.7	96.0a	65.8a	31.0a	0.7b	15.8a	0.3b	0.7c	0.5b	0.0	0.0a	0.0a
GAZELLE+MAIZE	0.00a	0.00b	0.00a	0.0a	0.0a	0.0a	6.3ab	1.0b	3.7b	58.0a	79.3a	68.7a	35.7a	23.0ab	29.3a	0.0	0.0a	0.0a
TGX1990-5F+MAIZE	1.00a	0.00b	0.50a	0.0a	0.0a	0.0a	58.0a	26.0b	42.0ab	33.7a	65.7a	49.7a	10.7ab	8.3bc	9.5b	0.0	0.0a	0.0a
Mean	1.06	0.56	0.81	9.6	1.0	5.3	26.9	38.9	32.9	51.1	46.9	49.0	11.9	13.1	12.5	0.0	0.056	0.028
LSD0.05	3.382	2.039	2.39	42.43	7.72	28.34	48.0	43.11	52.08	56.60	51.69	60.16	32.06	16.60	24.86	-	0.4288	0.26
CV%	176.1	201.7	177.8	242.7	424.3	331.1	98.1	60.8	96.3	60.9	60.6	76.3	148.2	69.6	113.2	0.0	424.3	586.8
	Short rains 2016-2017																	
	4 mm			5.6 mm			6 mm			6.5 mm			7 mm			8 mm		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	2.67a	0.67ab	1.67a	27.0a	6.0a	16.5a	35.3ab	85.0a	60.2a	13.7b	0.0b	6.8a	21.3a	8.3bc	14.8b	0.0	0.0a	0.0a
GAZELLE	0.00a	0.00b	0.00a	0.0a	0.0a	0.0a	23.3ab	0.0b	11.7ab	60.3ab	67.3a	63.8a	16.3a	32.3a	24.3ab	0.0	0.3a	0.16a
TGX1990-5F	0.00a	0.00b	0.00a	1.0a	0.0a	0.5a	2.7b	25.7b	14.2ab	89.7a	67.7a	78.7a	6.7a	6.7bc	6.7b	0.0	0.0a	0.0a
SB19+MAIZE	3.00a	2.67a	2.83a	27.3a	0.0a	13.7a	35.7ab	96.0a	65.8a	30.7ab	0.7b	15.7a	3.3a	0.7c	2.0b	0.0	0.0a	0.0a
GAZELLE+MAIZE	0.00a	0.00b	0.00a	0.0a	0.0a	0.0a	9.3ab	1.0b	5.2b	57.3ab	76.3a	66.8a	33.3a	22.7ab	28.0a	0.0	0.0a	0.0a
TGX1990-5F+MAIZE	1.00a	0.00b	0.50a	0.0a	0.0a	0.0a	54.7a	26.0b	40.3ab	33.7ab	65.7a	49.7a	10.7a	8.3bc	9.5b	0.0	0.0a	0.0a
Mean			0.83	9.4	1.0	5.1	26.8	38.9	32.9	47.6	46.3	46.9	15.3	13.2	14.2	0.0	0.056	0.028
LSD0.05	3.366	2.039	2.39	43.62	7.72	28.34	44.94	43.11	52.08	54.49	50.62	60.16	41.88	16.83	24.86	-	0.4288	0.26
CV%	166.5	201.7	177.8	260.0	424.3	331.1	92.1	60.8	96.3	63	60.1	76.3	150.7	70.3	113.2	0.0	424.3	586.8

LSD : Least significant difference, CV : Coefficient of variation, Soybean with 4 mm, 5.6 mm : Soybean with 5.6 mm, 6 mm : soybean with 6 mm, 6.5 mm : Soybean with 6.5 mm, 7 mm : Soybean with 7 mm, 8 mm : Soybean with 8 mm.

Table 4.10: Maize grain size (mm) long rains 2016 and short rains 2016-2017 at Embu and Mwea

	Long rains 2016														
	6 mm			7 mm			8 mm			9 .5 mm			10 mm		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
Sole Maize	1.7a	10.0a	5.85a	0.0a	75.3a	37.56a	25.7a	0.0	12.8a	67.3a	14.7a	41.0a	5.33a	0.00a	2.67a
SB19 + Maize	2.7a	16.7a	9.7a	0.0a	73.3a	36.65a	32.3a	0.0	16.1a	57.7a	10.0a	33.8a	7.33a	0.00a	3.67a
Gazelle + Maize	0.3a	11.3a	5.8a	0.0a	76.0a	38a	26.0a	0.0	13.0a	60.3a	12.0a	36.2a	13.33a	0.67a	7.00a
TGX1990-5F+ Maize	0.7a	11.0a	5.85a	16.0a	73.7a	44.85a	8.3a	0.0	4.2a	62.7a	15.3a	39.0a	12.33a	0.00a	6.17a
Mean	1.3	12.2	6.75	4	74.6	39.3	23.1	0.0	11.5	62.0	13.0	37.5	9.58	0.17	4.88
LSD	3.60	22.81	5.41	27.68	17.09	18.37	31.69	0.0	17.29	23.32	9.83	16.15	16.12	1.15	9.41
CV%	135.2	93.2	111.2	346.4	11.5	28.1	68.9	0.0	90	18.8	37.8	25.8	84.2	346.4	111.5
	Short rains 2016-2017														
	6 mm			7 mm			8 mm			9 .5 mm			10 mm		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
Sole Maize	1.7a	10.0a	5.8a	0.0a	72.7a	36.35a	25.7a	0.0	12.8a	67.3a	14.3a	40.8a	5.33a	3.00a	4.17a
SB19 + Maize	2.7a	16.7a	9.7a	0.7a	73.3a	37a	32.0a	0.0	16.1a	57.3a	10.0a	33.7a	7.33a	0.00a	3.67a
Gazelle + Maize	0.3a	11.3a	5.8a	0.0a	76.0a	38a	26.0a	0.0	13.0a	60.3a	12.0a	36.2a	13.33a	0.67a	7.00a
TGX1990-5F+ Maize	0.7a	10.0a	5.3a	16.0a	73.7a	44.85a	8.3a	0.0	4.2a	62.7a	16.3a	39.5a	12.33a	0.00a	6.17a
Mean	1.3	12	6.65	4.2	73.9a	39.05	23.1	0.0	11.5	61.9	13.2	37.5	9.58	0.92	5.25
LSD	3.60	22.39	5.41	27.32	17.94	18.37	31.79	0.0	17.29	23.55	9.39	16.15	16.12	5.502	9.41
CV%	135.2	93.4	111.2	328.2	12.1	28.1	68.9	0.0	90	19	35.7	25.8	84.2	300.4	111.5

LSD : Least significant difference, CV : Coefficient of variation ,6 mm : Maize size with 6mm, 7mm : Maize size with 7mm, 8mm : Maize size with 8mm, 9.5mm : Maize size with 9.5mm, 10mm : Maize size with 10mm.

4 .4.3 Effects of intercropping Maize-soybean on protein and oil content

The results for combined analysis of variance of soybean on protein content, oil content and dry matter did not showed significant difference between treatments x seasons x sites and seasons x sites ($p \leq 0.05$) (Table 4.11). The analysis of oil content gave signifcant difference between treatments x sites and not for protein content and dry matter. The treatments x seasons did not give significant difference for all parameters while the sites gave significant difference for oil content and not for other parameters. The seasons showed significant difference only for protein content and not for oil content and dry matter while the treatments gave significant difference for all parameters (Table 4.11, page 95).

Table 4.11: Mean square on soybean protein content, oil content and dry matter at Embu and Mwea during long rain of 2016 and short rain of 2016-2017

Source of variation	df	Protein content	Oil content	Dry matter
Replications	2	0.08	0.358	1.772
Treatment	5	72.85*	115.726*	11.421*
Season	1	213.49*	0.117^{NS}	0.222^{NS}
Site	1	42.97^{NS}	22.512*	9.592^{NS}
Treatment. Season	5	30.50^{NS}	2.887^{NS}	0.889^{NS}
Treatment. Site	5	2.47^{NS}	52.032*	2.269^{NS}
Season. Site	1	49.04^{NS}	3.690^{NS}	0.500^{NS}
Treatment. Season. site	5	2.73^{NS}	2.137	1.300^{NS}
Residual	46	19.32	2.241	1.450
Total	71			

df : degree of freedom

Soybean protein did not show significant difference between sites for the long rains 2016, but different treatments gave significant difference ($p \leq 0.05$) (Table 4.12). Soybean protein content was slighly higher in the long rain season (39.34 %) compared to the short rain season (35.85 %). Protein content ranged from 36 % to 43 % at Mwea while it ranged from 36 % to 42 % at Embu for the long rain season. However, during the short rains, it ranged from 31 % to 40 % at Mwea while it ranged from 36 % to 41 % at Embu. During the long rains soybean from Mwea increased slightly the amount of protein content than soybean from Embu while it was the contrary in the short rains. TGX1990-5F showed higher amount of 42.89 % of protein followed by GAZELLE (39.18 %) in sole crop compared to SB19 with 36.64% of protein content. However, SB19 produced more protein content (40.43 %) followed by TGX1990-5F (38.43 %) compared to GAZELLE with 37.99 % at Embu. From Mwea site, TGX1990-5F showed higher protein content of 43.02% than GAZELLE with 39.36 % in sole crop compared to SB19 with 36.64%. Intercropping reduced protein content considering the higher amount of protein content for each variety produced in sole crop than in intercropping i.e GAZELLE showed the highest protein content of 40.39 % than TGX1990-5F and SB19 which gave similar amount of protein content of 38 %. During the short rains, protein content gave significant diference between sites ($p \leq 0.05$), i.e, TGX1990-5F protein content was 40.14 % more than 36.15 % for GAZELLE compared to 34.53 % for SB19 in sole crop. The same situation happened at Mwea site, where TGX1990-5F was first in intercropping followed by SB19 compared to GAZELLE producing the higher amount of protein (Table 4.12, page 98).

However, oil content for the long rains of 2016 gave significant differences between sites and seasons, Soybean oil content was slightly higher in the long rain season (16.62 %) compared to the short rain season (16.54 %). Oil content ranged from 12 % to 19 % at Mwea while it ranged from 9 % to 21.08 % at Embu for the long rain season. However, during the short rains, it ranged from 14.98 % to 22.27 % at Mwea while it ranged from 9.58 % to 20.74 % at Embu. During the long rains Embu increased slightly oil content than Mwea while it was the contrary in the short rains. GAZELLE gave high amounts of 21.08 % in sole crop followed by TGX1990-5F with 18. 63 % compared to SB19 with 16.46 % at Embu. Variety GAZELLE recorded higher amount of oil content of 16.68 % than TGX1990-5F with 12.77 % compared to SB19 with lower amount of 9.37 % in intercrop. GAZELLE variety had higher amounts of oil content at Mwea with 22.98 % than SB19 with 15.29 % compared to TGX1990-5F in sole crop with 12.78 %. The same variety GAZELLE gave high amount of oil content followed by SB19 and TGX1990-5F showed the lowest oil content in intercrop. During the short rains the variety which had lowest amounts of oil content was SB19 and TGX1990-5F was in the middle while GAZELLE ranked the first. However, intercropping reduced gradually the amount of oil content in both sites and in both rains seasons (Table 4.12, page 98). Dry matter gave significant difference between sites and seasons ($p \leq 0.05$). Embu site did not give significant difference in both rains seasons. Dry matter ranged from 14 % to 16 % for the first season while it ranged from 15% to 16 % in the short rains in sole crop as in intercrop. The significant difference was shown at Mwea in both rainy seasons, Soybean dry matter was slightly higher in the short rain season (16.58 %) compared to the long rain season (16.47 %). Dry matter ranged from 15.11 % to 18.82 % at Mwea while it ranged from 14.87 % to 16.84 % at Embu for the long rain season. However, during the short rains, it ranged from 15.11 % to 18.82 % at Mwea while it ranged from 15.15 % to 16.84 % at Embu. In both rains seasons, Mwea increased slightly the amount of dry matter. TGX1990-5F had higher amount of dry matter of 18.82 % than SB19 with 16.77 % compared to 15.74 % mean for GAZELLE sole crop. The same variety TGX1990-5F showed the same results in intercrop compared to GAZELLE and SB19 which had the same amount of dry matter of 15 %. For the short rains, the same variety TGX1990-5F presented good perfomance giving higher dry matter of 17.19 % than 16.77 % for SB19 compared to GAZELLE with 15.74 % in sole crop. TGX1990-5F showed bigger dry matter of 18.82 % followed by GAZELLE with

18.19 % and SB19 gave the lowest amount of 15.11% in intercrop. Thus during the long rains and short rain season TGX1990-5F gave higher amounts of dry matter than other varieties in intercropping and in sole crop. However, intercropping did not affect negatively the amount of dry matter (Table 4.12, page 98).

Table 4.12: Soybean protein content, oil content and dry matter at Mwea and Embu during long rains of 2016 and short rains of 2016-2017

Long rains 2016									
	% Protein content			% Oil content			% Dry matter		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	36.51d	36.64c	36.57a	16.46c	15.29d	15.88d	16.68a	16.77ab	16.73ab
GAZELLE	39.18bc	39.36b	39.27a	21.08a	22.98a	22.03a	15.82a	15.74ab	15.78ab
TGX1990-5F	42.89a	43.02a	42.96a	18.63b	12.78e	15.71d	16.84a	18.21ab	17.53a
SB19+MAIZE	40.43b	40.39b	40.41a	9.37e	18.58c	13.98e	14.87a	15.11b	14.99b
GAZELLE+MAIZE	37.99cd	38.11bc	38.05a	16.68c	19.58b	18.13b	16.79a	15.86ab	16.33ab
TGX1990-5F+MAIZE	38.43bcd	38.54bc	38.49a	12.77d	15.20d	13.98e	16.15a	18.82a	17.48a
Mean	39.24	39.34	39.29	15.83	17.40	16.62c	16.19	16.75	16.47
LSD0.05	2.165	2.183	7.224	0.916	0.5763	2.46	2.501	2.875	1.979
CV%	3.0	3.1	11.7	3.2	1.8	9.0	8.5	9.4	7.3

Short rains 2016-2017									
	% Protein content			% Oil content			% Dry matter		
Treatment	Embu	Mwea	Mean	Embu	Mwea	Mean	Embu	Mwea	Mean
SB19	34.53ab	31.29b	32.91b	17.47c	15.93b	16.70b	16.01a	16.77cd	16.39ab
GAZELLE	36.15ab	31.10b	33.62b	20.74a	22.27a	21.51a	15.15a	15.74de	15.45ab
TGX1990-5F	40.14ab	34.94ab	37.54ab	19.03b	14.98b	17.00b	16.84a	17.55bc	17.19ab
SB19+MAIZE	38.90ab	37.51a	38.20ab	9.58e	15.61b	12.59c	15.53a	15.11e	15.32b
GAZELLE+MAIZE	33.79b	30.16b	31.98b	17.26c	18.66ab	17.96b	16.46a	18.19ab	17.33a
TGX1990-5F+MAIZE	41.17a	40.50a	40.84a	12.77d	15.20b	13.46c	16.81a	18.82a	17.82a
Mean	37.45	34.25	35.85	16.20	16.87	16.54b	16.13	17.03	16.58
LSD0.05	6.253	5.895	7.224	0.7205	5.456	2.46	2.049	1.217	1.979
CV%	9.2	9.5	11.7	2.4	17.8	9.0	7.0	3.9	7.3

LSD : Least significant difference, CV : Coefficient of variation

4.5 Discussion

4.5.1 Effects of intercropping maize – soybean on soil fertility

4.5.1.1 Soil pH

The results of soil (pH) did not give significant difference before planting (BP) between sites and seasons. However, after harvesting (AH), soil pH showed significant difference between sites and seasons ($p \leq 0.05$) in intercopping and in sole crop. However, 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 increasing of soil acidity of pH at Embu could be due to the drought which decreased the soil microorganisms activity for decomposition of organic matter which decrease acidity. In addition, it could be attributed to roots of the varieties cultivated which can produce proton and acidify the soil. This agrees 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 envorenment. 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 decomposition of organic matter caused by water from irrigation as suppliment of rainfall which allowed the balance on anions and cations. The anions produced associate with H+ in soil solution to cause no change in pH. In the short rains soil pH decreased slightly at Embu AH compared to soil pH BP. SB19 decreased soil pH to 6.11 AH compared to 5 obtained BP. At Mwea all varieties decreased soil pH acidity to 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 mocroorganisms activity in the soil at both sites caused by water from irrigation which allowed 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 in soil acidity compared to monocropping, due to higher organic material production.

4.5.1.2 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 have increased OC after harvest. 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 less decomposition of organic matter which could increase OC. In the short rain season, at Mwea, TGX1990-5F showed the highiest 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) than before planting (BP) and the increased OC was associated with high yields. . This could be justified by water brought by irrigation in both sites which could increase decomposition of organic matter, resulting to high production of OC. Following the key for interpreting nutrients provided by Landon (1990) on soil nutrients interpretation, Only TGX1990-5F fixed the amounts required for feeding the plants. Akinnifesi *et al.* (2007); Sebetha (2015); Nagar *et al*. (2016) reported that the soil organic carbon increase in the legume-cereal intercropping, while in monocropping cereal there was a small decrease. Matusso *et al.* (2012) observed 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.

4.5.1.3 Soil Nitrogen

Soil nitrogen did not give significant differences between sites and seasons before planting (BP) but soil N showed significant differences between sites and seasons after harvesting (AH) ($p \leq 0.05$). Soil N increased AH in both sites in the first season. 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 carbohydrate to produce more nodules, hence, nitrogen fixation. TGX1990-5F showed the highiest 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. Therefore, only TGX1990-5F achieved the high amount of N (0.58 %) while other varieties produced moderate soil N depeding on the scale for Landon (1991). This agrees with, Stagnari *et al.* (2017), who reported that, most recent research has focused on potential of intercropping in sustainable production and in particular grain legumes that can fix N_2 through biological mechanisms (BNF). In addition, Stoltz & Nadeau (2014), found that, intercropping had lower nitrogen balances compared with maize sole crop and tended to reduce the content of mineral nitrogen in the soil after harvest by, on average , 10kg ha^{-1}. Matusso *at al*. (2012) , Phiri *et al.* (2013) and Dwivedi *et al.* (2015) reported that, the major role of biological nitrogen fixation and the amounts of nitrogen tranferred to associated non-leguminous crops determines the extent of benefits. Nevertheless , Ndusha (2011) said that, SB24 and SB19 produced no significant differences in shoots weight, but advised that as both of them are promiscuous, they nodulated freely with different isolates as the nodulation reflect soil nitrogen fixation. According to Sahabi (2015), nitrogen fixation showed significant difference ($p < 0.05$) between cultivars and Anido variety fixed higher amount of 59.kg ha^{-1}. The Anido variety left greater amount of 14.3kg ha^{-1} of nitrogen in its residue for succeding crop. In addition, the same author revelead that, yield of maize found by using 100kgN ha^{-1} of NPK and top dressing did not show significant difference compared to soybean residue incorporeted without fertilizer application. Thus, small scale farmers can reduce their production cost by incorporating soybean residue and using promiscuous soybean.

4.5.1.4 Soil phosphorus

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 in both seasons. However, some soybean varieties increased amount of phosphorus in the soil both sites and both rain seasons in intercropping as in sole crop, but other 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 cultivated, hence reduction of soil P at Embu than Mwea. In contrast, at Mwea the increasing of P for both rain seasons can be justified by some nutrients produced by soybean or maize which could play the role for solubilisation of insolubale P, hence, high phosphorus production. This agrees with, 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. Variety 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. Variety 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. 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. Legume 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 agrees with Matusso (2014), who reported that, at Embu site, the avaible phosphorus values did not show any significant differences among treatments. However, phosphorus decreased from the long rains to short rains.

4.5.1.5 Soil Potassium

Soil 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. This increase of K for Mwea could be justified by the availability of the water for irrigation found at Mwea compared to Embu. The decrease of K for Embu could be justified by the insufficiency of water for irrigation some time which allowed the compaction of the soil, hence, soil defficiency in K occured. 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 have been caused by the presence of some minerals in the soil like cadminium. The K can also be fixed by high levels of clay minerals. SB19 presented the highest amount of K (1.24 Cmol/kg) AH but 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 observed 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 highiest 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.

4.5.2 Effects of intercropping maize – soybean on grain size

Intercropping affected negatively the grain size from the results found during long rains of 2016 at Mwea than Embu, because Mwea site gave significant difference with 2.67 % and 0.00 % respectively means for SB19 and GAZELLE for soybean size with 4 mm. A high proportion of soybean grain at both sites was 6.5 mm, where GAZELLE had significant difference compared to SB19 with 7.33% and 0.67% respectively. This agrees with, William (2012) who reported that, variety with early maturity are the most to give poor seed quality especially for those variety whose maturity are not unifom. Wet conditions, shading, pressures of some diseases, poor conditions between pysisological maturity and harvest can enhance the decrease of grain quality. SB19 variety is known for early maturity and produced poor seed quality because of the critical conditions which were present during the two rain seasons. GAZELLE the local variety had good grain size followed by TGX1990-5F and the last was SB19. This agrees with, Foundation (2011) who, reported that GAZELLE is a variety largely cultivated in Kenya and was released in 2009 by KARI Njoro and is known as variety with high yielding, large grain size, and attractive color. Whan *et al*. (2014), reported that, grain size is an important trait of both basic plant reseach, since grain formation and development is a fundamental aspect of reproduction, and breeding, as a component of yield and vigour. Thus, the genetic characteristic that determine seed size tend to either influence the seed size to increase or decrease depending of growing conditions. Most of the soybean good grain size ranged from 5.6 mm to 8 mm. This agrees with Shahin & Symons (2005) who reported that, depending on the varieties of soybean, grain size can range between 5.56 mm to 7.54 mm.

4 .5.3 Effects of intercropping Maize-soybean on protein, oil content and dry matter

According to the results obtained, TGX1990-5F showed significant difference compared to other varieties producing high amount of protein which ranged between (34.94 % to 43.02%) at both sites during two rain seasons. The second variety to produce high amount of protein was the local variety GAZELLE and the last was SB19. Intercropping affected sligthly the soybean protein considering the higher amount of protein for each variety received in sole crop than in intercropping. The higher production of protein for TGX1990-5F might be due to his genetic characteristics. GAZELLE variety produced highest amount of oil (21.08 %) compared to SB19 (16.46 %) at Embu in long rains of 2016. The higher production of oil for GAZELLE might be attributed to its bigger grain size compared to other varieties. Variety SB19 had the lowest amount of oil. This might be justified by its smaller size compared to other varieties. GAZELLE produced highest amount of oil in both sites and both rain seasons. Intercropping reduced slightly the amount of soybean oil than sole crop. Lithourgidis *et al*. (2011) found that, protein content and oil content can be affected positively or negatively by growth conditions of crops. Moreover, Erik (2005) reported that, intercropping can affect a series of quality factors, such as physical grain quality, ratio of nitrogen and sulphur concentrations, protein quality for wheat and fababean. In addition, Abdel *et al*. (2016) revealed that intercropping soybean-sunflower spaced at 20 cm (soybean) had the highest seed oil yields per ha compared to others spacing. Ayu *et al.* (2004) recorded maximum protein yield of sorghum under soybean plus sorghum system compared to sole sorghum. In many cereal-legume intercropping systems there is emanation of favourable exudates from the component legume to the associated cereal and this is suspected to have effects on the quality of the cereal in terms of protein yield. However, depending on dry matter, TGX1990-5F gave significant diference of dry matter (18.82 % compared to 15.11 %) for SB19 at Mwea for long rains of 2016. Embu site did not give significant difference during long rain of 2016 and short rains of 2016-2017. Musa *et al*. (2011) reported that intercropping increased chemical composition as dry matter, ash, protein, fiber content and tannin content of cowpea in maize-cowpea intercropping. In addition, Rusdy (2014) showed that intercropping of *Panicum maximum* and *Centrosema pubescens* gave dry matter which was significantly different ($p < 0.05$) than their monocrops.

4.6 Conclusion

The study showed that , TGX1990-5F 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 sole crop and in intercrop in both rain seasons. In addition, intercropping maize-soybean showed that TGX1990-5F variety presented high value of protein content in sole crops and in intercrops followed by GAZELLE compared to SB19. For the oil content, GAZELLE came first showing high value of oil content while TGX1990-5F was second. TGX1990-5F can be recommended to smallscale farmers for intercropping with maize because it can reduce the cost for N fertilizer fixing N biologicaly freely and can also produce high protein content and fight against mal nitrution and increase maize yields. GAZELLE had higher grain size and produced higher oil content compared to other varieties.

CHAPTER FIVE

5.0 GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 General discussion

The results of this study on evaluation of promiscuous soybean varieties for agronomic and grain quality triats in maize-soybean intercropping systems showed significant difference on plant height, yield biomass per plant, 100 grain weight, grain yield, harvest index and Land Equivalent Ratio for both crops, number of nodules per plant, shattering score (1-5), number of pods per plant. In addition number of seeds per pod, days to 50% flowering, days to 75% maturity did not show significant difference ($p \leq 0.05$) for soybean. Maize parameters did not show significant difference ($p \leq 0.05$). Significant differences were also shown on soil nutrients (pH, N, OC, P, K) after harvesting compared to soil nutrients before planting. In addition, significant difference was also shown in soybean protein content, oil content, dry matter and soybean grain size. Similary, germination % was higher during the long rains recording 90 % compared to the short rains that recorded between 67 to 79%. This could be due to little quantity of the rainfall combined with irrigation as supplement to rainfall in both sites in long rain season than the short rain seasons. This is in agreement with Etherington (1990); Kabir and Achakzai (2009); Guo *et al.* (2013) who reported that, water availability allow soil imbibition and provive good seedling growth while water stress inhibit good seedling growth.

The plant height (PH) showed significant difference between sites and seasons. Mwea recording the tallest soybean plant height ranging from 47 to 67 cm while Embu presented the shortest plant height which ranged between 40 to 55 cm in the long rains. This could be attributed to better condition of more water from irrigation at Mwea than Embu. These findings concur with those of Chavarria and Grape (2007) who reported that, water stress could affect plant height through inhibition of soil nutrients while regular water supply to plant allows their good growth enhancing plant height. However, Moles *et al.* (2009) reported that, plant height could be correlated to environemental variables and genetic makeup. However, days to 50 % flowering and 75 % maturity showed significant difference between sites. Days to 50 % flowering and 75 % maturity were low at Mwea compared to Embu. This might be due to low altitude at Mwea compared to Embu which is high altitude. This is in agreement with Sileshi (2013) who said that, soybean varieties can be early maturing because of some genetic characteristics or environment. However, intercropping did not reduce significantly days to 50 flowering and 75% maturity but only 1or 2 days could make increase on days to 50% flowering and 75% maturity in intercrop than in sole crop. This could be due to the shading caused by the maize. This findings agree with Matusso *et al.* (2012) who reported that, 1 or 2 days were added on days to 50% flowering and 75% maturity for soybean in intrercropping of maize-soybean than in sole crop due to shading effect of Maize. In addition, Soybean biomass showed significant difference ($p \leq 0.05$) between sites and seasons. TGX1990-F had the highest biomass of 12.9 t ha^{-1} followed by SB19 with 8.23 t ha^{-1} in sole crop and the variety which presented the lowest amount of biomass is GAZELLE with 3.54 t ha^{-1} in intercropping at Mwea. Variety TGX1990-5F gave the highest biomas of 14.7 t ha^{-1} compared to SB19 with the lowest biomass of 7.29 t ha^{-1} in sole crop at Embu. The high amount of TGX1990-5F could be due to its genetic characteristics to develop high vegetation than other varieties which result to high amount of biomass. Mwea showed the highest amount of biomass than Embu. This can be due to good adaptation of soybean genotypes cultivated at Mwea than Embu. However intercropping reduced soybean biomass than sole crops. This could be explained by the effect of shading of maize, hence, light interception. This was in agreement with Prasad and Brook, (2005a) who reported that in maize-sobean intercropping, the maize can increase their biomass while soybean biomass can decrease which is the result of maize shading. In addition number of Soybean nodules showed significant difference ($P \leq 0.05$) between sites but the seasons were not significantly different. TGX1990-5F recorded the highest number of nodules of 47 in intercropping while GAZELLE recorded the lowest number of nodules of 33.90 at Mwea in intercropping too. This could be due to varieties makeup. This agrees with Aniekwe (2014) who reported that the variety of TGX1876-4E had the highest number of nodules (12.72 in 2009) compared to TGX1904-6F had the least number of nodules (9.39) under different soil fertility. Houx, (2007) said that the presence of sufficient phosphorus in the soil can allow soybean variety to fix more nodules than the insufficient phosphorus which can decrease the amount of nodules. In addition, Maphosa (2015) reported that the promiscuous variety TGX-1937-1F showed higher number of nodules (28 per plant) while the highest percentage of active nodules (69%) was recorded by TGX-1740-2F when they were inoculated. However, the number of pods per plant showed significant difference between sites in sole crop and in intercrop in long rains while the short rains did not show significant difference to number of pods per plant. TGX1990-5F presented the highest number of pods of 107 followed by SB19 with 81 pods in sole crop. GAZELLE showed the lowest number of pods of 46 in intercropping at Mwea. In addition, intercropping reduced the number of pods per plant both seasons. This could be justified by the light interception caused by the shading of maize; hence, soybean could not receive the sunlight for photosthesis and carbohydrate formation to feed pods. Biabani *et al.* (2008) reported that the number of pods for soybean decreased in intercrop compared to sole crop. The seeds per pods did not show significant difference between sites. Intercropping did not affect the number of seeds per pod. This is in agreement with Matusso (2014) who reported intercropping maize soybean did not affect negatively the number of seeds per plant. Mwea site increased the number of pod shattering compared to Embu. This can be due to the low altitude of Mwea. The low altitude from Mwea increased temperature, and then it enhanced the stattering score compared to Embu. This agrees with Krisnawati and Adie

(2017) who revealed that, varieties of soybean with resistance to pods shattering resistance is most important of improvement soybean in tropics where the temperature can reduce the soybean yield by0 pods shattering. However, depending on the results obtained in the sole crop and in intercropping, intercropping reduced soybean 100 grain weight. Similar results were obtained by Undie *at al.* (2012) who reported that maize-soybean intercropping reduced 100 grain weight for soybean during two years (2007) and (2008). Intercropping system reduced soybean yield both sites and seasons. Variety GAZELLE recorded the highest yield of 1.7 t ha^{-1} compared to SB19 with the lowest yield of 0.15 t ha^{-1} in intercropping at Embu. Mwea produced higher yield compared to Embu both seasons. This could be explained by the competition between soybean and maize on water, nutrients, air and light compared to the sole crops (Aziz & El-razek , 2012 ; Waktola *et al*. 2014). Intercropping did not reduce maize yield both sites and seasons. This could be due to the capacity for maize to use efficiently the light, air and nutrients than soybean. This agrees with Siddiq & Mian (2011) who reported that intercropping did not affect cereal yield in cereal-legume cropping system. In addition, Mwea produced the highest HI both seasons than Embu. The highest HI produced at Mwea compared to Embu could confirm the highest soybean yield recorded as results to sufficient water which was provided by rainfall and irrigation to supplement rainfall at Mwea. GAZELLE gave the highest HI of 0.3 in sole crop and TGX1990-5F presented the lowest HI of 0.1 at Mwea in sole crop. Variety GAZELLE showed the highest HI of 0.39 in sole crop compared to SB19 which showed the lowest HI of 0.10 in intercropping at Embu. Intercropping reduced HI in both sites and both seasons.This agrees with Naim *et al*. (2012), who said that, the higher plant population in intercrops decrease HI while lower plant population in sole crops tend to increase HI. LER did not give significant difference between sites in the long rains 2016. TGX1990-5F showed the highest LER of 1.9 at Mwea while GAZELLE presented the lowest LER of 1.3. However, TGX1990-

5F showed the lowest LER of 1.5 at Embu compared to SB19 which presented the highest LER of 1.8 in the long rains 2016. During the short rains LER showed significant difference between sites ($p \leq 0.05$). This finding agrees with Sullivan (2003) ; Hugar and Palled (2008); Addo-Quaye (2011); Yusuf *et al.* (2012) who recorded LER greater than 1.00 in cereals-legumes cropping system. After harvesting in long rain season, the acidity increased at Embu and TGX1990-5F increased acidity (5.18) compared to pH 5.88. At Mwea the pH did not change AH in sole crop and in intercrop in long rain. In the short rains soil pH decreased slightly at Embu AH. This might be attributed to good mocroorganisms activity in the soil in both sites caused by water from irrigation which allowed good decomposition of organic matter from the crops, hence, soil neutrality. This agrees with Bandyopadhyay *et al.* (2007); Nagar *et al.* (2016) who reported that, the increased organic carbon production in green manure increased soils pH which allows the buffering of the soils. After harvesting at Embu, Organic Carbon increased in the soil in the long rains seasons. TGX1990-5F showed higher OC after harvest at Embu. This could be caused by the breaking down of organic matter which could enhance OC after harvest (Batubara, 2017). After harving (AH), Soil N showed significant differences between sites and seasons ($p \leq 0.05$). During the short rains, soil N increased only at Embu and decreased at Mwea. This could be due to the ability of the varieties used producing more nodules, which could allow more nitrogen fixation at Embu compared to Mwea. This result concurs with the one for Garg *et al*. (2004) who reported that, legumes in better environment must use more carbohydrate to produce more nodules, in order to fix nitrogen. TGX1990-5F recorded the highest soil N AH compared to SB19 which gave the lowest soil N AH in intercrop at Embu in long rain. However, some soybean varieties increased amount of phosphorus in the soil in both sites and both rain seasons in intercropping as in sole crop, but some other varieties did not. This might be due to some nutrients in the soil which could increase or decrease the disponibility of the P in the soil.

Some time also, the increasing and the insufficiency might be due to soybean varieties used. Hence, reduction of soil P at Embu and increasment of P at Mwea. 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. In addition, 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 justified by the availability of the water for irrigation found at Mwea compared to Embu which facilitated the mineralisation of K from organic matter. The decrease of K for Embu could be justified by the insufficient water for irrigation some time which could allow the compaction of the soil, 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. In addition, The high amount of soybean good grain size ranged from 5.6 mm to 8 mm. Those results have been confirmed by Shahin & Symons (2005) who reported that, depending on the varieties of soybean, grain size can range between 5.56 mm to 7.54 mm. According to the results found, TGX1990-5F showed significant difference producing high amount of protein which ranged now between (34.94 % to 43.02%) at both sites and during two rainy seasons. The higher production of protein content by TGX1990-5F might be due to his genetic characteristics. GAZELLE variety produced highest amount of oil content (21.08 %) compared to SB19 (16.46 %) at Embu in long rains of 2016. The higher production of oil content by GAZELLE might be attributed to its grain size being bigger compared to other varieties. Intercropping affected slightly the amount of oil content than sole crop. Depending on the results obtained Lithourgidis *et al.* (2011) found that seed quality traits, protein content and oil content can be affected positively or negatively by growth conditions of crops. However, depending to dry matter, TGX1990-5F gave significant diference of dry matter (18.82 % compared to 15.11 %) for SB19 at Mwea for long rains of 2016. Musa *et al*. (2011) reported that intercropping increased chemical composition as dry matter, ash, protein, fiber content and tannin content of cowpea in maize-cowpea intercropping.

5 .2 Conclusion

The study on evaluation of promiscuous soybean varieties for agronomic and grain quality traits in maize soybean intercropping system in Kenya, had two specific objectives. The first was to identify the most promiscuous soybean variety for intercropping with maize. The second was to determine the effect of intercropping maize-soybean on soil fertility and grain quality traits. The results revealed that plant height, yield biomass per plant, 100 grains weight, grain yield, harvest index, Land Equivalent Ratio, number of pods per plant for soybean decreased in intercrop compared to the sole crop in both sites and rainy seasons. In addition, intercropping had no effect on germination %, number of nodules per plant, shattering score (1-5), days to 50% flowering, days to 75% maturity, number of seed per pod in both sites and rainy seasons for soybean. However, the maize was not affected by intercropping in both sites and rainy seasons. In addition, variety TGX1990-5F showed higher number of nodules per plant followed by GAZELLE and the last was SB19 in both sites and rainy seasons. The most promiscuous variety TGX1990-5F showed higher yield between sites (Embu and Mwea) than GAZELLE between the sites too, but it didnt give significant difference for the long rains of 2016 in intercropping. According to the short rains of 2016-2017, TGX1990-5F had greater yield followed by SB19 and GAZELLE was the last in intercropping but also it didn't give significant difference. Furthermore, TGX1990-5F showed higher LER in intercrop compared to SB19 in ntercrop too in both sites and seasons. LER showed advantage between component crops in both sites and seasons. Finally TGX1990-5F was taken as suitable promisuous soybean for intercropping with maize.

According to the soil nutrients, the results showed that TGX1990-5F fixed high amount of N and other nutrients (OC, K and P), the same variety took the second place in both sites and in both rain seasons compared to other varieties. In addition, TGX1990-5F presented high value of protein content in sole crop and in intercrop. For the oil content, GAZELLE came first showing the highest amount of oil content followed by TGX1990-5F. So, TGX1990-5F can be recommended to smallscale farmers for intercropping with maize because it can produce protein and reduce the cost for N fertilizer due fixing N biologicaly freely. For grain size, GAZELLE as local variety showed greater size compared to other varieties.

5.3 Recommendations

Recommendations for future research :

- To grow TGX1990-5F in different intercropping patterns which could explain more some results of this study.
- As GAZELLE variety showed higher amount of oil content than others, breeding can be pursused into those two varieties. GAZELLE characteristcs for producing good size grains and high amount of oil content can be combined with TGX1990-5F characteristics. The two varieties characteristics can constitute one promisuous soybean variety with more interesting characteristics.

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