EVALUATION OF YIELD POTENTIAL AND MANAGEMENT PRACTICES AFFECTING SOYBEAN PRODUCTION IN WESTERN KENYA

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**A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN
AGRONOMY, UNIVERSITY OF ELDORET, KENYA**

2015

DECLARATION

Declaration by the candidate

I declare that this thesis is my original work and to the best of my knowledge, it has not been presented in any University.

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DEDICATION

This thesis is dedicated to my wife Sylvia, my daughters Valery and Lavender Wekesa and my parents Erastus and Alice Waswa for their moral support, love and patience.

ABSTRACT

Soybean production in Western Kenya is low despite its yield potential. This is due to poor soil fertility, spacing and genotypes among others. Eleven soybean genotypes were evaluated for two seasons in three agro ecological zones in Western Kenya to evaluate the influence of inter-row spacing and genotype on growth and yield performance of soybean under optimum rates of P and K fertilizer application. Four best performing and most preferred genotypes were then assessed on the contribution of legume fertilizer blend and organic inputs. The two experiments were laid in a randomized complete block design (RCBD) and replicated three times. Grain yield and yield component data were subjected to ANOVA using SAS. Genotype x Environmental x management interaction means were separated using LSD (α =0.05). Inter-row spacing of 45cm was significantly different from inter-row spacing of 75 cm on growth and yield performance of soybean genotypes. Soybean genotypes also performed better in long rains than short rain. Nyabeda-in Siaya County out-yielded Ekitale in Bungoma County and Kambare in Kisumu County in that order. The highest mean grain yield was obtained from Sc Squire (3200 kg ha^{-1}), while TGx 1987-62F recorded the highest mean biomass. Simple linear correlation coefficient for grain yield showed positive association with above ground biomass, Nodule mean score, and plant height, Number of pods per plant and 100-seed weight. Application of Sympal, manure, scum or combination, out-performed treatments with inoculation alone in biomass and grain yield. Combination of manure or scum with Sympal fertilizer gave higher overall yields. The best inter-row spacing across seasons and sites is 45cm. Sc Squire is the best genotype for grain yield across seasons, spacing and sites while TGx 1987-62F is the best genotype for biomass production and nitrogen fixation. Therefore achieving high yields would require combination of mineral fertilizer, with manure or scum, adaptable genotype and inter-row spacing of 45 cm.

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ACKNOWLEDGEMENT

My sincere appreciation goes to my supervisors: Prof Elmada Auma, Dr. Lucas Ngode and Dr. Fredrick Baijukya for their piece of advice, precious time and constant guidance throughout the period of study. They played a vital role in developing and designing research concepts, provided moral and academic support, contributed significantly in conceptualization and making the ideas real.

I would also like to thank my fellow students at University of Eldoret and members of staff in the department of Seed Crop and Horticultural Sciences for their support. My gratitude goes to the entire staff of International Centre for Tropical Agriculture (CIAT) for their support during field and Laboratory work. Special gratitude goes to Mr. John Mukalama, Mr. Benedict Aswani and Mr. Tom Oburu for their tireless assistance while working in the field and Maseno station.

I thank CIAT and International Institute of Tropical Agriculture, through N_2 Africa and TL II Project for funding the research phase of my studies. Lastly I thank my wife, children and friends for their support during the entire period of study.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Soybean production in Kenya remains low at an average of 5,000 metric tons (MT) a year. However, industrial demand for soybean products continued to grow from 50,000 MT in 2008 to about 120,000 MT in 2011 (FAO, 2011). In Kenya, human consumption of soybean accounts for 10-15% (or 10,000 – 15,000 MT) per annum meaning that part of the domestic human demand for soybean is fulfilled through import (Chianu *et al*., 2008). However, increased awareness on the health, nutritional and economic benefits among smallholder farmers has seen improvements in the development of soybean sub-sector notably in Western Kenya, where production has increased from 46 MT in 2010 to over 1,315 MT in 2011 (Mahasi *et al*., 2010). More than before, soybean has become a cash crop among smallholder. Farmers are engaging in home based value addition through their association by making soybean flour, Soy nuts, fortified flours for porridge like soybean-finger millet flour, soybean- sorghum flour, soya beverage, soya milk and Soya crunches (Woomer, 2007 and N2 Africa First phase Report 2009-2013).

Despite the rapid increase in demand, the average soybean yield in Western Kenya is 0.7 T ha^{-1} against a yield potential of 3.6 T ha^{-1} (Mahasi *et al*., 2010). The low soybean productivity is attributed to poor soil fertility, poor agronomic management by farmers, high incidences of diseases, moisture stress caused by mid-season drought and low usage of improved varieties by farmers (Batiano *et al*., 2011).

Improving soybean productivity can be achieved by maximizing the interaction: (G_L x G_R) x E x M. An integrated approach is needed to close legume yield gap. Basically, this equation states that the amount of yield attainable from farming system is a function of the genetic potential of its legume (G_L) and rhizobia (G_R) as conditioned by its environmental conditions (E) including soil, weather and agronomic management (M).Where GL = Legume genotype, GR= Rhizobium genotype, E = Environment and M = Management (Giller *et al*., 2013 and Ngalamu *et al.,* 2013). In this equation, environment encompasses, but not limited to, climate (temperature, rainfall, day length that encompasses length of growing season) and soils (acidity, aluminum toxicity and limiting nutrients.). Management includes aspect of agronomic management (use of fertilizers, sowing sates, plant density among others) (Vanlauwe *et. al*., 2010).

In the absence of biophysical constraints, maximum yield potential of crops like soybean is genetically determined. In the real sense, the observed "actual" yields of soybean depend on the prevailing environmental conditions and the management practices (Giller *et al.*, 2013). In Western Kenya where soils are depleted of nutrients, farmers are required to use fertilizers and improve the management practices (for example the planting densities and timing of weeding) in order to fully exploit the genetic potential of available soybean germplasm (Vanlauwe *et al.,* 2010). Studies conducted in Western Kenya (Misiko *et al.,* 2008) have shown that stress mitigation practices such as maximizing nutrient availability, planting densities and reducing competition from weed, disease, and insect pressure enhances soybean yields. The yield potential of widely grown soybean genotypes in different agro-ecological zones of Western Kenya and the relative contribution of the management aspects to their yields remain unknown. Understanding the yield potential of available soybean and combinations of factors to arrive at that yield potential is important in developing the best fit soybean technologies to base on-our recommendations for increasing soybean productivity in Western Kenya.

In Kenya, several soybean genotypes are available for use by farmers but differ in yields, agronomic characteristics including maturity periods, plant architecture, pods per plant and disease tolerance among others (Baijukya *et al.*, 2013). The fertilizer company MEA limited has also made available effective soybean inoculants that when appropriately used can increase soybean production (N2 Africa phase one final report 2009-2013). Although farmers' plant improved soybean genotypes and some use rhizobia inoculants the yield potential of these genotypes in different soybean growing areas and the relative importance of the factors in equation above remain unknown (Giller *et al.*, 2013 and Ngalamu *et al.*, 2013). The current study aimed at understanding the yield potential of the released and pre-released soybean genotypes in key soybean growing areas in Western Kenya as affected by key modifiers; plant population and nutrient application of the legume intensification process.

Baijukya *et al.*, (2013), research results in west Kenya indicate that soybean performance is a function of season, sites, management and genotype. Seasons varied due to precipitation amounts (Vandamme *et al.*, 2013) while Management depended on the type of fertilizer, spacing and genotype planted. In non responsive sites, there was no increase in yield following application of phosphorus especially sites with sandy soils. Also sites with high infestation of pests and diseases caused non responsiveness (van der sterre and Wieske, 2012).

1.2 Problem statement

Soybean cultivation is rapidly expanding in Western Kenya but productivity remains low. Declining soil fertility, poor crop management practices and inappropriate matching of genotypes with environment are among the factors attributed to low soybean productivity (Giller *et al.,* 2013). Moreover, the available soybean genotypes are grown broadly without taking into account of their suitability/adaptability to the conditions prevailing in different agro-ecological zones (Mahasi *et al.,* 2010). This situation is locking the expected benefits of soybean to poor households in terms of improving family nutrition, income, and improved soil fertility (Chianu *et al.,* 2009). Numerous options for soybean intensification in Western Kenya do exist for example, the use of improved genotypes, planting of soybeans on fertile soils as well as improving agronomic practices including spacing and fertilizer application (Baijukya *et al.,* 2010) and Alghandi (1991). However, the contribution of the above options to soybean yields under Western Kenya conditions remain poorly understood.

1.3 Justification of the study

Before any improvements to crop management practices are made, it is useful to know the potential yield of crops in the region of interest, and the gap between the potential yield and the actual yield obtained by the growers. Assessment of potential yield and yield gaps can help in identifying the yield limiting productivity of a crop. Appropriate management packages should be applied in order to arrive at desirable yields. Key modifiers should be understood (G x M x E). This is important to guide farmers on what are the expected yields and what should be done to arrive at the target yields from genotypes. This will also help to target genotypes to specific agro-ecological zone.

1.4 Objectives

The overall objective was to evaluate the yield potential of three released and eight pre-released soybean genotypes as influenced by crop management practices in the major agro-ecological zones of Western Kenya.

1.4.1 Specific Objectives

1. To determine the influence of spacing on growth and yield performance of different soybean genotypes under optimum rates of P and K fertilizer application.

2. To determine the contribution of special legume fertilizer (Sympal), Farm Yard Manure (FYM) and sugar waste on the performance of soybean.

3. To assess the influence of environment on performance of soybean genotypes

1.5 Research Hypothesess

1. Planting densities leads to differences in performance of soybean genotypes.

2. Application of different fertilizers leads to differences in performance of soybean genotypes.

3. Performance of soybeans differ across environments

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of soybean

Soybean is a crop grown worldwide where its origin is Asia (Tinsley, 2009). It is grown in a wide range of ecological conditions ranging from the tropics to 52^{o} N. In Kenya, soybean can grow at 1200-2200m above sea level (asl) under rainfall regimes of 300-1200 mm per year (KARI, 2005). Despite its wide range of growing conditions, production in Kenya is generally low. Production area and yield levels have remained stagnant with little annual change since 1990 (FAO, 2011). Western Kenya is leading in soybean production, with Butere/Mumias and Bungoma districts accounting for 80% of the total soybean production (Chianu *et al.,* 2008).

Soybean has multiple uses and benefits. It is the world's leading source of oil and proteins (Fedaku *et al.,* 2009). Soybean meal is rich in phosphorous (P), calcium (Ca) and iron (Fe) (Ogoke *et al.*, 2003) making it a perfect animal food supplement. It also has the potential to capture the infinite resource of atmospheric nitrogen gas into protein through the symbiosis with rhizobia bacterial. The protein rich grain directly addresses food and nutrition needs of the poor. Residues of soybean crop are high quality feed for livestock and add nitrogen to the soil enriching infertile soils and stimulating productivity of crops grown in rotation (Ojiem, 2006). The soybean grains have diverse opportunities for value addition for local processing by women.

2.2 Nitrogen fixation in Soybean

Inclusion of soybean in the farming systems can contribute to an improvement in soil nitrogen economy, since as a legume, soybean fixes nitrogen from the atmosphere (Baijukya *et al.*, 2010*)*. Effectiveness in fixing atmospheric nitrogen makes soybean have little or no demand on soil nitrogen and actually spares the same for the subsequent crop in rotation or the companion crops in an intercrop. The biomass from soybean is also an important source of feed, green manure and mulch (Chianu *et al.*, 2009). Sanginga *et al*., (2003) estimated that soybean can fix between 44-103 kg N ha^{-1} reducing the need for expensive nitrogen fertilizer. To enhance nitrogen fixation, soybean inoculation with *Rhizobia* increases effectiveness of the symbiosis between a legume plant and bacteria. Woomer *et al.*, (2011) estimated the population sizes of *Bradyrhizobium spp* at between 1.25 and 2.40 $\log_{10}$ cells per gram of soil is sufficient to induce a positive N-fixation by soybean provided that the rhizobia are both effective and infective

2.3 Yield and yield components of Soybean

In soybeans, yield variation of cultivars across locations and years has been associated with changes in number of seeds per plant per unit area (Eglin, 1998). Hence the yield component is largely determined during a period that begins in flowering and extends through the pod setting. Seed size traits in soybean i.e. length, width and thickness and their corresponding ratios play a crucial role in determining seed appearance, quality and yield (Rahmann *et al.*, 2011). The number of pods, 100-seed weight and seed number are the most important yield components of soybean. Leaf area index, Leaf area duration and dry matter accumulation during the reproductive stage influence yield components

(Akunda, 2001). Therefore to optimize yield then one has to provide necessary conditions that increase yield contributing factors.

2.4 Determination of soybean yield potential

Yield potential is defined as ‘the yield of a cultivar when grown in environment to which it is adapted with no water and nutrients limitation and with pests, water logging and other stresses effectively controlled (Evans and Fischer, 1999). On the other hand Potential yield is the maximum growth capable in a given environment (with potential stresses not controlled). In order to develop suitable strategies to improve the productivity levels of soybeans, it is therefore essential to understand the yield gap which is the difference between yield potential and potential yield (Giller *et al.*, 2013). Determination of potential yield requires a thorough understanding of crop growth and development, which in turn depends on several climatic factors that include temperature, rainfall, relative humidity and solar radiation and the agronomic management practices.

2.5 Agronomy of soybean

2.5.1 Agronomic management practices

Achieving high yield and best quality soybean requires appropriate agronomic management (Giller *et al.*, 2013). Soil condition (acidity, aluminum toxicity, nutrients, presence of beneficial micro-organisms like bacteria, fungi, algae, protozoa, earthworms and others) is one of the first things to consider when deciding to plant a crop (Okalebo *et al.*, 2003). Clay soils may be amended with organic mulch to increase the humus content to improve aeration and water infiltration (Vanlauwe *et al.*, 2010). Yield depends on several other factors too. Growing conditions at planting time will influence seed germination and seedling vigor. Previous studies done in Kenya (Mugendi *et al.,* 2009) showed that closing yield gap between farmers' yields and research yields will depend on what is currently possible in an experimental farm versus average farm, the best available technology as well as management .Establishment of optimum plant densities contributes to productivity and improves yield (Misiko *et al*., 2008). However, majority of farmers in Western Kenya still plant soybeans at wider inter row (75 cm) (N2 Africa first phase report 2009-2013). A concern, though, is that as seeding rate increases plant competition increases, generating stress on the canopy, minimizing the benefit to narrow row spacing, especially when environmental conditions limit plant growth. An advantage of narrow row spacing is more equidistant plant spacing that leads to increased canopy leaf area development and greater light interception earlier in the season (Akunda, 2001). These changes in canopy formation increase crop growth rate, dry matter accumulation, and seed yield (Andrade *et al.*, 2002). A biotic and biotic stresses can reduce yield of soybean when planted at narrow-row spacing. For example, moisture stress has been documented to reduce the yield benefit from narrow row spacing in Kansas by more than 20% (Heitholt *et al*., 2005).

2.5.2 Climatic conditions

Climate encompasses (among others), temperature, rainfall, relative humidity and solar radiation (Jaetzold *et al.,* 2005). Temperature influences physiological process such photosynthesis and biochemical process including germination, flowering and pod filling. Temperatures below 21°C and above 32°C can reduce floral initiation and pod set.

Extreme temperatures above 40°C are detrimental for seed production. Vanlauwe *et al*., (2003), research indicated that when soybean are grown at altitudes above 2000 m above sea level, they take too long to mature (above 6 months) but they out-yield those planted at lower altitudes. The research further showed that despite the fact that soybeans are drought tolerant, they do not do well under extreme rainfall regimes. Soybeans also require reliable and well distributed rainfall for good performance (Vandamme et *al.*, 2013). The most critical stage is during flowering and pod filling. Moisture stress often resulting from mid- season drought significantly reduces yield as it causes flower abortion and early senescence (Vandamme *et al.*, 2013). Consequently high relative humidity accelerates disease prevalence especially soybean rust (Baijukya *et al.*, 2013). Nevertheless, soybean is a hardy plant and well adapted to a variety of soils and climatic conditions.

2.6 Environment and genotype interactions

For soybean, genotypes by environment interactions are as much a function of genotypic, phenological and physiological traits of varieties (Giller and Titonell, 2013). Genotype by environment interaction describes the differential performance of genotypes across environments (G_L x E). A specific genotype does not always exhibit the same mean performance under all environments and different genotypes respond differently to a specific environment. The term G × E interaction commonly refers to yield variation that cannot be explained by the genotype main effect (G) or the environment main effect (E). Knowledge of the pattern and magnitude of genotype by environment interaction is important for understanding the response of different genotypes to varying environments and for identification of widely adapted genotypes (Mahasi *et al.*, 2010). In as much, the interrelation (G_L x E) can further be modified by the way the crop is managed (M), (i.e. G_L x E x M), including spacing, timing of weeding and use of fertilizers (Giller *et al.,* 2013).

Legume need to be targeted to environments which they grow well. The major factors which determine the suitability to climates are largely amount of rainfall, the distribution of rainfall and temperature (Giller *et al.,* 2013). Legume yield performance are also limited by nutrient deficiencies (particularly phosphorus but also other nutrients) Sanginga and Woomer, (2010). Phosphorus availability is often limited due to fixation. However, fixation can be overcome by using germplasm that is efficient at mobilizing and using phosphorus (Vandamme *et al.,* 2013).

Ensuring that genetic potential of legume is expressed in the field depends on good management (Vanlauwe *et al.,* 2001). Wide spacing or late planting reduces efficiency of the capture of light for photosynthesis and limits potential yield (Moosavi *et al.,* 2014).

Despite the major opportunities that soybean provides, there has been very limited adoption of appropriate spacing, genotype and nutrient management practices by farmers (Baijukya *et al.,* 2013). Little investment has been made in research to establish the best spacing, genotype and agronomic practices to optimize soybean production under variable soil fertility and environmental conditions. To achieve soybean intensification, farmers need to be prepared to consider additional inputs (fertilizers) and planting densities in order to exploit the genetic potential of soybean genotypes they grow (Giller *et al.,* 2013). Research conducted in Kenya by Misiko *et al.,* (2008) and Akunda, (2001) showed that narrow spacing has advantage due to more equidistant plant spacing that leads to increased canopy leaf area development and greater light interception earlier in the season than wider inter-row spacing. These changes in canopy formation increase crop growth rate, dry matter accumulation, and yield (Andrade *et al.,* 2002). Besides, abiotic and biotic stresses can mitigate the yield response of soybean to narrow spacing production. Moisture stress has been documented to reduce yield benefit from narrow spacing (Heitholt *et al.,* 2005). Research conducted in the upper Midwest and Southern Canada document a consistent yield advantage of 134 to 604 kg ha^{-1} when yields for narrow row planting (≤ 76 cm) are compared to yields obtained from wider row planting (≥ 76 cm) (Perdersen, and Lauer, 2004).

The effect of plant density on growth, plant characters and yield vary due varietal characters, growing season and genotype. Rahman *et al.,* (2011), reported that varieties that reach canopy closure prior to seed development contributes to high total dry matter (TDM) production and grain yield.

2.7 Integrated soil fertility management (ISFM) in soybean production

Integrated soil fertility management (IFSM) is defined as "the application of soil fertility management practices and the knowledge to adopt these local conditions, which maximize fertilizer and organic resource use efficiency and productivity. These practices include, appropriate fertilizers and organic input management combined with utilization of improved germplasm" Sanginga, and Woomer, (2010). These practices necessarily include appropriate fertilizer and organic input management in combination with the utilization of improved germplasm and their adaptation.

Current smallholder practice in Western Kenya use too little or no fertilizer, this then leads to mining the soil of its nutrients and leading to degraded, non-productive farming (Smaling *et al*., 1997). Many options exist to improve soil fertility status, therefore simply introducing improved crop varieties and modest amounts of mineral fertilizer may improve crop yields but at relatively low agronomic efficiency (AE) of nutrient use. Integrated Soil Fertility Management (ISFM) practices assist in overcoming a wide range of crop constraints, including those not directly related to nutrient supply (Sanginga and Woomer, 2010). Integrated Soil Fertility Management (ISFM) is particularly appropriate when employed in conjunction with less than optimal rates of fertilizer.

The recommendation of the African Fertilizer Summit (2006) to increase the fertilizer use from the current 8 to 50 kg ha^{-1} reinforces the role of fertilizer as key entry points for increasing crop productivity and attaining food security and rural well-being in Sub Saharan Africa (SSA). The impact will however vary depending upon agronomic efficiency of applied fertilizers which is defined as the amount of input (e.g. crop yield) obtained per unit fertilizer applied. The efficiency varies across regions, countries, farms and field within farms a greatly affects the returns to the recommended 50 kg $^{-1}$ (Samake *et al.,* 2005.)

Soil nutrient constraints may be overcome by use of manure and / or mineral fertilizer. In sandy soils, an over-supply of P can exacerbate incipient deficiency of zinc, but this problem can be avoided if animal manure is used (Zingore *et al.,* 2008). In soils that have been cropped repeatedly, other nutrients are often needed in addition to P, to correct deficiencies of potassium, calcium and magnesium, or micronutrients thus stressing the need for balanced fertilization (Zingore *et al.*, 2008).

Apart from spacing and genotype, fertilizes also play an important role in determination of soybean yield and yield components (Baijukya *et al.*, 2013). Farm yard manure and sugar cane waste are important organic sources capable of supplying sufficient amount of plant nutrients such as Mg, S, P, K, Fe, Mn, Zn and Cu (Khan and Muhammad, (2008). Research conducted in Pakistan by Khan and Muhammad, (2008), indicated that application of Farm yard manure and or Sugarcane waste in the fields as organic amendments enhances soil water holding capacity and aeration besides correcting soil acidity and nutrient deficiencies among small scale and large scale farmers. Sanginga and Woomer, (2007), illustrated that when mineral fertilizer and organic inputs were combined, strong interaction occurred, with maize yields comparable to those achieved from twice the level of mineral fertilizer. The effect was mainly attributed to greater fertilizer use efficiency resulting from improved soil moisture conditions. They also illustrated that combination of mineral and organic sources accelerate nutrient release. Baijukya *et al.*, (2013) in their research in Western Kenya also revealed that use of sympal fertilizer (Special legume fertilizer without nitrogen) with biofix (USDA 110) and adapted genotypes enhances nitrogen fixation, growth and soybean grain yield. Natural fixation of nitrogen by rhizobia through symbiotic relationship with soybeans reduces risks of acidity caused by addition of acidic fertilizers such urea (Baijukya *et al.*, 2010).

To fully understand the factors influencing soybean intensification, the current study was conducted to evaluate the influence of plant densities (manipulated through inter-row spacing) on growth and yield of soybean genotypes under key agro-ecological zone of west Kenya.

CHAPTER THREE

INFLUENCE OF SPACING, SITE AND SEASON ON GROWTH PERFORMANCE AND YIELD OF SOYBEANS GENOTYPES

ABSTRACT

Plant population is an important factor in determining the growth and yield of soybean. A two season experiment was conducted to evaluate the influence of spacing on the growth and yield performance of eleven (11) soybean genotypes at two levels of inter-row spacing (45 cm by 5 cm and 75 cm by 5 cm) in Western Kenya. The experiment was laid as split plot on randomized complete block design with three replicates. The experiment was conducted in long rains of 2012 and the short rains of 2012/2013. Biomass, number of pods, Nitrogen fixed, Plant height and grain yield data were collected. Data was analyzed using SAS. Means were separated using LSD (α=0.05). There was significant influence of inter-row spacing on the growth and yield performance of soybeans. Biomass accumulation ranged between 1360-4997 kg ha^{-1} at a spacing of 45 cm against 1236-4050 kg ha^{-1} at a spacing of 75 cm. Mean N_2-fixed was highest 101 kg ha^{-1} at a spacing of 45 cm compared to 69 kg ha^{-1} at a spacing 75 cm. The number of pods per plant were not significantly different at a spacing of 45 cm the mean was of 31 against a mean of 30 pods per plant at a spacing of 75 cm. Mean grain yield was 2401 kg ha^{-1} at spacing of 45 cm and 2005 kg ha^{-1} at spacing of 75 cm respectively. There was significant interaction between genotype with spacing, site and season. Nyabeda in Siaya was the best site in terms of biomass accumulation (3413 kg ha^{-1}), Nitrogen fixed (101 kg ha^{-1}) at inter row of 45 cm followed by Ekitale then Kambare. Long rains season out yielded the short rains season in all of the parameters measured. Inter row spacing of 45 cm is recommended to realize optimum soybean grain yield. Soybean genotype Sc Squire is recommended because it performed well across all sites and seasons, though the adoption will depend on its preferred traits by farmers.

3.1 Introduction

Smallholder cropping system in sub-Saharan Africa is characterized by low crop productivity due to poor soil fertility, with nitrogen and phosphorus as major limiting nutrients (Saginga *et al.*, 2003). Lack of appropriate soybean genotypes and agronomic practices also contribute to low crop yields (Giller *et al.*, 2013). Despite these constraints growing soybean is considered as a viable option for sustainable intensification of farming system (Vanlauwe *et al.*, 2003). This is because of its high nitrogen fixing potential and soil improving properties, food value as protein and vegetable oil (Giller, 2001). However, efforts to increase soybean production are hampered by several constraints, among which lack of adaptable soybean genotypes and appropriate management practices including spacing.

Moosavi *et al.,* (2014), through their research indicated that narrow spacing have yield advantage because they achieve canopy closure more quickly and intercept more light throughout the growing season. Rapid canopy closure also provides greater shading of weed seedlings as a result of increased light interception by soybean (Misiko *et al.*, 2008).

Zingore *et al.,* (2008) research results in Zimbabwe indicate that performance of soybean varies widely depending on site specific and climatic conditions as influenced by season. They also illustrated that soil organic carbon and available P are important determinants influencing soybean yields and soybean response to fertilizers and manure. Vandamme et al, (2013) research findings in Western Kenya revealed that soybean performance varied with season and site. Seasons with adequate and well distributed rainfall recorded high yields as compared to seasons with erratic and poor precipitation. Also Okoth *et al.,* (in press), research in Western Kenya found out that short rains season often experience mid season drought that affects soybean growth and yield performance as compared to long rains season.

There are a lot of opportunities for soybean intensification for example, use of improved genotypes, identifying appropriate niches for the available genotypes, as well as improving agronomic practices including spacing and fertilizer application (Baijukya *et al.,* 2013). However, their contribution to soybean yield potential remains less understood.

3.2 Materials and methods

3.2 .1 Experimental Sites

The study was conducted at three sites namely Kambare in Kisumu county 34.22’E , 00° 09′S alt. 1239 m above sea level); Nyabeda in Siaya 34° 25′E, 00° 08′N alt. 12951 m) and Ekitale in Bungoma 34° 43′E 00° 52′N altitude of 1539 m above sea level . The sites represent the broad agro-ecological zones of west Kenya, namely the low land, midlands and upper midlands with their major characteristics summarized in Table 1

Table 1: Selected characteristics of major agro-ecological of Western Kenya in which the study was conducted.

	Agro-ecological Zone		
Characteristic	Kambare-Kisumu (Low land)	Nyabeda-Siaya (Midland)	Ekitale-Bungoma (Upper midlands)
Altitude (m above sea level)	1239	1351	1539
Rainfall (mm per annum)	900-1100	1100-1450	1200-1800
Soils	Sandy, to sandy clays but many are sandy	Mixture of Sandy, sandy clay, sandy clay loam	Sandy clay to sandy clay loam
Population density (people/ sq. km)	800-900	600-900	800-1200
Mean annual temperature ^{0}C	22.3-22.7	21.4-22.3	21.1-22.0

Source: Jaetzold *et al.*, 2005.

3.2 .2 Soybean genotype studied

A total of 11 genotypes were used: Three varieties from Agri-Seed Company (Seedco.) namely Sc Squire, Sc Sequel and Sc S823-6-16); one dual purpose soybean variety TGx 1740-2F bred by IITA and released in Kenya as the four promising materials TGx1904-6F, TGx 1987-10F, TGx 1987-18F and TGx 1987-6F which were obtained from IITA-Malawi and three KARI varieties namely 835/5/30; SBH3/7/4 and EAI 3600. The Genotypes were classified as promiscuous (i.e. have the capacity to nodulate with variety of native Rhizobia) –All the TGx genotypes are promiscuous or specific (EAI 3600, Sc

Squire and Sc Sequele) (i.e. only nodulate with specific strain of Rhizobia bacteria). The genotypes had also varying maturity periods i.e. early, medium and long as shown in Table 2.

Table 2: Names, origin and agronomic traits of soybean genotypes used in the present study.

Genotype	Type	Origin	Maturity level[a]	Days maturity
EAI 3600	Variety	KARI	Early	80-90
TGx1740-2F	Breeding line	IITA	Early	95-100
SBH 3/7/4	Variety	KARI	Early	85-95
835/5/30	Variety	KARI	Medium	105-110
TGx1978-62F	Breeding line	IITA	Late	115-120
TGx1987-6F	Breeding line	IITA	Late	115-120
TGx1987-18F	Breeding line	IITA	Late	115-110
TGx1987-10F	Breeding line	IITA	Late	115-110
Sc Squire	Variety	Seed Co Zim.	Medium	105-110
Sc Sequel	Variety	Seed Co Zim.	Medium	105-110
C823-6-16	Accession	Seed Co Zim.	Medium	105-110

Source: N2 Africa final report 2009-2013

[a] Maturity level: Early = 80 -100 days to full maturity; Medium = 101-120 days to full maturity and Late = 121-160 days to full maturity.

The choice of these genotypes was based on the fact that they are highly preferred by both farmers and buyers for grain yield and quality.

3.2.3 Spacing

Two inter-row spacing were evaluated as shown below:-.

I. Spaced at 45 cm between rows and 5 cm within rows

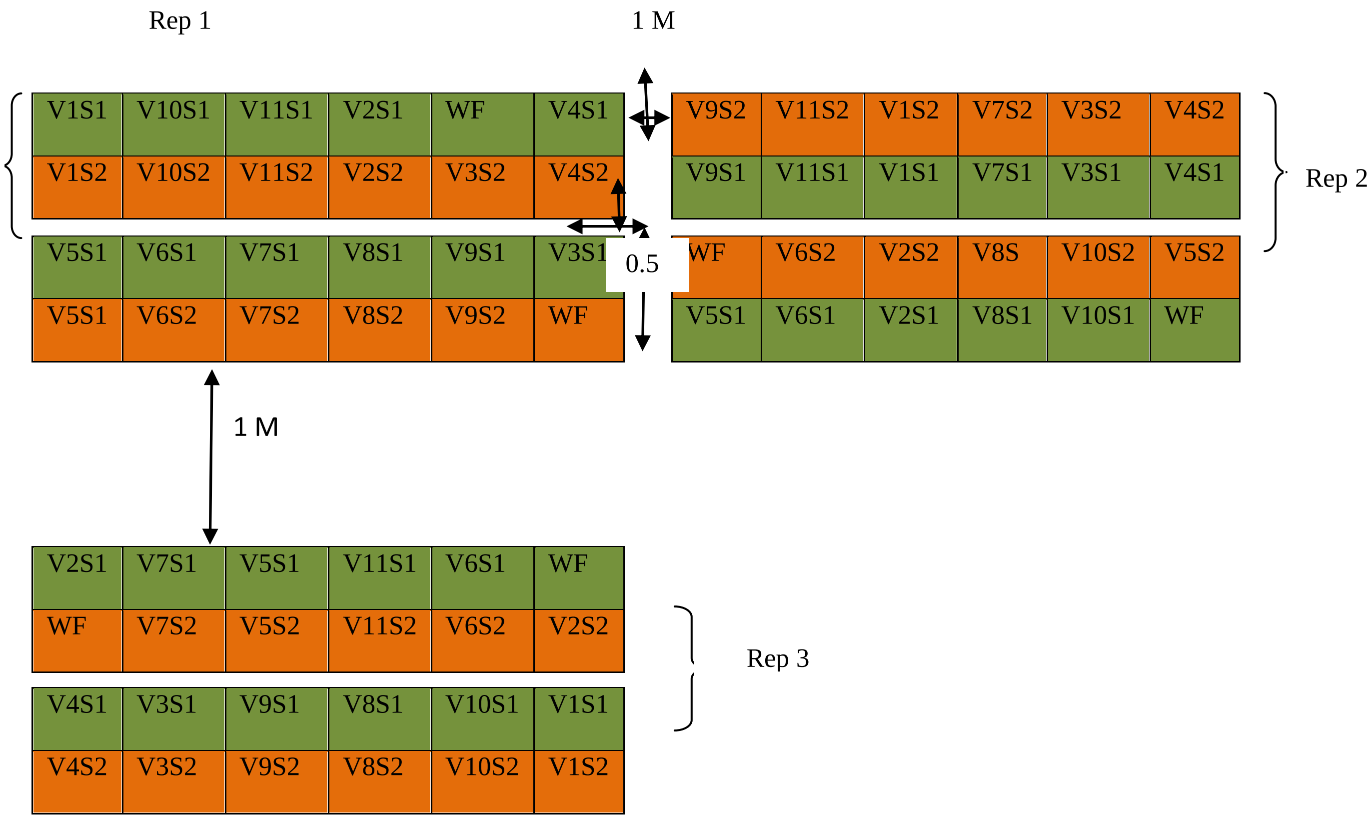
II. Spaced at 75 cm between rows and 5 cm within rows

Spacing of 75 cm (Inter-row) was used because it is the current common practice used by farmers in Western Kenya. While narrow inter –row spacing of 45 cm was used because it is the recommended spacing that gives maximum yields in Western Kenya (N2 Africa first phase report 2009-2013).

3.2.4 Experimental design and field layout

The experiment was laid out in Randomized Complete Block Design in a split-plot arrangement with genotype as main factor and soybean spacing as the sub-factor. The treatments were replicated three times at each site with a total of 66 plots per site. Three plots of weedy fallows were included for use as reference crop in determination of Biological Nitrogen Fixation (BNF). The plot size for inter-row spacing of 45 cm was 1.8 m by 3m giving plant population of 444, 4444 plants ha^{-1} while for inter-row spacing of 75 cm plot size was 3 m by 3 m giving plant population of 266,666 plants ha^{-1}.

Field layout



V1S1	V10S1	V11S1	V2S1	WF	V4S1
V1S2	V10S2	V11S2	V2S2	V3S2	V4S2
V5S1	V6S1	V7S1	V8S1	V9S1	V3S1
V5S1	V6S2	V7S2	V8S2	V9S2	WF

V9S2	V11S2	V1S2	V7S2	V3S2	V4S2
V9S1	V11S1	V1S1	V7S1	V3S1	V4S1
WF	V6S2	V2S2	V8S	V10S2	V5S2
V5S1	V6S1	V2S1	V8S1	V10S1	WF

V2S1	V7S1	V5S1	V11S1	V6S1	WF
WF	V7S2	V5S2	V11S2	V6S2	V2S2
V4S1	V3S1	V9S1	V8S1	V10S1	V1S1
V4S2	V3S2	V9S2	V8S2	V10S2	V1S2

Figure 1: Field layout to evaluate the influence of spacing and genotype on growth performance and yield of soybean

Key:

V = soybean genotype

WF =Weed fallow

S1 = Inter-row spacing of 45 cm

S2 = Inter-row spacing of 75 cm

3.2.5 Soil and organic manure sample collection and analysis

A composite soil sample was collected from the respective fields before planting from a depth of 0-20 cm using an auger and mixed to form one composite sample for each block at each site. A laboratory analysis was done on the samples to measure soil organic carbon, total N, extractable P, extractable K, soil pH (water) and particle size distribution (Table 3 and 4). A composite sample of farm yard manure and sugar cane waste was subjected to tests stated above according to Okalebo *et al.*, (2002).

Table 3: Physical-chemical characteristics of top (0-20 cm) soil at the experimental sites.

	Sites		
Soil characteristics	Ekitale-Bungoma county	Nyabeda-Siaya County	Kambare -Kisumu county
Total N (%)	0.08	0.23	0.14
Olsen P (mg kg^{-1})	4.94	4.07	1.82
Organic Carbon (%	1.02	2.81	1.86
pH H_2O	5.47	5.92	5.90
%Texture			
% Clay	24.85	56.81	48.83
% Sand	66.80	22.85	28.83
% silt	8.35	20.34	22.34
Textural classes	Sand clay loam	Clay	Clay loam

Table 4: Physical and chemical characteristics of manure and sugar cane waste (Scum)

Sample description	Manure	Scum
pH	9.04	10.00
EC	0.20	0.20
% C	17.27	41.00
% N	1.27	1.28
%Ca	0.50	0.60
%Mg	0.10	0.20
Zn (mg/kg)	245.00	180.00
% K	1.01	2.02
% P	0.36	0.30

3.2.6 Rainfall distribution during the growing seasons

Rainfall distribution and amounts varied among the sites (Appendix 6 and 7). At Ekitale and Nyabeda rainfall distribution was reliable and adequate in both seasons. However, at Kambare rains were erratic as it rained from day one until the first week of the second month followed by serious mid-season drought between 60 -100 days after planting during long rains 2012. The period coincided with pod setting and seed development stage. The same trend was observed during the short rains season.

3.2.7 Trial establishment and management

a) Land preparation and application of fertilizers

Fields were ploughed manually using ox-plough by the respective owners. The plots were then demarcated on the ploughed fields, leaving 1m stretch between plots and 0.5 m within plots to serve as paths. All plots received a blanket application of Sympal fertilizer (NPK+Ca+Mg +S+Zinc 0:23:16:10:4:1: trace), at the rate of 60 kg of elemental Phosphorus ha^{-1}, in furrows dug at about 10 cm deep then covered with a thin layer of soil after the fertilizer was applied. Seeds of all varieties were inoculated with BIOFIX rhizobia Inoculant containing a commercial rhizobia strain USD 110 to ensure that the genotypes express their full nitrogen fixation potential in different environments. The inoculants were applied at the rate of 10 g per kilogram seed following a two-step method (Somasegaran and Hoben, 1994). Soybeans were planted by drilling in open fallows dug 2 cm deep on 18 April, 2012 in long rains and 27 September, 2012.

b) Trial management

Three (3) weeks after planting, plants were thinned to 1 plant per 5 cm. Thinning was done to reduce competition among plants for vital resources such as nutrients, light and water. The fields were manually weeded using a hand hoe to ensure that there was no competition from weeds. At 50% flowering, soybean was sprayed with AMISTA-Extra to prevent rust infestation. The fungicide AMISTA-Extra was applied using a hand-operated backpack sprayer fitted with a 1.6/3 flood-jet nozzle, to control soybean rust at a rate of 0.75 l ha^{-1} or 25 ml / 16 l Knapsack with 3 application programs starting at flowering, thereafter every 21 days.

3.2.8 Data collected

a) Phenological dates

Variables were recorded as described by Fehr and Caviness (1977).

These included:-

a) Days to 50% flowering, which refers to the number of days to the time when 50% of the plants have at least one open flower.

b) Days to 50% podding referring to the number of days to the time when 50% of plants have at least one pod

c) Physiological maturity referring to when 95% of the pods had changed colour to brown

b) Biomass yield

At mid-podding (i.e. when plants have formed pods but pods are not filled with beans yet), biomass samples were taken from all plots by cutting the plants at the first node from the soil surface using a kitchen knife. Plants for biomass accumulation were randomly selected in an area of 0.5 m^2 within the net area. Samples were then packed in a well labeled paper bag (17 cm by 29 cm by 30 cm), dried at 65^0C to constant weight and then weighed using an electronic balance (5000 g). At this stage the weeds from weed fallow plots were also sampled. The weed fallow sampled were non N_2 fixing reference plants, the below ground biomass was excavated from the soil using a spade and soil was carefully removed and roots and nodules recovered (Woomer *et al.*, 2011).

c) Root nodule assessment

The roots and nodules were packed and stored in the cool box then transferred to the laboratory for further analysis. The roots were then detached of nodules, nodules counted and roots and nodules oven dried to determine their dry weights. Nodules were assessed either as highly effective (pink in colour), moderate (green) or ineffective (black) according to Woomer *et al*., (2011) method.

d) Determination of Biological Nitrogen Fixation (BNF)

The collected above-ground plant samples were used to determine the amount of nitrogen fixed using $^{15}N_2$ natural abundance method (Unkovich *et al.*, 2008). Non N_2 fixing reference plants were three weed plants sampled from the weedy fallow plots. The $^{15}N_2$ natural abundance method applies the principle that if a N_2-fixing plant is grown in a medium free combined N (mineral N or organic N) and is completely reliant upon symbiotic N_2 fixation for growth then the isotopic composition of the legume would be expected to be similar to that of atmospheric N_2 (δ ^{15}N %). On the contrary, if non N_2 fixing plant is grown in a soil containing mineral N, its δ ^{15}N value should be equal to that of soil mineral N taken up by the plant from the soil.

e) Plant height

Plant heights were taken at harvest. This was the height from the ground level to the tip of the stem, taken using a measuring tape on 10 randomly selected plants and the mean calculated.

f) Number of pods per plant

The numbers of pods per plant for ten randomly selected plants from the net plot were counted and mean calculated to represent the number of pods per plant in that plot.

g) Grain yield

At physiological maturity soybean genotypes were harvested from the net plot. The total fresh weight of pods, haulms and husks were taken and sub-samples taken and weighed using a sensitive balance. The sub-samples were brought to the laboratory at International Centre for Tropical Agriculture (CIAT) Maseno, air dried and haulm separated from the grains. The dry weight of seeds harvested in the net plot was recorded as plot seed yield and extrapolated to yield in kg ha^{-1} at 12 % moisture content.

h) One hundred (100)-seed Weight

The weights in grams of 100 clean soybean seed were randomly selected from each treatment. Moisture content was determined at 12% using a moisture meter. Weighing was done using a digital balance of (5000 ± 0.002 g).

3.2.9 Data analysis

Data was subjected to analysis of variance to determine the effects of spacing, sites, seasons, soybean genotype and their interaction using mixed linear model (Mixed procedure, SAS Institute 2012). The means of the sites, seasons, spacing and genotypes and their interactions were compared by least significance difference at $P \leq 0.05$. Simple linear correlation between yield and yield determining factors were also conducted.

The model for the experiment was:

$$Y_{ijkl} = \mu + S_i + Yj + RSY_{(k)ij} + SY_{lj} + G_l + GSYijl + GSil + GYlj + Em + SYGEijlm + \mathcal{E}_{ijkl}\mathrm{mn}$$

μ= the general mean.

S_i = effect to due ith Spacing

Y_j= effect due to jth season

R = effect due to kth Replicate

G_l = effect due to the lth genotype .

E_m = effect due to the mth site.

SYGE=effect due to interaction of spacing, season, genotype and site

$RS_{(k)ij}$= effect due to the jth replicate in the ith site.

GS_{li} = effect of the lth genotype in the ith site.

GY_{lj} =effect due to lth genotype in jth season

$\mathcal{E}_{ijkl\mathrm{mn}}$= the random error effect due to the kth replicate of the lth genotype in the ith site and j th season.

3.3 Results

3.3.1 Biomass yield

Inter-row spacing influenced biomass accumulation significantly (Table 5). Planting soybeans at an inter-row spacing of 45 cm accumulated more biomass (3383 kg ha^{-1}) than at inter-row spacing of 75 cm (2424 kg ha^{-1}). Spacing of soybean at an inter-row spacing of 45 cm had a biomass accumulation advantage of 25% more than at spacing of 75 cm.

Table 5: Effect of inter-row spacing on soybean grain yield (kg ha^{-1}) and other yield component across sites and seasons.

Spacing	Biomass (kg ha^{-1})	Grain Yield (kg ha^{-1})	Nodule score	Plant height (cm)	Pods plant^{-1}
Inter-row spacing of 45 cm	3383a	2401a	3a	49a	31a
Inter-row spacing of 75 cm	2424b	2005b	2b	46b	30a
LSD	193	113	0.2	2	2
CV%	27	30	29	20	28

Means with different letters in the column are significantly different at $P \leq 0.05$.

Genotypes also had significant differences as regards to biomass accumulation (Table 6). Promiscuous genotypes (nodulate with indigenous rhizobia) generally accumulated higher biomass per unit area when compared to specific genotypes. For instance TGx 1987-10F and TGx 1987-62F accumulated the highest biomass of 5393 kg ha^{-1} and 4999 kg ha^{-1} when compared to the specific varieties such as Sc Squire and EAI 3600 whose biomass was 1700 kg ha^{-1} and 2800kg ha^{-1} respectively across season, sites and spacing. On overall Sc Squire recorded the least biomass across all the three agro-ecological zones and spacing.

Table 6: Interaction between site, genotype and spacing on biomass yield in kg ha^{-1}

Genotype	Ekitale-Bungoma county		Nyabeda-Siaya county		Kambare-Kisumu county	
	45cm	75cm	45 cm	75 cm	45 cm	75 cm
835/5/30	1887a	1660a	3561c	3209c	3191c	1717a
EAI3600	2612b	1273a	4102d	2782b	2565ab	1660a
SBH3/7/4	2187ab	1919a	3409c	3153c	2030ab	1464a
SC 23-6-16	2397ab	2355ab	4203d	3158c	2405ab	1910a
SC Sequel	2082ab	2036ab	4400d	2862b	2345ab	1823a
Sc Squire	2145ab	1360a	3409c	2956b	3154c	1837a
TGx1740-2F	4747d	2195ab	4004c	3033bc	2767b	2251ab
TGx1904-6F	3489c	1678a	3627c	3882c	3371c	1635a
TGx1987-10F	5393e	4114d	5626e	4050c	2926b	1159a
TGx1987-18F	3791c	2844b	5273e	3516c	2521b	2804b
TGx1987-62F	4999d	3229c	4392c	3605c	2723b	1889a
LSD	**559**					
CV%	**23**					

Means with different letters in the column and row are significantly different at $P \leq 0.05$.

Biomass accumulation was also greatly influenced by site (Table 7). Nyabeda in Siaya county recorded the highest biomass (3413 kg ha^{-1}), followed by Ekitale in Bungoma county (2745 kg ha^{-1}) and Kambare in Kisumu county (2100 kg ha^{-1}). Nyabeda out-yielded Kambare and Ekitale by 62% and 25% respectively, while Ekitale out-yielded Kambare by 30%.

Table 7: Effect of site on soybean biomass yield (kg ha^{-1}) and other yield component across sites and seasons.

Site	Biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Nodule score	Plant height (cm)	Pods plant^{-1}
Ekitale	2745b	2019b	3b	45b	29b
Kambare	2100c	1452c	2c	44b	23c
Nyabeda	3413a	2816a	4a	57a	39a
LSD	236	139	0.2	2	3
CV%	27	30	29	20	28

Soybean growth and yield performance showed highly significant difference with regard to seasons as shown in Table 8. In long rain 2876 kg ha^{-1} biomass was accumulated as compared to 2622 kg ha^{-1} in short rain season. Long rain season out-yielded short rain season by 9.6% as shown in Table 7.

Table 8: Effect of season on genotype yield (kg ha^{-1}) and other yield components across sites.

Season	Biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Nodule score	Plant height (cm)	Pods plant^{-1}
LR 2012	2876a	2244a	4a	50a	32a
SR 2012	2622b	1523b	3b	47b	28b
LSD	192	114	0.2	2	2
CV%	27	30	29	20	28

Means with different letters are significant at $P \leq 0.05$ within measured parameters

The analysis of variance results showed that there was no significant interaction between spacing and genotypes as regards above ground biomass; however spacing interacted positively with site (Table 12). There was significant interaction between season and site and Season *genotype (at $P \leq 0.05$) as shown in table 12. Sites significantly interacted with spacing and genotypes with Nyabeda showing high interaction than Ekitale and Kambare (table 6).

3.3.2 Biological Nitrogen Fixation – (BNF)

Significant differences were seen in spacing where inter row of 45 cm resulted to overall highest nitrogen fixation as shown in Table 9. Planting soybean at inter-row spacing of 45 cm fixes 82.63kg ha^{-1} of Nitrogen when compared to 54.8 kg ha^{-1} at an inter-row spacing of 75 cm. This represents 33.7% increase in Nitrogen fixed at inter-row of 45 cm than 75cm.

Table 9: Interaction of spacing and genotypes on nitrogen fixed (kg ha^{-1}) across seasons at Kambare, Nyabeda and Ekitale

	Ekitale-Bungoma		Kambare-Kisumu		Nyabeda-Siaya	
Soybean genotypes	45 cm	75 cm	45 cm	75 cm	45 cm	75 cm
835/5/30	47.2c	39.8c	60.7c	38.8c	86.5abc	63.6c
EAI3600	65.3c	31.8c	64.1c	41.4c	102.6a	55.4c
SBH3/7/4	54.6c	48c	66.9c	36.6c	84.4ab	65.5c
SC 23-6-16	51.6c	47.2c	60.1c	39.4c	105.1a	65.6c
SC Sequel	52.1c	36c	58.7c	45.6c	110a	66.5c
Sc Squire	45.3c	34c	78.8c	45.9c	74.3abc	57.2c
TGx1740-2F	118.6a	54.9c	69.2c	45.9c	83.4abc	67.5c
TGx1904-6F	70.6bc	42c	84.3bc	40.9c	90.7b	55.4c
TGx1987-10F	134.8a	102.8a	83.3bc	40.8c	140.7a	97.9b
TGx1987-18F	91.8b	72.8bc	63c	45.1c	131.8a	87.9abc
TGx1987-62F	125a	80.7b	65.4c	44.3c	109.8a	81.8abc
LSD	34					
CV%	18.6					

Means with different letters are significant at $P \leq 0.05$ within measured parameters

Significant differences were also seen in various genotypes as shown in (Table 9). Genotypes TGx 1987-10F, TGx 1987-18F, TGx 1987-62F and TGx 1740-2F recorded the highest N fixed at Ekitale and Nyabeda while 835/5/30, SBH3/7/4 and Sc Squire performed relatively well in Kambare. Across sites, the genotype TGx 1987-10F was the highest fixer of N (fixed 140.7 kg ha^{-1} at an inter-row spacing of 45 cm and 102 kg ha^{-1} of

Nitrogen at inter-row spacing of 75 cm. The variety Sc Squire was a poor fixer of N across sites and spacing as shown in table 9.

Sites also differed significantly in terms of Nitrogen fixed (Table 9). Nyabeda fixed highest Nitrogen, then and Kambare fixed least. This represents 30% and 48.4% increment in Nitrogen fixed in Nyabeda when compared to Ekitale and Kambare respectively.

Analysis of variance also indicated that spacing and genotype did not significantly interact as regards amount of nitrogen fixed. However spacing interacted significantly with site and season (Table 12). Site also interacted positively with genotype and site*spacing*genotype as the P value at 0.05 was significant (Table 12).

3.3.3 Plant height

Spacing significantly affected plant height (Table 5). Due to narrow spacing at 45 cm soybean plants grew taller than at 75 cm. Narrow spacing led to high interception of light that is necessary for photosynthesis. Soybean genotypes were also significant with regard to plant height across seasons, sites and spacing. TGx 1987-10F, TGx 1987-62F and TGx 1987-18F recorded the highest while EAI 3600 recorded the lowest biomass across sites and seasons (Table 10). At inter-row spacing of 45 cm high plant height (49 cm) was recorded compared to 46 cm at inter-row spacing of 75 cm (Table 5). In terms of sites Nyabeda recorded the highest plant height $P \leq 0.05$) of 57 cm compared to Ekitale and Kambare that had 45 cm and 44 cm respectively as shown in table 7. Seasons also influenced plant height significantly. Long rains season recorded highest plant height 50 cm when compared to Short rains season which had a mean of 47 cm (Table 8).

Table 10: Effect of genotypes on growth and yield parameters across sites

Genotype	Biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Nodule plant^{-1}	Plant Height (cm)	Pod plant^{-1}
TGx 1987-10F	4100c	1943a	3b	53bc	32b
TGx 1987-62F	3644c	1964a	4c	54c	38c
TGx 1987-18F	3482c	1887a	3b	50b	36c
TGx 1740-2F	2586b	1982a	3b	49b	30b
SBH3/7/4	2542cd	1946a	3bcd	43c	29bc
EAI 3600	2476a	1666a	2a	41a	23a
TGx 1904-6F	2369a	1891a	3b	49b	29b
SC Sequele	2221a	1836a	3b	50b	30b
Sc Squire	2321a	2013b	3b	48b	28b
S 823-6-16	2220a	1802a	3b	52bc	31b
835/5/30	2160a	1790a	3b	48b	31b
Mean	2750	1883	2.8	48.8	30.3
LSD	417	231.6	0.5	4.2	5.2
Cv%	27	30	29	20	28

Means with different letters are significant at $P \leq 0.05$ within measured parameters

Spacing did not significantly interact with genotype however it interacted positively with sites and season with regard to plant height. The interaction of genotype and season; site and season, was very significant at $P \leq 0.05$ (Table 12).

Sites also showed significant interaction with genotype as shown in (Table 12). However there was no significant difference in the interaction between Season*Site*spacing*genotype.

3.3.4 Number of pods per plant.

There was no significance influence of inter-row spacing to number of pods per plant (Table 5).

In terms of sites, number of pods differed significantly in soybean genotypes (Table 7). Nyabeda was the best site with overall mean of 39, followed by Ekitale with 29 and Kambare ranked last with mean of 23 pods per plant.

Number of pods per plant was significantly affected by genotypes (Table 10). TGx 1987-62F, followed by TGx 1987-18F and then TGx 1987-10F had the highest pods per plant across sites, seasons and inter-row spacing. On the other hand EAI 3600 had the lowest number of pods per plant.

Number of pods per plant was significantly influenced by seasons (Table 8). The mean pod load per plant in long rains was 32 (pods per plant) while the mean for short rain was 28 pods per plant respectively. This represented 14.5% increase when long rain was compared with short rain season. Spacing interacted positively ($P \leq 0.05$) with genotypes and sites, season, site, spacing and genotype also interacted positively as regards number of pods (Table 12).

3.3.5 Grain yield

Some of the genotypes yielded better at an inter-row spacing of 75 cm than at 45 cm (Table 11). In other cases there were no significant differences within the genotype. In general planting soybean at an inter-row spacing of 45 cm had 22% yield advantage when compared to planting at 75 cm (Table 5). Comparisons of spacing in Nyabeda indicated that planting Sc Squire at an inter row spacing of 45cm gave a yield advantage of 22% against inter row spacing of 75 cm while 31% increase in grain yield was recorded for same genotype at Kambare and only 10% recorded in Ekitale (Table 6).

Sc Squire performed relatively well in terms of grain yield across all sites, seasons and spacing (Table 11). TGx 1987 62F, TGx 1987-10F and TGx 1904-6F also performed well across sites and spacing levels while EAI 3600 recorded low yields when compared to other genotypes. TGx 1987-10F, TGx 1987-6F and TGx 1987-18F are late maturing, TGx 1740-2F is a medium maturing while EAI 3600, SBH3/7/4, 835/5/30, Sc 823-6-16 and Sc sequele are early-medium maturing varieties. The early –medium maturing genotypes had low yields as compared to late maturing however Sc Squire performed outstanding well across all the sites.

The three sites also differed significantly (Table 7). Nyabeda ranked best with a mean of 2816 kg ha^{-1}, Ekitale had 2019 kg ha^{-1} and Kambare ranked least with 1452 kg ha^{-1} in terms f grain yield.

Soybean grain yield was significantly affected by season (Table 8). Yield performance was better in long rain season (2244 kg ha^{-1}) than short rain season (1524 kg ha^{-1}). Long rain had yield advantage of 47% when compared to short rain season (Table 8).

Table 11: Interaction between site, genotype and spacing on soybean grain yield in kg ha^{-1}.

Genotype	Ekitale -Bungoma county		Kambare –Kisumu County		Nyabeda –Siaya County	
	Spacing		Spacing		Spacing	
	45 cm	75 cm	45 cm	75 cm	45 cm	75 cm
835/5/30	1464b	1474b	1976bc	1282b	3237d	2750c
EAI3600	1283b	513a	1594b	1206b	3288d	2701c
SBH3/7/4	2503c	1941b	1330b	1143b	2755c	2681c
SC 23-6-16	1681b	1891b	819ab	1258b	3267d	2682c
SC Sequel	1588b	1509b	2146c	1573b	3271d	2857c
Sc Squire	2930c	1770b	2765c	1911b	3432d	2932c
TGx1740-2F	2864c	1755b	1091b	1023ab	3400d	2956c
TGx1904-6F	3053c	1408b	1313b	1309b	3361d	3213d
TGx1987-10F	2594c	3160d	1220b	1204b	3267d	3109d
TGx1987-18F	2578c	2559c	1418b	1126b	2669c	2345c
TGx1987-62F	2429c	2760c	1574b	1458b	3177d	3009d
LSD		**404**				
CV%		**24**				

Means with different letters are significant at P ≤ 0.05.

Results as indicated in table 12 show significant interaction between spacing and genotype, spacing and site, spacing with regards to grain yield. Analysis of variance results also indicated that there was positive interaction in season and sites on grain yield. The overall performance of eleven varieties was exemplarily good at Nyabeda; in long rain season and at inter row spacing of 45 cm. The yields ranged from 2755 kg ha^{-1} -3432 kg ha^{-1} (Table 11).

3.3.6 One hundred - seed weight

Inter row spacing did not significantly affect 100-seed weight of soybean genotypes across seasons and sites. Genotype and season had significant influence on 100 seed weight (g/100 seed) as shown table 12. Season and site, season and genotype and site with genotype interacted positively on 100 seed weight (Table 12).

Table 12: Variance analysis for studied soybean growth and yield components across spacing, genotype, sites and season.

source of variation	df	Biomass kg ha^{-1}	Grain yield kg ha^{-1}	Nodule score	No. of pods /plant	Plant height (cm)	100 seed wgt
Spacing	1	4373621*	16516916*	4ns	104ns	733*	6
Genotype	10	5388309*	508825*	2*	309*	7397*	49*
site	2	31689598*	90031313*	35*	8758*	0ns	122*
season	1	101561562*	50425675*	80*	1494*	163ns	50*
Replicate	2	857900ns	235500ns	4*	453*	209*	3ns
Season x site	2	16801037*	10006001*	0.27ns	9559*	1397*	120*
Season x Spacing	1	108409ns	164379ns	1ns	349ns	25ns	61ns
Season x Genotype	10	3516141*	484310ns	2ns	249*	234*	21*
Site x Spacing	2	3288142*	327048ns	0.1ns	706*	95*	19ns
Site x Genotype	20	2440085*	771812*	2ns	356*	312*	21*
Spacing x Genotype	10	354553*	364774ns	0.7ns	130*	124ns	9ns
Season x site x Spacing x Genotype	72	1203240ns	463638*	2*	174*	117ns	4ns
CV%		27	30	29	20	20	18

*Indicate significance at $P \leq 0.05$ level.

3.3.7 Simple linear correlation coefficients of grain yield and yield parameters

From the analysis of variance results (Tables 13, 1 4 and 15), grain yield was found to be positively correlated ($P<0.05$) with parameters such as above ground biomass, plant height, pod load, nodule mean score and 100-seed weight.

Table 13: Simple linear correlation coefficient of grain yield, growth and yield parameters at Ekitale-Bungoma County

	r value										
Grain yield vs	835/5/30	EAI 3600	S823-6-16	SBH3/7/4	Sequel	Sc Squire	TGx 1740-2F	TGx 1904-6F	TGx1987-10F	TGx 1987-18F	TGx 1987-62F
Above ground biomass	0.65**	0.82	0.69**	0.48	0.67	0.81**	0.81**	0.73**	0.67**	0.71**	0.67**
Nodule mean score	0.73**	0.52	0.80**	0.84**	0.35	0.64**	0.68**	0.23	0.83	0.7*	0.45
Plant height	0.54**	0.56	0.47	0.63**	0.51	0.82**	0.87*	0.38	0.15	0.35	0.36
Pod load	0.68**	0.62	0.75**	0.61**	0.644	0.74**	0.51**	0.35	0.82*	0.36**	0.51*
Seed weight	0.8**	0.78	0.75**	0.62**	0.72	0.91**	0.55**	0.52*	0.68**	0.68**	0.45

***, ** denote effects of significant at 5 and 1% probability level respectively.**

Table 14: Simple linear correlation coefficient of grain yield, growth and yield parameters at Nyabeda-Siaya County.

	r value										
Grain yield vs	835/5/30	EAI 3600	S823-6-16	SBH3/7/4	Sequel	Sc Squire	TGx 1740-2F	TGx 1904-6F	TGx1987-10F	TGx 1987-18F	TGx 1987-62F
Above ground biomass	0.44	0.38	0.83**	0.76**	0.34	0.81**	0.58**	0.58*	0.54**	0.51*	0.56**
Nodule mean score	0.61**	0.36	0.62*	0.23	0.65**	0.56*	0.48	0.82**	0.61*	0.57*	0.62**
Plant height	0.45	0.45	0.50*	0.19	0.16	0.51**	0.65**	0.33	0.38	0.67*	0.46
Pod load	0.37	0.28	0.39	0.81**	0.65**	0.63**	0.57**	0.97**	0.81**	0.76**	0.56**
Seed weight	0.65**	0.72**	0.85**	0.55*	0.72**	0.78**	0.51*	0.61**	0.52**	0.81**	0.27

***, ** denote effects of significant at 5 and 1% probability level respectively.**

Table 15: Simple linear correlation coefficient of grain yield, growth and yield parameters at Kambare –Kisumu county

	r value										
Grain yield vs	835/5/30	EAI 3600	S823-6-16	SBH3/7/4	Sequel	Sc Squire	TGx 1740-2F	TGx 1904-6F	TGx1987-10F	TGx 1987-18F	TGx 1987-62F
Above ground biomass	0.76**	0.90**	0.91*	0.62**	0.54*	0.83**	0.34	0.99**	0.84**	0.55**	0.77**
Nodule mean score	0.29	0.26	0.93**	0.85**	0.42	0.53*	0.11	0.55*	0.69**	0.54*	0.53*
Plant height	0.49	0.33	0.62**	0.15	0.18	0.60**	0.57**	0.28	0.28	0.27	0.37
Pod load	0.15	0.79*	0.53*	0.64*	0.72**	0.64**	0.81**	0.68**	0.64**	0.49	0.6**
Seed weight	0.61**	0.72**	0.54**	0.42	0.81**	0.84**	0.57*	0.67**	0.78**	0.56**	0.67**

***, ** denote effects of significant at 5 and 1% probability level respectively.**

3.4 Discussion

3.4.1Effect of treatments on biomass yield

a) Spacing

Inter row spacing of 45 cm recorded the highest biomass ($P \leq 0.05$) than inter row spacing of 75 cm. Higher above ground biomass at inter row spacing of 45 cm than 75 cm can be related to number of plants per unit area. At inter row spacing of 45 cm the number of plants were 44 per m^2 as compared to 26 plants per m^2 at 75 cm. Similar observation was made by Misiko *et al*. (2008) who demonstrated that increasing number of plants per unit area relates directly to dry matter accumulation per unit area. These results are also in agreement with Akunda, (2001) whose finding indicated that the growth of crops at high density is used to help attain efficient interception of irradiance.

b) Genotype

Soybean genotypes significantly differed in biomass accumulation. The grain–medium to early maturing genotypes were significantly different. TGx 1987-62F, TGx 1987-10F, TGx 1987-18F and TGx 1904-6F (late maturing genotypes-take 105-115 days to reach physiological maturity) had generally higher above ground biomass than Sc Squire, SBH3/7/4, 835/30, EAI 3600 and Sequele (early to medium maturity genotypes -80 to 95 days to reach maturity). The late maturing genotypes were bred for biomass production unlike the later which were bred for grain production (Mahasi *et al*., 2010). The results therefore suggest that varieties with longer maturity period produce high amount of biomass. According to Vanlauwe *et al*., (2003) high biomass of soybean is obtainable in late maturing varieties than in the early maturing

c) Site

Biomass accumulation differed significantly across different sites with Nyabeda, Ekitale and Kambare ranking best to worst in that order respectively. This was attributed to rainfall and initial soil status. In Kambare between 60 -100 days after planting there was serious mid-season drought. This also coincided with pod setting and seed development stage. The same trend was observed during both seasons. The unreliable and erratic rainfall in Kambare affected negatively the biomass accumulation of late maturing varieties. Soil analysis results also indicated that Nyabeda site had soil with moderate nitrogen levels, low Phosphorus levels, and moderate pH and with moderate organic carbon content. Soils at Ekitale and Kambare had low levels of Nitrogen, phosphorus and organic carbon. In particular soils at Ekitale site had a slightly acidic soil (below 5.5). The soils at Ekitale were Sandy clay loam while Kambare site had a clay loam soil. The sandy soil at Ekitale implies that there was low water retention capacity. Phosphorus was also supplied to all the treatments at a rate of 60 kg ha^{-1} however its availability might have been affected by the soil pH. This is consistent with observation by Mugendi *et al.*, (2011) and Vandamme *et al*., (2013) who made similar observations in Western Kenya where biomass accumulation was affected by rainfall distribution and initial soil status. According to Duncan (2002) P is most readily available between pH 6-7. With a reduction on soil pH, plant available phosphorus becomes increasingly tied up in aluminum phosphates. A combination of these factors might have been responsible for the low biomass accumulation in Kambare and Ekitale sites respectively.

d) Season

Long rain season had higher biomass accumulation than short rain season. This was attributed to reliable and well distributed rainfall in long rain (1200 mm) when compared to short rain (750 mm). These results are in agreement with findings by Chianu *et al.*, (2008), they reported that there is a tendency for many crops to fail during the short rain season however soybean generally survives due to its high drought tolerance capacity. The short rain was erratic and unreliable, this affected soybean vegetative growth. The results are also in agreement with Okoth *et al.*, (in press) whose findings indicate that mid season drought has detrimental effects on soybean biomass accumulation.

e) Interaction

3.4.2 Effect of treatments on amount of Nitrogen fixed

a) Spacing

Inter row spacing of 45 cm resulted to overall higher nitrogen fixation than 75 cm. Planting soybean at inter-row spacing of 45 cm fixes 82.63 kg ha^{-1} of Nitrogen when compared to 54.8 kg ha^{-1} at an inter-row spacing of 75 cm. This represents 33.7% increase in Nitrogen fixed at inter-row of 45 cm than 75 cm. At inter row spacing of 45 cm common effects of density of nitrogen fixation are attributed to high N_2-fixation per nodule at higher planting density than at low-density. Such responses are in turn supported by photosynthesis. The research results are in agreement with studies conducted by (Akunda, (2001) and Misiko *et al.*, 2008).

b) Genotype

Genotypes TGx 1987-10F, TGx 1987-18F, TGx 1987-62F and TGx 1740-2F recorded the highest N fixed at Ekitale and Nyabeda while 835/5/30, SBH3/7/4 and Sc Squire performed relatively well in Kambare. Across sites, the genotype TGx 1987-10F was the highest fixer of N (fixed 138 kg ha^{-1} at inter-row row spacing of 45 cm and 100 kg ha^{-1} of Nitrogen at inter-row spacing of 75 cm). The variety Sc Squire was a poor fixer of N (fixed 66 kg of Nitrogen per hectare at inter row spacing of 45cm and 46 kg of Nitrogen per hectare at row spacing of 75 cm). Because of their longer period, late maturing genotypes usually fix more N. Long maturing varieties have dense rooting system and have the capacity to fix nitrogen with indigenous rhizobia besides the applied rhizobia. This then gives them the advantage over the specific varieties. The findings indicated that late maturing varieties fixed more nitrogen per hectare as compared to early to medium maturing varieties under optimum conditions of agronomic management, environmental and climatic conditions. Similar results were reported in Western Kenya by Vanlauwe *et al*., (2003) and Vandamme et *al*., (2013).

c) Site

Sites also differed significantly in terms of amount of Nitrogen fixed. Nyabeda fixed an overall mean of 101.5 kg ha^{-1}, Ekitale fixed 78.0 kg ha^{-1} and Kambare fixed 68.4 kg ha^{-1}. This represents 30% and 48.4% increment in Nitrogen fixed in Nyabeda as compared to Ekitale and Kambare respectively. Poor nitrogen fixation in Ekitale could be attributed to high levels of exchangeable aluminum and manganese which hindered nodulation and nitrogen fixation. It is also known that low soil pH and high levels of exchangeable aluminum and manganese restrict rhizobia growth, nodulation and growth of host plant, resulting in low levels of N fixation (Zahran, 1999). Low organic carbon which acts as substrate for rhizobia could also be a reason for poor nitrogen fixed in Ekitale and Kambare. Ekitale and Kambare had soil pH < 5.5, while nodulating organisms (rhizobia) thrive well at pH of 6-7. The low levels of initial nitrogen in Kambare and Ekitale also impacted negatively to on microbial activities. Microbial activities require starter nitrogen before soybean starts to nodulate and fix nitrogen (Baijukya *et al.*, 2010).

d) Season

Nitrogen fixed was significantly higher in long rain season by 32% when compared to short rain season. The difference response in seasons can be attributed to differences in soil moisture in the two seasons. Reliable and well distributed in long rain season enhanced the activity of rhizobia. In van Kessel and Hartley, (2000) review they also reported that increased soil moisture increases potential of biological nitrogen fixation.

e) Interaction of spacing, genotype, site and season

Nitrogen fixed did not show significant interaction between site and spacing. However, Site interacted positively with genotype. Spacing interacted positively with genotype at $P \leq 0.05$. Positive interaction in Nyabeda with genotype is attributed to high availability of nutrients and reliable rainfall. Nyabeda had high carbon and moderate soil pH this may have boosted the microbial populations then eventually enhanced nitrogen fixation. Kambare and Ekitale, due to low organic matter and sandy soils, rhizobia population was low hence low nitrogen fixed. Performance of soybean varies widely depending on site-specific soil and climatic conditions, with soil organic carbon and available phosphorus (Zingore *et al.*, 2008 and Vanlauwe *et al.,* 2010).

3.4.3 Influence of treatments on Plant height.

a) Spacing

Spacing significantly affected plant height. Inter row spacing of 45 cm had higher mean (49.1 cm) in terms of plant height than inter row spacing of 75 cm (46.3 cm). Akunda, (2001) findings revealed that high plant density leads to high interception of light for photosynthesis which directs relates to dry matter accumulation.

b) Genotype

A significant difference was also observed in soybean genotypes with regard to plant height across seasons, sites and spacing. TGx 1987-10F, TGx 1987-62F, and TGx 1987-18F recorded the highest height across sites and seasons in that order. EAI 3600 recorded the lowest mean in plant height of 41.0 cm, while TGx 1987-10F recorded the highest mean of 53 cm. Generally, late maturing genotype were taller than medium to early maturing genotypes .Similar results were demonstrated by Mahasi *et al.,* (2010) and Ngalamu et al., (2013) where they found that late maturing varieties are taller than early maturing varieties due to genetic composition and enough time to utilize the available resources optimally.

c) Site

Significantly shorter plants were noted in Kambare than Ekitale and Nyabeda across seasons and spacing. This is attributed to site variations with respect to rainfall and initial fertility status among other factors and agreed with (Ojiem, 2006 and Vandamme *et al.*,

2013) findings which showed that there are different micro-ecological zones within western Kenya.

d) Season

Soybean genotypes plant height was affected significantly by seasons. Long rains had an overall mean height of 50 cm while short rains had a mean of 47 cm. This is consistent with observations by Okoth *et al.,* (in press) who reported that mid season drought has detrimental effects on soybean performance. Moisture stress in short rain season reduced plant height and profuse branching than long rain season.

e) Interaction of spacing, genotype, site and season

The interaction of season and site, season and genotype was very significant at $P \leq 0.05$. The highest interaction was seen in long rains at Nyabeda with TGx 1987-62F ranking the best and EAI 3600 giving least interaction. However there was no significant difference in interaction between Season, site, spacing and genotype. This is in agreement with research results by Giller and Titonell, (2013), their finding demonstrated that crop potential can be intensified by the interaction of Genotype, Environment and Management $\{G_L$ x E x M$\}$.

3.4.4 Influence of treatments on number of pods per plant

a) Spacing

The number of pods per plant, sampled within a plot, was not significant at inter-row spacing of 45 cm and 75 cm respectively. However, inter-row spacing of 45 cm gave the highest number of plants per m^{-2} (45 plants per m^{-2}) when compared to an inter-row of 75 cm whose mean was 26 plants per m^{-2}. Increase in plant population from 26 to 45 plants per $m-^{2}$ significantly increased pod number per m^{-2} by 1.7 times at an inter-row spacing of 45 cm compared to 75 cm. (Akunda, 2001 and Alghandhi, 1991) also found out that the increase in pod load at a narrow spacing is attributed to more plants per unit area than wider spacing that has few plants per unit area.

b) Genotype

Number of pods per plant was significantly affected by soybean genotypes. TGx 1987-62F, followed by TGx 1987-18F and then TGx 1987-10F had the highest among the best three in number of pods across sites, seasons and inter-row spacing while; EAI 3600 had the lowest number of pods per plant. TGx 1987-62 out-yielded others because of growth traits like having many branches and days to 50% flowering; being a late maturing variety it utilizes resources effectively as compared to early maturing varieties. The high pod load could have originated from its genetic composition (Baijukya et *al.,* 2013). The results are in agreement with those conducted by Mahasi e*t al., (2010)* in Western Kenya.

c) Site

In terms of sites, number of pods differed significantly in soybean genotypes and inter-row spacing. Nyabeda was the best site with overall mean of 39 pods per plant, followed by Ekitale with 29 pods per plant and Kambare ranked last with mean of 23 pods per plant. Precipitation amounts during critical flowering and pod setting period was poor in Kambare in both seasons. However, in Ekitale low yields can be attributed to sandy soils that have low water holding capacity, low Phosphorus and Nitrogen. This is due to multiple constraints that affect crop performance (Zingore *et al.,* 2011). Precipitation amounts in Nyabeda were reliable and well distributed. Vandamme *et al.,* (2013) and Okoth *et al.,* (in press) also found out that mid season affects soybean performance in Western Kenya. Good performance in Nyabeda is also attributed to initial soil status; the site had adequate levels of Nitrogen, carbon and pH favourable for soybean growth.

d) Season

Lower numbers of pods per plant were recorded in short rain season than in long rain season. The availability of soil moisture especially at critical stages of growth i.e. flowering, pod set & pod filing appear to be the most critical environment factor in determining anticipated number of pods per plant. Short rain season were erratic and reliable while long rains were well distributed and reliable. This is in agreement with research conducted by Okoth *et al.,* (in press) whose findings indicated that mid season drought often encountered in short rains has detrimental effects on soybean performance.

e) Interaction of spacing, genotype, site and season

Significant interaction in spacing and genotype indicate that manipulation of spacing can greatly influence yield. Genotype and site interaction was highly significant at ($P \leq 0.05$) for number of pods. Season interacted significantly with site and genotype at ($P \leq 0.05$). These results are in agreement with research conducted by Mahasi *et al.,* (2010) who reported that selection of soybean genotypes by farmers varies from site to site and highly depends on yield components such as number of pods.

3.4.5 Influence of treatments on grain yield

a) Spacing

Spacing influenced different soybean grain yield differently. Some of the genotypes yielded better at an inter-row spacing of 75cm than at 45 cm. In other cases there were no significant differences within the genotype. In general planting soybean at an inter-row spacing of 45 cm had 22% yield advantage when compared to planting at 75 cm. Comparisons of spacing in Nyabeda indicated that planting Sc Squire at an inter row spacing of 45cm gave a yield advantage of 22% against inter row spacing of 75 cm while 31% increase in grain yield was recorded for same genotype at Kambare and only 10% recorded in Ekitale.

Grain yield response to spacing varied from site to site and season. For instance TGx 1987-10F, TGx 1987-6F and TGx 1987-18F were not significantly different at Ekitale and Nyabeda at inter-row spacing of 45 cm and 75 cm. On the other hand TGx 1740-2F and TGx 1987-62F yielded better at inter row spacing of 45 cm than at 75 cm in the said sites. These results lead to the conclusion that inter row spacing of 45 cm may produce the highest soybean grain yield than 75 cm. Akunda, (2001) noted that narrow spacing has advantage because soybeans achieve canopy closure more quickly and intercept more light throughout the growing season. Soybean canopy development is a function of spacing, seeding rate and environment. The relative equidistant plant distribution leads to increased leaf area development and greater light interception early in the season.

b) Genotype

Soybean genotype differed in grain yield across seasons, site and spacing but the differences largely related to variation in maturity period. Sc Squire, TGx1740-2F and TGx 1987-62F seem to be well adapted in Nyabeda and recorded the highest yields. Sc Squire ranked best across the three sites and this could be attributed to efficient fertilizer use and conversion of assimilates from sink to source. TGx 1740-2F also seems to be stable in all agro-ecological zones. This research results agrees with findings in Western Kenya reported by Vandamme *et al., (2013)*. Their findings demonstrated that some soybean genotypes may be superior in low P soils than others. Also Sc Squire out-yielded others across the three sites because of its yield components such as number of pods per plant, 100-seed weight and other growth traits like leaf area ,days to 50% flowering and days to physiological maturity that contribute to highest yield (Lynch, 2011).

c) Site

The three agro-ecological zones also differed significantly in yield with Nyabeda ranking best with a mean of 2816 kg ha^{-1}, Ekitale had 2019 kg ha^{-1} and Kambare ranked least with 1452 kg ha^{-1}. These yields are way above the reported yields of 600-900 kg ha^{-1} in Western Kenya (Chianu *et al.,* 2008). Soybean yield obtained from the three sites differed significantly due to differences in soil characteristics and rainfall amounts and distribution. The high performance in Nyabeda is associated with initial soil status and reliable and well distributed rainfall. The soils in Nyabeda were moderately fertile clay soils with conducive soil pH (5.9) suitable for soybean growth. Okolebo *et al.,* (2003) found out that addition of Farm Yard Manure (FYM) improves Cation Exchange Capacity which leads to reduced Phosphorus fixation on the exchanges sites (soil colloids), it also improves soil water holding capacity and substrate for bacteria responsible for Nitrogen fixation. Sympal (special fertilizer blend) provided essential elements such P, K, Ca, Mg and Zn that were readily available for soybean absorption and utilization. In contrast, Ekitale, due sandy soils, must have had high leaching leaving, high presence of Fe and Al elements which reduces the availability of phosphorus through fixation (Okalebo *et al.*, 2002). Low performance of soybean in Kambare could also be attributed to low organic matter. Low organic matter implies low water holding capacity besides lack of food for soil micro-organism including rhizobia that assist in nitrogen fixation. Soybean yield is most sensitive to water deficits during reproduction. Soil water deficits during reproductive growth phase results in increased flower abortion, reduced pod number, reduced seed per pod and small seed. Therefore the yield and shoot growth may also decrease or stop (Pedersen and Laure, 2004). High temperatures also in Kambare favour the process of mineralization which is often associated with nitrogen loss through denitrifixation (Okalebo *et al.*, 2003).

d) Season

Soybean grain yield was significantly affected by season. Yield performance was better in long rain season than short rain season. Long rain had yield advantage of 47% when compared to short rain season. The high yields in the long rain season are attributed to the duration and amount of rainfall which was recorded during growth phase (1200 mm) compared to the short rain season 750 mm.

e) Interaction of spacing, genotype, site and season

Spacing interacted positively with genotype at ($P \leq 0.05$). There was also positive interaction between genotypes and site, this could be attributed to genotype adaptability i.e. genetic potential of soybean genotype differ from one to another. (Giller and Titonel, 2013) also found out that improving soybean productivity can be achieved by maximization of the interaction of Environment x Genotype x Management. ANOVA results also indicated that there was significant interaction between season, site, spacing and genotype. The positive interaction could be associated with the availability of soil moisture, conducive soil pH, adequate soil organic matter and initial nutrients status among the most critical environmental factors in determining the anticipated soybean yields (Vandamme *et al.,* 2013). This explains why Nyabeda performed well across seasons for almost all genotypes and spacing than Ekitale and Kambare.

3.4.6 Correlation between parameters.

Correlation results showed strong relationship between soybean grain yield and above ground biomass, plant height, number of pods per plant and 100-seed weight. The relationship was strong in Nyabeda and Ekitale; however in Kambare it showed weak relationship. This could be explained in terms of adverse effects of mid-season drought. The findings agree with result conducted in similar agro-ecological zone by Okoth *et. al., (in press*). He reported that Western Kenya experiences unreliable rainfall distribution leading to mid-season drought and this is repeatedly reducing soybean grain yield.

Grain yield also correlated positively with number of pods and 100 seed weight. These results were in line with findings reported by Mahasi *et al., (*2010) and Vanlauwe *et al.,* (2010) that irrespective of maturity, high yielding genotypes generally exhibited significantly high number of pods and seed than low yielding genotypes.

The results also showed that there was no significant correlation between yield, Nitrogen fixed and Nodule mean score. This implies that genotypes vary in their N uptake potential. Similar findings were reported in Western Kenya by Mugendi *et al.*, (2010).

3.5 Conclusions and recommendations

3.5.1 Conclusions

An inter-row spacing of 45 cm gives high soybean grain and biomass yield in Western Kenya. Sc Squire is the best grain genotype while TGx 1987-62F, TGx 1987-10F and TGx 1987-18 F have high biomass yield.

Therefore the present study leads to the following recommendations.

3.5.2 Recommendations

1. To optimize yield, small scale farmers in Ekitale, Nyabeda and Kambare should plant soybeans at an inter-row spacing of 45 cm
2. Sc Squire is the recommended genotype for high grain yield while TGx 1987-62F for high biomass and Nitrogen fixation.
3. Early maturing varieties such as EAI 3600, Sc Squire and TGx 1940-2F are recommended in Kambare and should be planted during the long rain season to avoid mid season droughts experienced in short rains that often lead to low yields. While TGx 1987-62F, TGx 1987-10F as well as Sc Squire are recommended for Nyabeda and Ekitale.

CHAPTER FOUR

CONTRIBUTION OF FERTILIZERS TO GROWTH PERFORMANCE OF SELECTED SOYBEAN GENOTYPES

ABSTRACT

Production and productivity of soybeans in Western Kenya has been declining due to inappropriate nutrient management technologies and lack of high yielding soybean genotypes among others. Much effort in research has concentrated on fertilizer rates, time of application, cereal legume integration and intensification but limited research has been done on the contribution of legume blended mineral fertilizer (Sympal), Farm Yard Manure (FYM) and sugar cane waste (*scum*) on soybean performance. An experiment was conducted in Western Kenya to ascertain the contribution of legume fertilizer blend, Farm Yard Manure (FYM) and scum on yield of soybean genotype in Western Kenya. The experiment was laid in a Randomized Complete Block Design (RCBD) as a factorial arrangement and replicated three times. Four soybean genotypes were evaluated. Grain yield and biomass data were subjected to ANOVA using SAS PROC mixed model. Genotype x Site x Nutrient management interaction means were separated using LSD (α =0.05) and standard errors. Application of Farm Yard Manure, Scum or Sympal fertilizer singularly did not show any significant difference in soybean grain and biomass yield however they showed significant increase in grain and biomass yield relative to inoculation alone. Combination of Sympal and Manure/ sugar cane waste recorded the highest biomass and grain yield across sites. Nyabeda site gave highest grain yields followed by Ekitale then Kambare. To ensure sustainable and viable soybean production

and productivity in western small holder farmers should use manure/ scum in combination with Sympal.

4.1 Introduction

In Western Kenya, soybean production is often constrained by low Phosphorus (P) and Nitrogen availability while large amounts of P fertilizers are needed to increase production levels (Smaling *et al.*, 1997). The selection of soybean genotypes that are tolerant to sub-optimal P conditions could help to increase cost effectiveness and sustainability of P fertilizer use in soybean cropping systems. Previous studies in Western Kenya have shown that soybean genotypes differ in their adaptability in various agro-ecological zones and response to phosphorus (Vandamme *et al., 2013*). Use of optimum levels of P would enhance high and sustainable yields; however, farmers in this region cannot afford to buy such amounts because of limited purchasing power (Vandeplas *et al.,* 2010). Therefore use of sub-optimal levels of inorganic fertilizers and organic inputs seems to be the most viable and sustainable option (Vanlauwe *et al.,* 2010). In the first experiment eleven genotypes were tested across the three sites under optimal levels of P and blanket application of farmyard manure at varying spacing. Results indicated that soybean yield was generally higher compared to the baseline however; it was not possible to quantify the contribution of Sympal, manure or inoculation alone. This was because Sympal, manure and inoculation were blanketly applied across genotypes. The objective of this study therefore was to assess the contribution of organic, inorganic and their combination on soybean performance.

The importance of farmyard manure is being realized again because of the high cost of commercial fertilizers and its long term adverse effect on soil chemical properties. Besides supplying macronutrients and micronutrients to the soil (Vanlauwe *et al*., 2001), farmyard manure also improves the physical and chemical properties of the soil Okalebo *et al.,* (2003). However, unless it is integrated with inorganic fertilizers, the use of farmyard manure alone may not fully satisfy crop nutrient demand, especially in the year of application. Gandah *et al.,* (2003) research findings indicated that animal manures are also useful in improving the efficiency of fertilizer recovery thereby resulting in higher crop yield. Studies conducted in India by Ghulam *et al., (2002*) indicated that sugar cane Waste (Scum) could be used to correct soil acidity and nutrient deficiencies among small scale and large scale farmers. Vanlauwe *et al.,* (2001) found out that highest and most sustainable gains in crop productivity per unit nutrient are achieved from mixtures of fertilizer and organic inputs. It has also been demonstrated that introducing improved crop varieties and modest amounts of mineral fertilizer may improve crop yields but at relatively low agronomic efficiency (AE) of nutrient use (Sanginga and Woomer, 2010). Therefore use of organic and inorganic fertilizers coupled with appropriate genotype and nutrient management strategies that address multiple crop production constraints is necessary for a sustainable and viable soybean production and intensification in small holder farming system in Kenya.

Accessing the best varieties, acquiring quality inoculants and identifying initial fertilizers serves as the initial basis for technology transfer (Giller *et al.,* 2013). Results from N2 Africa work in Western Kenya by Baijukya *et al.,* 2013, showed yield increase of 5-50%

following P application across the Action sites (Lake basin, Midland and upper mid lands) depending on P source and site. In some cases inoculation alone proved unnecessary or phosphorus addition alone was insufficient.

A number of soil management strategies have been identified and are soil –specific nutrient deficiencies (of K, Ca, Mg, Zn) that have led to legume specific fertilizer blends development for instance Sympal (Woomer *et al.,* 2013)

4.2 Materials and methods

4.2.1 Experimental sites

The study was conducted at three (3) sites, one in each of the major agro-ecological zones of Western Kenya, namely low land- Kambare in Kisumu county 34^{0} 44′ E ,00^{0} 05′S alt. 1278 m asl) with rainfall range of 600-1200 mm per annum; Midlands -Nyabeda in Siaya county (34 ^{0} 25′ E , 00 ^{0} 08’N alt. 1323 m asl) with rainfall range of 1000-1800 mm per annum and Upper midlands -Ekitale in Bungoma county (E34^{0} 43′E, 00^{0} 52′N′ 1479 m) with rainfall range of 1200-2200 mm.

The soil in Nyabeda and Kambare sites were deep, red, well drained, highly weathered with inherently low fertility classified ferrasols (Okalebo *et al.,* 2003), while the soils in Ekitale were sandy clay loam, dark red, poor in nutrients, thus require regular fertilization.

The rainfall in the three sites was bimodal, divided into two distinct season; long rain (LR) starting in March ending June and short rain starting from August ending

December. Mean annual rainfall in Nyabeda, Ekitale and Kambare averages 1100, 1450 and 600 mm per year respectively.

Table 16: Top soil (0-20cm) characteristics at experimental sites.

	Site		
Soil parameter	Ekitale_ Bungoma county	Kambare_ Kisumu County	Nyabeda_ Siaya county
pH	5.4	5.9	5.8
C%	1.02	1.13	2.45
N%	0.08	0.14	0.22
K (cmolc/kg	1.22	1.03	1.12
P mg/kg	4.8	1.84	4.87
Ca (cmolc/kg	0.55	0.57	0.59
Mg cmolc/kg	2.32	2.11	2.41
Zn mg/kg	8.34	4.03	8.54
Sand %	68	26	20
Silt %	06	21	23
Clay%	26	53	57
Textural class	Sandy class loam	Clay loam	clay

4.2.2 Soybean genotype planted

Four genotypes were planted i.e. TGx 1740-2F (IITA), EAI 3600 (Bred from KARI Njoro), Sc Squire (Seedco.) and TGx 1987-62F (IITA). These are genotypes which performed well from the first experiment. Sc Squire was selected because of rust tolerance and high oil content, TGx 1987-62 F was preferred because of high Biological Nitrogen Fixation and TGx 1740-2F was included because of the dual purpose nature and high protein content which fetches high market price. EAI 3600 was used as the local check as it grows across the three agro-ecological sites.

4.2.3 Treatments-Inorganic and organic Fertilizers tested

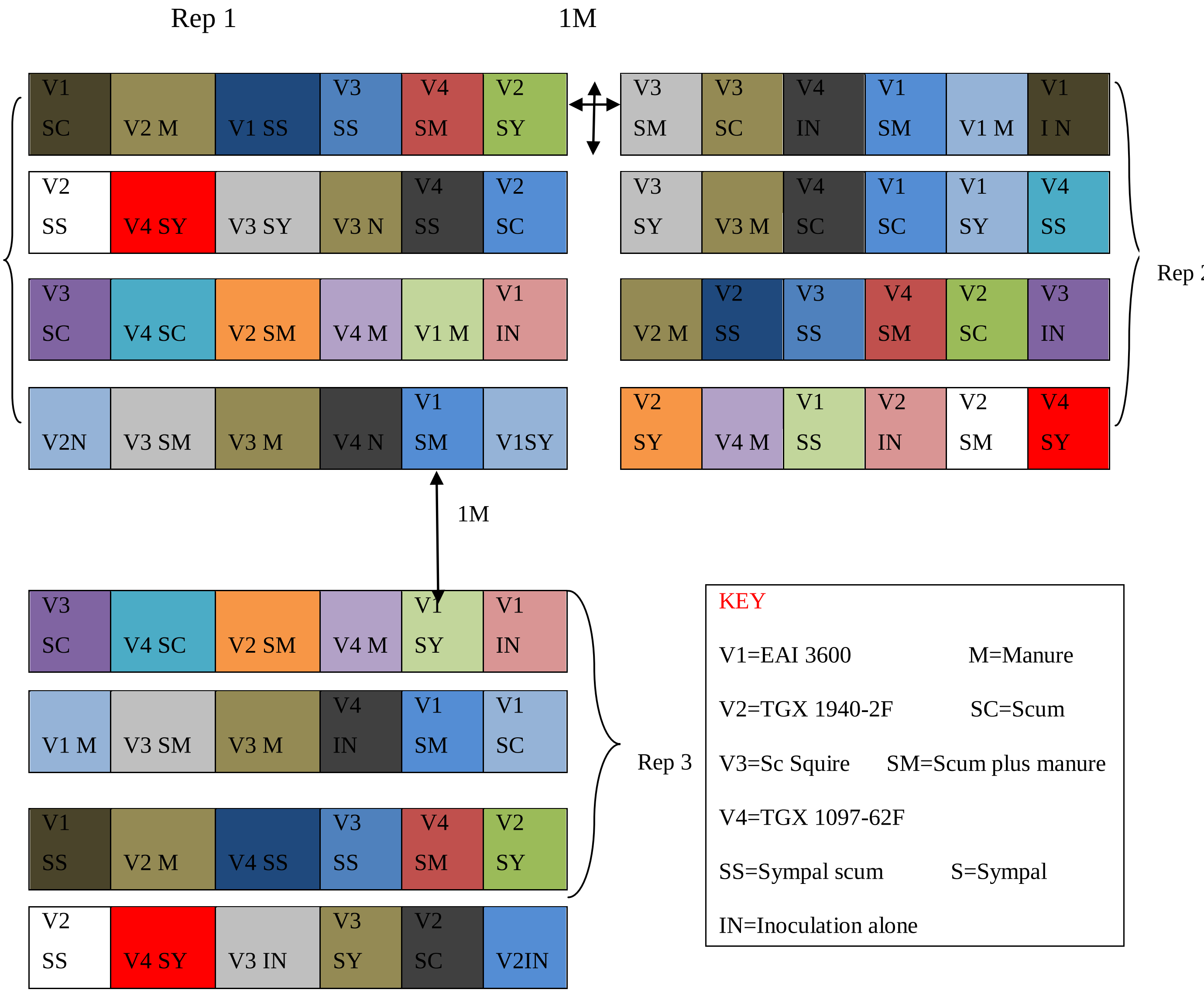
The treatments comprised of inorganic fertilizer (legume blend-Sympal), scum (sugar cane waste), Farm Yard Manure (FYM), Inoculation alone and Sympal plus manure and Sympal plus scum.

Sugar cane waste (scum) was included because most farmers around the sugar belt use this by-product during planting of their crops. Farm Yard manure is mainly used on cereal crops but rarely used to plant legume crops.

All treatments were planted with inoculated soybean. *Bradyrhizobium japonicum* (USDA 110) was used as the inoculant. Sympal was applied at the rate of 30 kg ha^{-1} and manure /Scum at the rate of 2 ton ha^{-1} at planting.

4.2.4 Experimental designs and layout.

The experiment was laid out in Randomized Complete Block Design in a factorial arrangement. It was replicated three times per site having a total of 24 plots per site each measuring 1.8 m x 3 m as shown in figure 2.



V1 SC	V2 M	V1 SS	V3 SS	V4 SM	V2 SY
V2 SS	V4 SY	V3 SY	V3 N	V4 SS	V2 SC
V3 SC	V4 SC	V2 SM	V4 M	V1 M	V1 IN
V2N	V3 SM	V3 M	V4 N	V1 SM	V1SY

V3 SM	V3 SC	V4 IN	V1 SM	V1 M	V1 I N
V3 SY	V3 M	V4 SC	V1 SC	V1 SY	V4 SS
V2 M	V2 SS	V3 SS	V4 SM	V2 SC	V3 IN
V2 SY	V4 M	V1 SS	V2 IN	V2 SM	V4 SY

V3 SC	V4 SC	V2 SM	V4 M	V1 SY	V1 IN
V1 M	V3 SM	V3 M	V4 IN	V1 SM	V1 SC
V1 SS	V2 M	V4 SS	V3 SS	V4 SM	V2 SY
V2 SS	V4 SY	V3 IN	V3 SY	V2 SC	V2IN

KEY

V1=EAI 3600	M=Manure
V2=TGX 1940-2F	SC=Scum
V3=Sc Squire	SM=Scum plus manure
V4=TGX 1097-62F	
SS=Sympal scum	S=Sympal
IN=Inoculation alone	

Figure 2: Field layout to determine the relative contribution of Manure, Scum, Sympal and Inoculation on soybean performance.

The factors were four soybean varieties, Sc Squire, TGx 1740-2F (SB 19), EAI 3600 and TGx 1987-62F. Six fertilizers were also tested: Sympal, Manure, sugar cane waste, Biofix (USDA 110), Sympal plus manure and Sympal plus sugar cane waste.

4.2.5 Cultural practices

a) Site preparation

The fields were prepared by oxen-plough and subsequently harrowed by farmers using hand hoes to improve the soil tilth before planting. After the field had been demarcated, it was leveled and brought to medium tilth, using hand tools.

Soil samples were taken to a depth of 20 cm in a zigzag pattern, before marking out experimental plots. The results of the physical and chemical properties are as shown in Table 16.

b) Planting

Planting was done in long rains 2013, the four soybean genotypes were planted in combination with six treatments; Farm Yard Manure, Scum, Inoculation alone, Sympal, Sympal plus manure and Sympal plus scum. P application was at sub optimal level which is 30 kg P ha^{-1} (*FURP 1994*) .All fertilizers were applied by banding at the time of planting i.e. 2-5 cm from the planting lines to avoid direct contact of seed with fertilizer. Manure was applied by banding in the furrows, following standard farmer practice, and mixed with soil before placing fertilizer and seed. Soybean was inoculated with USDA-110 inoculants strain containing *Bradyrhizobium japonicum* at the rate of 10 g Inoculant kg^{-1} of seed than planted at a spacing of 45 cm inter-row and 5 cm interplant. One fallow plot was included for assessment of biological nitrogen fixation in each replicate. The weed follow was mainly non leguminous grasses.

c) Weed control

The trial was kept weed free by hand weeding using hoes to reduce competition for space, moisture, nutrients and light. It was weeded twice during the growth phase.

d) Pest and disease control

The crops were sprayed with Amister xtra with two active ingredients azoxystrobin (200 g/l) and cyproconnazole (80 g/l) manufactured by Syngenta AG, Basle, Switzerland. The fungicide was applied with a hand-operated knapsack sprayer at rates of 0.75 l ha or 25 ml per 16 l knapsack with 3 application programs starting at flowering there-after at 21 days. The fungicide was sprayed to control soybean rust disease. Also confidor® was sprayed to control aphids and other insect pests that are common in the study area.

4.2.6. Data collected

a) Biomass yield

At 50% podding a section of the border 0.5 m^{-2} from each plot were selected. All shoots in the selected sections were cut, separated with pods, weight and stored in paper bags. Both fresh weights of pods and leaves + stems were taken separately. In the lab the samples were air dried for about two days then oven dried at 65^{0} c for 24 hr or to constant weight. Dry weights were then taken respectively.

b) Grain yield determination

At physiological maturity, soybean grain yields were determined from net plots (1.8 m^{-2}). All plants harvested were counted and recorded. Grain was separated from the pods (sub-sample), fresh weights determined then oven dried at 65° C to constant weight and dry weights recorded. Moisture content of the grain samples was determined using a moisture meter and grain yields were corrected to 12.5% moisture content.

4.2.7 Data analysis

a) Statistical model

$$Y_{ijkl} = \mu + E_i + RE_{(j)i} + G_k + GE_{ki} + F_l + FE_{li} + GF_{kl} + \mathcal{E}_{ijklm}$$

Where

μ= the general mean.

E_i = effect due to the i^{th} site.

$RE_{(j)i}$ = effect due to the j^{th} replicate in the i^{th} site.

G_k = effect due to the k^{th} genotype in the j^{th} replicate

GE_{ik} = effect of the k^{th} genotype in the i^{th} site.

F_l = effect due to l^{th} fertilizer type

FE_{li}=Effect due to l^{th} fertilizer type in the i^{th} site.

GF_{kl}= Interaction between the k^{th} genotype with l^{th} fertilizer type

$\mathcal{E}_{ijklm}$= the random error effect due to the j^{th} replicate of the k^{th} genotype in the i^{th} site.

b) Analysis of Variance

Analysis of variance was conducted to compare the fertilizers, genotypes and their interactions for significance with a mixed model ANOVA using proc mixed in SAS (SAS Institute Inc, 2012). Site (environment), fertilizers and genotype were treated as fixed effects and replicates were treated as random effects. Various response characteristics between the genotypes, environments, fertilizers and their interactions and means were separated using Least Significant Difference (LSD) at ≤ 0.05 confidence level and standard error of means.

4.3 Results

4.3.1 Influence of site, on biomass yield

Analysis of variance results indicated that sites had significant influence on biomass yield (Table 17). Nyabeda was the best site with mean biomass of 3661 kg ha^{-1}, while Ekitale had 3461 kg ha^{-1} and Kambare accumulated least biomass of 2401 kg ha^{-1}. These represent 44% biomass increment in Nyabeda as compared to Kambare and 1% increment in Nyabeda as compared to Ekitale

Table 17: Influence of site on biomass yield and grain yield (kg ha^{-1}).

Site	Biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Ekitale	3461a	1708b
Kambare	2401b	1422c
Nyabeda	3661a	2035a
LSD	318.1	294.7
CV%	31.2	23.6

Means with different letters within column are significantly at P≤ 0.05.

4.3.2 Influence of genotype on biomass accumulation

Soybean genotypes also significantly differed with respect to biomass yield across sites (Table 18). Dual purpose genotypes had high biomass yield when compared to grain varieties. TGx 1987-62F had the highest biomass accumulation across the three sites. This genotype reached 50% podding stage 87 days after planting As a result of longer growth period, biomass accumulation was more than TGx 1740 -2F; Sc Squire and EAI 3600 whose days to 50% podding were 70 days after planting. This represents increment in biomass yield of more than 42% for TGx 1987-62 over EAI 3600 and 34 % over TGx 1740 -2F respectively.

Table 18: Influence of genotype on biomass and grain yield (kg ha^{-1}) across sites.

Variety	Biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})
TGx 1987-62F	4374a	1478b
Sc Squire	2873b	2137a
TGx 1740-2F	2585b	1757b
EAI 3600	2514b	1478b
LSD	367	340
CV%	31.2	23.6

Means with different letters within column are significantly at $P \leq 0.05$.

4.3.3 Influence of fertilizers on biomass yield

Analysis of variance as shown in (Table 19) showed that fertilizers application significantly influenced biomass yields. Sympal plus Farm Yard Manure recorded the highest biomass but it was not significantly different from Sympal plus scum. However, the two were significantly different from Farm yard manure, scum and inoculation alone. Legume blended fertilizer did not show any differences with Farm Yard Manure and scum. On overall control plots (inoculation alone) had relatively low biomass per unit area as compared other fertilizers.

Table 19: Influence of Fertilizers on biomass accumulation and grain yield (kg ha^{-1}).

Fertilizer	Biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Sympal plus manure	3661a	2313a
Sympal plus scum	3634a	2118ab
Manure	3224b	1720c
Sympal	3088b	1694c
Scum	2952b	1630bc
None	1958c	858d
LSD	449	416
CV%	31.2	23.6

Means with different letters within column are significantly at $P \leq 0.05$.

4.3.4 The interactions on biomass yield

a) Interaction of sites and genotype on above ground biomass kg ha^{-1}

Sites and genotype had significant interaction on biomass yield (Fig 3). Nyabeda generally showed higher positive interaction with all genotypes when compared to Ekitale and Kambare. TGx 1987-62F seems more adaptable across sites.

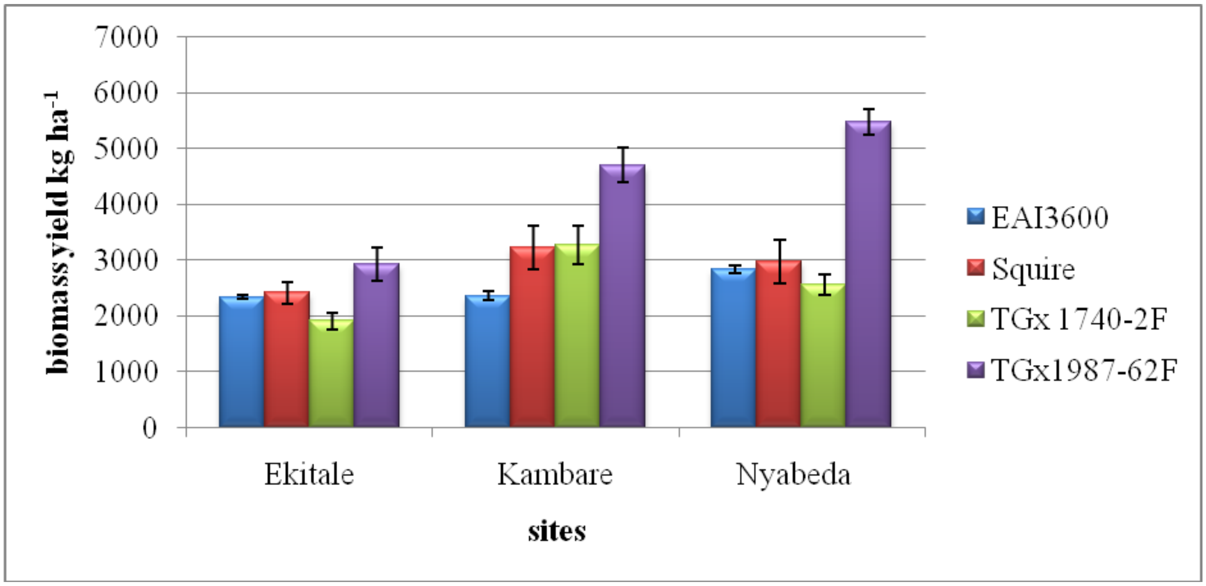


Figure 3: Influence of genotype and site on biomass yield in kg ha^{-1}.

b) Interaction of genotype and fertilizer

The four genotypes interacted significantly with various fertilizers as shown in figure 4 with higher interaction observed in treatments with Farm Yard Manure plus Sympal and Scum plus Sympal when compared to Farm Yard Manure, Scum, Sympal or inoculation singularly.

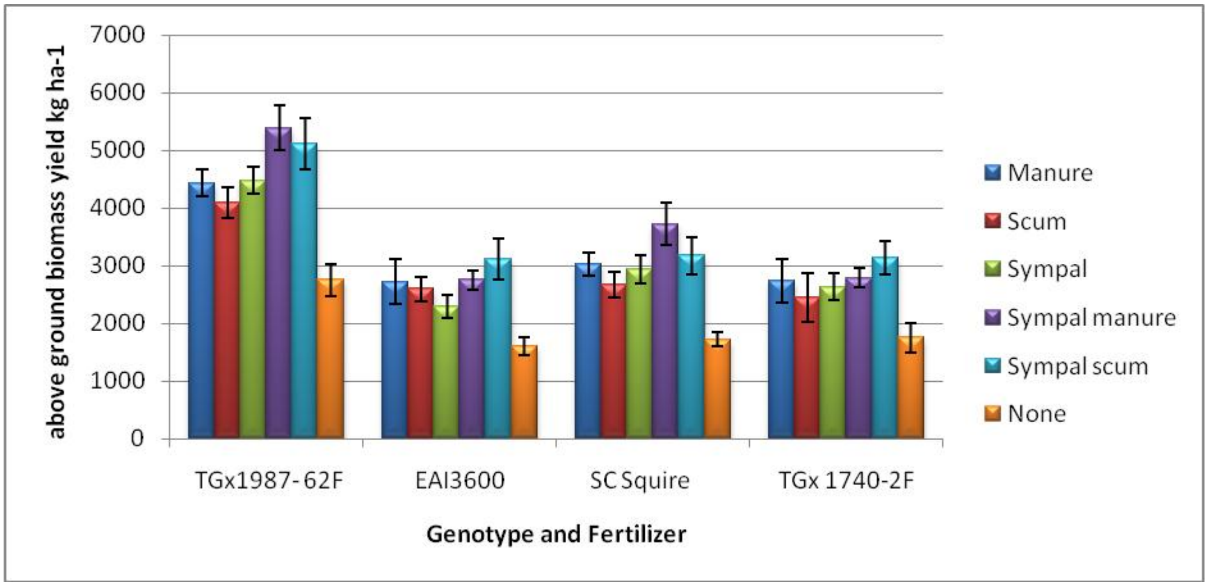


Figure 4: Influence of genotype and fertilizer on above ground biomass yield in kg ha^{-1}.

4.4. Influence of site, genotype, fertilizers and their interactions on grain yield

4.4.1 Influence of site on grain yield

Sites significantly varied in terms of grain yield (Table 17). Comparisons between sites, indicated that Nyabeda out yielded Ekitale by 16% and 30.1% in Kambare respectively.

4.4.2 Influence of genotype on grain yield

In terms of genotypes, the four genotypes performed differently across sites and fertilizers (Table 18). Sc Squire performed well across sites. The yields ranged from 1500-2800 kg ha^{-1} for Sc Squire, with high yields in Nyabeda and least yield Kambare. On overall mean comparisons indicated that Sc Squire out-yielded TGx 1987-62F by 30.8%, then by 18% for TGx 1740-2F and 34.1% for EAI 3600 respectively.

4.4.3 Influence of fertilizers on grain yield

Inorganic and organic fertilizer response differed significantly from site to site and with genotypes as shown in (Table 19). Sympal plus Farm Yard Manure and Sympal plus scum were not significantly different in terms of grain yield however they significantly differed with Sympal, Farm Yard Manure, scum and inoculation alone. High response was shown between Sympal plus manure, Sympal plus scum and squire especially in Nyabeda and Ekitale. Sympal, scum and manure did not show any significant difference in terms of grain yield. The grain yield across the three sites decreased in the order Sympal plus manure>Sympal plus Scum > Sympal >manure > Scum>Inoculation alone.

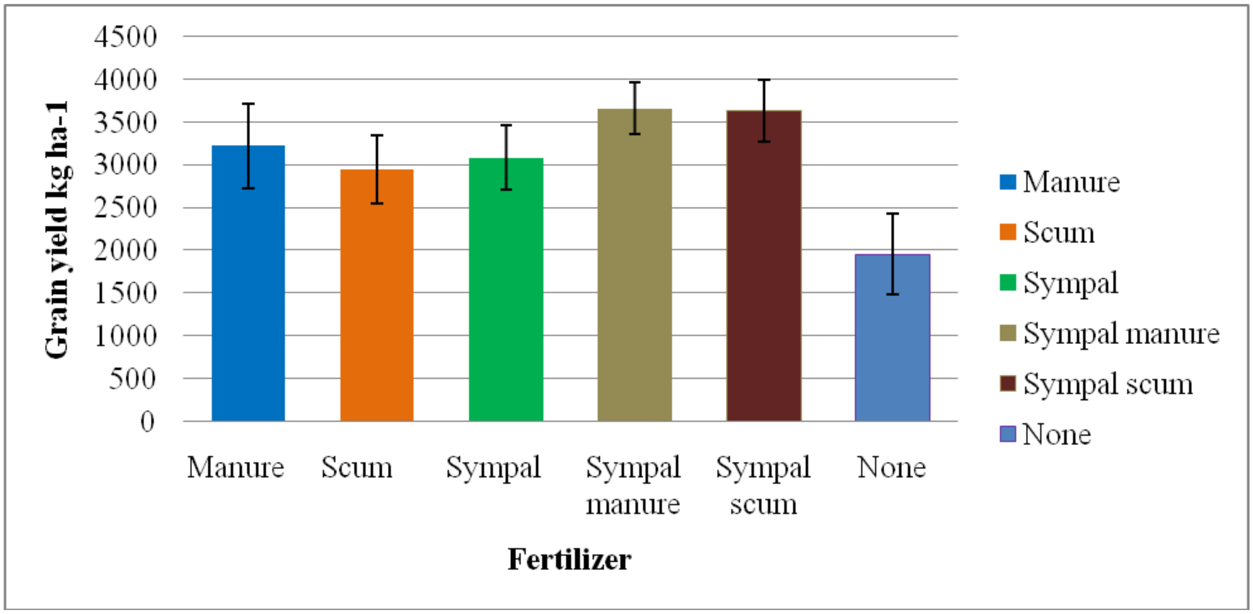


Figure 5: Influence of fertilizer on soybean grain yield in kg ha^{-1}.

4.4.4 Influence of the interactions on grain yield

a) Site and genotype

Sites interacted positively with genotypes (fig. 6). Nyabeda had higher interaction with Sc Squire followed by Ekitale and Kambare. Sc Squire recorded the highest yields across sites.

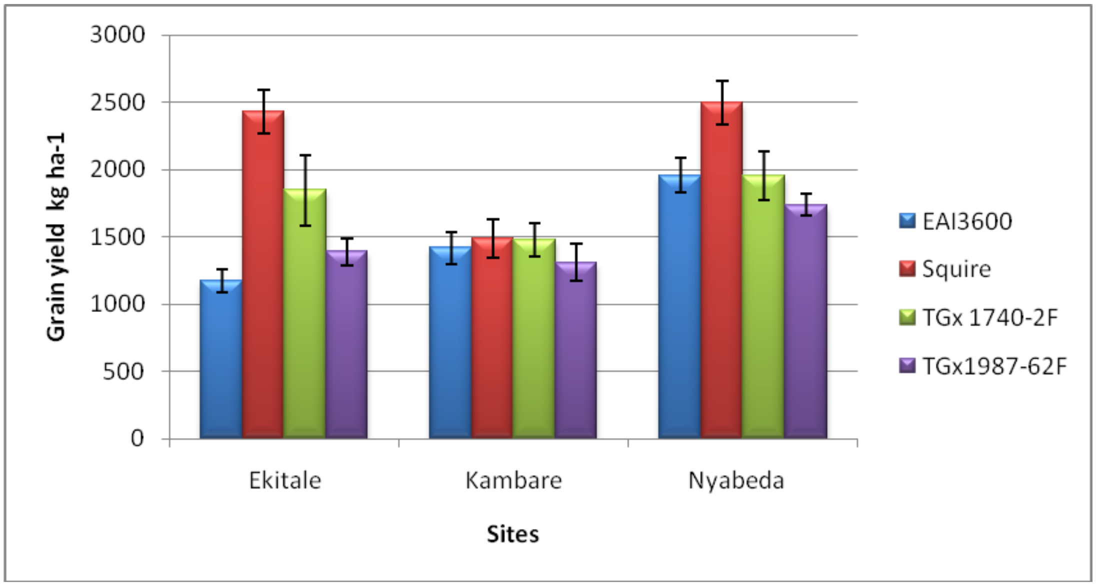


Figure 6: Interaction between genotype and site on soybean grain yield (kg ha^{-1}).

b) Genotype and Fertilizer

The four genotypes interacted significantly with various fertilizers as shown in figure 7 with higher interaction observed in treatments with Farm Yard Manure plus Sympal and Scum plus Sympal when compared to Farm Yard Manure, Scum, Sympal or inoculation singularly.

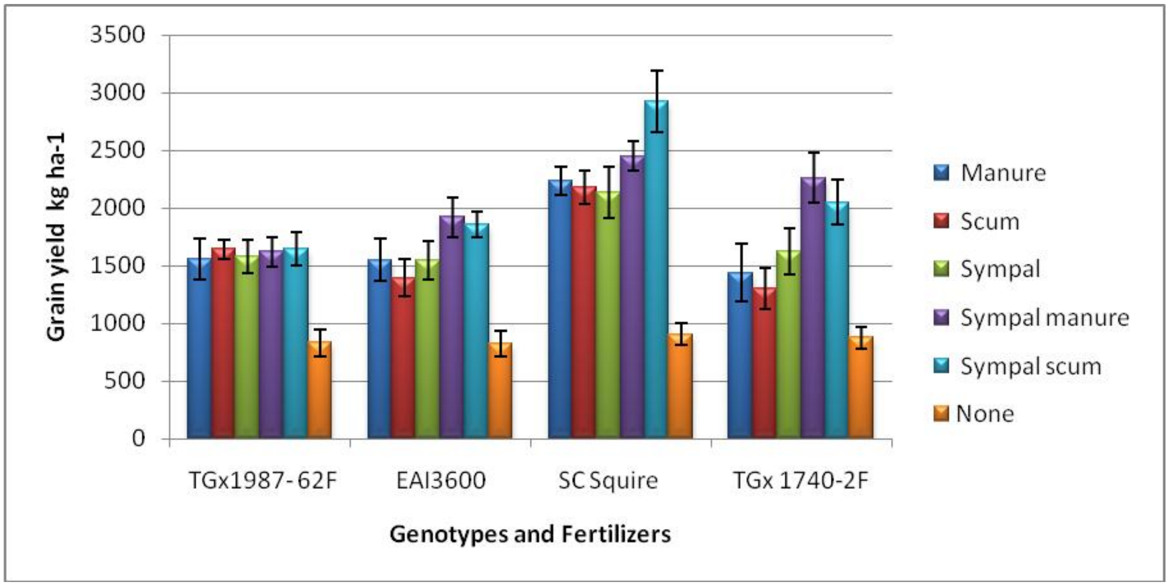


Figure 7: Interaction of soybean genotype and fertilizers on soybean grain yield.

c) Genotype, Site and Fertilizer

There was no significant interaction between genotype, site and fertilizer as seen in Appendix 10

d) Benefit cost ratio

The most profitable managements were Sympal plus scum and Sympal plus manure with Net revenue of Kshs 99,207 ha^{-1} and Kshs 105,900 ha^{-1} respectively. The net revenue across the three sites decreased in the order Sympal plus manure>Sympal plus Scum > Sympal >manure > Scum>Inoculation alone.

Table 20: Benefit cost ratio of fertilizer types across sites.

Management Strategy	Total cost	Net return	Benefit cost ratio
	kshs ha^{-1}		
None	17,889.00	43,389.00	2.89
Scum	28,997.00	60,578.00	3.58
Manure	27,114.00	62,886.00	3.72
Sympal	23,101.00	61,599.00	3.53
Sympal plus scum	67,703.00	99,207.00	4.27
Sympal plus manure	62,504.00	105,900.00	4.58

4.5 Discussion

4.5.1 Influence of treatments on biomass yield

a) Site

Variation in sites could be attributed to soil and rainfall amounts and distribution. Soil analysis results in (Table16) show that the soils in Ekitale were sandy loam, low in total N (0.08 g kg^{-1}) and available P (4.8 mg kg^{-1}) both of which the values were below critical levels (Okalebo *et al.,*2003) . Kambare soils had also low total Nitrogen, available P & K and organic carbon while in Nyabeda where the pH was moderate, total N was moderate and soil organic was moderate, performed relatively better than those at Ekitale and Kambare. The soil pH affects microbial activity and also leads to phosphorus fixation (Okalebo *et al.,* 2003). This then implies that applied phosphorus was not available to soybean hence low biomass. The results are in agreement with research conducted by (Okoth *et al.,* in press), whose finding indicated that mid season drought negatively affect biomass and yield of soybean in western Kenya.

b) Genotype

Soybean genotypes also significantly differed with respect to biomass yield across sites .Dual purpose genotypes had high biomass yield when compared to grain varieties. TGx 1987-62F had the highest biomass accumulation across the three sites. This genotype reached 50% podding stage 87 days after planting .As a result of longer growth period, biomass yield was more than TGx 1740 -2F; Sc Squire and EAI 3600 whose days to

50% podding were 70. Varieties that take long to mature have adequate time to fully optimize the resources i.e. light, water and nutrients as compared to early maturing varieties. The results are in agreement with (Vanlauwe *et al.,* 2003 & Mahasi *et al*., 2010), who found out that late maturing varieties accumulate more biomass than early maturing varieties because they have a long period to utilize the resources more efficiently than early maturing ones.

c) Fertilizer

Sympal plus manure recorded the highest biomass but it was not significantly different from Sympal scum. The results show that application of legume fertilizer blend (Sympal plus farm yard manure/ sugar waste (Scum)) improved biomass yield of soybeans by 46 %. Previous research by (Zingore *et al*., 2008) indicated significant increase in crop productivity when manure was applied in depleted soils due to its multiple benefits on soil biological, chemical and physical properties. (Gandah *et al*., 2003) also found out that manure supplies multiple nutrients, raises soil pH and improves soil organic matter which in turn increases the microbial population.

Lack of significant difference between Farm yard Manure and scum indicates that the two sources have same effect on physical and chemical properties on soil. On overall control plots (inoculation alone) had relatively low biomass per unit area as compared other fertilizers. This could be attributed to infertile soils often associated with multiple constraints to crop productivity; this implies that single technologies are often ineffective to significantly enhance crop productivity (Zingore *et al.,* 2010).

d) Interactions of site, genotype, and fertilizers on biomass yield

In Kambare biomass yield was generally lower than Nyabeda and Ekitale because of confounding factors. Rainfall distribution was poor especially during critical periods i.e. seed germination, 50% flowering and 50% podding). Phosphorus was also supplied to all the treatments at a rate of 30 kg ha^{-1} however its availability might have been affected through fixation. According to Duncan, (2002) P is most readily available between pH 6-7. With a reduction on soil pH, plant available phosphorus becomes increasingly tied up in aluminum phosphates. A combination of these factors might have been responsible for the low biomass yield of soybean in Kambare and Ekitale than Nyabeda.

Kambare site showed slight increase in yield in treatments with Scum. This could be attributed to the fact that Scum has high potassium that is limiting in Kambare. The interaction between site and fertilizer was not as significant as site and genotype. This implies that site and genotype have more influence on biomass yield than fertilizer. Therefore planting genotypes to sites where they are most adaptable leads to higher yields.

4.5.2 Influence of treatments on grain yield

a) Site

Soybean grain yield in Kambare and Ekitale were low due to initial poor soil status. The soils in Kambare had low organic carbon, available P and N conditions that are not favourable for soybean production. Low organic carbon reduces storage capacity of soil nutrients and reduction in soil fertility (Mpepereki *et al., (2000).* Rainfall distribution and amounts also played a vital role in grain yield across sites. In Kambare the yields were generally lower, than Nyabeda and Ekitale because of mid-season drought. At Kambare rainfall distribution was poor especially during critical periods i.e. 50% flowering and 50% podding .The middle season drought led to flower abortion and poor seed set. Okoth *et al.,* (in press) reported that most legume yield loss in western Kenya occur due to moisture stress at critical stages including flowering, podding and pod filling

b) Genotype

Mean comparisons indicated that Sc Squire out-yielded TGx 1987-62F by 30.8%, then by 18% for TGx 1740-2F and 34.1% for EAI 3600 respectively. The good performance of Sc Squire might be attributed to its high yield potential which is correlated to its high weight of 100 seeds and number of pods per plant compared to TGx 1740-2F, TGx 1987-62F and EAI 3600. Sc Squire also seems to have high nutrient use efficiency and adaptability to biotic and abiotic stresses. Sc Squire has been identified as one of the best soybean varieties in evaluations carried in different agronomic trials (Baijukya *et al.*, 2013).

c) Fertilizer

Inoculation of soybean without fertilizer application generally recorded low yields across sites although with slight improvement in Nyabeda, which is attributed to high nutrient availability Similarly, Baijukya et al., (2013), reported that in some cases inoculation alone proved unnecessary or phosphorus addition alone was insufficient to realize good soybean yields. Response of inorganic fertilizer alone was limited. However in treatments with inorganic and organic fertilizers the yields were better than single treatments of manure, scum, Sympal or inoculation alone. This is in agreement with research reported by Mandal *et al.,* (2009) who found out that, the beneficial effects of integrated use of fertilizer significantly increase yield in soybean grain yield with application of inorganic fertilizer and farm yard manure. This then clearly indicate that soils in western Kenya are depleted and require an integrated approach for high yields and sustainable crop production. The combined use of inorganic fertilizers (macro-nutrients, secondary nutrients and micro-nutrients), organic manure and scum significantly increased grain yields due to supply of multiple nutrients, improvement in moisture availability and increase in soil pH providing favourable conditions for soybean production (De Ridder and van Keulen, 1990; Mpepereki et al., 2000).

Sympal plus scum gave the highest yields in Kambare, this could be attributed to the fact scum contain high amounts of potassium as compared to manure and as seen from the soil results, Kambare was deficient in K. Therefore additional K from Scum may have promoted metabolism for enzymatic activities, regulated soybean water use as it controls the opening and closing of stomata and played vital role in physiological and biochemical process such photosynthesis and seed formation (Uchida *et al., 2000*)

d) Interactions of site, genotype and fertilizer

The low soybean grain yields in inoculation alone and fertilized treatments in Kambare were due to poor soil fertility status of the soil with low soil organic carbon and available P besides erratic and unreliable rainfall (Vandamme *et al.,* 2013*)*. Baijukya *et al.,* (2013) research results in Western Kenya showed that performance of soybeans varies widely depending on site-specific soil and climatic conditions. The limited response to fertilizer in Kambare could also be associated with deficiencies of essential micro-nutrients such as B and Co (Giller, 2001). The infertile sand soils in Ekitale are associated with complex constraints to soybean productivity, implying that single technologies are often ineffective to significantly enhance crop productivity (Zingore *et al.,* 2011).

The soils in the three study sites were a representative of majority of soils in Western region, which are severely deficient of available P, which is below critical levels of 15 mg kg^{-1} soil (Okalebo *et al.,* 2003). Therefore grain yield response to P application was highly pronounced in all sites. The grain yield across the three sites decreased in the order Sympal plus manure>Sympal plus Scum > Sympal >manure > Scum>Inoculation alone.

e) Benefit cost ratio of fertilizer types

The Benefit cost ratio indicated that the profitable managements were Sympal plus manure and Sympal plus scum. Sympal alone was not significant to manure and scum alone. The application of farm yard manure alone improved the total biomass and soybean grain yield only over the inoculation but could not significantly yield over Sympal plus manure or Sympal plus scum. This is perhaps because the farmyard manure and scum released nutrient very slowly and the released nutrients in the year of application may not be adequate to the crop nutrient demand. The findings are agreement with the result conducted by (Woomer, 2007) whose findings indicated that integration of farm yard manure with inorganic fertilizers boosted crop yield.

4.6 CONCLUSIONS AND RECOMMENDATIONS

4.6.1 Conclusions

1. Integrating fertilizers particularly on the infertile soils leads to high and sustainable soybean yields.

2. Application of manure/ scum in combination with Sympal fertilizer gives the highest yield response for the study sites in Western Kenya.

3. Growing improved and adaptable soybean varieties with inorganic and organic fertilizers enhances biomass and grain yield.

4.6.2 Recommendation

1. Small scale farmers in Western Kenya are advised to plant Sc Squire and TGx 1740-2F using Sympal, inoculants and organic manure as the two genotype are the most adaptable and high yielding across the three sites.

2. Alternatively in depleted sites, farmers are advised to plant high Biological Nitrogen fixing genotypes such as TGx 1987-62F, TGx 1987-6F and TGx 1987-10F especially in Ekitale. These will replenish the nitrogen levels as seen in the amounts of Nitrogen fixed.

3. Sugar cane waste (Scum) is equally a good source of organic matter as well as farm yard manure. It has adequate zinc and potassium content. The potassium and zinc present in scum are important in enzyme activation thus promotes metabolism.

CHAPTER FIVE

OVERALL CONCLUSIONS AND RECOMMENDATION

5.1 OVERALL CONCLUSIONS

1. Planting soybean at an inter-row spacing of 45 cm leads to high grain and biomass yields.

2. The genotype Sc Squire is adaptable and gives high grain yields while TGx 1987-62F produces high biomass yield and amount of nitrogen fixed.

3. Soybean yield can be maximized when the interactions of inorganic fertilizer, organic manure/scum, improved germplasm, environment and agronomic management are adopted relative to farmers practice.

4. The amount of nitrogen fixed highly correlates to maturity period of soybean genotypes and above ground biomass. Long maturing varieties fixes more nitrogen than short maturing varieties.

5.2 OVERALL RECOMMENDATIONS

a) Farmers

1. To increase soybean productivity, small scale farmers need to adopt an inter-row spacing of 45 cm.
2. Small scale farmers in Western Kenya are advised to plant Sc Squire for higher grain yield as it is adaptable across the major agro-ecological zones.

3. Alternatively in depleted sites, farmers are advised to plant high Biological Nitrogen fixing genotypes such as TGx 1987-62F, TGx 1987-6F and TGx 1987-10F to intensify production and system productivity.
4. Matching soybean genotypes with agro-ecological zone will increase Biological Fixation, grain yield and thus productivity of smallholder farms.
5. Small scale farmers can optimize soybean yield by combining legume mineral fertilizer with well decomposed organic matter such as farm yard manure or scum depending on their availability in their respective areas.

b) Further Research

1. Sugar cane waste (Scum) is equally a good source of organic matter as well as decomposed farm yard manure. More research is needed to ascertain the mechanistic reactions that are involved in influencing soybean performance.

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APPENDICES

Appendix I: Analysis of variance on effect of season, site, spacing and genotype on biomass yield in kg ha^{-1}.

Source of variation	df	Mean Square	F Value	Pr > F
Spacing	1	64373621.7	67.8	<.0001
Genotype	10	5388309.1	5.7	<.0001
Site	2	31689598.2	33.4	<.0001
Season	1	101561562.3	106.9	<.0001
Replicate	2	857900.9	0.9	0.4065
Season x site	2	16801037.7	17.7	<.0001
Season x Spacing	1	108409.4	0.1	0.7357
Season x Genotype	10	3516141.5	3.7	0.0001
Site x Spacing	2	3288142.3	3.5	0.0328
Site x Genotype	20	2440085.6	2.5	0.0004
Spacing x Genotype	10	354553.8	0.4	0.9574
Season x site x Spacing x Genotype	72	1203240.5	1.3	0.0936
Error	262	949661.7		
Total	395			
CV%		27		

Appendix II: Analysis of variance on effect of season, site spacing and genotype on grain yield kg ha^{-1}.

Source of variation	df	Mean Square	F Value	Pr > F
Spacing	1	16516916.9	50.2	<.0001
Genotype	10	508825.2	1.6	0.1231
Site	2	90031313.8	273.6	<.0001
Season	1	50425675.3	153.3	<.0001
Replicate	2	235500.2	0.7	0.4898
Season x site	2	10006001.3	30.4	<.0001
Season x Spacing	1	164379.6	0.5	0.4803
Season x Genotype	10	484310.7	1.5	0.1498
Site x Spacing	2	327048.8	1.0	0.3715
Site x Genotype	20	771812.2	2.4	0.0012
Spacing x Genotype	10	364774.7	1.1	0.3557
Season x site x Spacing x Genotype	72	463638.9	1.4	0.0279
Error	262	329025.3		
Total	395			
CV%		30		

Appendix III: Analysis of variance on effect of season, site, spacing and genotype on nodule mean score ha^{-1}.

Source of variation	df	Mean Square	F Value	Pr > F
Spacing	1	3.6	2.9	0.0893
Genotype	10	1.6	1.3	0.02505
Site	2	35.2	27.8	<.0001
Season	1	80.1	63.3	<.0001
Replicate	2	3.5	2.8	0.0434
Season x site	2	0.27	0.2	0.8067
Season x Spacing	1	1.15	0.9	0.3409
Season x Genotype	10	2.2	1.8	0.0676
Site x Spacing	2	0.1	0.1	0.9913
Site x Genotype	20	1.3	1.0	0.4196
Spacing x Genotype	10	0.7	0.6	0.8442
Season x site x Spacing x Genotype	72	1.7	1.4	0.0355
Error	262	1.2		
Total	395			
CV%		29		

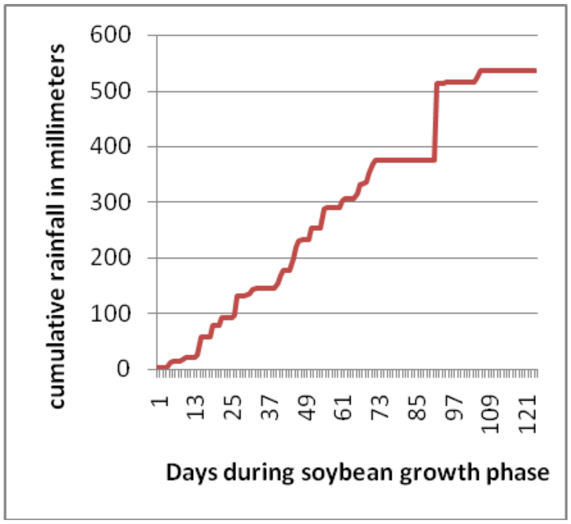
Appendix IV: Analysis of variance on effect of season, site, spacing and genotype on pods per plant.

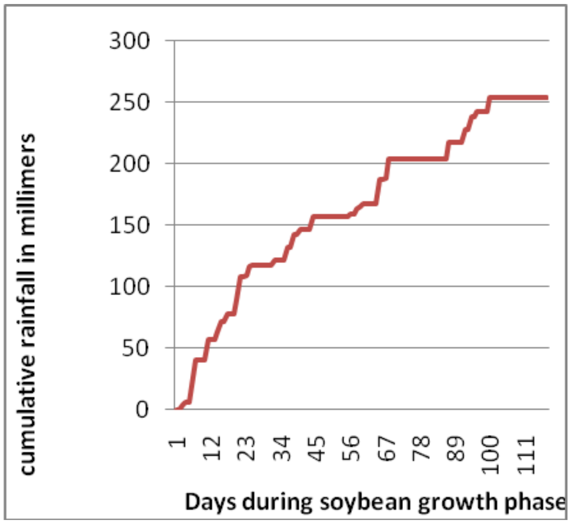
Source of variation	df	Mean Square	F Value	Pr > F
Spacing	1	104.98	0.8	0.3814
Genotype	10	308.65	2.3	0.0151
Site	2	8757.93	64.1	<.0001
Season	1	1494.37	10.9	0.0011
Replicate	2	453.28	3.3	0.0377
Season x site	2	9559.55	70.0	<.0001
Season x Spacing	1	349.94	2.6	0.1106
Season x Genotype	10	249.06	1.8	0.0567
Site x Spacing	2	706.67	5.2	0.0063
Site x Genotype	20	356.18	2.6	0.0003
Spacing x Genotype	10	130.01	0.9	0.486
Season x site x Spacing x Genotype	72	174.42	1.3	0.0864
Error	262	38.48		
Total	395			
CV%		20		

Appendix V: Analysis of variance on effect of season, site, spacing and genotype on Plant height

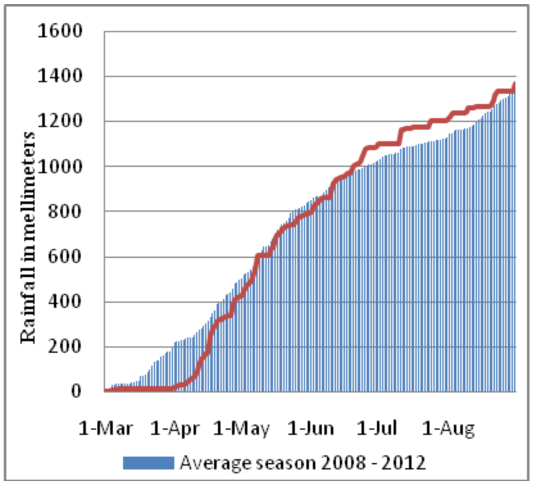
Source	df	Mean Square	F Value	Pr > F
Season	1	732.5	7.8	0.0
Site	2	7397.4	78.9	<0.0001
Rep	2	0.0	0.0	1.0
Sp	1	163.9	1.8	0.2
Gen	10	209.3	2.2	0.0
Season x site	2	1396.5	14.9	<0.0001
Season x Spacing	1	25.1	0.3	0.6
Season x Genotype	10	234.0	2.5	0.0
Site x Spacing	2	95.4	1.0	0.4
Site x Genotype	20	312.7	3.3	<0.0001
Spacing x Genotype	10	124.2	1.3	0.2
Season x site x Spacing x Genotype	72	116.6	1.2	0.1
Error	262	93.7		
Total	395			
CV%		20		

Appendix VI: Influence of Rainfall on soybean performance long rain and short 2012-Kambare.

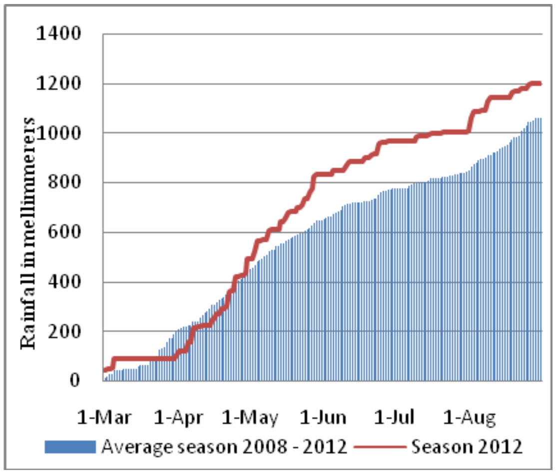




Appendix VII: Influence of Rainfall on soybean performance long rain & short 2012-at Nyabeda and Ekitale in Siaya and Bungoma counties respectively.



Cumulative daily rainfall, 2012 long rains season as recorded at Nyabeda site in relation to average daily rainfall over 4 years (2007/08-2011/12). Source: Siaya County Agriculture Office.



Cumulative daily rainfall during 2012 long rains season as recorded at Ekitale site in relation to average daily rainfall over 4 years (2007/08 – 2011/12). Source: Bungoma County Agriculture Office.

Appendix VIII: Analysis of variance for 100 seed weight (g/100 seed) for eleven soybean genotypes planted in long rain 2012 at two spacing levels evaluated in three agro-ecological zones of Western Kenya.

		Mean squares						
Source of variation	df	BM	YLD	N-Fixed	NS	PH	PL	SW
site	2	28384177*	77151687*	10361*	19*	5866*	15306*	122*
Replicate	2	1440465*	309968	1467*	2	123	9	3
Spacing	1	29665099*	663741*	33775*	0.32*	28*	428*	6
Genotypes	10	5825207*	760916*	6339*	4.4*	861*	812*	49*
Site x Spacing	2	824324*	447586	578	0.4	35*	118*	19
Site x Genotypes	20	1593530*	1639058*	825*	2.7*	174*	301*	21*
Spacing x Genotypes	10	453386	403873	191	0.56	45*	59	9
Site x Spacing x Genotypes	20	403112	444668	439*	0.45	57	54	4
pooled Error	130	259034	266439	269	0.7	48	44	7

*Indicates significance at $P \leq 0.05$ level.

Appendix IX Analysis of variance for eleven soybean varieties planted in short rain 2012 at two spacing levels evaluated in three agro-ecological zones of Western Kenya.

		Mean squares				
Source of variance	df	BM	Yld	NMS	PHT	SWT
Site	2	21814611*	21592113*	11*	1700.25*	14.15
Replicate	2	5252437*	1213096*	0.0004	446.60*	11.18
Spacing	1	26309440*	9548015*	0.21	65.13	3.04
Variety	10	7907888*	442337*	14*	425.42*	41.80*
Site x Spacing	2	1312718	1126606*	1.3*	160.99	6.94
Site x Variety	20	3525751*	636737*	0.81	164.14*	5.44
Spacing x Variety	10	443822	220377	0.66	108.92	14.78*
Site x Spacing x Variety	20	753953	410922*	1.5	66.45	5.33
Pooled error	130	787073	216052	0.76	94.62	7.38

*Indicates significance at $P \leq 0.05$ level.

BM, Yld , N Fixed, NS, PHT, PL and , SW indicate Biomass yield (kg ha^{-1}), Grain yield (kg ha^{-1}) Nitrogen fixed (kg ha^{-1}), Nodule Mean scores(scale of 1-5), Plant Height (cm), Pod Load and 100 seed weight (g/ 100 seed) production per hectare respectively.

Appendix X: Analysis of variance on effect of Site, fertilizer and genotype on biomass yield kg ha^{-1}.

Source	df	Mean Squares	F-value	P>F
Site	2	25453897.8	27.3	<.0001
Replicate	2	2464085.9	2.6	0.0747
Genotype	3	41099109.6	44.1	<.0001
Fertilizer	5	13975162.1	14.9	<.0001
Site x Genotype	6	6081418.2	6.5	<.0001
Site x Fertilizer	10	337447.9	0.4	0.9609
Genotype x Fertilizer	15	697549.3	0.7	0.7320
Site x Genotype x Fertilizer	30	375760.2	0.4	0.9976
Error	142	902401.5		
Total	216			
CV%		21.3		

Appendix XI: Analysis of variance on effect of Site, fertilizer and genotype on grain yield kg ha^{-1}.

Source of variation	DF	Mean Squares	F value	P >F
Site	2	6775618.3	8.5	0.0003
Replicate	2	1230327.6	1.5	0.2185
Genotype	3	4970681.6	6.2	0.0005
Fertilizer	5	9089803.9	11.4	<.0001
Site*Genotype	6	1303679.3	1.6	0.1433
Site*Fertilizer	10	454146.9	0.6	0.8382
Genotype*Fertilizer	15	1158821.2	1.5	0.1331
Site*Genotype*Fertilizer	30	795655.4	0.9	0.4834
Error	142	800273.2		
Total	216			
CV%		23.6		