

**EFFECTS OF MAIZE (*Zea mays* L.) – SOYBEAN (*Glycine max* (L.) Merrill)  
INTERCROPPING PATTERNS ON YIELDS AND SOIL PROPERTIES IN TWO  
CONTRASTING SITES OF EMBU AND MERU COUNTIES, KENYA**

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degree of Master of Science (Integrated Soil Fertility Management) in the School of  
Agriculture and Enterprise Development of Kenyatta University**

**October, 2014**

**DECLARATION**

This thesis is my original work and has not been presented for a degree in any other university.

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## **DEDICATION**

In memory of my late father Mateus Materusse Matusso.

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## Abbreviations and Acronyms

ANOVA	Analysis Of Variance
ASL	Above Sea Level
CAN	Calcium Ammonium Nitrate
LAI	Leaf Area Index
LER	Land Equivalent Ratio
LM 3	Lower Midland
UM 3	Upper Midland
PAR	Photosynthetically Active Radiation
TSP	Triple Super Phosphate
US\$	United State dollar
WAP	Weeks After Planting
MBILI-MBILI	Two by two
MAI	Monetary Advantage Index
BCR	Benefit Cost Ratio
SOM	Soil Organic Matter
SSA	Sub-Saharan Africa
ISFM	Integrated Soil Fertility Management
RUE	Radiation Use Efficiency
AEZ	Agro-Ecological Zone
RCBD	Randomized Complete Bock Design
KCL	Potassium Chloride
SOC	Soil Organic Carbon
LR	Long Rain
SR	Short Rain
PAR	Photosynthetic Active Radiation
HIV/AIDS	Human Immunodeficiency Virus/Acquired Immunodeficiency Syndrome
FURP	Fertilizer Use Recommendation Project
BNF	Biological Nitrogen Fixation
HI	Harvest Index
LER	Leaf Equivalent Ratio
WAP	Weeks After Planting
ATC	Agricultural Training Centre

## ABSTRACT

In the central highlands of Kenya, the adoption of integrated soil fertility management technologies such as maize-soybean intercropping system is being promoted as one of the options to address low crop productivity and soil fertility depletion among the farmers of this region. This study aimed to: (i) determine the effects of maize-soybean intercropping patterns on yields, N uptake, and soil properties; (ii) determine the effects of different maize-soybean intercropping patterns on light interception and leaf area index; (iii) quantify the land equivalent ratio of various maize soybean intercropping patterns. The study areas were Embu – Agriculture Training Centre in Embu district (Embu County) and Kamujine in Tigania East district (Meru County). The main treatments were four maize – soybean intercropping patterns (conventional-1maize:1soya; MBILI-2maize:2soya; 2maize:4soya; 2maize:6soya) and two sole crops of maize and soybean, respectively. The experimental design was a randomized complete block design with four replications, and plot size of 7.0 m by 4.5 m. The study was carried out in two seasons (long rain 2012 and short rain 2012). The soil was sampled at 15 cm depth. All biophysical data were subjected to Analysis of Variance and means separated using Least Significant Difference of mean at 95% ( $p \leq 0.05$ ). The results showed that, the maize-soybean intercropping patterns had significant effect on maize stover and grain yields during both seasons at Embu site. During the long rain 2012, the soybean yields were reduced by 60 and 81% due to the intercropping with maize, at Embu and Kamujine, respectively; whereas during the 2012 SR, the yields were reduced by 52 and 78% as effect of intercropping with maize at Embu and Kamujine sites, respectively. In general, the soil nitrate-N was reduced due to intercropping patterns. The soil organic matter was significantly ( $p \leq 0.05$ ) affected by the treatments at Kamujine site. The intercropping patterns affected significantly ( $p \leq 0.0001$ ) the photosynthetically active radiation intercepted and the leaf area index at both sites. During both seasons at both localities, the total land equivalent ratio values greater than unit. From the results of this study, the use of MBILI maize-soybean intercropping pattern can be recommended to the farmers of central highlands of Kenya because of more efficient resources use and higher yields.

## CHAPTER ONE: INTRODUCTION

### 1.1. Background

Smallholder farmers are the most important food security stakeholders in Sub-Saharan Africa (FAO, 2011), who mainly practice subsistence agriculture characterized by low crop productivity due to the soil nutrient depletion (Mugwe *et al.*, 2007). The majority of these farmers lack financial resources to purchase sufficient amount of mineral fertilizers to replace soil nutrients removed through harvested crop products (Jama *et al.*, 2000), crop residues, and through loss by runoff, leaching and as gases (Bekunda *et al.*, 1997). Consequently, poor soil fertility has emerged as one of the greatest biophysical constraint to increasing agricultural productivity hence threatening food security in this region (Mugwe *et al.*, 2009; Mugendi, 1997). Therefore, it is necessary to adopt improved and sustainable technologies in order to guarantee improvements in food productivity and thereby food security (Landers, 2007; Gruhn *et al.*, 2000). Such technologies include the use of integrated soil fertility management practices (ISFM) such as improved intercropping systems of cereals with grain legumes as one of its main components (Mucheru-Muna *et al.*, 2010; Sanginga and Woomer, 2009).

Cereal – grain legume intercropping has potential to address the soil nutrient depletion on smallholder farms (Sanginga and Woomer, 2009). The legumes play an important role in nitrogen fixation (Peoples and Craswell, 1992), and are important source of nutrition for both humans and livestock (Nandwa *et al.*, 2011). In the central highlands of Kenya, cereal – legume intercropping is already being widely practiced by the smallholder farmers where the most predominant are maize-common bean, maize-cowpea as well as maize-pigeonpea

(Jaetzold *et al.*, 2006). According to Sanginga and Woomer (2009) intercropping cereal and grain legume crops helps maintain and improve soil fertility, because crops such as cowpea, mung bean, soybean and groundnuts accumulate from 80 to 350kg nitrogen (N) ha<sup>-1</sup> (Peoples and Craswell, 1992). For instance, soybean can positively contribute to soil health, human nutrition and health, livestock nutrition, household income, poverty reduction and overall improvements in livelihoods and ecosystem services, than many others leguminous grain crops (Rakasi, 2011; Raji, 2007). Moreover, intercropping maize with soybean was reported to be profitable in terms of land utilization, in western Kenya (Kipkemoi *et al.*, 2002).

Although soybean is relatively new crop for smallholder farmers in the central highlands of Kenya, its cultivation is expected to gain popularity in the near future due to the increasing demand on food to their families and fodder for their livestock (Mugendi *et al.*, 2010). It is mostly being intercropped with maize using the conventional 1:1 intercropping system, recommended by the Kenyan Ministry of Agriculture. However, field trials conducted in western Kenya showed improved intercropping system of two rows of cereal followed by two rows of leguminous crop, known as Mbili in Kiswahili, to be more profitable than the conventional intercropping system, due to its efficiency in use of resources, particularly land, nutrients, light and water (Woomer *et al.*, 2004).

Nevertheless, intercropping of cereal-legume may lead to reduction in yield of the legume component because of the adverse competitive effects (Willey *et al.*, 1983). Often, the cereal component with relatively higher growth rate, height advantage and a more extensive rooting system is favored in the competition with the associated legume crop. Thus, the greater yield loss of the minor crop is mainly due to reduced photosynthetically active radiation (PAR)

reaching the lower parts of the intercrop canopy, occupied by the minor legume (Liu *et al.*, 2010). The intensity and the quality of solar radiation intercepted by the canopy are important determinants of yield components and therefore yield of soybean since it is sensitive to shading (Liu *et al.*, 2010; Purcell, 2000). Light levels during the late flowering to mid pod formation stages of growth have been found to be more critical than during vegetative and late reproductive periods (Liu *et al.*, 2010; Schou *et al.*, 1978).

Therefore, any interventions that lead to increased amount of PAR interception by the minor crop have potential to increase the yield of the minor crop and increase productivity of the intercropping system (Mashingaidze, 2004). For instance, Woomeer and Tungani (2003) reported that MBILI system had resulted in 20 per cent more light penetration to the minor legume component when compared to the conventional intercropping pattern. Improved intercropping systems are part of ISFM technologies (Mucheru-Muna *et al.*, 2010; Sanginga and Woomeer, 2009) and in central highlands of Kenya the information is scarce in regard to optimum cropping pattern of maize-soybean.

## **1.2. Statement of the Problem**

In the central highlands of Kenya, low soil fertility is one of the major constraints causing decreased maize production and other staple food and income generating crops, leading to hunger and poverty, where over 90 per cent of farmers are resource poor smallholders. The situation is worsened by continued mining of nutrients, poor nutrient conservation practices, increasing population growth and land scarcity. The adoption of maize-soybean intercropping system is being promoted as one of the options for increasing crop production by the farmers. Available evidence indicate that improved intercropping systems with integration of legume

as part of ISFM technologies have large scope for increasing crop yields and householder income. However, small scale farmers of this region lack information on optimum cropping pattern. The purpose of this study was therefore to evaluate the effect of maize-soybean intercropping pattern on maize and soybean yields and soil properties.

### **1.3. Justification of the Study**

The intercrop of maize and soybean is an alternative system for small-scale farmers to improve income and food production per unit of area (Mukhala *et al.*, 1999), and lessen the risk of total crop failure due to environmental limitations (Prasad and Brook, 2005). Woomer and Tungani (2003), after several years of on-farm trials found that MBILI system resulted in an increase of 422 kg maize, 443 kg pulses and KSh 23300 net returns (about US \$300) per hectare over conventional intercropping, in Western Kenya. Also, in recognition of the economic and nutritional importance of soybean as grain legume and maize as important cereal crop, smallholder farmers of many countries prefer the cultivation of soybean and maize in mixture as against sole cropping system (Muoneke *et al.*, 2007). Soybean possesses a very high nutritional value; it contains 20 percent oil, 40 per cent high quality protein, as against 7 percent rice, 12 per cent wheat, 10 per cent maize, 20 to 25 percent other pulses (Raji, 2007). Its protein is rich in the valuable amino acid lysine (5 percent) in which most cereals are deficient. It also contains a good amount of minerals, salts, and vitamins (Singh, 1983).

## **1.4. Research questions**

The following research questions guided this study;

- i. Which is the maize – soybean intercropping pattern that gives maximum economic yields, efficient N uptake and improved soil properties?
- ii. Which is the maize – soybean intercropping pattern that uses light more efficiently and gives the highest leaf area index in each of the contrasting sites?
- iii. Which maize-soybean intercropping pattern gives the highest Land Equivalent Ratio (LER) in each of the contrasting sites?

## **1.5. Objectives**

### **1.5.1. General objective**

To evaluate the effect of maize-soybean intercropping patterns on yields, soil properties, and performance in terms of land equivalent ratio.

### **1.5.2. Specific objectives**

The specific objectives of the study are to:

1. Determine the effects of different maize–soybean intercropping patterns on yields, N uptake and soil properties.
2. Determine the effects of different maize–soybean intercropping patterns on light interception and leaf area index in two contrasting sites.
3. Quantify the land equivalent ratio of different maize–soybean intercropping patterns in two contrasting sites.

## **1.6. Hypotheses**

The study was guided by the following research hypotheses:

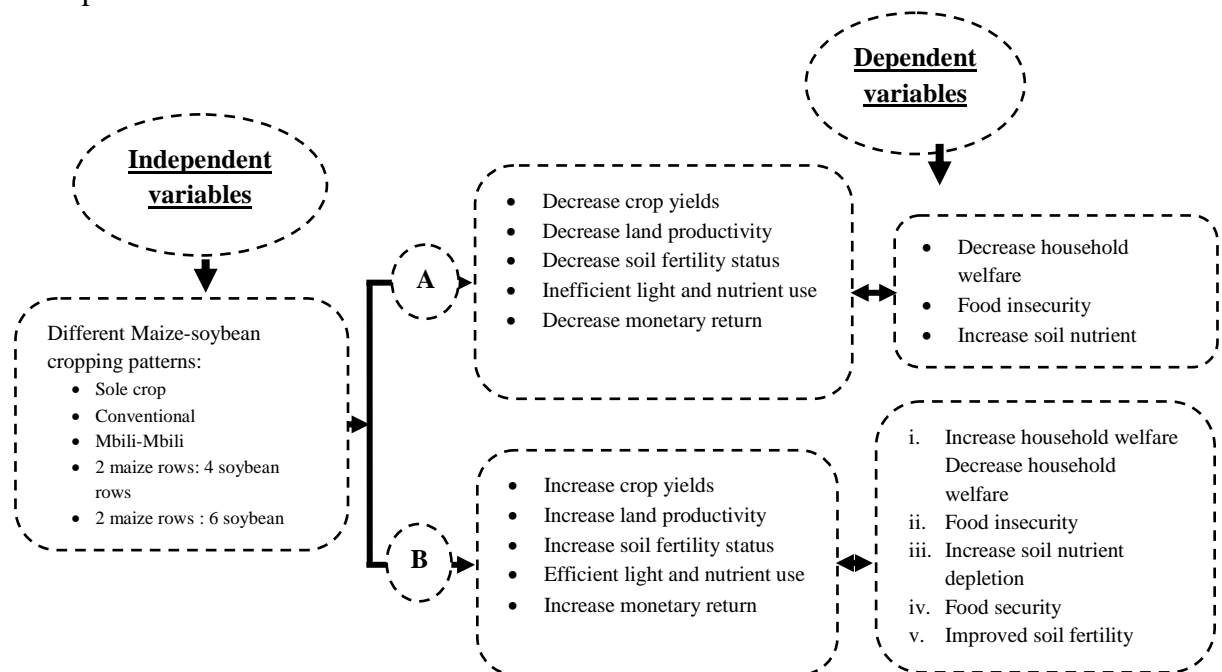
1. The MBILI intercropping pattern gives significantly higher yields than conventional intercropping pattern.
2. The 2:6 intercropping pattern of maize-soybean is more efficient in light use and gives higher leaf area index than conventional (1M:1S) intercropping pattern.
3. The 2M:6S intercropping pattern of maize-soybean significantly improves soil properties more than the conventional intercropping pattern.
4. Nitrogen uptake and land equivalent ratio is significantly higher in 2M:4S intercropping pattern than the MBILI (2M:2S) intercropping pattern.

## **1.7. Significance of the study**

This study will contribute to providing useful information on optimum maize-soybean intercropping pattern which should guide smallholder farmers on the management of this new crop in the region. Further, the study will add value on the ISFM technologies that are being promoted in Africa. Lastly, the study will bring useful information which can guide extension services on better management practices of maize-soybean cropping system to be recommended to the smallholder farmers of the central highlands of Kenya.

## 1.8. Conceptual framework

The maize-soybean intercropping system is being promoted for smallholder farmers in the central highlands of Kenya, using the conventional practice (scenario A in Figure 1.1) that has been proven not efficient by several researchers (Mucheru-Muna *et al.*, 2010), leading to an decrease in household welfare, food insecurity and increase soil nutrient depletion (Sanginga and Woomer, 2009). The use of optimum cropping pattern plus other ISFM practices (scenario B in Figure 1.1) has potential for improving light and nutrient use resulting in increased yields hence contributing to household welfare and food security (Mucheru-Muna *et al.*, 2010; Woomer and Tungani, 2003). The dependent variables in this study are the different cropping patterns while the dependent variable comprises yield and soil components.



**Figure 1.1:** Conceptual diagram showing linkages among variables in the study.

### **1.9. Definition of terms**

*Soil* is a three-dimensional, dynamic, natural body occurring on the surface of the earth that is a medium for plant growth and whose characteristics have resulted from the integrated effect of climate and living matter acting upon parental material, as modified by relief, over periods of time (Gupta, 2011).

*Soil fertility* is the inherent capacity of the soil to provide essential chemical elements for plant growth. A fertile soil is not necessarily a productive soil because productivity emphasizes the capacity of soil to produce crops and be expressed in terms of yields (Gupta, 2011).

*Biological Nitrogen Fixation (BNF)* is the assimilation of free nitrogen from the air by soil organisms, eventually making the nitrogen available to plants (Foth, 1990).

*Soil nutrient depletion* is the process by which the soil loses its nutrients and is not replenished in the same amounts. There are three basic processes through which nutrients are depleted in soil, they are: (i) crop removal, (ii) leaching losses and (iii) loss in gaseous form (Gupta, 2011).

*Farming system* is an agricultural enterprise, activity or business consisting of a combination of inputs (e.g. crop varieties, land, farm practice, etc.) whether in numbers, amounts, sequences and timing used to satisfy specific objectives of the farmer under a specified environmental setting (Silwana, 2000).

*Intercropping* is the cultivation of two or more crops simultaneously on the same piece of land in competition among them (Willey *et al.*, 1983).

*Leaf Area Index (LAI)* was defined by Watson (1947) as the total one-sided area of leaf tissue per unit ground surface area.

*Photosynthetically Active Radiation (PAR)* is the amount of light available for photosynthesis, which is light in the 400 to 700 nanometer wavelength range. PAR changes seasonally and varies depending on the latitude and time of day.

*Land equivalent ratio (LER)*, defined as the total land area required under monocropping to give the yields that are obtained under intercropping mixture, is normally used for analysis of possible advantages of intercropping (Willey *et al.*, 1980).

## CHAPTER TWO: LITERATURE REVIEW

### 2.1. General overview

Soil fertility depletion in smallholder farms is the fundamental biophysical root cause for declining per capita food production in Sub-Saharan Africa (Sanchez *et al.*, 1997). An average of 660 kg N ha<sup>-1</sup>, 75 kg P ha<sup>-1</sup>, and 450 kg K ha<sup>-1</sup> has been lost during the last 30 years from about 200 million ha of cultivated land in 37 African countries (Braun *et al.*, 1997). The major reasons for the nutrient depletion process are: the breakdown of traditional practices and the low priority given to the rural sector (Sanchez *et al.*, 1997). Increasing pressures on agricultural land have resulted in much higher nutrient outflows and the subsequent breakdown of many traditional soil fertility maintenance strategies, such as fallowing land, intercropping cereals with legume crops, mixed crop-livestock farming, and opening new lands (Sanchez *et al.*, 1997). Thus, continued population pressure has reduced farm sizes to the point where farms can only provide adequate living for their families if the land is farmed very intensively and if there is off-farm income (Sanchez *et al.*, 1997). Lack of an effective fertilizer supply and distribution system has resulted in reduced crop productivity and food insecurity as the main consequences of the soil fertility depletion in Africa (Palm *et al.*, 1997).

Because of that, soils have come under intensive cultivation only recently as human populations have increased, often leading to greater net losses of Soil Organic Matter due to reduced organic inputs, the faster rate of Soil Organic Matter turnover under cultivation, and increased losses from soil erosion. As a result Soil Organic Matter and the supply of N have

declined as natural fallows shortened or vanished, and the short- to medium-term capital store of N has effectively been used up. For the replenishment of N there are three principal sources, biological N<sub>2</sub> fixation, organic resources recycled within the cropping field or concentrated from a larger area, and mineral N fertilizers. Any proposed interventions must generate cropping systems that are productive, sustainable, and economically attractive for smallholder subsistence farmers (Buresh *et al.*, 1997). In the most densely populated areas, such as central highlands of Kenya, land scarcity prohibits the devotion of land to restoration of soil fertility. In this region, the use of mineral fertilizers is less than 20 kg N ha<sup>-1</sup> and 10 kg P ha<sup>-1</sup> (Muriithi *et al.*, 1994), due to their unavailability and high prices (Jama *et al.*, 2000). Furthermore, the use of manure is also limited due to its low availability in required amounts to sustain crop production when used exclusively (Kihanda, 2004). Thereby, integrated nutrient management options need to be sought and the efficient use of these inputs also need to be properly addressed for sustainable soil fertility management on smallholder farms (Mucheru-Muna *et al.*, 2008).

## **2.2. Role of legume in integrated soil fertility management**

Poor soil fertility and nutrient depletion continue to represent huge obstacles to securing needed harvest in SSA (Sanginga and Woomer, 2009). Integrated soil fertility management (ISFM) technologies, which combine various existing soil fertility management techniques, and where improved leguminous crops play multiple roles in soil fertility improvements, food and fodder provision, are considered of particular importance to overcome this situation in most smallholder farming systems of the region (Nandwa *et al.*, 2011; Mugendi *et al.*, 2011).

Several studies have been carried out in recent years and proven the beneficial effects of legumes on soil fertility improvements (Sanginga and Woomer, 2009). For instance, in Kenya Mugwe *et al.* (2009) found that herbaceous legumes improved soil fertility properties, especially cations (Ca, K and Mg). In Tanzania Tuaeli and Friesen (2003) reported that the soil fertility was improved after incorporation of *Dolichos* and *Mucuna* to the soil. In Uganda, Fishler and Wortmann (1999) reported that maize grown following crotalaria produced significantly higher yield than the one without leguminous cover crop, and they attributed the positive effect to high nitrogen and phosphorus benefits and nutrient pumping ability of legumes from deeper horizons.

In addition to the reports about the ability of herbaceous legumes to increase soil fertility properties, there are also studies showing the huge contribution of nitrogen-fixing trees to soil fertility improvement. For example, in Kenya Rutunga *et al.* (1999) showed that maize yield was increased by up to 100 percent after six-months of fallow period with *Tephrosia vogelii*, which accumulated 154 kg N ha<sup>-1</sup>. However, grain legumes are more acceptable to smallholder farmers than herbaceous legumes or nitrogen-fixing trees, which occupy land meant for food production (Peoples and Craswell, 1992), indicating some tradeoffs that need to be accommodated (Odendo *et al.*, 2011). For instance, Oyewole *et al.* (2000) found that smallholder farmers preferred cowpea-maize to mucuna-maize double cropping to keep grain producing cowpea in the system although the benefits of cowpea was less than that of mucuna.

### **2.3. Cereal-legumes intercropping systems**

In intercropping system there is one main crop cultivated with one or more added crops where the main crop is of primary importance due to economic or food production reasons (Brintha and Seran, 2009). In the SSA region, cereal and grain legumes intercrop is the most practiced by smallholder farmers (Odendo *et al.*, 2011; Sanginga and Woomer, 2009). The major reason why these farmers intercrop cereals and grain legumes is because they are particularly important human food as they are rich in protein and are sometimes sold for cash income (Odendo *et al.*, 2011). In addition, intercrops give them the stability of the yields over several seasons (Ofori and Stern, 1987; Steiner, 1982), when one crop fails, the other might still give a reasonable yield (Prasad and Brook, 2005; Beets, 1982; Steiner, 1982). Furthermore, grain legumes help maintain and improve soil fertility due to their ability to biologically fix atmospheric nitrogen (Sanginga and Woomer, 2009; Jarenyama *et al.*, 2000; Ofori and Stern, 1987; Horwith, 1985; Willey *et al.*, 1983).

### **2.4. Benefits of intercropping**

The intercropping of maize and legumes is widespread among smallholder farmers due to the ability of the legume to cope with soil erosion and with declining levels of soil fertility. The principal reasons for smallholder farmers to intercrop are flexibility, profit maximization, risk minimization against total crop failure, soil conservation and improvement of soil fertility, weed control and balanced nutrition (Shetty *et al.*, 1995). Other advantages of intercropping include potential for increased profitability and low fixed costs for land as a result of a second crop in the same field (Thobatsi, 2009). Furthermore, intercrop can give higher yield than sole crop yields, greater yield stability, more efficient use of nutrients, better weed

control, provision of insurance against total crop failure, improved quality by variety, also maize as a sole crop requires a larger area to produce the same yield as maize in an intercropping system (Viljoen and Allemann, 1996). For example, regularly intercropped pigeonpea or cowpea can help to maintain maize yield to some extent when maize is grown without mineral fertilizer on sandy soil in Sub-humid zones of Zimbabwe (Waddington *et al.*, 2007). Intercropping maize with cowpea has been reported to increase light penetration in the intercrops, reduce water evaporation, and improve conservation of the soil moisture compared with maize alone (Ghanbari *et al.*, 2010).

On the other hand, it is often believed that traditional intercropping systems are better in weeds, pests and diseases control compared to the monocrops, but it must be known that intercropping is an almost infinitely variable, and often complex, system in which adverse effects can also occur. Weed growth basically depends on the competitive ability of the whole crop community, which in intercropping largely depends on the competitive abilities of the component crops and their respective plant populations (Willey *et al.*, 1983). For instance, intercropping of cereals and cowpea has been observed to reduce striga infestation significantly (Khan *et al.*, 2002). This was attributed to the soil cover of cowpea that created unfavorable conditions for striga germination (Mbwaga *et al.* 2001). Mashingaidze (2004) found that maize-bean intercropping reduced weed biomass by 50-66 percent when established at a density of 222,000 plants ha<sup>-1</sup> for beans equivalent to 33 percent of the maize density (37,000 plants ha<sup>-1</sup>). Weed suppression in maize-groundnut intercropping was reported by Steiner (1984). Other studies where intercropping systems were used as an integrated weed management tool reported the same results (Caporali *et al.*, 1998; Rana and Pal, 1999).

For pests and diseases, the most commonly quoted effect is that one crop can provide a barrier to the spread of a pest or disease of the other crop (Willey *et al.*, 1983). Brown (1935) noted that bud worm infestation in sole maize was greater than in maize intercropped with soybean. Sekamatte *et al.* (2003) reported that soybean and groundnut are more effective in suppressing termite attack than common beans. The average percentage of maize stalk borer infestation was significantly greater in monocropped (70 percent) than in intercropped maize-soybean (Martin, 1990).

Moreover, intercropping systems control soil erosion by preventing rain drops from hitting the bare soil where they tend to seal surface pores, prevent water from entering the soil and increase surface runoff (Seran and Brintha, 2010). Kariaga (2004) found that in maize-cowpea intercropping system, cowpea act as best cover crop and reduced soil erosion than maize-bean system. Reddy and Reddi (2007) found that taller crops act as wind barrier for short crops, in intercrops of taller cereals with short legume crops. Similarly, sorghum-cowpea intercropping reduced runoff by 20-30 percent compared with sorghum sole crop and by 45-55 percent compared with cowpea monoculture. Also, soil loss was reduced with intercropping by more than 50 percent compared with sorghum and cowpea monocultures (Zougmore *et al.*, 2000).

#### **2.4.1. Radiation use efficiency (RUE)**

Intercropping of high and low canopy crops helps to improve light interception and hence yields of the shorter crops requires that they be planted between sufficiently wider rows of the taller once (Seran and Brintha, 2010). For instance, Ennin *et al.* (2002) found that per cent PAR intercepted by intercrops was 4 per cent greater in closer row arrangements of soybean

and maize than in equally spaced 2 rows soybean: 2 rows maize. Reddy *et al.* (1980) reported that millet-groundnut intercrop system was 28 percent more efficient in light use than their monocrops, which was attributed to approximately 30 percent greater LAI of the intercrop than the sole crops. Leaf area index of a canopy is important for predicting crop growth and yields (Xinyou *et al.*, 2003). A reasonable LAI is critical to maintain high photosynthetic rates and the yield (Xiaolei and Zhifeng, 2002). If the index is too low, not enough light will be absorbed and if too high, lower leaves will not receive enough light and will thus be a liability (Brintha and Seran, 2009).

#### **2.4.2. Nitrogen dynamics and uptake by maize-soybean in intercrop**

Of all nutrients, N is required in the greatest quantity for plant growth, and the capacity of soils to supply N to plants is inextricably linked to the amount and nature of the soil organic matter (SOM). According to Giller *et al.* (1991), there are three main forms of N capital, i) mineral N ( $\text{NH}_4^+$  - N and  $\text{NO}_3^-$  - N) susceptible to losses (also known as soil mineral N); ii) organic N which is in the SOM, which is mineralizable in the relatively short term (months) and medium term (1 to 5 years); and, iii) long-term N capital is essentially the more recalcitrant part of SOM that contributes relatively little to N supply within 5 to 10 years. This mineral N has been reported to be dynamic in the soil because both nitrate-N ( $\text{NO}_3^-$  - N) and ammonium-N ( $\text{NH}_4^+$  - N) may be recycled within the soil biota, taken up by the crop, retained within the soil matrix or lost through leaching, volatilization, nitrification and denitrification processes (Barrios *et al.*, 1998).

Although nitrogen is one of the major plant nutrients, in the central highlands of Kenya many soils are severely N deficient (Mugwe *et al.*, 2011), and studies from SSA and elsewhere

confirm the importance of N nutrition in crop yields, and the potential for use of soil inorganic N as predictors of yields. For example, in Zambia Barrios *et al.* (1998) obtained strong correlations between maize grain yields and pre-season inorganic N in surface soil. In Uganda, Stephen (1967) cited by Ikerra *et al.* (1999) reported that soil  $\text{NO}_3^-$ -N 4 WAP was highly correlated with maize yields. In Nigeria, Webert *et al.* (1995) obtained a highly significant relationship between maize grain yields and soil nitrate-N at 2 to 8 WAP. On the other hand, Van Kessel and Roskoski (1988) found that maize grown at the closer row spacing with cowpea registered higher N-uptake during the first 7 WAP, whereas maize grown at the widest row spacing had higher N-uptake during the last 4 WAP before the final harvest. Li *et al.* (2002) found that when the roots of two species intermingled N uptake was  $384 \text{ kg N ha}^{-1}$  while, when the roots of the two species were separated completely, it was reduced by 21 percent.

## **2.5. Limitations of intercropping**

Intercropping can lead to reduction in yield of one or more of component crops due to adverse competitive effects (Willey and Rao, 1980). Competition between component crops for growth limiting factor is regulated by basic morpho – physiological differences and agronomic factors such as proportion of crops in the mixture, fertilizer applications and relative sowing time (Willey and Rao, 1980). Where component crops are arranged in definite rows the degree of competition is determined by the relative growth rates, growth duration and proximity of roots of the different crops (Willey and Rao, 1980). In cereal-legume intercrops, cereal component with relatively higher growth rate, highest advantage and a more extensive rooting system is favored in the competition with associated legume

(Ofori and Stern, 1987). A review by Ofori and Stern (1987), of 40 published papers showed that the yield of the legume component declined on average by about 52 percent of the sole crop yield whereas the cereal yield was reduced by only 11 percent. The general observations from this are that yields of the legume components are significantly depressed by cereal components in intercropping, which is attributed to reduced photosynthetically active radiation (PAR) that reaches the lower parts of the maize canopy occupied by the soybean crop. Another limitation of intercropping is often thought to be difficulties concerned with practical management of intercropping especially where there is a high degree of mechanization or where the component crops have different requirements for fertilizer and pesticides (Willey *et al.*, 1980).

## **2.6. Biological Nitrogen Fixation (BNF) in cereal – legume cropping systems**

One promising alternative that can substantially reduce investment in fertilizers is the inclusion of legumes in the various cereals farming systems (Osunde *et al.*, 2004), due to the fact that legumes have the ability to biologically fix nitrogen from the atmosphere, which is the major source of N in legume-cereal mixed cropping systems (Fujita *et al.*, 1992). For instance, Osunde *et al.* (2004) found that without the addition of fertilizer the proportion of N derived from N<sub>2</sub>-fixation was about 40 percent in the intercropped soybean and 30 percent in the sole crop, and with application of 40 kg N ha<sup>-1</sup> N<sub>2</sub>-fixed by the sole cropped soybean was significantly greater than that fixed by intercropped system. Yusuf *et al.* (2007) found that maize grain yield was 46 percent significantly higher when grown after soybean than after maize and natural fallow.

## **2.7. Nitrogen transfer in cereal-legume intercropping systems**

Evidence suggests that associated non-legumes may benefit through N-transfer from legumes (Fujita *et al.*, 1992). This N-transfer is considered to occur through root excretion, N leached from leaves, leaf fall, and animal excreta if present in the system (Fujita *et al.*, 1992). The limited studies carried out within SSA suggested that N<sub>2</sub>-fixed by a leguminous component may be available to the associated cereal in the current growing season (Eaglesham *et al.*, 1981), known as direct N transfer (Stern, 1993). Eaglesham *et al.* (1981) showed that 24.9 percent of N fixed by cowpea was transferred to maize. However, Ofori and Stern (1987) and Danso *et al.* (1993) reported that there is little or no current N transfer in cereal-legume intercropping system. In addition, Fujita *et al.* (1992) reported that benefits to associated non-leguminous crop in intercropping systems is influenced by component crop densities, which determine the closeness of legume and non-legume crops, and legume growth stages.

Despite claims for substantial N-transfer from grain legumes to the associated cereal crops, the evidence indicate that benefits are limited (Giller *et al.*, 1991). Benefits are more likely to occur to subsequent crops as the main transfer path-way is due to root and nodule senescence and fallen leaves (Ledgard and Giller, 1995).

## **2.8. Residual effects of cereal-legume cropping system**

The intercrop legume may accrue N to the soil and this may not become available until after the growing season, improving soil fertility to benefit a subsequent crop (Ofori and Stern 1987; Ledgard and Giller, 1995). For instance, Yusuf *et al.* (2009) found that maize grain yield was 46 percent significantly higher when grown after soybean than after maize and

natural fallow. Kumwenda *et al.* (1998) reported that sunnhemp (*Crotalaria juncea*), Tephrosia (*Tephrosia vogelii*) and velvet bean (*Mucuna pruriens*) green manure often resulted in maize yields of 3-6 t ha<sup>-1</sup> even with no addition of mineral N fertilizer. Moreover, Chibudu (1998) found that maize yields were increased about 25 percent and 88 percent after maize-mucuna and maize-cowpea intercropping systems, respectively. Phiri *et al.*, (1999) found that maize yields were increased about 244 percent after maize-*Sesbania sesban* intercropping system. Kureh and Kamara (2005) found that maize grain yield was 28 percent higher after one year of soybean and 21 percent higher after one year of cowpea than in the continuously cropped maize. Maize grain yield was 85 percent higher after two years of soybean, and 66 percent higher after two years of cowpea than in the continuously cropped maize.

Furthermore, Akinnifesi *et al.* (2007) found that over 4 consecutive cropping seasons, grain yields of maize increased by 340 percent in gliricidia-maize intercropping, when compared to unfertilized sole maize. Bationo *et al.* (1995) reported that intercropping of cowpea with millet may enhance millet grain yields by 30 percent above the control. According to Peoples and Herridge (1990) to maximize the contribution of legume N to a following crop, it is necessary to maximize total amount of N in legume crop, the proportion of N derived from N<sub>2</sub> fixation, the proportion legume N mineralized and the efficiency of utilization of this mineral N. Unfortunately, it is not always possible to optimize these factors.

### **2.9. Effects of shading on soybean yield**

Intensity and quality of solar radiation intercepted by a soybean canopy during the reproductive period is an important environmental factor determining soybean yield and yield

components (Liu *et al.*, 2010; Mathew *et al.*, 2000). Hardman and Brun (1971) stated that the yield of soybean is controlled by the availability of photosynthates during post-flowering stage of development. Schou *et al.* (1978) reported that light levels during late flowering to mid pod formation stages of growth are more critical than during vegetative and late reproductive periods in determining the yield of soybean. Taylor *et al.* (1982) concluded that pod abortion caused by lack of photosynthate supply late in the growing period is a major factor limiting yield of soybean. Duncan (1986) suggested that light intercepted during and after seed initiation is a major determinant of yield. In an experiment by Jiang and Egli (1993), shade imposed from first flower to early pod-fill reduced flower production and increased flower and pod abscission, resulting in reduced pod number and yield. They also found canopy photosynthesis during flowering and pod set to be an important determinant of seeds  $m^{-2}$ , and that the impact of shading on seeds  $m^{-2}$  depends on duration of shading.

Furthermore, Herbert and Litchfield (1982) observed that pod number per plant was the most important component responsible for differences in soybean yield between different row widths and densities within a particular year, while a change in seed size resulted in the yield difference between 2 consecutive years. Thus, there is a differential response of yield components to changes in environmental conditions. Shading (49-20 per cent of ambient light) resulted in lengthening of internodes and increased lodging in soybean plants (Ephrath *et al.*, 1993). Light enrichment initiated at late vegetative or early flowering stages increased seed yield 144 to 252 percent, mainly by increasing pod number. While light enrichment beginning at early pod formation increased seed size 8 to 23 percent, resulting in a 32 to 115 percent increase in seed yield (Mathew *et al.*, 2000).

### **2.10. Intercropping productivity**

One of the most important reasons for intercropping is to ensure that an increased and diverse productivity per unit area is obtained compared to sole cropping (Sullivan, 2003). For instance, using LER in a maize-soybean intercropping system, Kipkemoi *et al.* (2002) reported that it was greater than one under intercrop. Muoneke *et al.* (2007) found that the productivity of the intercropping system indicated yield advantage of 2-63 percent as depicted by the LER of 1.02-1.63 showing efficient utilization of land resource by growing the crops together. Raji (2007) had also reported higher production efficiency in maize/soybean intercropping systems. Addo-Quaye *et al.* (2011) found that LER was greater than unity, implying that it will be more productive to intercrop maize and soybean than grow them in monoculture. Allen and Obura (1983) observed LER of 1.22 and 1.10 for maize-soybean intercrop in two consecutive years. Prasad and Brook (2005) reported that Land equivalent ratios of all maize-soybean intercrops were greater than unity (1.30 to 1.45), indicating higher efficiency of intercropping compared to sole crops.

### **2.11. Constraints of cereal-legume intercropping system contribution to soil fertility management in smallholder farms**

Despite the benefits of cereal-legumes intercropping systems in ISFM, there are some constraints that need to be curbed so as to attain progress (Mugendi *et al.*, 2011; Odendo *et al.*, 2011). For instance, in some of countries within the region the soils are acidic with limited phosphorus availability (Sanchez *et al.*, 1997), which is harmful for BNF process and therefore lessen the N contribution of the legume component to system (Giller, 2001; Fujita and Ofosu-Budu, 1996). This is worsened by the current use of mineral fertilizers that is still low among smallholder farmers (Palm *et al.*, 1997), which is associated to accessibility and affordability of appropriate fertilizer due to financial and infrastructure problems (Jama *et al.*, 2000). Lack of access to improved seed on time to these farmers, which is associated to poor market and policy are also contributing negatively to the successful contribution of these systems (Mugendi *et al.*, 2011).

Moreover, legume trees and legume cover crops have been repeatedly demonstrated to improve and maintain soil fertility under different environmental conditions, compared to grain legumes intercropping systems (Mugendi, 1997; Mugendi *et al.*, 1999; Kumwenda *et al.*, 1998; Mugwe *et al.*, 2011; Bationo *et al.*, 2011). However, they have increasingly emerged as the least prioritized by smallholder farmers under their prevailing circumstances, which can be largely attributed to their lack of short-term benefits of both food and income (Mugendi *et al.*, 2011; Bationo *et al.*, 2011).

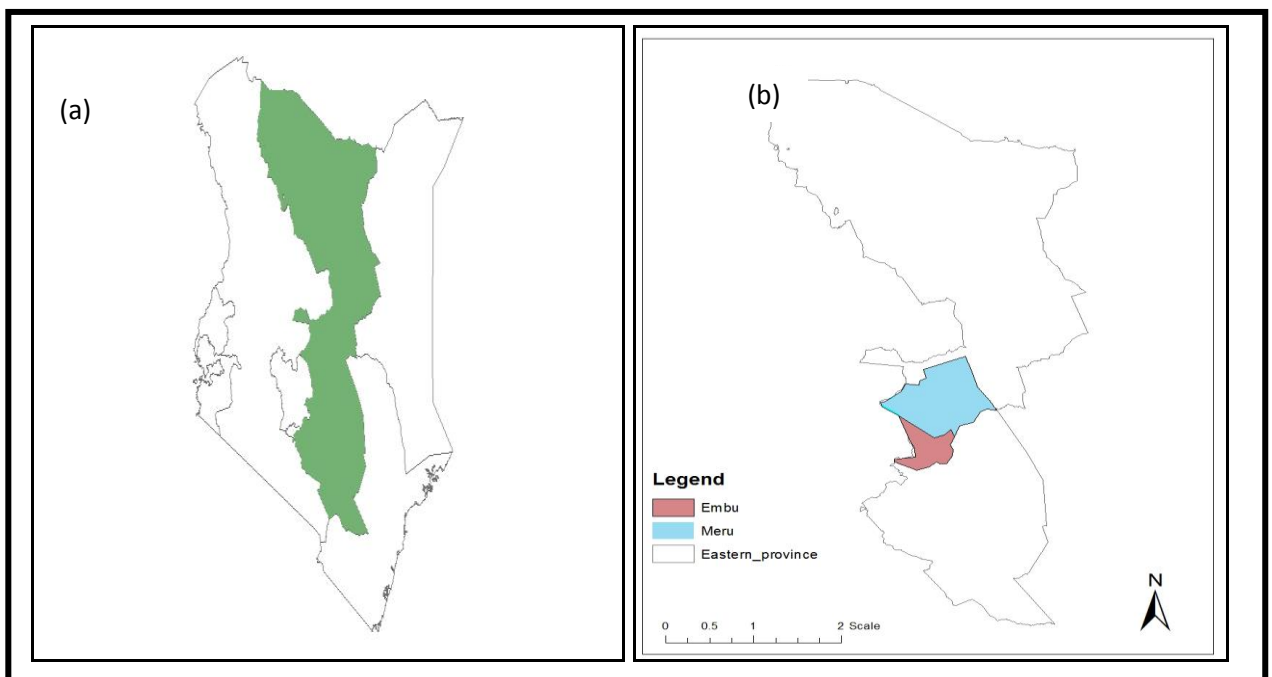
Furthermore, there is lack of information and knowledge about fertility management technologies because most of the research that has been done related to cereal-legumes

intercropping system in the past decades had less involvement of farmers, particularly the resource-constrained farmers (Mugendi *et al.*, 2011; Maphumo, 2011), which is worsened by low know how of extension services on legume-based ISFM technologies (Maphumo, 2011). Consequently, there are misconceptions among smallholder farmers about the role of legumes in the soil fertility management (Mtambanegwe and Maphumo, 2009). As consequence of these, the optimum productivity of cereal-legume systems is still a big challenge to the stakeholders involved in this sector. This study will therefore contribute to useful information to smallholder farmers, extension services and other stakeholders on the optimum intercropping patterns, contribution of the system to the soil and the economic aspect of the maize-soybean cropping system.

## CHAPTER THREE: MATERIALS AND METHODS

### 3.1. Description of the study area

The experiment was carried out in two counties of central highlands of Kenya, namely Embu West and Tigania East sub counties. Figure 3.1 shows the map of the study area.

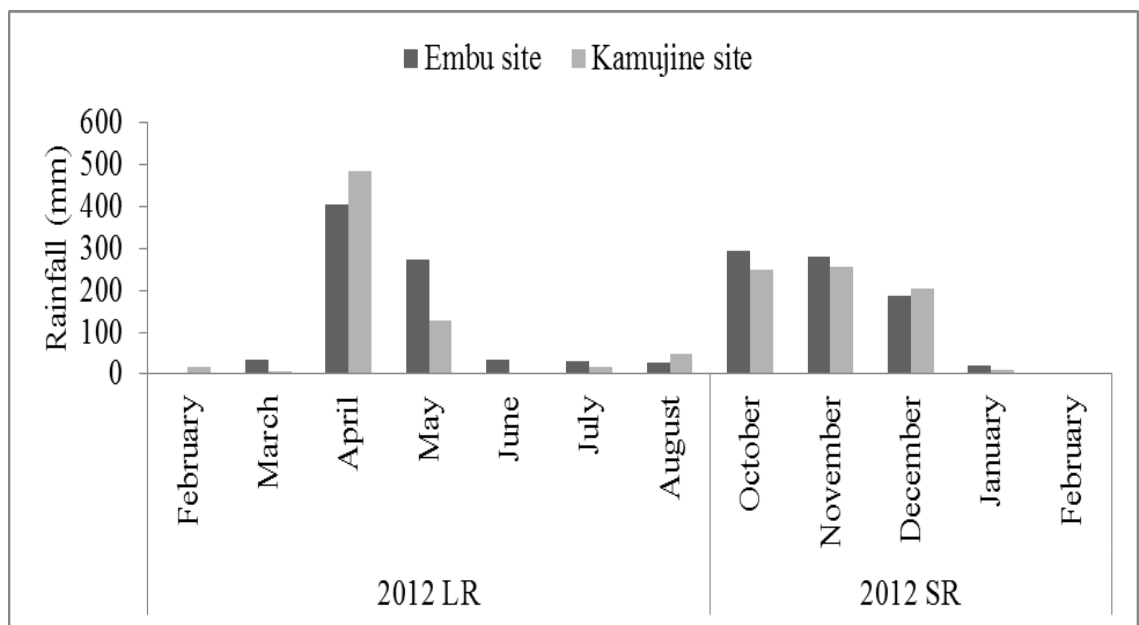


**Figure 3.1:** Map of Kenya (a) and the study area (b)

#### 3.1.1. Embu West Sub County

Embu West District is located in Embu County, in the central highlands of Kenya, and occupies an area of 708 Km<sup>2</sup> and is bordered by Mbeere district to the East and South East, Kirinyaga to the West and Meru South to the North. The experimental site lies within N 0° 31' 4.2'' E 37° 27' 20'' and at 1468 m above the sea level (ASL), at Embu Agricultural Staff Training College (Jaetzold *et al.*, 2006).

Diagnosis study carried out in the central highlands of Kenya have reported soil fertility constraints, particularly N and P deficiencies, low carbon content and low soil pH (Gachimbi *et al.*, 2002). The major agro-ecological zone (AEZ) is Upper Midland 2 (UM 2). The soils are mainly humic Nitisols and the total arable land area is 478 Km<sup>2</sup> with total available agricultural land area covering 371 Km<sup>2</sup>. The major enterprises include maize/sorghum – bean, potatoes, sweet potatoes, cabbages, kales, tomatoes, onions, Arabica coffee, bananas, citrus, avocados and passion fruit (Jaetzold *et al.*, 2006). The average annual rainfall varies from 909 to 1230 mm with long rainy season between March and June and short rainy season between October and December, respectively. Rainfall for the two seasons in which the experiment was conducted is presented in Figure 3.2.



**Figure 3.2:** Rainfall amount in 2012 at Embu-ATC and Kamujine sites, Kenya

**Table 3.1:** The soil characteristics at Embu site and Kamujine Sites, Kenya

Soil parameter	Embu – ATC Site	Kamujine Site
pH in water <sub>(1:2.5)</sub>	5.30	5.50
Total N (%)	0.03	0.01
Total organic carbon (%)	2.64	1.88
Extractable P (ppm)	13.40	9.54
Exchangeable Ca (C mol kg <sup>-1</sup> )	0.22	0.21
Exchangeable Mg (C mol kg <sup>-1</sup> )	0.53	0.53
Exchangeable K (C mol kg <sup>-1</sup> )	0.12	0.08
Clay (%)	65	45
Sand (%)	17	20
Silt (%)	18	35

Embu Sub County is one of the thirteen sub counties, which make up Eastern Province. The population densities in Embu Sub County are relatively high, with Central Division having 743 persons km<sup>-2</sup> in 1999 and expected to grow to 869 by the year 2008. The district intercensal growth rate dropped sharply from a high rate of 3.08 percent per annum between 1979-1989 to moderate 1.7 percent per annum between 1989 and 1999. This sharp drop may be explained by various reasons, among them being a general decline in fertility rate due to the increasing awareness of the importance of family planning. The available agricultural land per household was 0.82 ha per household of 4.44 persons in 1979 compared to the 1999 figure of 0.6 ha for an equivalent number of persons per household, i.e. 4.40 persons (Jaetzold *et al.*, 2006). In other words the available agricultural land per person is continuously decreasing, from 0.18 ha in 1979 to 0.14 ha per person in 1999 (Jaetzold *et al.*, 2006). This decreasing trend has serious implications on per capita land productivity, particularly under the soil fertility depleted soils as found in Embu District. According to the Report on Poverty in Kenya (2000), 56 percent of the population in Embu District is absolutely poor while 43.5 percent of this was categorized as chronically poor. The

HIV/AIDS pandemic has played a major role in raising the mortality rates among the population, with the prevalence rate of 30 percent (Jaetzold *et al.*, 2006).

### **3.1.2. Tigania East Sub County**

Tigania East Sub County is located in Meru County, in the central highlands of Kenya and it occupies 108.6 km<sup>2</sup>. The experimental site lies within N 0° 6' 19.5'' E 037° 64' 39.6'' and at 935 m above the sea level (ASL), at Kamujine Dispensary in Mikinduri Division. The major agro-ecological zones are Lower Midlands 3 and Upper Midland 3 (LM 3 and UM 3), the soils are mainly eutric Nitisols and humic Cambisols. The annual average temperature varies from 19.2 °C to 22.9 °C (Jaetzold *et al.*, 2006). Table 3.1 shows the soil characteristics of the soils in Kamujine.

The district has relatively high population density of 285 persons per km<sup>2</sup> due to its suitability for farming activities. The spatial distribution of the available land per household and per person ranges from 0.05 to 0.55 ha. There are cases of high absolute levels of poverty in the district. The major enterprises include crop systems, namely horticultural crops, maize, banana and Irish potato, and livestock system namely goat and cattle. The average annual rainfall varies from 1000 to 2200 mm with long rainy season between March and June and short rainy season between October and December, respectively (Jaetzold *et al.*, 2006). Rainfall for the two seasons in which the experiment was conducted is presented in Figure 3.2.

In general (Table 3.1), the soils in the two contrasting sites were different. For instance, at Embu site they were relatively acidic compared to Kamujine site. The total N (%) was

slightly higher at Embu site compared to Kamujine. The soil organic carbon was 40 percent higher at Embu site than at Kamujine, and at this site the soil texture was relatively lighter (45 percent clay) than at Embu site (65 percent clay).

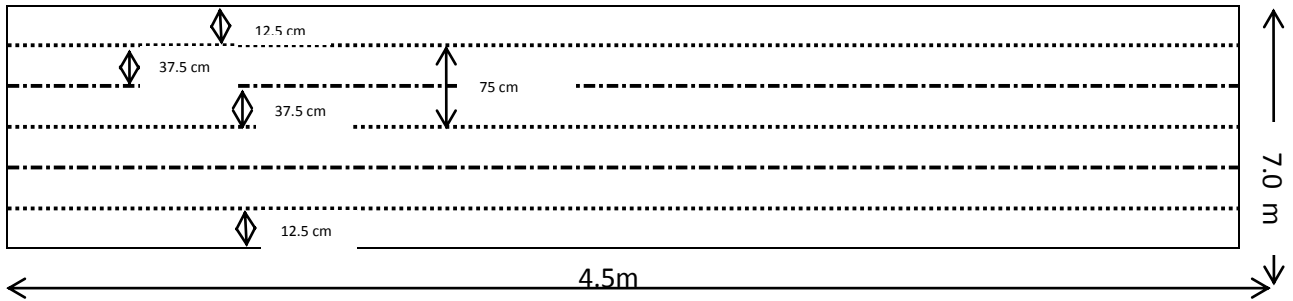
### 3.2. Experimental design

The experiment in this study was established in Embu-ATC (Embu West district) and in Kamujine (Tigania East district) in March 2012 and it was laid out as a randomized complete block design (RCBD). There were four replicate blocks and plot sizes measuring 7 m x 4.5 m. The cropping system was of sole maize (*Zea mays* L.), sole soybean (*Glycine max* (L.) Merrill) and maize (M) – soybean (S) intercropping with cropping patterns (Table 3.2 and Figure 3.3, 3.4, 3.5 and 3.6).

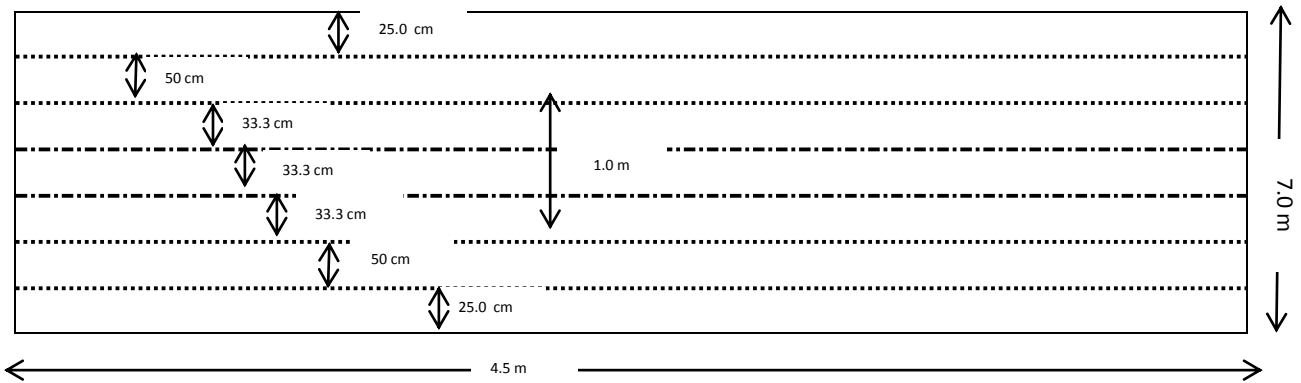
**Table 3.2:** Treatments in the two sites (ATC-Embu and Kamujine)

<b>Cropping system</b>	<b>Cropping system</b>
Sole maize	Maize-Soybean (2:2)
Sole soybean	Maize-Soybean (2:4)
Maize-Soybean (1:1)	Maize-Soybean (2:6)

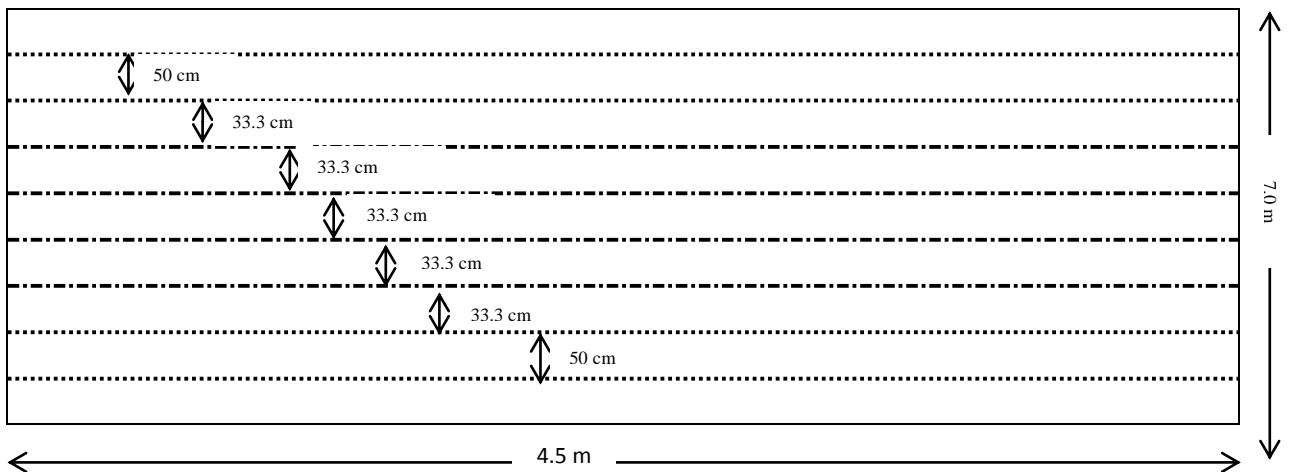
The maize – soybean was intercropped in four types of intercrops will be done as shown below.



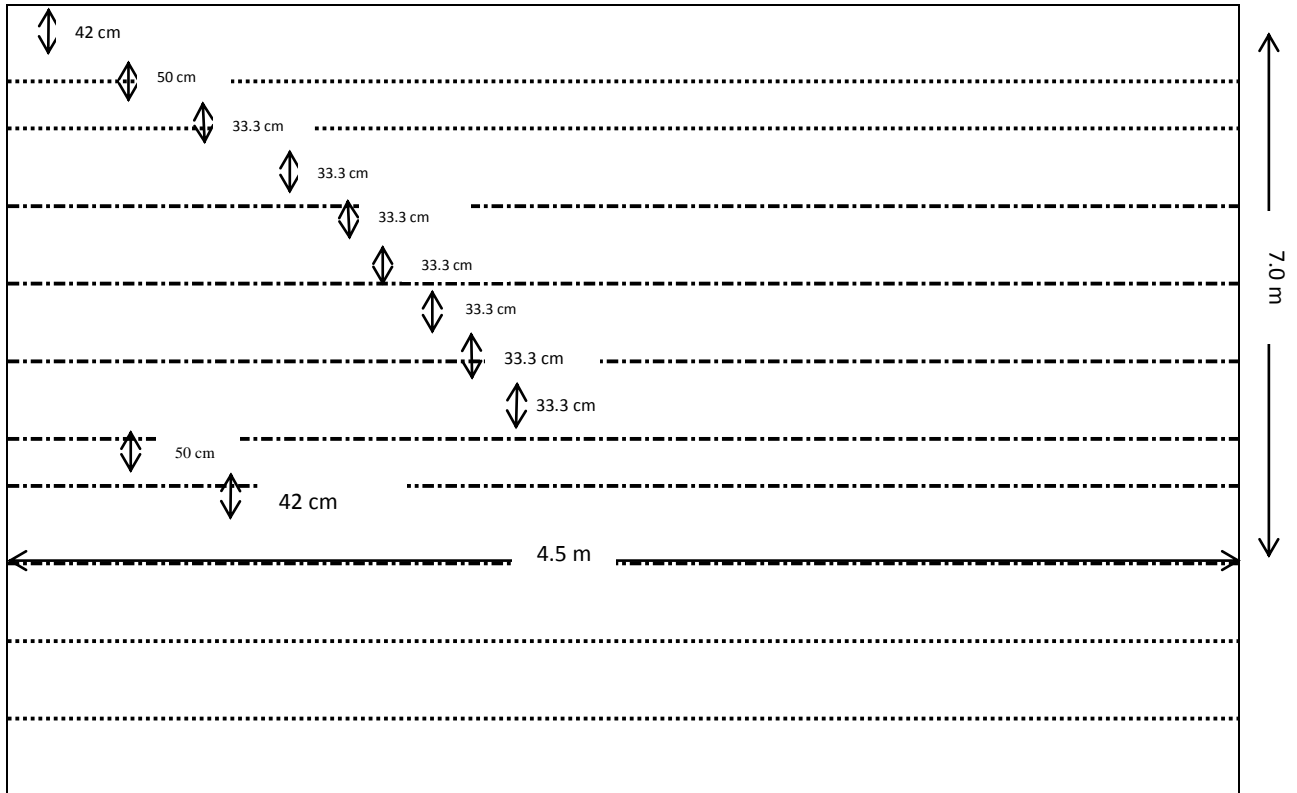
**Figure 3.3:** Schematic representation of maize – soybean intercrop planted in alternate rows at an inter-row spacing of 37.5 cm in the conventional system, 1M:1S. **Key:** ..... Maize row; ----- Soybean row



**Figure 3.4:** Schematic representation of MBILI intercrop showing intercrop with two rows of soybean in between two rows of maize spaced at 1.0m. Soybean-soybean spaced at 33.3 cm and maize-maize spaced at 50 cm. **Key:** ..... Maize row; ----- Soybean row



**Figure 3.5:** Schematic representation of 2M:4S showing intercrop with four rows of soybean in between two rows of maize spaced at 166.5 cm. Soybean-soybean spaced at 33.3 cm and maize-maize spaced at 50 cm.



**Figure 3.6:** Schematic representation of 2M:6S showing intercrop with four rows of soybean in between two rows of maize. Soybean-soybean spaced at 33.3 cm and maize-maize spaced at 50 cm.

### 3.3. Management of the experiment

The fields were ploughed using hand hoe and left as such for two weeks. Plots measuring 7.0 x 4.5 m were marked just before planting. Pathways measuring 3.0 m and 2.0 m were left between the blocks and plots, respectively. At Embu-ATC, planting was done on the 23<sup>rd</sup> of March and 12<sup>th</sup> of October 2012 for the 1<sup>st</sup> and 2<sup>nd</sup> seasons, respectively. At Kamujine, planting was done on the 26<sup>th</sup> of March and 15<sup>th</sup> of October 2012 for the 1<sup>st</sup> and 2<sup>nd</sup> seasons, respectively. The sole maize (*Zea mays* L.) var. DK 8031 was planted at a spacing of 0.75 m 0.50 m inter and intra-row, respectively. The number of hills per row was 10 with three seeds

per hill in order to ensure maximum plant population and to account for germination failure; and two weeks after germination the excess plants were thinned out to remain with two plants per hill. The sole soybean (*Glycine max* (L.) Merrill) var. Gazelle was hand drilled at a spacing of 0.45 m × 0.10 m in inter and intra – row spacing resulting to 62 plants per row to ensure maximum germination/population and the excess plants were thinned out to remain with the recommended population of 31 plants per row after 2 weeks of emergence. The following external nutrient replenishment inputs were applied per plot: 6 kg of manure equivalent to 30 kg N ha<sup>-1</sup>, applied two weeks before planting; 94.5 grams of CAN as source of N, equivalent to 30 kg N ha<sup>-1</sup>, for soybean the Nitrogen (starter N) was applied at sowing while for maize it was applied when the crop had six leaves, as top dressing; 189 grams of TSP as source of P, equivalent to 60 kg P ha<sup>-1</sup>, which was applied at sowing. The fertilizers were applied accordingly to the recommendation from FURP (1987). Management practices were the same for both the monocrop and the maize – soybean intercrop.

### **3.2.1. Maize and soybean harvest and yields**

Maize and soybean grain and stover was harvested at maturity from a net area of each treatment demarcated after leaving out two rows on each side of the plot and the first two and the last two maize/soybean plants on each row to minimize the edge effect (Table 3.3). The entire plants on the plots was harvested by cutting at the ground level and weighted to represent the total fresh weight. Maize/Soybean cobs/pods were manually separated from the stover, sun-dried, and packed in sacks before threshing. After threshing, moisture content of the grains was determined using a moisture meter and grain yield adjusted to 12 percent

moisture content using the following formula. Similarly, the yields and harvest index were calculated using the following formulas.

$$\text{Adjusted yield} = \text{measured yield} * \frac{(100 - \text{sample moisture content})}{(100 - \text{standard moisture content})} \quad (1)$$

$$\text{Yield (t/ha)} = 10 * \frac{\text{Dryweight (kg/m}^2\text{)}}{\text{Net area (m}^2\text{)}} \quad (2)$$

$$\text{Harvest Index (HI) (\%)} = \frac{\text{Grain yield (t/ha)}}{\text{Total biomass yield (t/ha)}} * 100 \quad (3)$$

**Table 3.3:** Net plot area per treatment at Embu and Kamujine sites

<b>Intercropping pattern</b>	<b>Total plot size (m<sup>2</sup>)</b>	<b>Net plot (m<sup>2</sup>)</b>
Sole maize	7.0m×4.5m=31.5	6.0m×3.5m=21.0
Sole soybean	7.0m×4.5m=31.5	4.95m×3.9m=19.3
Maize-Soybean (1M:1S)	7.0m×4.5m=31.5	5.25m×3.5m=18.4
Maize-Soybean (2M:2S)	7.0m×4.5m=31.5	4.8m×3.5m=16.9
Maize-Soybean (2M:4S)	7.0m×4.5m=31.5	5.3m×3.5m=18.7
Maize-Soybean (2M:6S)	7.0m×4.5m=31.5	4.5m×3.5m=15.8

### 3.2.2. Soil sampling and determination of soil mineral nitrogen

Soil samples for determination of mineral N were taken from 0-15 cm depth at 0, 2, 4, 6, 8, 12, 16 and 20 weeks after planting (WAP) , in all plots, during the LR season (March-August/2012). The soil samples was taken at 10 different spots per plot then bulked to give one composite sample, this aimed to eliminate the variability of inorganic N. After sampling the soil samples were packed in cooler boxes and delivered to the laboratory within 24 hours.

To avoid any further mineralization before extraction, the samples were stored in the fridge at 5 °C. The soil extraction was done using 2M KCl, then the analysis of extractable nitrate ( $\text{NO}_3^-$ ) through a flow injection system, using cadmium reduction column method, followed by determination of extractable ammonium using colorimetric method through a flow injection system (Okalebo *et al.*, 2002).

### **3.2.3. Determination of maize and soybean N uptake and plant height**

Destructive random sampling of maize and soybean plants was carried out at 4, 6, 8, 12, 16 and 20 WAP (harvest) for determination of N concentration in the plant tissue. The plants were taken from an area outside the net plot. The samples were taken to the laboratory and oven-dried at 60 °C for 48 hours, milled and sieved through a 1.0 mm sieve and then analyzed separately for nitrogen concentration using Kjeldahl acid digestion method, followed by colorimetry method (Okalebo *et al.*, 2002). Nitrogen uptake by maize and soybean crops was determined by multiplying the dry matter yields ( $\text{kg ha}^{-1}$ ) with nitrogen concentration (%). Also, height of maize and soybean plants was taken at the time of plant sampling for N determination (i.e., at 4, 6, 8, 12, 16 and 20 WAP).

### **3.2.4. Determination of changes in soil chemical properties**

First, soil samples from the experimental sites were collected at 0 – 15 cm depth of analysis for organic carbon, total nitrogen using standard methods (Okalebo *et al.*, 2002), extractable P, Ca, Mg, K, Na using Mehlich-1 (M1) extraction method. The P and  $\text{Mg}^{2+}$  were determined colourimetrically in a spectrophotometer while  $\text{Ca}^{2+}$ , and  $\text{K}^+$  were determined using flame photometer.

To determine changes in soil chemical properties, soil sampling was done at the beginning of the experiment in March long rain (LR) and at the end in October short rain (SR) of 2012. Soil samples were taken at 0 – 15 cm depth during the two sampling periods. The samples were analyzed for Extractable phosphorous (P) and the exchangeable cations ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ) were determined through Mehlich-1 (M1) extraction method, where P and  $\text{Mg}^{2+}$  were determined colourimetrically in a spectrophotometer while  $\text{Ca}^{2+}$ ,  $\text{K}^+$  and  $\text{Na}^+$  were determined using a flame photometer. Total N was determined using Kjeldahl acid digestion method, using an automatic CN elemental analyzer 2000 (Okalebo *et al.*, 2002), while organic carbon was determined by combustion using an elemental analyzer CNS-2000 analyzer using an automatic CN 2000.

### 3.3. Determination of light interception and leaf area index

Radiation interception of photosynthetically active radiation was measured in both the sole crop and the different intercropping patterns using a Sunfleck Ceptometer. The measurements were taken between 11.30 am and 01:30 pm (local time) at an interval of fourteen days. The PAR intercepted was then calculated according to Goudriaan (1988) as follows;

$$\% \text{ PAR intercepted} = \frac{(\text{PAR}_a - \text{PAR}_b)}{\text{PAR}_a} * 100 \quad (4)$$

Where,  $\text{PAR}_a$  = PAR above the canopy and  $\text{PAR}_b$  = PAR below the canopy.

The determination of LAI was done using the inversion of transmitted PAR, as indicated in the equation according to Goudriaan (1988)

$$L = \frac{\left[ \left( 1 - \frac{1}{2K} \right) f_b - 1 \right] \ln \tau}{A(1 - 0.47 f_b)} \quad (5)$$

Where,  $L$  is leaf area index;  $K$  is the extinction coefficient for the canopy, given as  $k = \frac{1}{2\cos\theta}$  with  $\theta$  the zenith angle of the sun;  $f_b$  is the fraction of incident PAR;  $\tau$  is the ration of PAR measured below the canopy to PAR above the canopy;  $A$  is given as  $A = 0.283 + 0.785a - 0.159a^2$ , with  $a$  the leaf absorptivity in the PAR band (typically around 0.9).

### 3.4. Performance of the intercropping Maize – Soybean systems

To evaluate the intercrop's performance, land equivalent ratio was calculated using formula provided by Willey (1980) thus;

$$LER = \frac{X_{yi}}{X_{ys}} + \frac{Y_{yi}}{Y_{ys}} \quad (6)$$

Where,  $X_y$  and  $Y_y$  refer to X (maize) and Y (soybean) yields, respectively. The subscript "i", refers to the intercrop and the subscript "s" the sole crop.

### 3.5. Data analysis

Data of maize and soybean yields, soil mineral N and N uptake by maize and other growth parameters were subjected to analysis of variance using SAS version 8. To test for significant differences between different cropping pattern and conventional intercropping systems, the yields were subjected to *t-student* test at 95 per cent of significance level ( $p < 0.05$ ).

## CHAPTER FOUR: RESULTS AND DISCUSSION

### **4.1. Effects of different maize–soybean intercropping patterns on yields and N uptake, and soil properties**

#### **4.1.1. Effect of intercropping pattern on maize yields**

##### **4.1.1.1. Plant height**

The intercropping of maize and soybean did not affect maize plant height in both sites (Embu and Kamujine), during all the sampling periods. However, at Embu the conventional (1M:1S) had the tallest maize height during the early stage of the crop growth (4, 6 and 8 WAP, with 47.45 cm, 76.08 cm and 147.85 cm, respectively) than all the other intercropping patterns, including the sole crop, but at the end of the season (12 and 16 WAP) the sole crop had the tallest plants with 266.00 cm and 266.08 cm, respectively. Whereas in Kamujine, the MBILI (2M:2S) had the tallest plants during the early stages (4, 6 and 8 WAP, with 69.70 cm, 134.20 cm and 214.30, respectively) compared to the other intercropping patterns, at the end of the season, the conventional treatment recorded the tallest plants.

**Table 4.1:** Mean maize plant height (cm) during 2012 LR at Embu and Kamujine sites

Location	Treatment	4 WAP	6 WAP	8 WAP	12 WAP	16 WAP
Embu	Sole maize	46.58	71.88	144.98	266.00	266.08
	Maize-Soybean (1M:1S)	47.45	76.08	147.85	260.88	260.88
	Maize-Soybean (2M:2S)	45.23	73.43	140.13	260.13	260.13
	Maize-Soybean (2M:4S)	41.70	69.15	131.45	247.38	247.38
	Maize-Soybean (2M:6S)	45.03	70.13	139.48	254.95	255.15
<i>p</i> -value		0.5082	0.6313	0.3599	0.6619	0.6603
LSD <sub>(0.05)</sub>		10.58	15.24	25.74	40.63	40.55
Kamujine	Sole maize	66.20	119.83	212.73	219.18	219.20
	Maize-Soybean (1M:1S)	69.50	118.23	210.18	230.55	230.55
	Maize-Soybean (2M:2S)	69.70	134.20	214.30	226.45	226.53
	Maize-Soybean (2M:4S)	68.75	127.45	212.78	217.18	217.18
	Maize-Soybean (2M:6S)	58.63	125.18	207.00	223.60	223.68
<i>p</i> -value		0.0805	0.1672	0.7916	0.5112	0.5085
LSD <sub>(0.05)</sub>		12.71	20.65	19.97	26.16	26.14

ns – not significant;

The findings on this study are similar to those of Undie *et al.* (2012), Muoneke *et al.* (2007), Alvarenga *et al.* (1998) and Yunusa (1989) who did not find significant differences in terms of plant height, between sole maize and intercropping with soybean. Similarly, Thobatsi (2009) and Watiki *et al.* (1993) found that maize intercropped with cowpea did not have any effect on maize plant height.

#### 4.1.1.2. Maize yield component

At Embu during both seasons, maize stover and grain yields were significantly affected by the intercropping pattern (Table 4.2). For instance, during 2012 LR the MBILI treatment recorded significantly higher stover and grain yields ( $13.12 \text{ t ha}^{-1}$ ,  $p=0.0001$  and  $6.11 \text{ t ha}^{-1}$ ,  $p \leq 0.0001$ , respectively) than all the other treatments, excluding the conventional (for the grain yield and stover yield) and also sole maize treatment (for the stover yield). During the 2012 SR, similar trend emerged with the MBILI treatment recording significantly the highest

stover and grain yield  $7.62 \text{ t ha}^{-1}$ ,  $p \leq 0.0001$  and  $5.62 \text{ t ha}^{-1}$   $p=0.0467$ , respectively. It is only during 2012 LR when the harvest index (HI) was significantly affected by the intercropping patterns, where the 2M:6S treatment observed the highest HI of 37.30 percent than all the other treatments. Slightly different situation was observed during 2012 SR, where although not significantly different ( $p=0.5398$ ) from other treatments, the MBILI treatment recorded numerically the highest HI of 42.22% (Table 4.2). These differences between the two seasons in terms of HI may be related to variations in rainfall and/or differences in weed pressure.

During both seasons at Kamujine site, maize stover yield was significantly ( $p \leq 0.05$ ) affected by the intercropping pattern (Table 4.2). For instance, during 2012 LR the conventional treatment produced significantly the highest stover yield ( $3.87 \text{ t ha}^{-1}$ ,  $p=0.0461$ ). During this season, the grain yield was not significantly affected by the intercropping patterns ( $p=0.0704$ ); however, the sole maize treatment recorded numerically the highest value of  $3.36 \text{ t ha}^{-1}$  while and 2M:6S treatment recorded the lowest yield. The lower maize yields under 2M:6S treatment could be related to the lower plant density compared to other treatments. During the 2012 LR, the maize stover yield was strongly significantly ( $p \leq 0.05$ ) positively correlated with the N uptake at all the sampling periods, excluding 16 WAP and 20WAP. During the 2012 SR, the MBILI treatment recorded significantly the highest stover and grain yield ( $6.55 \text{ t ha}^{-1}$ ,  $p=0.0005$  and  $3.55 \text{ t ha}^{-1}$   $p=0.0006$ , respectively) than all the other treatments, except sole maize and conventional treatments. At Embu site, the harvest index was not significantly affected by the intercropping patterns during both seasons ( $p=0.4243$  and  $p=0.4908$ , respectively). However, the MBILI (during the 2012 LR) and 2M:4S (during the 2012 SR) treatments observed numerically the highest HI of 51.40 and 37.29 percent, respectively (Table 4.2).

**Table 4.2:** Mean maize yields and harvest index at Embu and Kamujine

Location	Treatment	Stover yield (t/ha)		Grain yield (t/ha)		Harvest Index (%)	
		2012 LR	2012 SR	2012 LR	2012 SR	2012 LR	2012 SR
Embu	Sole maize	11.73	8.14	4.95	4.58	29.95	36.02
	Maize-Soybean (1M:1S)	12.64	7.74	5.49	5.16	30.45	39.27
	Maize-Soybean (2M:2S)	13.12	7.62	6.11	5.62	31.80	42.22
	Maize-Soybean (2M:4S)	8.89	4.91	4.05	3.48	31.30	41.43
	Maize-Soybean (2M:6S)	5.26	4.45	2.74	3.16	37.30	41.52
<i>p-value</i>		0.0001***	<0.0001***	<0.0001***	0.0467*	0.0168*	0.5398
LSD <sub>(0.05)</sub>		2.59	1.31	0.87	1.79	4.23	8.63
Kamujine	Sole maize	3.81	6.00	3.36	2.98	47.05	32.90
	Maize-Soybean (1M:1S)	3.87	6.34	3.09	3.44	44.59	35.03
	Maize-Soybean (2M:2S)	2.95	6.55	3.07	3.55	51.40	35.14
	Maize-Soybean (2M:4S)	2.59	4.83	2.47	2.86	49.23	37.29
	Maize-Soybean (2M:6S)	1.90	3.97	1.9	1.82	50.39	32.19
<i>p-value</i>		0.0461*	0.0005***	0.0704ns	0.0006***	0.4243	0.4908
LSD <sub>(0.05)</sub>		1.43	1.00	1.07	0.64	8.24	6.55

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .

Similar results of increased maize yield under MBILI treatment found at Embu site were also reported by Undie *et al.* (2012) in Nigeria under maize-soybean intercrop, Mucheru-Muna *et al.* (2010) in the central highlands of Kenya and Woomer *et al.* (2004) in western Kenya with maize-beans, and Solanki *et al.* (2011) in India with maize-blackgram. This could be due to the fact that the MBILI intercrop arrangement offer better opportunities to the components to utilize available resources more effectively than the conventional (1M:1S) intercropping pattern. Rajat De and Singh (1979) stated that the modified 2M:2S system affords a better solar energy harvest than the 1M:1S crop arrangement, because the former might have provided sufficient light to the lower leaves to continue photosynthesis. Furthermore, Brintha and Seran (2009) stated that productivity rates increases with LAI because of increased total light interception, but larger LAI values often cause no more increases and then decreases on a ground basis, probably due to respiratory CO<sub>2</sub> loss from heavily shaded leaves and stems. However, when the plant population is different the yield difference is determined by population density rather than crop arrangement (Rajat De and Singh, 1979), which was not the case in this particular situation. Similarly, Sikirou and Wydra (2008), Dapaah *et al.* (2003), Mpairwe *et al.* (2002) and Olufemi *et al.* (2001) reported higher cereal grain yield under intercropping system compared to its sole crop. Maize grain yield differs with different legume species and intercropping produces higher maize grain yield than in pure stand.

On the other hand, Thobatsi (2009) in South Africa, Silwana and Lucas (2002) also observed reduction in maize yield under intercropping system compared to its monocrop, under similar environment of limited rainfall conditions, as it was observed at Kamujine site during 2012 LR. In this site it was necessary to supplement with irrigation water because the crop had started to suffer from water stress due to lack of rainfall during flowering period, as it can be

seen in the Figure 3.3. Amede (1995) stated that one of the factors that reduces maize grain yield is dry conditions that occur specially during the flowering period. Higher populations under intercrops compared to monocrop under stress conditions might result in intercrop yields being lower than sole crop yields due to increased competition for moisture (Natarajan and Willey, 1986). Yield reductions involving one or all intercropping components in intercropping could be associated to inter-specific competition for nutrients, moisture and/or space (Adaniyan *et al.*, 2007). Moreover, Kamujine has a light texture soil, which has low moisture holding capacity (Jaetzold *et al.*, 2006), resulting therefore in reduced yields under intercropping (Natarajan and Willey, 1986).

The efficiency of a crop variety to convert the dry matter into economic yield is determined by its harvest index. The higher the value, the higher will be dry matter conversion efficiency. The absence of significant differences in HI of maize observed during 2012 SR at Embu and Kamujine sites agrees with results by Haseeb-ur-Rehman *et al.* (2010) and Egbe *et al.* (2010) in maize-cowpea intercropping; Saleem *et al.* (2011) in maize-legume intercropping systems; and, Carruthers *et al.* (2000) in maize-soybean intercropping who reported that the intercropping systems did not affect the harvest index of maize component.

#### **4.1.2. Effect of intercropping pattern on soybean yields and growth parameters**

##### **4.1.2.1. Plant height**

The intercropping of soybean with maize did not affect soybean plant height either at Embu or Kamujine. However, at Embu the intercrop of soybean with maize resulted in an increase of soybean plant height of about 9.34, 7.36, 10.91, and 7.19 percent in 4, 6, 8 and 12 WAP, respectively compared to its pure stand. Similar scenario was observed at Kamujine, where

the intercrop resulted in an increase of soybean plant height of about 16.24, 12.64, and 3.84 percent in 4, 6 and 8 WAP, respectively compared to the sole soybean; while during the late sampling periods (12 and 16 WAP) the intercrop of soybean with maize resulted in reduction of soybean plant height of about 15 percent compared to its monocrop (Table 4.3).

**Table 4.3:** Mean soybean plant height (cm) during 2012 LR at Embu and Kamujine sites

Location	Treatment	4 WAP	6 WAP	8 WAP	12 WAP	16 WAP
Embu	Sole soybean	13.10	15.73	28.33	44.50	44.50
	Maize-Soybean (1M:1S)	13.88	16.98	30.88	42.38	42.38
	Maize-Soybean (2M:2S)	13.63	15.70	31.80	47.95	47.95
	Maize-Soybean (2M:4S)	13.70	14.98	28.73	47.18	47.35
	Maize-Soybean (2M:6S)	14.45	16.63	30.70	46.20	46.08
<i>p</i> -value		0.6984ns	0.4751ns	0.7654ns	0.9129ns	0.9049ns
LSD <sub>(0.05)</sub>		1.97	2.51	6.64	13.83	13.61
Kamujine	Sole soybean	10.83	17.63	31.83	28.83	29.18
	Maize-Soybean (1M:1S)	12.63	18.48	30.48	25.13	25.25
	Maize-Soybean (2M:2S)	11.53	18.63	27.78	24.55	24.65
	Maize-Soybean (2M:4S)	12.93	20.18	33.10	27.28	27.28
	Maize-Soybean (2M:6S)	11.70	18.33	29.45	27.88	27.95
<i>p</i> -value		0.3239ns	0.7800ns	0.3711ns	0.4736ns	0.4448ns
LSD <sub>(0.05)</sub>		2.28	4.27	5.82	5.71	5.72

ns – not significant;

Increased soybean plant height under intercrop with maize was also been reported by Muoneke *et al.* (2007), though they observed it only at 8 WAP and Ennin *et al.* (2002) in all sampling periods. Competition for light under intercropping could have induced taller plants at the different cropping pattern compared to sole cropping of soybean (Ijoyah and Fanen, 2012). According to Keating and Carberry (1993) increased plant height of the lower component is typical responses in the intercrop due to increased far: red ratio what is this intercepted at the lower levels of the intercrop canopy. Similar Carr *et al.* (1995) who found that intercropping wheat and lentil increased lentil plant height in intercrop compared to its monocrop. On the other hand, the observed reduction of soybean plant height under intercrop

with maize compared to its sole crop during the late sampling periods (12 WAP and 16 WAP) in Kamujine is similar to observations by Undie *et al.* (2012) only at 4 WAP.

#### 4.1.2.2. Number of days to flowering and podding

During 2012 SR, soybean's growth duration to 50 percent flowering was not significantly affected by intercropping patterns in both sites (Embu and Kamujine, with  $p=0.8598$  and  $p=0.1937$ , respectively). However, there was a slight delay of 1 day in terms of days to 50 percent flowering in intercropped treatments compared to sole soybean in both sites. This could probably be due to shading effect of maize which reduces effective heat unit accumulation, resulting in longer required growth period. Still during 2012 SR, intercropping patterns affected significantly ( $p=0.0017$  and  $p=0.0069$ ) the number of days to 50 percent podding in Embu and Kamujine, respectively. For instance, in both sites podding was delayed by to 2 days due to intercropping with maize (Table 4.4).

**Table 4.4:** Mean soybean days to flowering and podding (2012 SR) at Embu and Kamujine

Location	Treatment	Days to 50% flowering	Days to 50% podding
Embu	Sole soybean	40.50	57.50
	Maize-Soybean (1M:1S)	41.00	59.50
	Maize-Soybean (2M:2S)	40.75	59.75
	Maize-Soybean (2M:4S)	40.75	59.25
	Maize-Soybean (2M:6S)	40.75	59.50
<i>p</i> -value		0.8598ns	0.0017**
LSD <sub>(0.05)</sub>		0.9642	0.9642
Kamujine	Sole soybean	36.75	54.75
	Maize-Soybean (1M:1S)	37.50	55.75
	Maize-Soybean (2M:2S)	37.50	55.75
	Maize-Soybean (2M:4S)	37.50	56.75
	Maize-Soybean (2M:6S)	37.50	56.75
<i>p</i> -value		0.1937ns	0.0069**
LSD <sub>(0.05)</sub>		0.77	1.05

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p < 0.01$ ; \*\*\*significant at  $p < 0.001$ .

Similarly, Muoneke *et al.* (2007) did not find any significant differences in terms of days to 50 per cent flowering of soybean intercropped with maize. In maize-cowpea intercropping, Mpangane *et al.* (2004) did not also find significant differences on 50 percent flowering due to cropping system. Hardley *et al.* (1983) stated that flowering is dependent on both genotype and environment.

#### **4.1.2.3. Soybean yields and components**

During both seasons in both sites, the soybean yield was significantly affected by the intercropping pattern. During the 2012 LR, the yields were reduced by 60 and 81 percent due to the intercropping with maize, at Embu and Kamujine, respectively; whereas, during the 2012 SR, the yields were reduced by 52 and 78 percent as a result of intercropping with maize, at Embu and Kamujine, respectively (Table 4.5). At Embu, during 2012 LR, the sole soybean observed significantly the highest stover yield ( $1.41 \text{ t ha}^{-1}$ ,  $p = 0.0015$ ), followed by the 2M:6S intercrop pattern with  $1.03 \text{ t ha}^{-1}$  which was statistically different from MBILI ( $0.53 \text{ t ha}^{-1}$ ,  $p = 0.0015$ ) and conventional ( $0.40 \text{ t ha}^{-1}$ ,  $p = 0.0015$ ) intercropping patterns, but not significantly different from the 2M:4S intercropping pattern. Also, the sole soybean treatment gave statistically the highest grain yield ( $1.44 \text{ t ha}^{-1}$ ,  $p=0.0002$ ) than all the intercropping patterns, followed again by the 2M:6S treatment ( $0.88 \text{ t ha}^{-1}$ ,  $p=0.0002$ ), which was significantly different from other intercropping patterns (conventional, MBILI and 2M:4S). Similar results were obtained during 2012 SR, where sole soybean treatment recorded statistically the highest stover yield ( $1.45 \text{ t ha}^{-1}$ ,  $p \leq 0.0001$ ), followed by the 2M:6S treatment ( $1.17 \text{ t ha}^{-1}$ ,  $p \leq 0.0001$ ), which was statistically different from the rest of the

intercropping patterns. Although the conventional treatment observed 28 percent higher stover yield than the MBILI treatment, they were not statistically different among them. The monocropped soybean observed also the highest grain yield ( $1.65 \text{ t ha}^{-1}$ ,  $p \leq 0.0001$ ) than all other treatments, followed by the 2M:6S treatment with  $1.01 \text{ t ha}^{-1}$  ( $p \leq 0.0001$ ), which significantly differed from the rest of the treatments. During this season, there was positive correlation between the soybean grain yield and soil nitrates, and soil mineral N, with  $r=0.56$  ( $p=0.0109$ ) and  $r=0.45$  ( $p=0.047$ ), respectively.

During both seasons, the harvest index of soybean was significantly ( $p=0.0004$  and  $p=0.0003$ , respectively) reduced by the intercropping patterns. For instance, during 2012 LR the sole soybean treatment observed the highest HI of 50.28 percent which was significantly ( $p=0.0004$ ) different from all other treatments. Similar results were obtained during 2012 SR, where sole soybean recorded significantly ( $p=0.0003$ ) the highest HI (53.52 per cent) than all the other treatments, excluding the 2M:4S treatment. During the 2012 LR, the soybean stover yields was significantly ( $p \leq 0.05$ ) positively correlated with the N uptake at all the sampling periods, except at 16 WAP and 20WAP.

At Kamujine during 2012 LR, the sole soybean treatment gave statistically the highest stover and grain yields ( $1.09 \text{ t ha}^{-1}$ ,  $p \leq 0.0001$  and  $0.56 \text{ t ha}^{-1}$ ,  $p=0.0007$ , respectively) than all the other treatments, followed by the 2M:6S treatment with  $0.78 \text{ t ha}^{-1}$  for the stover yield, which was significantly different ( $p \leq 0.0001$ ) from the other intercropping patterns. However the soybean yields from MBILI intercropping pattern was not statistically different from the conventional intercropping pattern. During the 2012 LR season, there was significant positive correlation between the soybean grain yield and, soil mineral N, with  $r=0.73$  ( $p=0.0002$ ) and

$r=0.76$  ( $p \leq 0.0001$ ), respectively. During 2012 SR, monocropped soybean treatment observed also significantly the highest stover yield ( $1.27 \text{ t ha}^{-1}$ ,  $p=0.0004$ ) than all the other treatments. Similarly, sole soybean treatment recorded the highest grain yield of  $0.72 \text{ t ha}^{-1}$  ( $p \leq 0.0001$ ) than all the other treatments. During this season, there was also positive correlation between the soybean grain yield and, soil mineral N, with  $r=0.61$  ( $p=0.0043$ ) and  $r=0.60$  ( $p \leq 0.0053$ ), respectively. During both season, the harvest index of soybean was not significantly ( $p=0.0864$ ;  $p=0.0988$ ) affected by the intercropping patterns; however, it was numerically reduced by the intercropping patterns. In general, the yields increased with about 23 and 26 percent in the second season compared to the first season, at Embu and Kamujine, respectively. Probably due to the cumulative effects of the goat manure that was applied in the first and second seasons, and also due to root and nodule senescence.

**Table 4.5:** Mean soybean yields and harvest index at Embu and Kamujine

Location	Treatment	Stover yield (t ha <sup>-1</sup> )		Grain yield (t ha <sup>-1</sup> )		Harvest Index (%)	
		2012 LR	2012 SR	2012 LR	2012 SR	2012 LR	2012 SR
Embu	Sole soybean	1.41	1.45	1.44	1.65	50.28	53.52
	Maize-Soybean (1M:1S)	0.40	0.76	0.26	0.41	39.26	35.38
	Maize-Soybean (2M:2S)	0.53	0.55	0.35	0.42	39.98	43.17
	Maize-Soybean (2M:4S)	0.60	0.83	0.46	0.76	42.95	47.98
	Maize-Soybean (2M:6S)	1.03	1.17	0.88	1.01	45.99	46.60
<i>p-value</i>		0.0015**	0.0001***	0.0002***	< 0.0001***	0.0004***	0.0003***
LSD <sub>(0.05)</sub>		0.43	0.28	0.39	0.18	4.02	5.73
Kamujine	Sole soybean	1.09	1.27	0.56	0.72	32.39	36.41
	Maize-Soybean (1M:1S)	0.18	0.21	0.05	0.07	19.44	23.74
	Maize-Soybean (2M:2S)	0.19	0.24	0.04	0.08	19.29	24.31
	Maize-Soybean (2M:4S)	0.52	0.58	0.17	0.30	22.42	36.56
	Maize-Soybean (2M:6S)	0.78	0.83	0.24	0.37	22.55	33.65
<i>p-value</i>		< 0.0001***	0.0004***	0.0007***	< 0.0001***	0.0864	0.0988
LSD <sub>(0.05)</sub>		0.13	0.39	0.20	0.08	10.17	12.52

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .

At Embu during the 2012 LR, there were significant differences in soybean stover yield ( $p=0.0278$ ) among the rows in 2M:4S treatment, where the row next to the maize plant observed 16.7 percent lower yield than the row far away from the maize plant. For the grain yield, the row far away from the maize plant gave 20 percent significantly higher ( $p=0.0009$ ) yield than the row next to maize plant. During the 2012 SR, the soybean stover and grain yields were 9.5 and 14.8 percent significantly ( $p = 0.0113$  and  $p = 0.0108$ , respectively) higher in the middle row than in the row next to the maize plant, respectively. At Kamujine during the 2012 LR, there were no significant differences ( $p = 0.7292$ ) on soybean stover yield between the middle row and the row next to the maize plant; whereas the grain yield in the middle row was 21 percent significantly ( $p=0.0251$ ) higher than in the row next to the maize plant. During the 2012 SR, the soybean stover and grain yields were 22.2 and 25.9 percent significantly ( $p=0.0088$  and  $p=0.0085$ , respectively) lower in the closer row than in the middle row, respectively (Table 4.6).

**Table 4.6:** Shading effect on soybean yield in the 2M:4S during 2012 LR and 2012 SR at Embu and Kamujine sites

Location	Row position	Maize-Soybean (2M:4S)			
		Stover yield (t/ha)		Grain yield (t/ha)	
		2012 LR	2012 SR	2012 LR	2012 SR
Embu	Middle	0.07	0.095a	0.05	0.061a
	Closer	0.06	0.086b	0.04	0.052b
<i>p-value</i>		0.0278*	0.0113**	0.0009***	0.0108**
LSD <sub>(0.05)</sub>		0.01	0.007	0.01	0.007
Kamujine	Middle	0.05	0.066	0.019	0.034
	Closer	0.05	0.054	0.015	0.027
<i>p-value</i>		0.7292	0.0088**	0.0251*	0.0085**
LSD <sub>(0.05)</sub>		0.01	0.009	0.004	0.005

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .

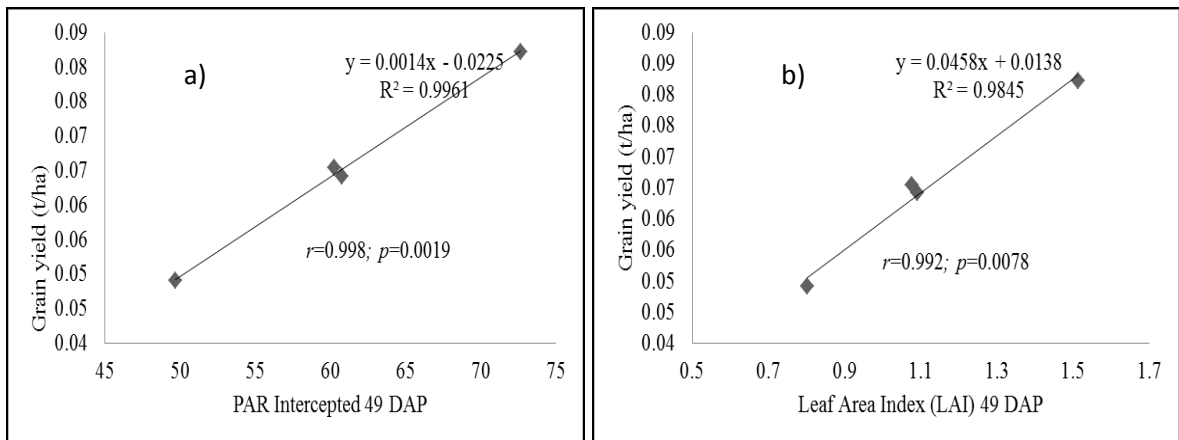
At Embu during the 2012 LR, there were significant differences in soybean stover yield ( $p=0.0179$ ) among rows in 2M:6S intercropping pattern. The middle row recorded about 27.3 percent higher yield than the row next to the maize row. For the grain yield, the middle row observed 30 percent significantly higher ( $p=0.0236$ ) than the row closer to maize plant. During the 2012 SR, the soybean stover yield did not show significant differences ( $p=0.1008$ ) between the row next to the maize plant and one in the middle row; however, it was numerically 7.7 percent higher in the middle row than in the row next to the maize plant. The grain yield was 25 percent significantly ( $p=0.0297$ ) higher in middle row than in the closer row. At Kamujine during the 2012 LR, there were no significant differences ( $p=0.1049$ ) on soybean stover yield between the row middle row and the row closer to the maize plant; whereas the grain yield in the middle row was 33.3 percent significantly ( $p=0.0305$ ) higher than in the closer row. During the 2012 SR, the soybean stover and grain yields were 40.0 and 44.6 percent significantly ( $p=0.0051$  and  $p=0.0017$ , respectively) higher in the middle row than in the closer row, respectively (Table 4.7).

**Table 4.7:** Shading effect on soybean yield in the 2M:6S treatment during 2012 LR and 2012 SR at Embu and Kamujine sites

Location	Row position	Maize-Soybean (2M:6S)			
		Stover yield (t/ha)		Grain yield (t/ha)	
		2012 LR	2012 SR	2012 LR	2012 SR
Embu	Middle	0.11	0.13a	0.10	0.12a
	Closer	0.08	0.12a	0.07	0.09b
<i>p-value</i>		0.0179*	0.1008	0.0236*	0.0297*
LSD <sub>(0.05)</sub>		0.03	0.02	0.03	0.02
Kamujine	Middle	0.086	0.10a	0.024	0.065a
	Closer	0.066	0.060b	0.016	0.036b
<i>p-value</i>		0.1049	0.0051**	0.0305*	0.0017**
LSD <sub>(0.05)</sub>		0.025	0.03	0.007	0.02

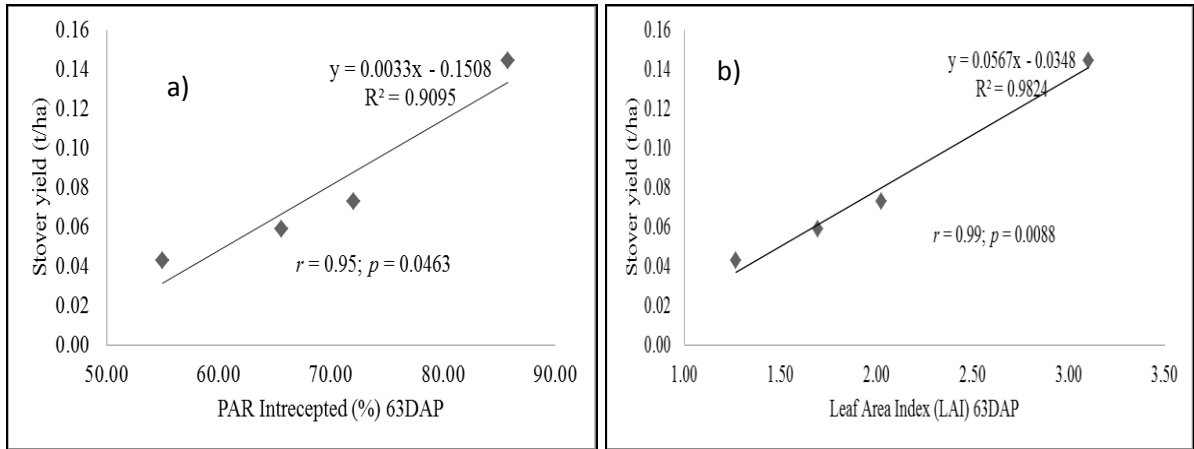
ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .

At Embu site, during the 2012 SR there was statistically significant strong positive correlation between soybean grain yields of the middle row and PAR intercepted ( $r=0.998$ ;  $p=0.0019$ ) and LAI ( $r=0.992$ ;  $p=0.0078$ ), at 49 DAP (Figure 4.1).

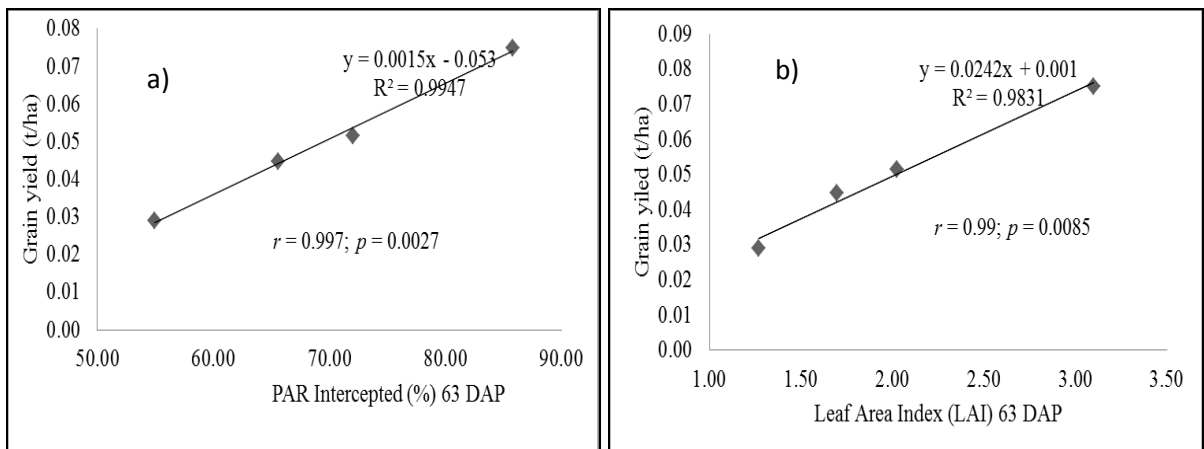


**Figure 4.1:** Relationship between soybean grain yield with PAR intercepted (a) and LAI (b) in middle rows during 2012 SR at Embu site.

At Kamujine site, during 2012 SR also middle rows showed existence of significant correlation between soybean yields and light intercepted and leaf area index, at 63 DAP. For instance, soybean stover yield was strongly positive correlated with the PAR intercepted ( $r=0.95$ ;  $p=0.0463$ ) and LAI ( $r=0.99$ ;  $p=0.0088$ ), as indicated by Figure 4.2. Similarly, there was strong positive correlation between soybean grain yield with the amount of light intercepted ( $r=0.997$ ;  $p=0.0027$ ) and LAI ( $r=0.99$ ;  $p=0.0085$ ) (Figure 4.3)



**Figure 4.2:** Relationship between soybean stover yield with PAR intercepted (a) and LAI (b) in middle rows during 2012 SR at Kamujine site.



**Figure 4.3:** Relationship between soybean grain yield with PAR intercepted (a) and LAI (b) in middle rows during 2012 SR at Kamujine site

The reduction of soybean yields under intercropping with maize or sorghum has also been reported by several researchers (Ijoyah and Fanen, 2012; Egbe, 2010; Muoneke *et al.*, 2007; Muneer *et al.*, 2004; Heibsch *et al.*, 1995; Olufajo, 1992; Pal *et al.*, 1992; Neupane, 1983). This reduction in soybean yields under intercropping could be due to interspecific competition between the intercrop components for water, light, air and nutrients, and also the aggressive effects maize ( $C_4$  species) on soybean, a  $C_3$  species (Egbe, 2010; Muoneke *et al.*,

2007). According to Heibsch *et al.* (1995), crops with C<sub>4</sub> photosynthetic pathways have been known to be dominant when intercropped with C<sub>3</sub> species like soybean. The shading of soybean by the maize plants (taller) may also have contributed to the reduction of the yields of intercropped soybean. Olufajo (1992) reported that shading by the taller plants in mixture could reduce the photosynthetic rate of the lower growing plants and thereby reduce their yields. This observation was confirmed in this study where lower soybean yields were recorded in the rows next to the maize plant compared to the middle row, and the yields positively correlated with the PAR intercepted. In addition, Lesoing and Francis (1999) stated that water stress and shading were probably the two major factors, which contribute to reduced legume component yield under intercropping. Moreover, Natarajan and Willey (1980) and Sivakumar and Virmani (1980) reported that stover yield often shows a positive correlation with the amount of radiation intercepted by crops in intercropping systems. However in the current study there was a positive correlation between grain yield with the amount of radiation intercepted by crops in intercropping treatments.

The reduction of harvest index of the legume component observed in this study was also reported by other researchers (Alhassan *et al.*, 2012; Zaefarian *et al.*, 2007). The reduction was mainly due to maize shading effects on soybean, which caused the legume component to allocate its photosynthates to vegetative growth and height increasing for competing with taller maize. On the other hand, the findings at Kamujine site are in agreement with Carruthers *et al.* (2000) who reported that the HI for intercrop soybean was not significantly different from monocrop soybean.

#### **4.1.2.4. Effects of maize–soybean intercropping patterns on N uptake by maize**

##### **4.1.2.4.1. Soil mineral N**

At Embu during 2012 LR, no significant differences were observed in soil nitrate – N content ( $\text{NO}_3^-$  - N) among the intercropping patterns during all the sampling periods at 15 cm depth, except at 12 WAP where the 2M:4S treatment observed significantly ( $p=0.0285$ ) higher  $\text{NO}_3^-$  - N content ( $9.01 \text{ mg kg}^{-1}$ ) than all other treatments, excluding sole maize treatment. At harvest (20 WAP) the MBILI and 2M:4S treatments observed significantly ( $p=0.0525$ ) the lowest  $\text{NO}_3^-$  - N content ( $8.24 \text{ mg kg}^{-1}$  and  $9.15 \text{ mg kg}^{-1}$ , respectively) than the sole soybean and conventional treatments, with  $14.95 \text{ mg kg}^{-1}$  and  $14.62 \text{ mg kg}^{-1}$ , respectively. This is an indication that intercropping may have reduced the soil nitrate that moved to region where it could not be easily absorbed by plant roots. Similarly, at Kamujine during the same season (2012 LR), no significant differences were observed in soil nitrate – N content ( $\text{NO}_3^-$  - N) among the intercropping patterns during all the sampling periods, except at 20 WAP where sole soybean treatment recorded statistically ( $p = 0.0301$ ) higher  $\text{NO}_3^-$  - N content ( $8.24 \text{ mg kg}^{-1}$ ) than all other treatments, except the 2M:4S treatment (Table 4.8).

**Table 4.8:** Mean soil nitrate-N at different periods during 2012 LR at Embu and Kamujine sites

Location	Treatment	Weeks After Planting (WAP)						
		0	4	6	8	12	16	20
		Nitrate – N (NO <sub>3</sub> <sup>-</sup> - N) mg kg <sup>-1</sup>						
Embu	Sole maize	5.19	9.18	6.55	6.65	6.72	4.59	8.24
	Sole soybean	7.42	9.81	8.62	7.83	5.78	5.76	14.95
	Maize-Soybean (1:1)	6.95	11.36	6.06	8.17	4.71	5.01	14.62
	Maize-Soybean (2:2)	10.22	6.08	7.80	8.77	5.66	5.10	12.20
	Maize-Soybean (2:4)	8.77	10.07	6.50	8.07	9.01	5.56	9.15
	Maize-Soybean (2:6)	8.76	8.50	7.49	5.53	4.69	7.16	10.38
<i>p-value</i>		0.4638	0.1780	0.9224	0.7915	0.0285*	0.7444	0.0525*
LSD <sub>(0.05)</sub>		5.36	4.04	5.52	5.23	2.62	3.69	5.01
Kamujine	Sole maize	13.31	5.75	7.38	5.47	5.12	5.17	3.73
	Sole soybean	12.87	9.37	9.00	8.79	8.06	6.67	8.24
	Maize-Soybean (1:1)	10.71	8.51	6.25	4.12	4.38	4.08	3.78
	Maize-Soybean (2:2)	11.94	6.31	4.14	5.57	3.40	4.30	3.14
	Maize-Soybean (2:4)	14.72	6.40	6.38	6.06	5.76	5.32	6.14
	Maize-Soybean (2:6)	9.53	8.04	6.62	6.51	4.01	4.93	1.66
<i>p-value</i>		0.6283	0.7124	0.2385	0.0567	0.0728	0.4762	0.0301*
LSD <sub>(0.05)</sub>		6.70	5.71	3.86	2.80	3.13	2.84	3.90

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .

The low soil nitrate content observed at harvest (20 WAP) in maize – soybean intercrop agrees with results of Ye *et al.* (2008) who reported that the soil nitrate N was lower under faba bean – pea intercrop than under their monocrops. Li *et al.* (2005) and, Zhang and Li (2003) also reported that intercropping maize with faba beans decreased the soil nitrate – N content at harvest. Intercropping faba beans with wheat reduced the nitrate concentration in soil profile (Stuelpnagel, 1993). This might be due to the complimentary root distribution of cereal/legume intercrop or the increased time of plant uptake of N by maize in intercropping systems (Li *et al.*, 2005). For instance, Li *et al.* (2005) found that in the maize – faba beans system, maize roots were distributed in both the profiles of maize and faba beans. Thus, maize could utilize the nitrate in the strip of intercropping faba beans (Li, 1999).

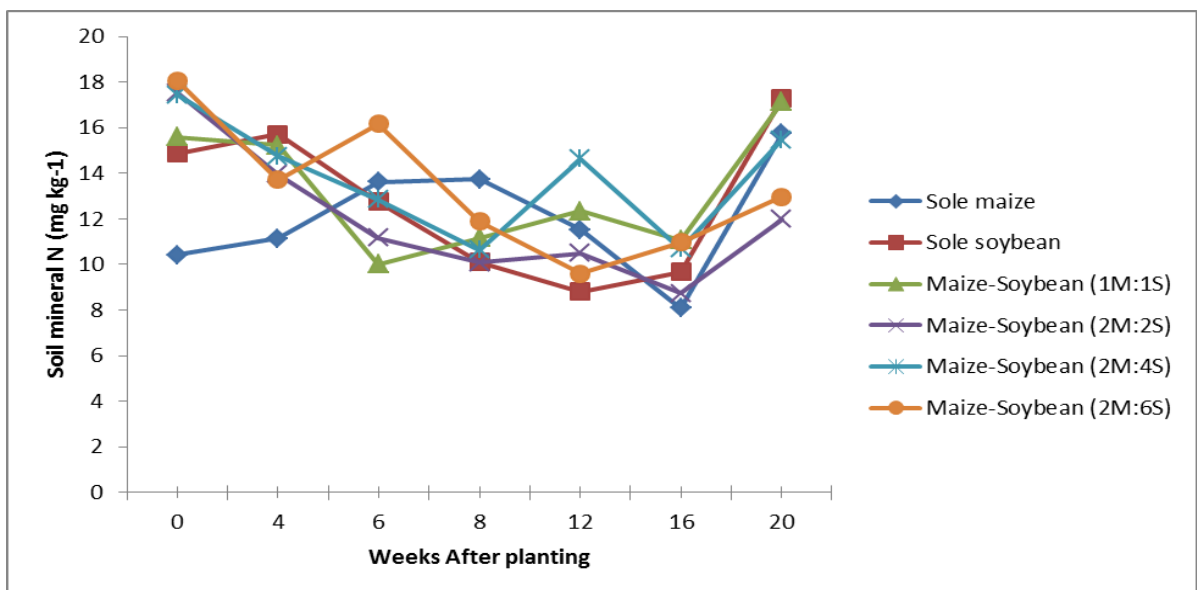
At Embu during 2012 LR, no significant differences were observed in soil ammonium – N content ( $\text{NH}_4^+$  - N) among the intercropping patterns during all the sampling periods. Similar results were also observed at Kamujine, where the treatments had no significant effect of soil ammonium – N (Table 4.9). The findings indicate that intercropping patterns had little effect on soil ammonium nitrogen. Similar results were also observed by Huang *et al.* (2011) on soil ammonium N under maize-legume intercropping systems. However, there was a general increase in general increase in ammonium – N at the end of the season. This increase could be due to dry soil conditions that helped the microorganisms to mineralize organic – N from residues into ammonium – N, making it available in the soil solution at that particular period. Similar findings were also reported by Anggria *at al.* (2012) who found that under dry conditions with aerobic conditions the ammonification of organic residues was faster than the oxidation of ammonium to nitrate, and resulted in a higher ammonium accumulation.

**Table 4.9:** Mean soil ammonium-N at 0–15 cm soil depth sampled at different periods during 2012 LR at Embu and Kamujine sites

Location	Treatment	Weeks After Planting						
		0	4	6	8	12	16	20
		<b>Ammonium – N (NH<sub>4</sub><sup>+</sup> - N) mg kg<sup>-1</sup></b>						
Embu	Sole maize	5.24	5.07	5.82	4.96	5.87	2.99	3.54
	Sole soybean	7.45	5.89	4.14	2.28	3.03	3.90	2.32
	Maize-Soybean (1:1)	7.64	3.86	3.96	2.99	7.63	6.06	2.52
	Maize-Soybean (2:2)	7.31	4.78	4.61	3.41	3.77	4.14	3.75
	Maize-Soybean (2:4)	8.67	4.69	6.26	2.56	5.64	5.16	6.32
	Maize-Soybean (2:6)	9.31	5.23	8.67	6.36	4.91	3.80	2.59
<i>p-value</i>		0.8610	0.7855	0.2338	0.0930	0.4800	0.7602	0.4771
LSD <sub>(0.05)</sub>		6.92	2.91	4.29	3.12	5.06	4.57	4.63
Kamujine	Sole maize	6.42	5.11	4.84	3.25	3.53	1.72	3.78
	Sole soybean	6.86	5.29	2.39	5.59	6.28	5.62	4.60
	Maize-Soybean (1:1)	5.84	4.33	6.95	5.42	3.49	5.17	3.45
	Maize-Soybean (2:2)	3.96	3.71	3.79	4.62	6.99	4.77	2.89
	Maize-Soybean (2:4)	7.51	6.53	6.85	1.27	5.16	5.49	3.12
	Maize-Soybean (2:6)	6.11	5.66	4.73	4.47	6.48	3.98	4.10
<i>p-value</i>		0.6406	0.7239	0.5532	0.1578	0.5169	0.3174	0.6718
LSD <sub>(0.05)</sub>		4.41	3.97	5.87	3.56	4.91	3.88	2.38

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .

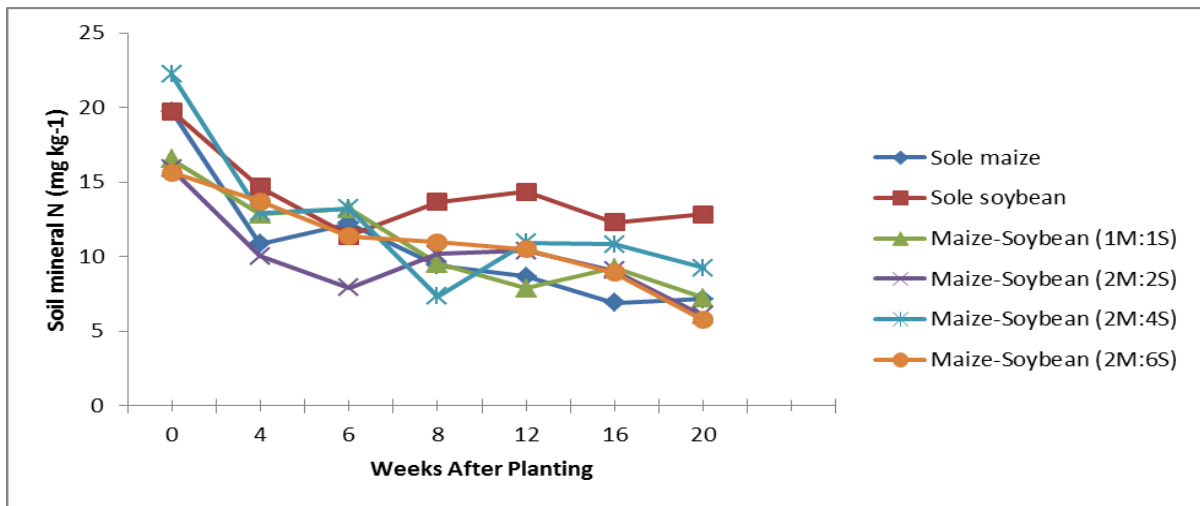
At Embu during 2012 LR, no significant differences were observed in soil mineral – N content among the intercropping patterns during all the sampling periods. However, there was general increase of soil mineral N for the MBILI, sole soybean and conventional treatments, where the MBILI treatment observed the highest value (51.06 percent) followed by the sole soybean with 16.21 percent (Figure 4.4). On the other hand, there was general decrease of soil mineral N for the sole maize, 2M:4S, and 2M:6S treatments, where the sole maize recorded the highest decrease of 31.60 percent (Figure 4.4).



**Figure 4.4.** Soil mineral – N trend at 0–15 cm soil depth sampled at different periods during 2012 LR at Embu.

Similarly, Hauggaard-Nielsen *et al.* (2001a) did not find significant differences on soil mineral N at harvest in the 0-25 cm soil layer under pea sole crop compared to the other treatments. The increase on soil mineral N for sole soybean and some of the intercropping treatments was also reported by Rusinamhodzi (2006) who found that soil mineral N had increased in sole cowpea and cowpea-cotton treatments but not sole cotton cropping system.

At Kamujine during 2012 LR, no significant differences were observed in soil mineral – N content as result of the treatments during all the sampling periods. Despite that, there was general decrease of soil mineral N in all the treatment, where the sole maize and sole soybean treatments recorded the highest (63.76 percent) and the lowest (34.92 percent) values, respectively (Figure 4.5).



**Figure 4.5.** Soil mineral – N trend at 0–15 cm soil depth sampled at different periods during 2012 LR at Kamujine

Similarly, Hauggaard-Nielsen *et al.* (2001b) observed higher soil mineral N at harvest in the 0-25cm soil layer under pea sole crop compared to the other treatments independent of cropping strategy. Hauggaard-Nielsen *et al.* (2001c) observed that the lowest soil inorganic N deficit was observed in pea sole crop and the greatest in barley sole crop. This suggests that legume and non-legume intercrops are not likely to increase soil N in the long term, but rather deplete it (Hauggaard-Nielsen *et al.*, 2001c). Jensen (1996) equivalently concluded that the N balance was positive for sole cropped pea, whereas it was negative for barley and pea-barley in all years.

#### 4.1.2.4.2. Nitrogen uptake by maize and soybean

At Embu during 2012 LR, the N uptake of maize and soybean was significantly affected by the intercropping patterns (Table 4.10). For instance, at 4 WAP the sole soybean yielded significantly the highest N amount (2.75 percent N,  $p=0.0026$ ) than all the other treatments, excluding intercropped soybean. This was strongly correlated ( $r=0.81$ ;  $p=0.0988$ ) with soil mineral at the same sampling period (4 WAP); however the correlation was not significant at  $p=0.05$ . At 16 WAP the sole soybean had significantly accumulated the lowest N (0.35 percent N,  $p \leq 0.0001$ ) than all the other treatments, except soybean under 2M:2S, 2M:4S and 2M:6S treatments. Also, the N uptake by soybean during this period was positively correlated ( $r=0.48$ ;  $p=0.4125$ ) with soil mineral N at the same sampling period. The maize under MBILI treatment observed significantly ( $p \leq 0.0001$ ) the highest N uptake of  $14.88 \text{ kg ha}^{-1}$  than all other treatments, followed by maize under 2M:6S, which was not significantly different to soybean component under all the treatments; and sole soybean observed significantly the lowest N uptake ( $0.13 \text{ kg ha}^{-1}$ ), though not statistically different from other soybean treatments. Also, maize under MBILI treatment observed significantly the highest N uptake to the grain ( $9.41 \text{ kg ha}^{-1}$ ) than sole soybean, soybean under MBILI, soybean under 2M:4S and soybean under 2M:6S treatments. The N accumulated in maize grain was positively correlated with soil mineral N at 4 and 16 WAP, with  $r=0.87$  ( $p=0.0543$ ) and  $r=0.81$  ( $p=0.0995$ ), respectively. In general, the N accumulation by maize under intercropping treatments was generally lower than for sole cropping, particularly up to 12 WAP (Table 4.10).

**Table 4.10:** Mean N uptake by maize and soybean during 2012 LR at Embu and Kamujine sites

Location	Treatment	Crop	Weeks After Planting					N uptake (kg ha <sup>-1</sup> )	
			4	6	8	12	16	20	Stover
			Plant N concentration (%)						
Embu	Sole maize	Maize	1.69	1.73	2.79	2.52	1.78	9.32	6.12
	Sole soybean	Soybean	2.75	1.96	2.88	1.48	0.35	0.13	2.67
	Maize-Soybean (1M:1S)	Maize	1.30	1.69	2.67	2.18	1.95	9.21	7.02
		Soybean	2.59	2.02	2.98	2.19	1.21	1.19	5.75
	Maize-Soybean (2M:2S)	Maize	1.38	1.39	2.80	2.02	2.16	14.88	9.41
		Soybean	2.43	2.02	3.34	2.08	0.53	0.44	3.78
	Maize-Soybean (2M:4S)	Maize	1.82	1.87	2.72	2.45	1.88	7.52	7.25
		Soybean	2.25	2.07	3.53	2.07	0.60	0.33	1.56
	Maize-Soybean (2M:6S)	Maize	1.02	1.34	2.33	2.39	1.90	10.00	6.58
	Soybean	2.20	1.90	2.93	1.99	0.45	0.31	3.15	
<i>p</i> – value			0.0026**	0.4320	0.1942	0.6001	<0.0001***	<0.0001***	0.0041**
LSD <sub>(0.05)</sub>			0.86	0.74	0.80	0.94	0.73	3.54	3.70
Kamujine	Sole maize	Maize	1.60	1.66	1.97	1.43	1.07	3.95	3.30
	Sole soybean	Soybean	3.00	2.60	3.16	3.31	0.69	1.27	2.92
	Maize-Soybean (1M:1S)	Maize	1.24	1.61	1.78	1.43	1.04	3.50	4.30
		Soybean	2.87	4.28	2.97	2.22	0.26	0.06	0.25
	Maize-Soybean (2M:2S)	Maize	1.31	1.33	2.05	1.77	1.75	4.85	3.47
		Soybean	3.26	2.79	2.68	1.72	0.38	0.07	0.21
	Maize-Soybean (2M:4S)	Maize	1.73	1.79	2.43	1.79	0.61	1.44	2.13
		Soybean	2.79	2.12	2.98	2.84	0.71	0.35	0.86
	Maize-Soybean (2M:6S)	Maize	0.97	1.28	2.27	1.09	0.86	1.52	2.84
	Soybean	3.20	3.19	2.72	1.78	0.99	0.56	1.09	
<i>p</i> – value			<0.0001****	<0.0001*	0.0102**	0.0031**	0.0053**	<0.0001***	<0.0001***
LSD <sub>(0.05)</sub>			0.87	0.99	0.78	1.00	0.65	1.78	1.47

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .

During 2012 LR at Kamujine site, intercropping systems affected significantly the N uptake by maize and soybean (Table 4.10). For instance, at 4 WAP the soybean under MBILI treatment had accumulated significantly higher N (3.26 percent N,  $p \leq 0.0001$ ) than maize under different treatments. The N uptake was highly positively correlated ( $r=0.79$ ;  $p=0.1089$ ) with soil mineral N of the same sampling period. At 6 WAP the soybean under conventional treatment yielded significantly the highest N (4.28 percent N,  $p \leq 0.0001$ ) than all the other treatments. At 8 WAP the soybean sole acquired significantly the highest N (3.16 per cent N,  $p=0.0102$ ) than sole maize and maize under conventional, MBILI, and 2M:6S treatments.

The N uptake by maize was significantly positively correlated ( $r=0.88$ ;  $p=0.051$ ) with soil mineral N during the same period. At 12 WAP the sole soybean also recorded significantly the highest N (3.31 percent N,  $p=0.0031$ ) than all the other treatments, excluding soybean under 2M:4S treatment. During this sampling period, the amount of N accumulated by soybean was highly significantly positively correlated ( $r=0.91$ ;  $p=0.0301$ ) with soil mineral N of the same period and soil mineral N at 16 WAP ( $r=0.89$ ;  $p=0.0437$ ), respectively. Whereas towards the end of season (at 16 WAP) the maize under MBILI treatment acquired statistically the highest N (1.75 percent N,  $p=0.0053$ ) than all the other intercropping patterns. At harvest, still the maize under MBILI treatment accumulated significantly the highest N ( $4.85 \text{ kg N ha}^{-1}$ ,  $p < 0.0001$ ) than all other treatments, except sole maize and maize under conventional treatments. At this moment the amount of N yielded by soybean was strongly correlated ( $r=0.78$ ;  $p=0.1201$ ) with the soil mineral N for the period. For the grain, the maize under conventional treatment observed significantly the highest N uptake ( $4.30 \text{ kg ha}^{-1}$ ,  $p \leq 0.0001$ ) than all other treatments, excluding sole maize, maize under MBILI, sole soybean and maize under 2M:6S treatments (Table 4.10).

The greater N acquisition by a non-legume crop intercropped with a legume is frequently reported in literature (Francis, 1986; Stern, 1993; Li *et al.*, 2001; Shata *et al.*, 2007). In cereal-legume intercropping, an increase in N acquisition may be derived in two ways. First, the difference in competitive abilities of component species may increase N uptake by cereal, which in most cases has higher competitive ability relative to legume. This may conversely stimulate nodulation in legume, as noted by Rerkasem *et al.* (1988) for beans intercropped with maize. Second, an increase in N acquisition may also be attributed to N transfer to cereal from legume (Brophy *et al.*, 1987). The higher N facilitation may enable cereal to absorb more N in intercropping systems than in sole cropping systems, or it may increase the N fixation ability of legumes and may transfer from legume to cereal (Ning *et al.*, 2012). However, in the experimental sites the soils are moderately acidic (pH=5.33 and pH=5.46, at Embu and Kamujine sites, respectively), limiting phosphorus availability, which is harmful for BNF process and therefore lessen the N contribution of the legume component to system.

Furthermore, according to Jones and Giddens (1985) there are a number of factors that affect N<sub>2</sub> fixation by legume in acid soil. The number of compatible rhizobia in the rhizosphere and the degree of infection of the root by the bacteria are important factors, which are controlled by environmental conditions such as soil pH. Thus, in cereal-legume intercropping, without N-fixing and transfer, the N demand of each intercrop may also increase N competition, particularly when relatively low amount of fertilizer-N and soil-N are used (Li *et al.*, 2003a; Li *et al.*, 2003b). Simpson (1965) stated that in some of the intercropping systems, competition by the legume for N is high and results in reduced N uptake by the cereal, and in this study it resulted in higher uptake by soybean as compared to the maize component. On the other hand, the higher N uptake by maize observed under

MBILI treatment at Kamujine site could be due to the fact that during that time the legume component had accomplished its N requirements and about to be harvested. Therefore, the competition for N could be reduced to its minimum.

#### **4.1.2.5. Effects of maize – soybean intercropping patterns on chemical soil properties**

At Embu site, before planting the pH values were not significantly different ( $p=0.6585$ ) among the treatments, and ranged from 5.30 (for conventional and MBILI treatments) to 5.37 (for sole soybean treatment). Results of soil pH at harvest showed that the treatments did not significantly ( $p=0.5581$  and  $p=0.7956$ , respectively) affect the soil pH. However, there was a general decrease across the seasons the highest and lowest reduction was observed in the sole maize (2.49 percent) and the conventional (0.57 percent) treatments, respectively. This situation was not expected because manure that was applied as blank was supposed to have increased the soil pH in all the treatments due to its buffer capacity; but, probably the exchangeable cations were leached from the topsoil (0-15 cm) because of the heavy rains that were registered during the seasons. It also could be due to the quality of the manure applied, that probably had not enough cations on it that could raise the pH of the soil. At Kamujine, although there were also no significant differences in the three sampling periods ( $p=0.3046$ ,  $p=0.1946$  and  $p=0.0835$ , respectively), the situation was slightly different at Embu because the pH values increased from the pre-season to post second season, where the sole maize recorded the highest increase (8.31 percent) and 2M:6S treatment with the lowest value of 4.03 percent (Table 4.11).

**Table 4.11:** Mean soil pH in various treatments at Embu and Kamujine

Location	Treatment	pH (water, 1:2.5)		
		At planting	2012LR	2012SR
Embu	Sole maize	5.36	5.20	5.23
	Sole soybean	5.37	5.20	5.26
	Maize-Soybean (1M:1S)	5.30	5.32	5.27
	Maize-Soybean (2M:2S)	5.30	5.34	5.26
	Maize-Soybean (2M:4S)	5.36	5.32	5.30
	Maize-Soybean (2M:6S)	5.31	5.25	5.22
<i>p-value</i>		0.6585	0.5581	0.7956
LSD <sub>(0.05)</sub>		0.12	0.21	0.13
Kamujine	Sole maize	5.41	5.62	5.90
	Sole soybean	5.43	5.51	5.71
	Maize-Soybean (1M:1S)	5.55	5.63	5.91
	Maize-Soybean (2M:2S)	5.41	5.55	5.73
	Maize-Soybean (2M:4S)	5.49	5.62	5.87
	Maize-Soybean (2M:6S)	5.48	5.49	5.71
<i>p-value</i>		0.3046	0.1946	0.0835
LSD <sub>(0.05)</sub>		0.15	0.15	0.19

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .

At Embu site, the available phosphorus values did not show any significant differences ( $p=0.2373$ ,  $p=0.6963$ ,  $p=0.3224$ , respectively) among the treatments, during all the sampling periods. However, the P values generally decreased from the pre-season to the post second season. Similar situation was observed at Kamujine site, where P values were also not significantly different during the three sampling periods ( $p=0.7243$ ,  $p=0.6508$  and  $p=0.6775$ , respectively). However, P also decreased from the pre-season to post second season (Table 4.12).

**Table 4.12:** Mean available Phosphorus at Embu and Kamujine

Location	Treatment	Phosphorus (ppm)		
		At planting	2012LR	2012SR
Embu	Sole maize	12.85	12.81	8.43
	Sole soybean	13.21	13.74	7.94
	Maize-Soybean (1M:1S)	12.21	15.03	8.99
	Maize-Soybean (2M:2S)	12.65	13.39	8.93
	Maize-Soybean (2M:4S)	15.78	13.62	9.31
	Maize-Soybean (2M:6S)	13.68	13.46	8.20
	<i>p-value</i>	0.2373	0.6963	0.3224
<i>LSD</i> <sub>(0.05)</sub>		3.09	2.86	1.40
Kamujine	Sole maize	9.50	10.84	6.21
	Sole soybean	9.50	12.15	6.64
	Maize-Soybean (1M:1S)	10.21	12.20	6.48
	Maize-Soybean (2M:2S)	8.76	13.01	6.36
	Maize-Soybean (2M:4S)	9.18	10.27	6.37
	Maize-Soybean (2M:6S)	10.02	12.56	7.20
	<i>p-value</i>	0.7243	0.6508	0.6775
<i>LSD</i> <sub>(0.05)</sub>		2.13	3.88	1.33

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .

This generalized decline of available P under different cropping systems was also reported by Ahmad and Rao (1982) who found that sole maize, sole cowpea, maize-pigeonpea, pigeonpea-cowpea treatments had resulted in reduction of extractable P. This suggests that the P inputs applied as black were not enough to satisfy the needs of the crops and remain in the soil (Ahmad and Rao, 1982).

At Embu site, before planting the  $\text{Ca}^{2+}$  values were not significantly different ( $p=0.2670$ ) among the treatments and ranged between 0.26 and 0.18  $\text{Cmol kg}^{-1}$  for 2M:4S and MBILI treatment, respectively. After harvesting the first (2012 LR) and second (2012 SR) seasons Calcium was not significantly affected ( $p=0.4209$  and  $p=0.7795$ , respectively) by the

treatments. However, Calcium recorded a general decrease from the preseason to post second season. At Kamujine site, there were also no significant differences in the three sampling periods ( $p=0.6791$ ,  $p=0.4224$  and  $p=0.1715$ , respectively); and, similarly the  $\text{Ca}^{2+}$  values observed reduction at the end of 2012 SR (Table 4.13).

At Embu site, the  $\text{Mg}^{2+}$  values were comparable among the treatments, during the sampling periods. However, the values slightly decreased from the preseason to the post second season. Slightly different situation was observed at Kamujine site, where  $\text{Mg}^{2+}$  values were only significantly ( $p \leq 0.0001$ ) affected by the treatment during 2012 SR, having sole maize treatment observed statistically the highest  $\text{Mg}^{2+}$  value of  $0.37 \text{ Cmol kg}^{-1}$  than all other treatments (Table 4.13).

At Embu site, the  $\text{K}^+$  values were comparable among the treatments, during the sampling periods. However, the  $\text{K}^+$  values generally decreased from the preseason to the post second season. Similar situation was observed at Kamujine site, where  $\text{K}^+$  values were also not significantly different in the three sampling periods. But differently from Embu site, at Kamujine site they showed three different trends, where in the sole maize and 2M:6S treatments the values remained constant; in the sole soybean and conventional treatments the values were slightly increased; and in the MBILI and 2M:4S treatments, the values decreased from the preseason to post second season (Table 4.13).

**Table 4.13:** Effect of intercropping patterns on soil chemical properties (exchangeable cations) during 2012 LR and 2012 SR at Embu and Kamujine sites

Location	Treatment	Ca <sup>2+</sup> (cmol kg <sup>-1</sup> )			Mg <sup>2+</sup> (cmol kg <sup>-1</sup> )			K <sup>+</sup> (cmol kg <sup>-1</sup> )		
		(Baseline)	2012LR	2012 SR	(Baseline)	2012LR	2012 SR	(Baseline)	2012LR	2012 SR
Embu	Sole maize	0.25	0.24	0.08	0.55	0.49	0.47	0.13	0.10	0.04
	Sole soybean	0.20	0.19	0.07	0.54	0.54	0.53	0.12	0.12	0.08
	Maize-Soybean (1M:1S)	0.25	0.24	0.09	0.53	0.49	0.48	0.11	0.11	0.05
	Maize-Soybean (2M:2S)	0.18	0.16	0.09	0.50	0.46	0.46	0.10	0.08	0.06
	Maize-Soybean (2M:4S)	0.26	0.20	0.10	0.55	0.53	0.52	0.12	0.11	0.07
	Maize-Soybean (2M:6S)	0.20	0.18	0.10	0.51	0.44	0.44	0.11	0.10	0.05
<i>p-value</i>		0.2670	0.4209	0.7795	0.5922	0.5326	0.4484	0.6801	0.5579	0.3850
LSD <sub>(0.05)</sub>		0.07	0.10	0.04	0.09	0.13	0.10	0.05	0.04	0.04
Kamujine	Sole maize	0.21	0.20	0.15	0.50	0.46	0.37	0.08	0.08	0.08
	Sole soybean	0.27	0.22	0.15	0.50	0.50	0.28	0.06	0.08	0.07
	Maize-Soybean (1M:1S)	0.22	0.26	0.16	0.54	0.49	0.29	0.07	0.08	0.08
	Maize-Soybean (2M:2S)	0.22	0.22	0.07	0.53	0.52	0.26	0.09	0.08	0.07
	Maize-Soybean (2M:4S)	0.22	0.17	0.09	0.57	0.54	0.34	0.08	0.06	0.06
	Maize-Soybean (2M:6S)	0.18	0.22	0.10	0.49	0.58	0.33	0.07	0.08	0.07
<i>p-value</i>		0.6791	0.4224	0.1715	0.4743	0.5672	<0.0001***	0.4306	0.3612	0.4704
LSD <sub>(0.05)</sub>		0.11	0.09	0.08	0.09	0.14	0.03	0.02	0.02	0.02

ns – not significant; \*\*\*significant at  $p \leq 0.001$ .

During 2012 SR at Embu site, there were significant differences in soil total N as affected by intercropping patterns. For instance, the MBILI treatment observed the highest N value of 0.05 percent ( $p=0.0530$ ) than all other intercropping patterns, excluding the 2M:4S treatment. Whereas, the soil organic carbon was not affected by the intercropping patterns ( $p=0.2460$ ); however, the 2M:6S treatment observed numerically the highest SOC value of 2.56 percent than all other treatments. In general, the SOC was higher under intercropping treatments than under sole cropping systems, probably due to higher crop residues produced under intercropping compared to sole cropping systems (Table 4.14).

Different situation was observed at Kamujine site, where the soil total N was not affected by the intercropping patterns ( $p=0.0800$ ). This could be due to relatively slow turnover times for SOM, making the incorporation of residue into total N small. Whereas, the SOC was significantly affected by the intercropping and the conventional treatment recorded the highest value of 2.46 percent,  $p=0.0020$  (Table 4.14). In general, the SOC at this site was not expected to be relatively low under intercropping treatments than under sole crop treatments. The higher SOC values observed at Embu site compared to Kamujine site could be due to relatively higher precipitation recorded at first location which resulted in lower mineralization rate and therefore higher SOC.

**Table 4.14:** Effect of intercropping patterns on soil chemical properties (soil total N and SOC) during 2012 SR at Embu and Kamujine sites

Location	Treatment	Soil total N (%N)	Soil Organic C (%C)
Embu	Sole maize	0.01	2.48
	Sole soybean	0.02	2.48
	Maize-Soybean (1M:1S)	0.02	2.50
	Maize-Soybean (2M:2S)	0.05	2.53
	Maize-Soybean (2M:4S)	0.03	2.48
	Maize-Soybean (2M:6S)	0.02	2.56
<i>p-value</i>		0.0530*	0.2460
LSD <sub>(0.05)</sub>		0.02	0.09
Kamujine	Sole maize	0.03	2.31
	Sole soybean	0.00	2.14
	Maize-Soybean (1M:1S)	0.02	2.46
	Maize-Soybean (2M:2S)	0.02	2.03
	Maize-Soybean (2M:4S)	0.02	2.30
	Maize-Soybean (2M:6S)	0.005	1.96
<i>p-value</i>		0.0800	0.0020**
LSD <sub>(0.05)</sub>		0.02	0.22

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .

The increase in the soil pH values in intercropped systems compared with sole cropping systems as encountered at Kamujine site, demonstrates that intercropping lead to reduction in soil acidity compared to monocropping systems, probably due to higher organic material generation. Similarly, Esekhadé *et al.* (2003) observed higher soil pH in intercropping treatments compared with soil under monocropping. Yasin *et al.* (2010) argued that, decomposition product of organic matter (maize) in the soil can play a role as soil pH regulator. Contrarily to the findings in this study, Dahmardeh *et al.* (2010) found that intercropping of maize-cowpea had significantly increased the phosphorus and potassium in soil, and that the lowest P level was observed in the sole maize treatment. Although not significantly different from other treatments, the lowest P level was also observed in sole

maize at Kamujine site. Similarly, Suwanarit *et al.* (1998) did not find significant effect of corn-groundnut intercropping system on available phosphorus. The soil mineral – N observed under sole legume treatment at Kamujine site was also reported by Dahmardeh *et al.* (2010), who found that soil mineral – N was significantly higher under sole cowpea treatment than in the other treatments.

The higher SOC observed in this study under intercropping treatments compared to their sole crops was also reported by several other authors (Bichel, 2013; Sainju *et al.*, 2009). Bambrick (2009) reported that tree based intercropping systems had greater potential for carbon storage than conventional cropping systems due to the fact that carbon is stored in the biomass of growing trees and trees provide additional carbon inputs (leaves, roots) that contribute to the SOC pool. As reported at Embu site, Zhang *et al.* (2007) also did not find significant differences on SOC under intercropping treatments compared to their pure stands. On the other hand, the absence of differences in soil total N observed at Kamujine site was also reported by Bichel (2013) in Argentina under maize-soybean intercropping systems. Mazzoncini *et al.* (2011) reported that soil total N stocks significantly changed after 15 years, and recommended long-term studies, especially when focusing on the SOM pool. The SOM have been used as indicators of the effects related to biomass source and amounts on soil organic matter dynamics in cropping systems (Bayer *et al.*, 2009). Soil chemical properties in terms of macro-, meso- and micro-nutrients after a cropping period depends on the type of crops planted and cropping systems used (Ibeawuchi, 2007).

#### **4.2. Effects of maize-soybean intercropping patterns on light interception and Leaf Area Index**

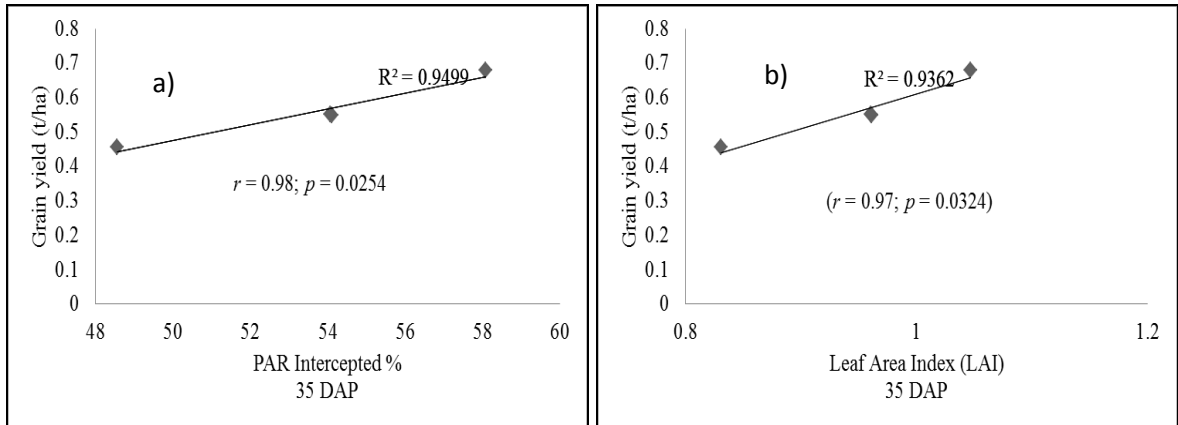
At Embu during the 2012 SR, significant differences ( $p \leq 0.001$  and  $p \leq 0.05$ ) were observed in light interception (PAR) and leaf area index (LAI), respectively for maize and soybean during the sampling period as affected by the intercropping patterns, except during 49 days after planting (DAP). For instance, during the 35 DAP sole soybean intercepted significantly ( $p=0.0002$ ) more light (58.23 percent) and LAI of 1.03 ( $p=0.0003$ ) than all other treatments and/or crop, excluding sole maize, soybean in 2M:2S, 2M:4S and in 2M:6S treatments. In this period only soybean under MBILI treatment showed existence of significant strong correlation between grain yield and PAR intercepted ( $r=0.98$ ;  $p = 0.0254$ ) and LAI ( $r=0.97$ ;  $p=0.0324$ ), as shown by the figure 4.6. While at 63 DAP the soybean in MBILI treatment observed statistically ( $p = 0.0310$ ) the highest light interception (84.15 percent) than sole soybean, maize and soybean under 2M:4S, and maize under 2M:6S treatments (Table 4.15).

At Kamujine site during the same sampling period, where both PAR and LAI were significantly (35 DAP with  $p \leq 0.0001$  and  $p \leq 0.0001$ ; and, 49 DAP with  $p=0.0476$  and  $p=0.0342$ , respectively) affected by the intercropping patterns. At 35 DAP the sole soybean recorded statistically the highest PAR of 62.08 percent ( $p \leq 0.0001$ ) and LAI of 1.18 ( $p \leq 0.0001$ ) compared to all other treatments. Whereas, during the time of 49 DAP maize under MBILI treatment intercepted significantly more light (80.69 percent,  $p=0.0476$ ) than all other treatments, excluding sole soybean, sole maize, soybean under MBILI and maize under 2M:6S treatments. In the same period (49 DAP), still maize under MBILI treatment showed the highest LAI of 2.06 than all other treatments, except soybean under monocrop (Table 4.15).

**Table 4.15:** Mean PAR and LAI of maize and soybean during 2012 SR at Embu and Kamujine sites

Location	Treatment	Crop	35 DAP		49 DAP		63 DAP	
			PAR%	LAI	PAR%	LAI	PAR%	LAI
Embu	Sole maize	Maize	57.23	1.03	66.50	1.28	83.40	3.61
	Sole soybean	Soybean	58.23	1.09	54.97	1.00	73.12	2.87
	Maize-Soybean (1M:1S)	Maize	32.41	0.47	56.55	0.99	74.19	2.74
		Soybean	41.65	0.66	56.67	0.99	78.05	3.06
	Maize-Soybean (2M:2S)	Maize	45.88	0.74	61.00	1.24	74.10	3.21
		Soybean	53.70	0.95	66.92	1.45	84.15	4.26
	Maize-Soybean (2M:4S)	Maize	42.67	0.70	55.58	0.95	69.05	2.34
		Soybean	55.89	1.00	48.74	0.87	68.24	2.40
	Maize-Soybean (2M:6S)	Maize	46.34	0.75	51.38	0.87	66.95	2.23
	Soybean	53.82	0.95	59.13	1.10	77.73	3.35	
<i>p</i> – value			0.0002***	0.0003***	0.2850	0.3564	0.0310*	0.0962
LSD <sub>(0.05)</sub>			10.10	0.25	14.97	0.52	10.95	1.33
Kamujine	Sole maize	Maize	49.86	0.85	69.39	1.52	76.47	2.28
	Sole soybean	Soybean	62.08	1.18	75.72	1.67	80.93	2.65
	Maize-Soybean (1M:1S)	Maize	36.24	0.55	67.17	1.37	78.90	2.54
		Soybean	32.51	0.48	54.79	0.95	67.68	1.89
	Maize-Soybean (2M:2S)	Maize	43.71	0.71	80.69	2.06	84.23	3.24
		Soybean	41.66	0.66	70.60	1.46	79.48	2.60
	Maize-Soybean (2M:4S)	Maize	37.44	0.57	64.10	1.21	71.74	2.08
		Soybean	41.38	0.66	65.62	1.38	73.57	2.00
	Maize-Soybean (2M:6S)	Maize	48.87	0.82	67.97	1.37	76.84	2.34
	Soybean	23.26	0.33	65.17	1.37	80.98	2.48	
<i>p</i> – value			<0.0001***	<0.0001***	0.0476*	0.0342*	0.1417	0.2026
LSD <sub>(0.05)</sub>			8.83	0.20	13.35	0.54	11.05	0.93

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .



**Figure 4.6:** Relation between soybean grain yield under MBILI treatment with PAR (a) and LAI (b) during 2012 SR at Embu site

The higher light interception showed by sole soybean treatment at Embu and Kamujine sites was also reported by Ghanbari *et al.* (2010), who observed that the cowpea-maize intercropping and maize sole crop had showed a lower light interception compared to cowpea sole crop. Studying wheat-faba bean intercropping, Eskandari (2011) found that the mean of PAR interception averaged over sampling dates by sole cropped bean was significantly higher than that for sole cropped wheat. Studying maize-peas intercropping, Kanton and Dennett (2008) found that at 36 DAP the sole peas were intercepting 30 percent more light than sole maize. Studying maize-bean intercropping, Tsubo *et al.* (2001) found that sole beans showed higher PAR intercepted than sole maize. Studying southern pea-sweet corn intercropping system, Francis and Decoteau (1993) found that monocropped southern pea had intercepted more light than monocropped sweet corn at 52 and 66 DAP. Solanki *et al.* (2011) reported that sole soybean intercepted more light as compared to maize+soybean and sole maize at 75 DAP.

Varies studies, particularly in tropical, have shown that intercrops intercept more PAR than sole crops, for example, Sivakumar and Virmani (1980) with maize-pigeon pea, Bandyopadhyay (1988) with sorghum-mung bean, and Tsubo *et al.* (2001) with maize-bean intercrops. The present study confirmed that MBILI treatment capture more radiant energy than sole crops, but the differences between this treatment and the sole maize crop (at Embu site) or soybean crop (at Kamujine site) were relatively small and not significant. This might be probably due to the differences in agro-ecological zonation and rainfall patterns between the two sites, where at Embu site (upper midland) had received more rainfall which made the maize crop to respond positively as it allowed faster leaf area growth and plant height, and therefore more light was intercepted; whereas, at Kamujine site (lower midland) had received less rainfall which made the maize crop to retard its initial growth rate compared to soybean and not being able to cover the soil surface very early resulting in lower interception of PAR compared to soybean. Also, Soybean plants, being deep rooted, can to some extent withstand dry periods (Prasad and Brook, 2005).

Environmental factors such as limited moisture, influences the leaf area development (Afuakwa and Crookston, 1984). Tsubo *et al.* (2001) stated that faster leaf area growth can cause higher PAR intercepted during the vegetative stage. Radiation interception varies from seedling emergence to crop harvest (Natarajan and Willey, 1980; Sivakumar and Virmani, 1980) and depends largely on the canopy leaf area (Tsubo *et al.*, 2001). The higher PAR conversion efficiencies of intercrop systems relative to the sole crops may be due to spread of light over greater leaf area, and more efficient distribution of light in their canopies during early stages of growth (Addo-Quaye *et al.*, 2011). Keating and Carberry (1993) concluded that cereal and legume can differ in PAR interception because of differences in their vertical

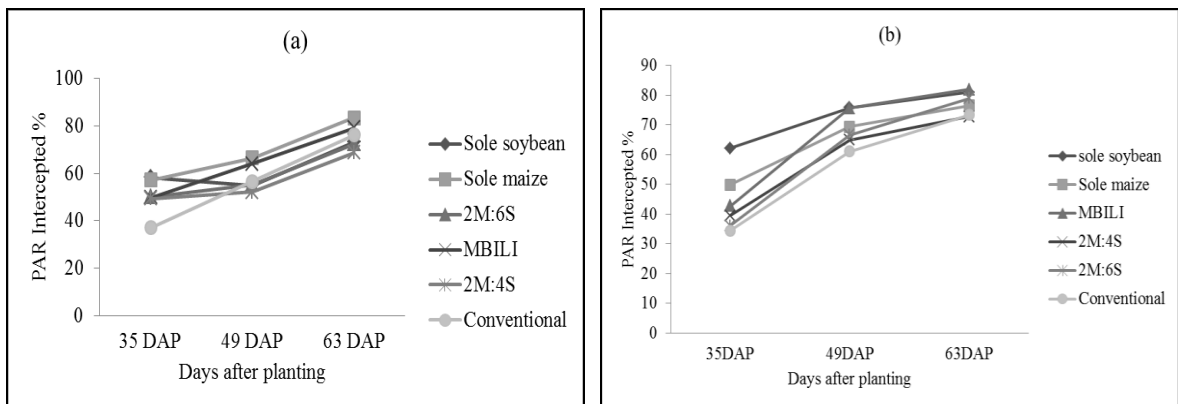
arrangement of foliage and canopy architecture and can therefore intercept more PAR compared to sole crops. Moreover, it has been found by several investigators (Reddy and Willey, 1981; Sivakumar and Virmani, 1984; Watiki *et al.*, 1993) that LAI patterns follow the patterns of radiation interception.

The higher LAI observed during 49 DAP with intercropped maize at Kamujine agrees with the results of Baldé *et al.* (2011) who found that maize intercropped with pigeonpea or brachiria had higher LAI than sole maize crop; and, Thobatsi (2009) who found maize intercropped with cowpea long duration cultivar had significantly higher LAI of 2.23 compared to medium season cultivars. Higher maize LAI when intercropped with soybean during 2012 SR could be attributed to sufficient rainfall at the beginning of the season that stimulated maize leaf growth.

Similarly, the reductions of maize LAI under intercropping systems have been also reported by other researchers (Thobatsi, 2009; Zegada-Lizarazu, *et al.*, 2006; Bilalis *et al.*, 2005). The absence of differences in maize LAI between all treatments in both sites (Embu and Kamujine) at 63 DAP and at 49 DAP in Embu site correspond with results of Filho (2000) who did not find any significant differences between sole maize and maize intercropped with cowpea. Twala and Ossom (2004) also did not find any significant differences in LAI between maize monocrop and maize intercropped with sugar beans or groundnuts. These results support the fact that different climatic conditions will result in different leaf development patterns of maize, with or without intercropping.

In general, at Embu site monocropped maize and the MBILI treatments intercepted numerically more light than all other treatments, at 69.04 and 64.29 percent during the

sampling period, respectively. The MBILI treatment intercepted 10.43 per cent more light than the conventional treatment (Figure 4.7). While, at Kamujine site monocropped soybean and the MBILI treatment intercepted numerically more light than all other treatments, with averages of 72.91 and 66.73 percent, respectively. The PAR intercepted by the MBILI treatment was 15.66 percent above the one that the conventional treatment had intercepted (Figure 4.7).



**Figure 4.7:** PAR Intercepted (%) during 2012 SR at Embu (a) and Kamujine (b) sites

Similar results were also reported by Woomeer and Tungani (2003) who found that beans had intercepted 20 percent more light under MBILI treatment than under conventional crop arrangement. These findings demonstrate the advantages of light penetration to the MBILI intercropping pattern which offer realizable potential for smallholder farmers to improve the performance of their maize-legume enterprise (Woomeer and Tungani, 2003).

The Table 4.16 shows that in both sites (Embu and Kamujine) the amount of light intercepted by the legume component and LAI were significantly ( $p \leq 0.05$ ) affected by maize shade. For instance at Embu site, 35 DAP the middle row intercepted significantly ( $p=0.001$  and

$p \leq 0.0001$ ) 19.97 and 19.0 percent more light than the closer row, in the 2M:4S and 2M:6S treatments, respectively. During the time of 49 DAP, the closer row had significantly ( $p \leq 0.0001$  and  $p = 0.0029$ ) intercepted 19.12 and 19.45 percent less light than the middle row, in the 2M:4S and 2M:6S treatments, respectively. Similarly, at Kamujine the closer row had significantly ( $p < 0.0001$  and  $p = 0.012$ ) intercepted 17.21 and 6.79 percent less light than the middle row, in the 2M:4S and 2M:6S treatments, respectively, at the time of 35 DAP. During the time of 49 DAP, the middle row had significantly ( $p = 0.0051$  and  $p = 0.0021$ ) intercepted 14.58 and 19.90 percent more light than the closer row, in the 2M:4S and 2M:6S treatments, respectively. At 63 DAP, the PAR intercepted by the closer row was 12.40 and 21.10 percent statistically ( $p = 0.0027$  and  $p < 0.0001$ ) lower than the one that was intercepted by the middle row, in the 2M:4S and 2M:6S treatments, respectively (Table 4.16).

**Table 4.16:** Effects of maize shade on PAR intercepted of soybean during 2012 SR at Embu and Kamujine sites

Location	Row position	35 DAP		49 DAP		63 DAP	
		2M:4S	2M:6S	2M:4S	2M:6S	2M:4S	2M:6S
		PAR	PAR	PAR	PAR	PAR	PAR
Embu	Middle	63.94	61.71	66.87	68.68	78.03	87.05
	Closer	43.97	42.71	47.75	49.23	66.05	71.25
<i>p</i> – value		0.001***	<0.0001***	<0.0001***	0.0029**	0.0001***	0.0092**
LSD <sub>(0.05)</sub>		9.13	6.16	7.12	11.58	5.59	11.24
Kamujine	Middle	48.82	53.23	61.69	69.08	75.55	84.51
	Closer	31.61	46.44	47.11	49.18	63.15	63.41
<i>p</i> – value		<0.0001***	0.012*	0.0051**	0.0021**	0.0027**	<0.0001***
LSD <sub>(0.05)</sub>		5.31	5.05	9.85	11.36	7.74	6.53

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p < 0.01$ ; \*\*\*significant at  $p < 0.001$ .

At Embu site during 2012 SR, at 35 DAP the middle row observed significantly ( $p=0.001$  and  $p<0.001$ ) 1.24 and 1.17 higher LAI than the closer row with 0.71 and 0.67, in the 2M:4S and 2M:6S treatments, respectively. During the time of 49 DAP, the closer row had significantly ( $p<0.0001$  and  $p=0.0029$ ) recorded 0.52 and 0.55 lower LAI than the middle row, in the 2M:4S and 2M:6S treatments, respectively. At 63 DAP, the LAI observed by the middle row was 1.04 and 1.47 statistically ( $p=0.001$  and  $p=0.0078$ ) higher than the one that was recorded by the closer row, in the 2M:4S and 2M:6S treatments, respectively (Table 4.17).

At Kamujine site, during 35 DAP the closer row had significantly ( $p<0.0001$  and  $p=0.0124$ ) observed lower LAI with values of 0.46 and 0.76 than the middle row (0.82 and 0.93), in the 2M:4S and 2M:6S treatments, respectively. During the time of 49 DAP, the middle row had significantly ( $p=0.008$  and  $p=0.0017$ ) recorded higher LAI with values of 1.17 and 1.40 than the closer row that observed 0.80 and 0.83, in the 2M:4S and 2M:6S treatments, respectively. At 63 DAP, the LAI recorded by the closer row was 0.81 and 1.42 statistically ( $p=0.001$  and  $p<0.0001$ ) lower than the one that was showed by the middle row, in the 2M:4S and 2M:6S treatments, respectively (Table 4.13). Similar effects of shading on legume component have been reported by several authors (Hang *et al.*, 1984; Stirling *at al.*, 1990; Ali, Jeffers and Henderlong (2003). For instance, Ali *et al.* (2003) found that alternate row of soybean had intercepted 31 percent more PAR than alternate narrow rows at 74 DAP.

**Table 4.17:** Effects of maize shade on LAI of soybean during 2012 SR at Embu and Kamujine sites

Location	Row position	35 DAP		49 DAP		63 DAP	
		2M:4S	2M:6S	2M:4S	2M:6S	2M:4S	2M:6S
		LAI	LAI	LAI	LAI	LAI	LAI
Embu	Middle	1.24	1.17	1.33	1.38	3.23	4.20
	Closer	0.71	0.67	0.81	0.83	2.19	2.73
<i>p</i> – value		0.001**	0.001*	<0.001	0.002	0.00	0.0078
LSD <sub>(0.05)</sub>		0.25	0.20	0.17	0.33	0.58	1.02
Kamujine	Middle	0.82	0.93	1.17	1.40	2.43	3.04
	Closer	0.46	0.76	0.80	0.83	1.62	1.62
<i>p</i> – value		<0.0001**	0.0124	0.008	0.001	0.00	<0.0001
LSD <sub>(0.05)</sub>		0.11	0.13	0.27	0.32	0.45	0.43

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .

### 4.3. Effects of maize–soybean intercropping patterns on land equivalent ratio (LER) of maize and soybean

During both seasons at both locations, the partial LERs values were significantly affected by the intercropping patterns ( $p < 0.0001$ ). For instance, during 2012 LR at Embu site, the total LER values showed greater yield advantage of intercropping maize and soybean over component sole crops, though yield advantage varied from 81 percent to 22 percent. During this season, the MBILI treatment observed significantly the highest LER value (1.81,  $p = 0.0019$ ) than all the other treatments. However, the partial LERs for both maize and soybean were all less than 1.00, except for maize where the MBILI was 48 percent significantly ( $p \leq 0.0001$ ) more productive than the conventional treatment, which was 11 percent more productive than pure maize. Whereas, during 2012 SR the total LERs values observed yield advantage varied from 43 to 20 percent; and, the partial LERs for both maize and soybean were also less than 1.00, excluding for maize in MBILI and conventional

treatments that was numerically 6 and 5 percent, respectively, more productive than pure maize. In this second season, conventional treatment was significantly (1.43,  $p=0.0005$ ) more productive than all other treatments, excluding the MBILI treatment (Table 4.18).

During 2012 LR at Kamujine site, the total LER values showed greater yield advantage of intercropping maize and soybean over component sole crops, though yield advantage varied from 55 to 11 per cent. During this period, the 2M:6S treatment observed statistically the highest LER value (1.55,  $p\leq 0.0001$ ) than all the other treatments. The partial LERs for both maize and soybean were all less than 1.00. Whereas, during 2012 SR the total LERs values observed yield advantage varying from 28 to 22 percent; and, the 2M:4S treatment showed significantly the highest LER value (1.29,  $p=0.0024$ ) than the maize and soybean monocrops, followed by the MBILI treatment with LER of 1.28 ( $p=0.0024$ ), but they were not statistically different from the other intercropping patterns. The partial LERs for both maize and soybean were also less than 1.00, excluding the one for maize in the MBILI treatment, which significantly (1.12,  $p\leq 0.0001$ ) more productive than pure maize treatment (Table 4.18). Probably the greater LER of intercrops was mainly due to a greater resource use and resource complementarity than when the species were grown separated.

**Table 4.18:** Mean land equivalent ratio (LER) during 2012 LR and SR at Embu and Kamujine sites

Location	Treatment	Partial LER				Total LER	
		Maize		Soybean		2012 LR	2012 SR
		2012 LR	2012 SR	2012 LR	2012 SR		
Embu	Sole maize	1.00	1.00	---	---	1.00	1.00
	Sole soybean	---	---	1.00	1.00	1.00	1.00
	Maize-Soybean (1M:1S)	1.11	1.05	0.24	0.38	1.35	1.43
	Maize-Soybean (2M:2S)	1.48	1.06	0.33	0.32	1.81	1.38
	Maize-Soybean (2M:4S)	0.90	0.68	0.41	0.52	1.31	1.20
	Maize-Soybean (2M:6S)	0.49	0.61	0.73	0.71	1.22	1.32
	<i>p-value</i>	<0.0001***	<0.0001***	<0.0001***	<0.0001***	0.0019**	0.0005**
LSD <sub>(0.05)</sub>	0.27	0.18	0.25	0.09	0.35	0.19	
Kamujine	Sole maize	1.00	1.00	---	---	1.00	1.00
	Sole soybean	---	---	1.00	1.00	1.00	1.00
	Maize-Soybean (1M:1S)	0.97	1.08	0.14	0.14	1.11	1.22
	Maize-Soybean (2M:2S)	0.99	1.12	0.14	0.16	1.13	1.28
	Maize-Soybean (2M:4S)	0.95	0.86	0.41	0.43	1.36	1.29
	Maize-Soybean (2M:6S)	0.93	0.65	0.63	0.60	1.55	1.25
	<i>p-value</i>	<0.0001***	<0.0001***	<0.0001***	<0.0001***	<0.0001***	0.0024**
LSD <sub>(0.05)</sub>	0.07	0.12	0.09	0.17	0.12	0.16	

ns – not significant; \*significant at  $p \leq 0.05$ ; \*\*significant at  $p \leq 0.01$ ; \*\*\*significant at  $p \leq 0.001$ .

Intercropping maize with soybean showed advantages in land use efficiency expressed as LER, when compared with their sole crops. A LER greater than 1.00 has also been reported with maize-soybean (Yusuf *et al.*, 2012; Addo-Quaye *et al.*, 2011; Pawar *et al.*, 2011; Solanki *et al.*, 2011; Ullah *et al.*, 2007; Thole, 2007; Kipkemoi *et al.*, 2001 ), maize-cowpea (Dahmardeh *et al.* 2010; Hugar and Palled, 2008), and maize-beans (Yilmaz *et al.*, 2008; Odhiambo and Ariga, 2001). The lower LERs for soybean observed in both sites can be explained by the findings of Ofori and Stern (1986) who reported that light is the most important factor determining LER of maize and soybean intercropping and LER declines when legume becomes severely shaded as shown by Light measurements. Furthermore, the higher productivity of the intercrop system compared to the sole crop may have resulted from complementary and efficient use of growth resources by the component crops (Li *et al.*, 2006; Li *et al.*, 2003). For instance, Sivakumar and Virmani (1980) observed that in maize-pigeon pea intercrop, dry matter production per unit of PAR intercepted was higher in the mixture than in sole crops, which was confirmed in this study through higher light interception in intercropping treatments compared to monocrops.

## **CHAPTER FIVE: SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS**

### **5.1. Summary of findings**

The maize-soybean intercropping patterns had significant effect on maize stover and grain yields during both seasons at Embu site. In this site, the MBILI treatment recorded the highest stover and grain yields. During 2012 LR at Kamujine site only the maize stover yield was significantly affected by maize-soybean intercropping patterns. The conventional treatment observed the highest stover yield than 2M:6S treatment; but it was statistically at par with the one recorded by the MBILI treatment. And during the 2012 SR, the maize stover and grain yields maize-soybean intercropping patterns affected significantly the MBILI treatment recorded the highest stover and grain yields.

During both seasons in both sites, the soybean yield was significantly affected by the intercropping pattern. During the 2012 LR, the yields were reduced by 60 and 81 percent due to the intercropping with maize, at Embu and Kamujine, respectively; whereas, during the 2012 SR, the yields were reduced by 52 and 78 percent as a result of intercropping with maize, at Embu and Kamujine, respectively. At Embu, during 2012 LR, the sole soybean observed significantly the highest stover yield than all the intercropping patterns. Also, the sole soybean treatment gave statistically the highest grain yield than all the intercropping patterns. Similar results were obtained during 2012 SR, where sole soybean treatment recorded statistically the highest stover yield than all the other treatments. The monocropped soybean observed also the highest grain yield than all other treatments.

The maize-soybean intercropping patterns affected significantly soil nitrate-N only at harvest (20 WAP) at both locations, and at 12 WAP at Embu site. But in general, the soil nitrate-N was reduced by the intercropping patterns. The soil mineral-N was not significantly affected by the maize-soybean intercropping patterns at Embu site; and at Kamujine site it was only affected at harvest (20WAP). Generally the mineral N decreased across the season explained mainly by depletion of N as a result of plant uptake and the dry conditions experienced towards the end of the season.

The N uptake of maize and soybean was significantly affected by the intercropping patterns, at both locations. For instance, at 4 WAP the sole soybean observed significantly the higher N amount than all the other treatments, which was strongly correlated with soil mineral at the same sampling period. At 16 WAP the sole soybean had accumulated significantly the lowest N compared to all the other treatments. Also, the N uptake by soybean during this period was positively correlated with soil mineral N at the same sampling period. The maize under MBILI treatment observed significantly the highest N uptake while sole soybean observed significantly the lowest N uptake, which was statistically at par other soybean treatment. Still the maize under MBILI treatment observed significantly the highest N uptake to the grain than other treatments. In general, the N accumulation by maize under intercropping treatments was generally lower than that for sole cropping.

During 2012 LR at Kamujine site, the soybean under MBILI treatment had accumulated significantly the highest N than maize under different treatments, at 4 WAP. During this time the N uptake was highly positively correlated with soil mineral N of the same sampling period. At 8 WAP the soybean sole acquired significantly the highest N than sole maize and

maize under conventional, MBILI, and 2M:6S treatments. At this time the N uptake by maize was significantly positively correlated with soil mineral N during the same period. At 12 WAP the sole soybean also recorded significantly the highest N than all the other treatments, excluding soybean under 2M:4S treatment. During this sampling period, the amount of N accumulated by soybean was highly significantly positively correlated with soil mineral N of the same period and soil mineral N at 16 WAP, respectively. At harvest, still the maize under MBILI treatment accumulated significantly the highest N than all other treatments. At this moment the amount of N yielded by soybean was strongly correlated with the soil mineral N for the period. For the grain, the maize under conventional treatment observed significantly the highest N uptake than all other treatments, excluding sole maize, maize under MBILI, sole soybean and maize under 2M:6S treatments.

The maize-soybean intercropping patterns had no significant effect on soil pH, extractable phosphorus, exchangeable calcium and potassium, and extractable ammonium at both locations. Although, the available Phosphorus was not affected by the treatment, it recorded a general decrease from the pre-season to 2012SR at all locations of the study. The exchangeable magnesium was significantly higher under maize sole crop at Kamujine site during 2012 SR. The soil organic carbon was significantly affected by the intercropping patterns at Kamujine site where the conventional treatment observed the highest SOC, but it was not affected at Embu site.

The intercropping patterns affected significantly the PAR intercepted and the leaf area index at both sites. During 35 DAP at Embu site, the soybean sole crop intercepted significantly more light and leaf area index (LAI) than all other treatments and/or crop. In this period only

soybean under MBILI treatment showed existence of significant strong correlation between grain yield and PAR intercepted and LAI. Whereas, at 63 DAP the soybean in MBILI treatment observed statistically the highest light interception (84.15 percent) than sole soybean, maize and soybean under 2M:4S, and maize under 2M:6S treatments. At Kamujine site during the same sampling period, where both PAR and LAI was significantly affected by the intercropping patterns. At 35 DAP the sole soybean recorded statistically the highest PAR and LAI than all other treatments. Whereas, during the time of 49 DAP maize under MBILI treatment intercepted significantly more light than all other treatments.

During both seasons at both locations, the partial LERs values were significantly affected by the intercropping patterns. For instance, during 2012 LR at Embu site, the total LER values showed greater yield advantage of intercropping maize and soybean over component sole crops, though yield advantage varied from 81 percent to 22 percent. During this season, the MBILI treatment observed significantly the highest LER value than all the other treatments. Whereas, during 2012 SR the total LERs values observed yield advantage varied from 43 to 20 percent. In this second season, conventional treatment was significantly more productive than all other treatments, excluding the MBILI treatment.

During 2012 LR at Kamujine site, the total LER values showed greater yield advantage of intercropping maize and soybean over component sole crops, though yield advantage varied from 55 to 11 percent. During this period, the 2M:6S treatment observed statistically the highest LER value than all the other treatments. Whereas, during 2012 SR the total LERs values observed yield advantage varying from 28 to 22 percent; and, the 2M:4S treatment showed significantly the highest LER value than the maize and soybean monocrops, followed

by the MBILI treatment with LER, but they were not statistically different from the other intercropping patterns.

## **5.2. Conclusions**

The maize-soybean intercropping patterns had significant effect on maize stover and grain yields during both seasons and sites. The MBILI treatment recorded significantly the highest maize stover and grain yields.

During both seasons in both sites, the soybean yield was significantly affected by the intercropping pattern. During the 2012 LR, the yields were reduced by 60 and 81 percent and during the 2012 SR, the yields were reduced by 52 and 78 percent as a result of intercropping with maize.

The N uptake of maize and soybean was significantly affected by the intercropping patterns, at both locations. The maize under MBILI treatment observed significantly the highest N uptake to the stover and to the grain than all other treatments.

The maize-soybean intercropping patterns had no significant effect on the soil chemical properties at both locations, excluding exchangeable Magnesium and soil organic carbon, at Kamujine site.

The intercropping patterns affected significantly the PAR intercepted and the leaf area index at both sites. The soybean sole crop intercepted significantly more light and leaf area index (LAI) than all other treatments and/or crop. Towards the end of the season, the soybean in MBILI treatment observed statistically the highest light interception than other treatments.

The total LER values showed greater yield advantage of intercropping maize and soybean over component sole crops, though yield advantage varied from 81 percent to 20 percent, during both seasons and locations.

### **5.3. Recommendations and areas for further research**

The major recommendation emanating from this study for farmers is to use the MBILI maize-soybean intercropping pattern because it showed efficient resources use.

Three issues are suggested for future research:

1. There is need to quantify the BNF activity of different intercropping patterns that could assist to explain some findings of this study.
2. To assess the water use efficiency and soil moisture content of the maize-soybean intercropping during different sampling periods of the season.
3. There is a need to conduct future studies on N balances under varying amounts of inputs in particular manure and phosphorus.

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## APPENDICES

**Appendix 1:** Analysis of Variance for maize stover yield, during 2012 LR at Embu-ATC site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	10.3206724	3.4402241	1.22	0.3462
<b>Treatment</b>	4	171.2968594	42.8242149	15.14	0.0001

**Appendix 2:** Analysis of Variance for maize stover yield, during 2012 SR at Embu-ATC site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	4.21125131	1.40375044	1.95	0.1757
<b>Treatment</b>	4	48.92206458	12.23051615	16.97	<.0001

**Appendix 3:** Analysis of Variance for maize grain yield, during 2012 LR at Embu-ATC site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	1.26758643	0.42252881	1.32	0.3144
<b>Treatment</b>	4	27.76532152	6.94133038	21.64	<.0001

**Appendix 4:** Analysis of Variance for maize grain yield, during 2012 SR at Embu-ATC site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	1.43503939	0.47834646	0.36	0.7857
<b>Treatment</b>	4	17.95050090	4.48762522	3.34	0.0467

**Appendix 5:** Analysis of Variance for maize stover yield, during 2012 LR at Kamujine site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	0.74071915	0.24690638	0.30	0.8276
<b>Treatment</b>	4	11.19860055	2.79965014	3.36	0.0461

**Appendix 6:** Analysis of Variance for maize stover yield, during 2012 SR at Kamujine site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	9.63133652	3.21044551	7.61	0.0041
<b>Treatment</b>	4	19.31909196	4.82977299	11.45	0.0005

**Appendix 7:** Analysis of Variance for maize grain yield, during 2012 LR at Kamujine site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	2.18093898	0.72697966	1.50	0.2653
<b>Treatment</b>	4	5.56512343	1.39128086	2.87	0.0704

**Appendix 8:** Analysis of Variance for maize grain yield, during 2012 SR at Kamujine site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	3.12169727	1.04056576	5.98	0.0098
<b>Treatment</b>	4	7.52864085	1.88216021	10.82	0.0006

**Appendix 9:** Analysis of Variance for soybean stover yield, during 2012 LR at Embu-ATC site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	0.04698110	0.01566037	0.20	0.8954
<b>Treatment</b>	4	2.77661959	0.69415490	8.80	0.0015

**Appendix 10:** Analysis of Variance for soybean stover yield, during 2012 SR at Embu-ATC site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	0.38427796	0.12809265	3.83	0.0391
<b>Treatment</b>	4	2.02965718	0.50741429	15.17	0.0001

**Appendix 11:** Analysis of Variance for soybean grain yield, during 2012 LR at Embu-ATC site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	0.03327029	0.01109010	0.17	0.9145
<b>Treatment</b>	4	3.77912858	0.94478215	14.49	0.0002

**Appendix 12:** Analysis of Variance for soybean grain yield, during 2012 SR at Embu-ATC site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	0.06260868	0.02086956	1.54	0.2546
<b>Treatment</b>	4	4.19036864	1.04759216	77.37	<.0001

**Appendix 13:** Analysis of Variance for soybean stover yield, during 2012 LR at Kamujine site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	0.16158423	0.05386141	8.09	0.0032
<b>Treatment</b>	4	2.46022977	0.61505744	92.42	<.0001

**Appendix 14:** Analysis of Variance for soybean stover yield, during 2012 SR at Kamujine site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	0.34642013	0.11547338	1.78	0.2045
<b>Treatment</b>	4	3.12448087	0.78112022	12.04	0.0004

**Appendix 15:** Analysis of Variance for soybean grain yield, during 2012 LR at Kamujine site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	0.19604052	0.06534684	3.81	0.0397
<b>Treatment</b>	4	0.71215958	0.17803989	10.37	0.0007

**Appendix 16:** Analysis of Variance for soybean grain yield, during 2012 SR at Kamujine site.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
<b>Block</b>	3	0.04570205	0.01523402	6.36	0.0080
<b>Treatment</b>	4	1.13850676	0.28462669	118.78	<.0001