EFFECT OF MAIZE- SOYA BEAN INTERCROPPING PATTERNS ON GROWTH, YIELD AND PHOTOSYNTHETIC ACTIVE RADIATION OF SOYA BEANS IN KAIMOSI-VIHIGA COUNTY, KENYA

BY

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DECLARATION

This thesis represents an original contribution and has not been submitted for award of a degree at any other academic institution.

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SUPERVISORS' DECLARATION

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DEDICATION

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ABSTRACT

Cereal-legume combination is the common form of intercropping by most small-scale farmers in Sub-Saharan Africa (SSA). This is because of small pieces of land owned by farmers small causing overexploitation of resources like nutrients thus low productivity leading to food insecurity. In Kenya, food insecurity is rampant leading to importation of foodstuffs. The adoption of technologies like intercropping and use of agricultural inputs have been promoted to boost crop production. In Kaimosi, Vihiga County, majority of farmers despite the adoption of intercropping system have not appreciably improved the production particularly of soya bean that has remained at 0.2t ha-1 against potential of 2.5t ha-1. Therefore, there is need to further explore the best agro-technology like optimum intercropping pattern with a view to increased productivity and thus solving the global problem of food insecurity and poverty in the county. Maize-soya beans intercropping system helps improve soil fertility, protects the farmer against total crop failure, help in curbing the issue of food insecurity and increases farmers' income. The objectives of this study was therefore to; determine the effect of maize- soya bean intercropping patterns on growth parameters of soya beans; determine the effect of maize-soya bean intercropping patterns on Photosynthetic Active Radiation and determine the effect of maize -soya bean intercropping patterns on yield parameters of soya beans. The study was conducted in Kaimosi Friends University research farm in Vihiga County. Complete randomized block design was used with six treatments which included; sole soya beans, sole maize, 1maize:1soyabean (1M: 1S), 1maize:2soyabean (1M: 2S), 2maize-2soyabean (2M: 2S) and 2maize:4soyabean (2M: 4S) each replicated four times. Each plot measured 3m x 3m and a space of 1m was left between them. Soya bean and maize varieties used were SB19 and H513 obtained from Kenya Seed Company, Kakamega. Three seeds were planted per hole and later thinned through uprooting to retain two seedlings per hole. 50% of each crop type were randomly tagged for data collection from each treatment and data collected after every 14 days from date of sowing. The study was carried out during the long and short rain seasons. Parameters such as soya bean height, number of leaves and leaf area index; Photosynthetic Active Radiation, pod length and pod number and yield were determined from the tagged soya beans plants in each treatment. Collected data was analyzed using GenStat statistical package version 15.2 to test for the significant differences between different intercropping patterns. Findings indicated that intercropping pattern had significant impact on growth and yield parameters. However, intercropping pattern significantly increased the growth of soya bean with highest height and leaf number found in 1M:1S pattern and the least in 2M;4S, while the highest LAI evidenced in 2M:4S and the least in 1M:2S pattern. Despite intercropping increasing the height of soya beans, it was not significant. The significant increase in growth in 1M: 2S pattern was because of positive phototropism and good PAR interception that led to optimum growth rate at 70 days after planting. The amount of PAR intercepted was significantly increased by the intercropping pattern ($p<0.05$) with the highest PAR recorded in 1M: 2S pattern followed by 2M: 4S and the least 1M: 1S at 70 DAP. The high PAR observed in 1M: 2S pattern was due to good spatial arrangement that provided a greater PAR conversion efficiency and maximum vegetative growth that enhanced high PAR interception. Intercropping pattern had a significant increase on pod number, pod length and final yield. This was due to optimum vegetative growth and high PAR interception during the vegetative and flowering stage, which reduced flower abortion and increased photosynthate production, for optimum number of pods, pod length and yield as seen in 1M: 2S pattern. The highest number of pods were recorded in 2M: 4S while the least recorded in 1M; 1S patter. The longest pods were recorded in 1M: 2S pattern followed by 2M: 2S while the least 2M: 4S with 3.84cm, 2.78cm and 2.26cm respectively. The highest yields were recorded in 1M; 2S pattern followed by 2M: 4S and least in 1M: 1S.There was significantly strong positive relationship between yields and the growth parameters, yield parameters and PAR ($p\leq0.05$). The positive correlation could be due to availability of growth material for the intercrop. Intercropping indicated yield advantage with an LER> 1. The findings from this study suggest the 1M: 2S intercropping pattern has potential for adoption since it recorded the highest soya bean height, number of leaves, pod length, intercepted the highest PAR, dry weight yields and efficiency in material utilization. The main recommendation derived from this study is therefore for agroecologists and small-scale farmers to practice the 1M: 2S arrangement of maize and soya bean since it exhibited effectual utilization of limited resources while at the same time giving maximum returns.

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ACRONYMS AND ABBREVIATION

AEZ	Agro-Ecological Zone
ANOVA	Analysis of Variance
ASL	Above Sea Level
ISFM	Integrated Soil Fertility Management
LAI	Leaf Area Index
LR	Long Rains
SR	Short Rains
GoK	Government of Kenya
FAO	Food and Agriculture Organization
PAR	Photosynthetic Active Radiation
CRBD	Completely Randomized Block Design
RUE	Radiation Use Efficiency
SOC	Soil Organic Carbon
DOS	Days after sowing
MT	Mega tones
UM	Upper Midland
LM	Lower Midland
WAP	Weeks after Planting
WAS	Weeks After Sowing
1S:1M	1 Line of maize and 1 Line of soya bean
1S:2M	1 Line of maize and 2 Line of soya beans

2M:2S	2 Line of maize and 2 Line of soya beans
2S:4S	2 Line of maize and 4 Line of soya beans
F: RF	Infra-red radiation
Chl	Chlorophyll
Chl a	Chlorophyll a
Chl a/b	Ratio of chlorophyll a and b
PSI	Photosystem I
PSII	Photosystem II
R/Rr	Far Red Radiation
KARI	Kenya Agriculture Research Institute
LER	Land Equivalent Ratio

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

The global human population is projected to surpass 9.8 billion by the year 2050, potentially leading to a significant global food security crisis (United Nations, 2017). Local farmers have a crucial role in ensuring adequate food supply within the Sub-Saharan Africa region. These farmers take part in subsistent agriculture featured by low crop productivity due to poor intercropping patterns (Nciizah *et al*., 2022). Most of them are insufficiently informed on the optimum intercropping patterns that can contribute to increased crop growth and yield hence presenting a significant challenge to the overall food security within the region. The prevailing assumption among farmers is that the output potential of a crop is mostly determined by its height. This is attributed to the crop's ability to exhibit more competitive vigor, produce larger supporting fruit, and survive external disturbances such as wind.

According to a study conducted in the humid forest zone of Mount Cameroon (Begna, 2020), a significant positive connection has been seen between plant height and yield characteristics in a maize-soya bean intercropping system. This association suggests that taller plants tend to produce heavier fruits, longer fruit length, and heavier grain. Bitew *et al. (*2021) additionally, observed that the growth rate (height) of soya beans cultivated in a dual-row pattern with maize was much greater compared to soya beans sown in an alternative row configuration with maize. A study in northern Ghana on intercropping of cow peas and maize showed significant taller plants for both intercrops than their monocrops (Tetteh *et al*., 2021). This needs to be further investigated using other new intercropping pattern to conclude if indeed intercropping pattern has significant influence on height of intercrops in different intercropping pattern and region.

In Kenya, food scarcity is also a major concern where about 1.8 million people in rural and marginalised areas are faced with acute level of food insecurity leading to importation of nearly all foodstuff (Republic of Kenya, 2013). Vihiga County is home to a total population of 590,013 individuals, resulting in a population density of 1046 individuals per square kilometer. Its' land area is 563.8km^2 and 404.8 km^2 of this is arable. Vihiga is perpetually food insecure where the poverty incidence is estimated at 65% of the population (Maja and Ayano, 2021). The county is also faced with the problem of land dilapidation due to over-cultivation on small pieces of land and the nature of soil, which is prone to erosion leading to low farm production. This factor contributes to both food scarcity and poverty in the county. Farmers are therefore encouraged to embrace scientific approaches and resources that have been created in the past years to combat the difficult task of feeding the ever-growing population. Guaranteeing adequate supply of food, while preserving natural resources possess a significant challenge to agricultural strategists and scientists worldwide (Richard *et al*., 2022). There is a need for further enhancement of crop yield levels by adopting appropriate intercropping patterns that guarantees farmers of high quality yields.

In the intercropped field, the number of green leaves per intercrop is obtained and compared to another intercrop (Wu *et al*., 2021). There is a positive correlation between the quantity of green leaves observed and the rate of growth in maize-soya bean. This is an essential feature used in establishing the influence of intercrop varieties on the leaf growth and production of other crops. The intercropping of cowpeas and sorghum in a research study conducted in western Kenya (Samwel *et al.*, 2023) resulted in a notable increase in the number of leaves and plant height for both cowpeas and sorghum at the six-week mark after planting, as compared to mono-cropping. Adoption of the right intercropping system that can guarantee maximum vegetative growth and hence food availability is required especially to farmers in areas like Kaimosi, Vihiga County.

Technologies which infuse integrated soil fertility management (ISFM) practices like enhanced intercropping systems of specific cereal crop with legumes (maize and soya beans) are recommended (Karume *et al*., 2022). The method of intercropping cereal and legume crops is widely adopted by small-scale farmers due to its effective utilization of resources, including land and inputs comprising labour, biological diversity within the agricultural system, provides security against crop failure, increased monetary returns and control of pests and diseases (Yilmaz, Atak, & Erayman , 2008). While carrying out intercropping farming it is necessary to ensure that the intercrops do not compete for space, nutrients and solar radiation for optimum productivity, which is greatly influenced by the right intercropping pattern (Lithourgidis *et al*., 2011). Thus, it is sound to try other methods of intercropping such as one line of maize followed by two lines of soya bean to ascertain if it will allow optimum utilization of growth resources such as nutrients, solar radiation and reduce competition for optimum productivity.

Cereal-legume intercropping is a widely used agricultural method among small-scale cultivators in Western Kenya. This innovative agro-technique has been in existence since ancient times and has made a significant contribution to the achievement of agricultural sustainability (Dwivedi *et al.,* 2015). The most commonly intercropped plant combinations were maize-common bean, maize-cowpea, and maize-pigeon pea, as reported by (Jaetzold *et al.,* 2006). Soya beans has gained popularity among farmers in Vihiga County, where it is majorly intercropped with maize and this agronomic practice is projected to advance in future owing to the growing demand for food and forage for cattle as highlighted by Mugendi *et al*. (2010). However, intercropping pattern that will provide maximum output in terms of food and feeds of soya beans is yet to be identified.

The typical intercropping system for soya bean and maize involves planting one line of maize followed by one line of soya bean (1M: 1S), as recommended by the Ministry of Agriculture. An alternative iteration system, known as Managing Beneficial Interaction in Legume Intercrops (MBILI) or mbili-mbili in Kiswahili, was investigated and recommended by SACRED Africa, a non-governmental organization (NGO) based in Bungoma, Kenya (Mongare *et al.,* 2020). The process entails the establishment of two parallel rows for each intercrops. In accordance with the findings of a field study conducted in Central Kenya, it was observed that the utilization of two rows of cereals followed by two rows of legume crops resulted in significantly higher profitability compared to the typical intercropping system. The efficiency in utilization of resources, including land, nutrients, light, and water, was credited to this phenomenon (Matusso *et al.,* 2014). The technology is reported to enhance the legume production to a considerable extent, while maintaining a consistent maize yield. This is achieved through the implementation of staggered row spacing, which facilitates enhanced light penetration through the maize canopy, without altering the plant densities.

In a study conducted by Raza *et al. (*2022), it was observed that the intercropping of maize and soya beans resulted in a notable increase in the Leaf Area Index (LAI), crop growth rate (CGR), and net assimilation rate (NAR) for both crops under semi-arid conditions in Pakistan. In a study conducted in the highlands of Kenya, Mucheru-Muna *et al. (*2010) found that the growth rate and pod length of soya beans were significantly higher when planted in a double row arrangement with maize, resulting in a higher yield compared to soya beans planted in an alternate row arrangement with maize, which is the conventional method. The Leaf Area Index (LAI) of a canopy plays a crucial role in predicting crop development and yields. Maintaining an optimal leaf area index (LAI) is crucial for sustaining elevated rates of photosynthesis and maximizing crop yield (Fang *et al*., 2019). According to Brintha and Seran (2010), insufficient light absorption occurs when the index is too low, whereas inadequate light distribution to lower leaves, resulting in their diminished functionality, is observed when the index is excessively high. The aforementioned research was carried out in localities with different climatic condition (temperature, rainfall, humidity and atmospheric pressure, topography and soil) yet the results were not conclusive hence further investigation ought to be carried out in different areas such as Kaimosi in Vihiga Kenya to augment those findings.

Intercropping of cereal-legume might lead to decline in yield of the legume component due to the adverse competitive effects. 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 (Akanmu *et al.,* 2023). Consequently, a decrease in the amount of photosynthetic active radiation (PAR) reaching the lower regions of the intercrop canopy, where the legume is situated, has a substantial impact on both growth and pod formation (Liu, Liu , Wang, Jin, & Harbert, 2010). The interception of solar radiation by the canopy has a crucial role in determining the yield components and overall yield of soya beans, as the crop is highly responsive to shading. The intensity and quality of solar radiation are key factors influencing these outcomes. According to Begna (2020), the significance of light intensity and levels is greater during the late flowering to mid pod development stages of growth compared to the vegetative and late reproductive phases. Hence, it is plausible that interventions aimed at augmenting the level of photosynthetic active radiation (PAR) interception by soya beans possess the capacity to enhance pod formation, thereby resulting in increased soya bean yield and heightened productivity within the intercropping system.

As an illustration, Kinyua *et al. (*2023) observed that the MBILI system facilitated a 20% greater penetration of light to the soya bean component in comparison to the conventional intercropping pattern. From the foregoing, it indicates some deficiency in knowledge on the response of legumes to the PAR and yield in study done in Northan Tanzania. Therefore, more data is required especially where other patterns are used in studies.

Contradictory results have been reported on yield and its parameter from different researchers where different pattern yielded conflicting result. For instance, Muoneke *et al. (*2007) in Nigeria, Mongare *et al. (*2020) in western Kenya and Matusso *et al. (*2014) in central Kenya. Whereas these researchers reported higher yields in mbili mbili than other patterns, their findings differ with the research carried out in Malaysia by Baghdadi *et al*, (2016) who showed that 50:50 and 75:25 had no yield difference to those of monocrops. In a study conducted by Muoneke *et al. (*2007) in Nigeria, the researchers investigated the effects of intercropping maize and soya beans. The results indicated a significant decrease in the number of soya bean pods per plant by 46% during the early season. Additionally, the intercropping patterns resulted in reduced yields of both crops, with decreases of 42% and 46% observed in the late season for maize and soya beans, respectively.

Conversely, the augmentation of maize planting density resulted in a decrease in soya bean seed yield by 21% and 23% when the maize population reached 44,440 and 53,330 plants per hectare, respectively, in comparison to intercropping at a density of 38,000 maize plants per hectare. Furthermore, Matusso *et al. (*2014), in Embu and Meru, Kenya showed that maize-soya beans intercropping pattern reduced soya beans yield significantly during both seasons in both sites. The MBILI maize-soya beans intercropping pattern was suggested to farmers residing in the Central Highlands of Kenya since it offers the potential for enhanced utilization of resources and increased yield. The pattern considered by earlier researchers need also to be tried in others regions with additional patterns such as one line of maize and two line of soya been to ascertain early findings.

Mongare *et al. (*2020) undertook research in western Kenya and the results showed that maize and soya beans monocrops yielded much greater as opposed to both MBILI and conventional systems. The study by Mong'are *et al. (*2020) however, recommended MBILI intercropping system as an optimum method of intercropping maize and soya beans. Baghdadi *et al. (*2016) in Malaysia experimented on corn (maize) and soya bean combination of 75:25, 50:50 and 25:75 in addition to mono crop of maize and soya beans. The results indicated that these ratios produced yields comparable to that of monoculture maize, which measured at 14.77 t/ha. These findings diverged from previous research conducted on the subject. This calls for further research with additional intercropping pattern to ascertain the findings of earlier done research.

The intercropping system demonstrated a greater relative yield total value compared to the monocrop cultivation of corn and soya beans. The combination consisting of 50:50 mixture had a significantly higher mean relative yield (RYT) value of 1.15 than that of other ratios. Due to these variations in results obtained in different research areas and with varying intercropping patterns, an optimum intercropping pattern is yet to be identified especially in regions with land scarcity that can maximize the output with minimum use of available resources hence solving the issue of food security and poverty at large.

1.2 Statement of the problem

In the global context, as population increases, land as a factor of production remains the same. This persistent concern perpetuates the issue of insufficient food supply leading to poverty and hunger. In western Kenya unpredicted weather pattern, poor methods of farming, poor soil fertility, topography, high population and, pieces of land owned by most farmers and lack of proper intercropping policy has led to overexploitation of resources thus low food production, low income and hunger (Maja & Ayano, 2021).

Despite farmers adopting intercropping system of maize with grain legume to increase food supply for the expanding population they have still not achieved high production due to adopting unsound intercropping patterns such as conventional methods. Other intercropping combination such as one line of maize and two line of soya bean (1M: 2S) are yet to be adopted especially by small-scale farmers of Vihiga County.

It is a common belief by farmers that yield potential of a crop depends on the heights of the crop since taller plants tend to exhibit greater aggressive vigour and produce larger, more robust fruits that are better equipped to endure disruptive factors like wind. Although studies by Begna *et al.* *(*2020) and Bitew *et al.* *(*2021) have shown that taller crops show competitive vigour and large supportive fruits, which can withstand disturbing events like winds, this is yet to be scientifically verified in an intercropping pattern like one line of maize and two line of soya beans (1M:2S). Furthermore, it has been observed that maize plant shades the legume to varying extents in different intercropping patterns whose consequence is lengthening of internodes and lodging of the legumes, which impact on growth of soya beans in terms of height and vegetative growth. This is yet to be scientifically confirmed in other system of intercropping such as one line of maize and two line of soya bean that is being practiced by small-scale farmers of Vihiga County.

Varied canopies brought about by intercropping system also affects the amount of PAR interception by the leaves underneath which determines the amount of light available for photosynthesis. The amount of light intercepted together with nutrients and water available affects flowering and number of pods on legume intercrop and this has a direct impact on final yield. The optimum PAR interception for maximum yield of the various intercropping pattern is yet to be established.

The important environmental factor responsible for soya bean yield components and final yield in the framework of an intercropping is the quantity and value of solar radiation seized by a soya bean cover in the course of the reproductive period. In some studies, different responses of yield components of soya bean to changes in environs created by various cropping patterns, environmental condition width and plant densities have given varied results, whose scientific explanation are hardly conclusive.

1.3 Objectives

1.3.1 General objective

To assess the effect of maize-soya beans intercropping patterns on growth and performance of soya beans in Kaimosi Vihiga County, Kenya

1.3.2 Specific objectives

i. To evaluate the effects of maize-soya beans intercropping patterns on growth parameters of soya beans in Kaimosi Vihiga County
ii. To determine the effects of maize-soya beans intercropping patterns on yield components of soya beans in Kaimosi Vihiga County

iii. To determine the effects of maize-soya beans intercropping patterns on PAR of soya beans in Kaimosi Vihiga County

1.4 Research Hypotheses

i. Maize-soya beans intercropping patterns have no effect on growth parameters of soya beans
ii. Maize-soya beans intercropping patterns have no effect on yield components of soya beans
iii. Maize-soya beans intercropping patterns have no effect on PAR of soya beans

1.5 Justification

The world human population is expected to go beyond 9.8 billion by 2050, which may create a serious challenge of food security on a global scale. In the region of Sub-Saharan Africa, there exists a population of smallholder farmers who are great stakeholders of food security who take part in subsistent agriculture featured by low crop productivity due to poor intercropping patterns. Most farmers are insufficiently informed on the optimum intercropping patterns that can lead to increased growth rate and yield hence presenting a potential danger to the maintenance of food security within the geographic area (United Nations, 2017). Adoption of the right intercropping system that can guarantee increased food production and hence food availability is required. Various researchers have conducted experiment to come up with the right intercropping pattern that can give vigorous growth, high PAR interception and high yield yet the problem of food insecurity is still persistent in Vihiga County. Therefore, more studies are required to come up with the preeminent intercropping pattern that will give high growth rate, PAR interception and yield such as one line of maize followed by two line of soya bean to be scientifically introduced to farmers in Vihiga County through farmers training and field trials with farmers.

Thus, the study adds to literature the comparative analysis of the intercropping system. It also contributes to the agricultural policy formulation to the government, where the findings will guide the national and county government in developing policies that embrace scientific technologies such as intercropping system. In addition, the study provides the right intercropping system that has potential to increase productivity of intercrops to farmers.

CHAPTER TWO

LITERATURE REVIEW

2.1 General overview

Intercropping is a common farming practice done for subsistence purposes in Sub-Saharan countries (Liu, Liu , Wang, Jin, & Harbert, 2010). This is because most farmers lack sufficient land to practice mono cropping. Intercropping entails the practice of concurrently cultivating multiple distinct crops within a singular agricultural plot throughout a designated period. One crop is usually the main crop and one or more other crops are of different types. In most cases, this is preferably done between legumes and other food crops. The fundamental significance of the important crop is typically attributed to its economic or food production implications (Brintha & Seran, 2010). Leguminous plants are those which are able to fix nitrogen into the soil using rhizobium bacteria in their root nodules. Examples of leguminous crops include soya beans, common beans, groundnuts, sesame, mug bean and cowpeas.

The prevalent practice of intercropping in western Kenya involves the cultivation of maize and grain legumes, which are the primary food crops in the region (Bationa *et al*., 2011). While maize plays a crucial role in ensuring the availability of food, grain legumes provide as versatile sources of household protein, contribute to soil nitrogen fixation, and provide livestock feed (Brooker, *et al.,* 2015). The lack of synchronization between maize output and population growth results in significant challenges related to food insecurity and poverty. The average maize yield is generally below 1.0 tons per hectare (t ha^{-1}), which is significantly lower than its potential output of 5.0 t ha-1. Similarly, legume yields are below 0.2 t ha^{-1} compared to their potential yield of 2.5 t ha^{-1}. These lower yields can be attributed to various factors such as inadequate soil fertility, unsound intercropping practices, and the presence of the striga weed, which negatively affects maize production (KARI, 2013). Maize-legume intercropping is a component of the Integrated Soil Fertility Management (ISFM) method. Agriculturalists, researchers and development agencies are therefore urged to make sound decisions on maize-legume intercropping systems for improved productivity (Shyamal & Patra, 2013).

Vihiga is always a food deficit county (Government of Kenya, 2004). The poverty incidence (per capita daily income of less than a dollar) is valued at 65% of the population (KNBS, 2010). Food insecurity is widespread and nearly all foodstuffs are imported (Republic of Kenya, 2013). Interventions are thus required to assist in restoration of agricultural production for food security such as the adoption of improved farm technologies like intercropping systems among others (Republic of Kenya, 2007).

The average maize production observed in Vihiga of four bags/acre is significantly lower as opposed to the anticipated yield of 15 bags per acre (Lusigi, 2018). Thus, it is essential to invest in modern agricultural technologies such as use of mbili-mbili intercropping, mechanization of the farms to ensure timeliness in farm operations. Use of organic pesticide in control of pest and diseases which are environmental friendly, use of improved seeds which are adaptable to specific environmental conditions and use of organic fertilizer which improves soil fertility, conserve soil microbes and reduces environmental pollution. All these work to improve food production with minimal environmental pollution. This is in track with the Government of Kenya, (2004) that recommended the use of enhanced technology in farming activities to increase yields leading to high food production hence food security.

The optimal usage of land resources in situations characterized by land scarcity leads to subsistence farming practice is one of the justifications of intercropping in traditional farming system (Muoneke *et al*., 2007). Relative maize population density in a maize-soya bean intercropping system plays a crucial role when establishing the optimal productivity. Intercropping is a significant agricultural method that contributes to the enhancement and variation of productivity per unit area, in contrast to the monoculture approach (Sullivan, 2003). Cereal and grain legume intercropping is a widely used agricultural method among small-scale farmers in the Sub-Saharan Africa (SSA) region. This is because legumes are essential food crops due to their high protein content and potential for generating revenue through sales (Odendo *et al.,* 2011). In addition, these intercrops assure them of yield stability at the end of production season since when one crop fails due to either environmental or other factors, the farmer can still benefit from the other crop (Ojiewo *et al*., 2015; Wezel, *et al.,* 2014 and Odendo *et al.,* 2011). Legumes are also important as they aid in preserving and mending soil fertility by the capacity to fix nitrogen into the soil.

2.2. Effects of Intercropping on Growth components

Plant growth refers to the process by which a plant or its many components experience a permanent and measurable increase in size, mass, and/or volume (Liu *et al*., 2021). The growth parameters encompass measurements such as plant height, leaf count, and leaf area. The measurement of plant height refers to the vertical distance from the highest point of the plant's apex to the level of the ground, typically denoted in meters (Gholami *et al.,* 2009). The plant height parameter is an essential characteristic that impact much on growth of cereal crops. Usually, most farmers have the belief that the yield potential of a crop is mostly influenced by its height, as taller plants tend to exhibit greater competitive vigour and produce bigger productive fruit. Additionally, taller crops are better equipped to endure disruptive factors like as wind. A positive correlation of height with yields parameters was established indicating that, taller plants produce heavy fruits, long fruit length and heavy grain in maize- soya bean intercropping system as per the study conducted by Begna *et al. (*2020) within the humid forest zone of Mount Cameroon.

According to Bitew *et al. (*2021), it was observed that sole cropping resulted in the attainment of maximal plant height, hence establishing the taller crop as significantly superior to the intercrops. A study by Wei *et al., (*2022a) in Xinjiang China, who intercropped maize and soya beans showed significantly higher value of crop growth rate for both maize and soya beans. Mugendi, *et al. (*2010), also indicated that the growth rate (height) of soya beans was significantly greater when cultivated in a dual row layout with maize compared to when planted in an alternate row configuration with maize. A study in Botswana on intercropping of cowpeas and sorghum showed a significant taller plant for both intercrops than their monocrops (Gao *et al*., 2010).

Complementary use of growth resources like nutrients and other environmental factors such as light has led to positive increase in plant height. In a study conducted in northern Ethiopia, Sibhatu *et al. (*2015) in an intercropping system involving sorghum and cowpeas observed that the intercropped plants exhibited increased height and grain yield per plant. This enhancement was attributed to the nitrogen fixation facilitated by the cowpea legume, which stimulated apical meristematic activity and consequently promoted overall growth. In a study conducted in the

Mediterranean region, Salama *et al. (*2022) observed enhanced height and grain weight in cowpeas when intercropped with maize. This improvement was attributed to the increased nitrogen intake facilitated by nitrogen fixation, which played a crucial role in grain filling. Generally, it has been shown that during intercropping, taller plants have considerable effects on under-storey. However, the findings from previous research do not provide the causes that are exhaustive which need further research.

The number of leaves is the optimum leave count observed on a plant (Deblonde & Ledent, 2001). In the intercropped field, the quantity of green leaves per intercrop is obtained and compared to another intercrop. Usually there is a positive correlation between the quantity of green leaves observed and their spatial distribution, and the rate of growth. The utilization of intercrop types to assess their impact on the growth and yield of companion crops is a crucial aspect (Wu *et al.*, 2021). The intercropping of cowpeas and sorghum demonstrated a notable increase in the number of leaves and plant height for both cowpeas and sorghum at the six-week mark following planting, as compared to the growth observed in monocrop conditions within a dryland region (Baker *et al.*, 2021). In a study conducted by Agbaje *et al. (*2002), it was demonstrated that the presence of intercropped cowpeas and maize resulted in a higher leaf count when compared to monocropped plants. According to the findings of Mohamed *et al. (*2020), there was an observed increase in the vegetative growth of cowpeas when intercropped with maize. In the previous studies, only alternating rows of the intercrops were used. It is not known how the plant leaves will be affected in other intercropping patterns.

The Leaf Area Index (LAI) refers to the quantification of the total green leaf area in relation to a given unit of ground area. The absorption of photosynthetic active radiation (PAR) by the canopy of individual crops in the intercrop system is influenced by both leaf area index (LAI) and canopy structure, as observed by Zhang *et al. (*2023). Cereal crop with growth advantage shade the legume and if their population is higher, it leads to decrease in growth and output of legume. At reduced maize population, the legume receives about 50% of incident light whereas 20% is received at high maize population density. Therefore, high maize population leads to reduced yield of intercrop consisting only of 30% of monocrop yield (Begna *et al.*, 2020). An investigation in Embu by Matusso *et al. (*2014) on mbili mbili maize-soya beans intercropping system, found significant differences in leaf area index (LAI). In that study only soya bean under mbili-mbili, treatment indicated strong correlation between grain yield and LAI. According to Matusso *et al.*, (2014), it has been suggested that an increase in leaf area index (LAI) may not necessarily lead to a further gain in production. In fact, it may result in a drop in output due to the loss of respiratory CO_2 from highly shadowed leaves and stems. The Leaf Area Index (LAI) of a canopy plays a crucial role in predicting crop development and yields. Maintaining an optimal leaf area index (LAI) is of utmost importance for sustaining elevated rates of photosynthesis and maximizing crop productivity (Fang *et al.*, 2019). Insufficient light absorption occurs when the index is too low, whereas inadequate light distribution to lower leaves, resulting in their reduced photosynthetic capacity, is observed when the index is excessively high.

The researches so far have established varied effects of PAR, LAI on radiation in single or mbili-mbili intercropping pattern. A study done in the Democratic Republic of Congo (DR. Congo) (Khonde *et al.,* 2022) also reveal significant effect of intercropping maize and soya bean. The study revealed that the Leaf Area Index (LAI) plays a vital role in the operation of ecological linkages, as it is involved in various activities. The findings revealed a significant level of competition for space use within the associations, as opposed to the monocultures of the cover plant (soya bean). This suggests that the Leaf Area Index (LAI) of the dominant species, specifically maize in this instance, had a direct influence on the subordinate species, namely soya bean. The potential negative impacts on the growth and grain output of soya beans resulting from a decrease in the leaf area index can be attributed to the potential influence of competition for growing space on the legume's symbiotic physiology (Khonde *et al.,* 2022). In addition, it has been observed that an increase in plant density leads to a considerable reduction in Leaf Area Index (LAI) in maize-soya bean intercropping systems compared to solo soya bean cultivation. This is mostly attributed to the adverse effects of maize shade and water stress on the growth and development of soya bean plants, as highlighted by Raza *et al. (*2021). Therefore, it is imperative to investigate alternative intercropping patterns, such as the arrangement of one row of maize followed by two rows of soya bean in order to explain some scientific phenomena of intercropping.

2.3. Effects of Intercropping on Yield parameters of companion crops

The important environmental factor responsible for soya bean yield components and final yield in an intercropping system is the quantity and quality of solar radiation captured by a soya bean cover in the course of the reproductive period (Liu *et al.,* 2021). Mongare *et al. (*2020) stated that the amount of light in the course of late flowering to mid pod formation stages of growth are more significant than during vegetative growth and late reproductive periods in influencing the yield of soya beans when intercropped with cereals.

According to Meena *et al. (*2015), an increase in the far-red energy ratio has been found to be associated with reduced branching and leaf count within the canopy of intercropping systems. This is due to the positive impact of leaf area index (LAI) on radiation interception, up to a certain optimal threshold (approximately 4). Above this threshold, the additional surface area has minimal influence on light interception. It is worth noting that the planting density resulting from various intercropping patterns plays a crucial role in determining the LAI. Greater LAI habitually leads to no rise in throughput rather than decreasing it due to respiratory CO_2 losses from intense canopy.

In their respective studies, Matusso *et al. (*2014) and Lemma *et al. (*2009) observed that insufficient irradiance during the flowering stage of soya bean and common bean plants resulted in a higher percentage of flowers being aborted, ultimately leading to a reduced number of pods per plant. The aforementioned observations align with the conclusions drawn by Jat *et al. (*2012), wherein they proposed that the primary factor impeding soya bean output is pod abortion triggered by insufficient photosynthate availability during the later stages of growth. According to Gao *et al. (*2010), the capture of light during and after seed initiation is a crucial factor in determining crop output. In a study conducted by Fang *et al*. (2019), canopy brought from first flower to early pod-fill decreases flower production and improves flower and pod abscission, ensuing in abridged pod number and yield.

In addition, Tana & Urage, (2017), reported that quantity of pod per plant greatly determined yields in different row widths and densities in a specific year, besides variation in sizes of seeds gave a difference in yields for two subsequent years. Therefore, diverse yield component responds differently to variation in localities. The presence of a canopy, which results in the attenuation of around 49-20% of ambient light, has been found to contribute to the elongation of internodes and an increase in lodging in soya bean plants. The implementation of enhanced light at the late vegetative or early flowering stages resulted in a substantial increase in seed output, with a notable improvement ranging from 144% to 252%. This enhancement primarily occurred through the multiplication of pod numbers. According to Mathew *et al. (*2000), the introduction of light improvement during the initial stages of pod formation resulted in an increase in seed length ranging from 8% to 23%. Additionally, this intervention led to a significant improvement in seed yield, with a range of 32% to 115% seen in maize-soya bean intercropping systems. The impact of intercropping system on pod number, pod length and subsequent yield of soya beans needs to be investigated further since the forgone results are not conclusive.

Cereal-legume intercropping boost soil nutrient levels and enrich the soil with right elements for usage by the subsequent plants. This is because leguminous plants have rhizobium bacteria in their root nodules whose major role is to convert atmospheric nitrogen into the soil for use by the plants (Saranraj *et al*., 2023). The primary objective of crop production is to convert solar energy to stored food energy. However, any reduction in solar energy interception leads to reduction in yield (Gholami *et al.,* 2009). When growing two crops in the same field, there is likelihood of competition for resources such as light, which negatively affect yield of the understory plant due to shading brought about by taller plants.

Cereals such as maize are prominent crops in terms of growth and root system and has a better competitive advantage for resources such as nutrients and light than soya bean, which leads to reduction in yield of soya beans in an intercropped system (Caporali *et al.,* 1998). The growth advantage of maize lead to shading of soya beans which lowers the growth and yield of soya beans. According to a study conducted by Tetteh *et al*., (2021), the yield of legume crops decreased by an average of almost 52% compared to the yield of monoculture crops. In contrast, grain output had a comparatively smaller reduction of only 11%. Based on this evidence, it can be inferred that the yields of legume constituents in an intercropping system are notably diminished by the presence of cereal components. This reduction can be attributed to a drop in photosynthetic active radiation (PAR) that penetrates the underneath maize cover occupied by the minor legume in maize cowpeas intercropping in southern Ghana ((Tetteh *et al*., 2021).

Intercropping is a technology of maximizing profit from small fields that subsistence farmers own. However, this farming system bring about the propagation of diseases to under-storey crop and low light interception by under-storey leaf. This may lead to low photosynthesis that affect both growth, pod formation and yield hence affecting general productivity of the under-storey crop such as soya bean (Callaghan *et al.*, 1994). The drop in harvest of the lower crop might also be owing to interspecific competition and inhibitory impact of maize, a C_4 species on soya beans, a C_3 crop. Typically , C_4 species have dominant photosynthetic pathway compared to C_3 crop species such as soya beans (Dreyer, 2021). Maize-soya bean intercropping is widespread across Eastern and Central African, Uganda, Rwanda, Burundi, DR Congo and North Tanzania (Natarajan & Willey, 1986).

According to the findings of Khonde *et al. (*2022), a more significant decrease in soya bean production was observed in the context of intercropping. Interspecific competition between the intercrop components for essential resources such as water, light, air, and nutrients, as well as the competitive advantage of maize (a C4 species) over soya bean (a C3 species), were identified as contributing factors. Dreyer (2021) has observed that the prevalence of C4 photosynthetic pathway crops tends to be higher when they are intercropped with C3 species such as soya bean. The potential decrease in intercropped soya bean yields may be attributed to the shadowing effect caused by the taller maize plants. The decrease in soya bean production may also be attributed to the shadowing effects of maize on soya bean plants. This shading leads to the allocation of photosynthates by the legume component towards vegetative development and increased height, in order to compete with taller maize plants (Ali *et al.*, 2012).

In a recent study conducted by Papathanasiou *et al. (*2022), it was discovered that the occurrence of low irradiance during the flowering stage of common bean plants resulted in a significant increase in the percentage of aborted flowers. This, in turn, had a detrimental effect on the total quantity of pods produced per plant, eventually affecting the final yield of the crop. According to KARI, (2013), Emuhaya Sub-County- a lower middle agro-ecological zone in Vihiga County has the lowest soya beans yields when intercropped with maize (2.5 t ha^{-1}). When comparing agricultural productivity in various counties within the Western Region, it is observed that Kisii County yields an average of 3.2 tons per hectare (t ha-1). In contrast, Kakamega County, specifically in Kakamega South, exhibits a slightly higher average yield of 3.8 t ha-1. Mumias, also located in Kakamega County, demonstrates a comparatively higher yield of 5.9 t ha-1. Lastly, Gem in Siaya County showcases an average yield of 3.7 t ha-1. The limited intercropping patterns used in previous studies may not provide conclusive responses on how intercropping reduces the yield of soya bean. Thus further studies using different intercropping patterns such as one line of maize and two line of soya bean need to be tried in order to come up with a more convincing reasons.

2.3.1 Land Equivalent Ratio (LER)

The Land Equivalent Ratio (LER) refers to the aggregate land area required in a monocropping system to get the same yield as that attained in an intercropping system. Normally it shows combined yield for assessing the efficiency of intercropping (Bacchi *et al.*, 2021). Land Equivalent Ration which is equal to 1 shows that there is no yield benefit in intercropping as the similar yield can be achieved with sole-cropping at the recommended density for mixed cropping, with no modification of the entire area of land. On the other hand, a LER less than 1 indicate that, the yield attained in intercropping can be realized in mono cropping from a lesser space. Nevertheless, a LER greater than 1 indicates yield advantage and bigger land is required to harvest an equivalent return of each crop when grown as a solitary crop at the recommended density compared to intercropping. The partial land equivalent ratio (LER) is used to determine the relative competitive ability of the component crop within an intercropping system. Therefore, crops exhibiting higher partial light efficiency ratios (LER) are considered to possess greater competitiveness in relation to growth-limiting factors compared to those with low partial LER (Justes *et al.*, 2021).

For instance, Mudare *et al.* (2022) established greater land production in maize-soya bean yield than other systems. According to a study conducted by Muoneke *et al. (*2007), the intercropping system of maize and soya bean demonstrated a yield advantage ranging from 2% to 63%. This was evidenced by the Land Equivalent Ratio (LER) values of 1.02 to 1.63, indicating efficient utilization of land resources through mixed cropping. The study conducted by TOFA *et al. (*2019) provided confirmation that a Land Equivalent Ratio (LER) over 1 signifies that intercropping maize and soya bean would yield superior results compared to cultivating them individually. Gong *et al. (*2020) as well obtained a LER of 1.30 to 1.45 when they intercropped maize and soya bean, signifying greater productivity of intercropping equated to mono cropping. Efficiency of land use needs to be further analyzed using different intercropping patterns to confirm if the same outcome will be realized. It would be rather interesting to establish LER in other intercropping patterns than the conventional ones used in previous studies.

2.4. Effect of intercropping on Photosynthetic Active Radiation

Photosynthetic active radiation is the radiation that is captured by the plants to carry out photosynthesis process. It denotes the spectra range (wave band) of solar radiation spanning from around 400-700 nanometers which is utilized by photosynthetic organisms during the process of photosynthesis. Radiant energy for photosynthesis is also known as solar radiation. The relationship between the photosynthetic active radiation (PAR) intercepted by a plant during its growth cycle and the accumulated biomass has been found to be proportional (Alados *et al.,* 1996). Intercropping is considered a more advantageous cropping technology due to its superior radiation usage efficiency, resulting in enhanced yields per unit of incident radiation. The optimal intercropping strategy for crops with contrasting canopy heights aids in increasing light interception and hence growth and yield of the shorter crops (Brintha & Seran, 2010). Difference in maturity period of intercrop is of great advantage since it allows the use of inadequate resources such as light at different times (Martin & Snaydon, 1982).

Shade brought about by the taller crop leads to reduced assimilate production of the minor intercrop (legume) due to less PAR getting to underneath minor crop (Keating & Carberry., 1993). Soya bean is known to be sensitive to shade especially during pod formation. The yield component (vegetative development, blooming, and podding) and final yield are significantly impacted by the strength and quality of solar radiation, which is impeded by the presence of a crop canopy (Liu *et al.,* 2021). Radiation use efficiency and PAR are affected highly in different intercropping patterns. Ennin *et al. (*2002) observed that the percentage of photosynthetic active radiation (PAR) captured by intercrops was 4% higher when soya bean and maize were arranged in more compact rows, compared to intercrops consisting of two lines of maize followed by two lines of soya beans (mbili-mbili). In a study conducted by Feng *et al. (*2019), it was observed that the intercropping pattern of maize and soya bean resulted in higher levels of light interception and radiation usage efficiency compared to solitary crop cultivation.

These findings were attributed to an enhanced leaf area index, improved light interception, and increased dry matter production. In a study conducted by Yang *et al. (*2022), it was observed that a decrease in the ratio of infra-red radiation to far-red radiation (R/Fr) had a substantial effect on the elongation of soya bean stems under normal light conditions. Conversely, at low light intensity, the opposite tendency was observed.

The growth of plants in low light conditions is influenced by the ratio of red to far-red light (R/Fr) and the intensity of light. Nevertheless, the (R/Fr) ratio exhibited a positive correlation with both the total biomass and leaf area of soya bean plants, even when subjected to identical light intensity conditions. In a similar vein, it is observed that the overall biomass of geranium and snapdragon plants exhibits an increase when exposed to extra far-red (Fr) radiation, particularly in conditions where the ratio of red (R) to far-red (Fr) light is low. According to Brintha & Seran, (2010), photosynthesis serves as the fundamental process for the buildup of organic matter. The enhancement of photosynthesis can be observed when there is a decrease in infra-red radiation, particularly in situations when light intensity is either normal or low. In contrast to the Emerson enhancement effect, it is possible to raise the photosynthetic efficiency of short wavelengths by increasing the presence of long wavelengths. According to Zhou *et al. (*2018), it has been noted that photosystem I (PSI) has a heightened state of excitement in response to shorter wavelengths of light, in contrast to photosystem II (PSII). This heightened state of excitement in PSI directly affects the photochemistry. Furthermore, Reddy *et al. (*1980) observed that the millet-groundnut intercrop system exhibited a 28% increase in light usage efficiency compared to their respective monocrops. This improvement was mostly related to the intercrop's approximately 30% higher leaf area index (LAI) in comparison to the solo crops.

A study conducted by Matusso *et al. (*2014) in Embu, on the intercropping system of mbili mbili (maize-soya beans) revealed notable variations in light interception, specifically photosynthetic active radiation (PAR). It was shown that only the soya bean crop under the mbili-mbili treatment exhibited a substantial link between grain yield and the amount of PAR intercepted. At 63 days after planting (DAP), the MBILI treatment exhibited the maximum light interception (84.2%) among the soya bean crops, surpassing the solitary soya bean, maize-soya bean (2:4), and maize-soya bean (2:6) treatments. As far as many researches use to correlate the effect of PAR on yield have been done using few intercropping pattern the data is contradictory and insufficient thus there is need to investigate this using other patterns of intercropping such as one line of maize to two lines of soya beans to ascertain the findings.

CHAPTER THREE

MATERIALS AND METHODS

3.1 The study area, soil and climate

The research was conducted at the research farm of Kaimosi Friends University (KAFU) situated in Vihiga County, specifically in Hamisi Sub-County, which is located in the western region of Kenya from March to December 2021. It is located on longitude $34^0 50'$E and latitude 0^0 07' N, the altitude is 1625m above sea level (Lusigi, 2018). Vihiga County is classified into two primary agro-ecological zones, namely the upper and lower midlands. The delineation of these zones governs the spatial distribution of land use and the arrangement of human settlements within the county. The lower midland zone is composed of Emuhaya and Luanda Sub-Counties, whereas the upper midland zone consists of Hamisi, Sabatia, and certain areas of Vihiga. According to the Republic of Kenya, (2008), Kaimosi is characterized by the presence of fertile and well-drained soils, predominantly composed of red loamy sand soils that originate from sedimentary and basalt rocks. The soils are hydric acrisols, deep well drained slightly acidic to alkaline. The area enjoys tropical type of climate with relief rainfall that ranges from 1500mm to 2000mm which is well distributed throughout the year. The rains are divided into two distinct seasons: the long and short season rainfall. The long rainy season often spans from the month of March to July, whilst the short rainy season typically occurs from August to November (Lusigi, 2018).

The high population density of 1046 individuals per square kilometer existing in Vihiga County has led to population pressure. The County has a land area is 563.8km^2 and only 404.8 km^2 of this is arable. Vihiga is perpetually food insecure where the poverty incidence is estimated at 65% of the population (Maja and Ayano, 2021). The lack of synchronization between maize output and population growth results in significant challenges related to food insecurity and poverty. The county is also faced with the problem of land degradation due to over-cultivation on small pieces of land and the nature of soil, which is prone to erosion leading to low farm production. The average maize yield is generally below 1.0 tons per hectare (t ha^{-1}), which is significantly lower than its potential output of 5.0 t ha-1. Similarly, legume yields are below 0.2 t ha^{-1} compared to their potential yield of 2.5 t ha^{-1}. These lower yields can be attributed to various factors such as inadequate soil fertility, intercropping practices, and the presence of the striga weed, which negatively affects maize production (KARI, 2013).

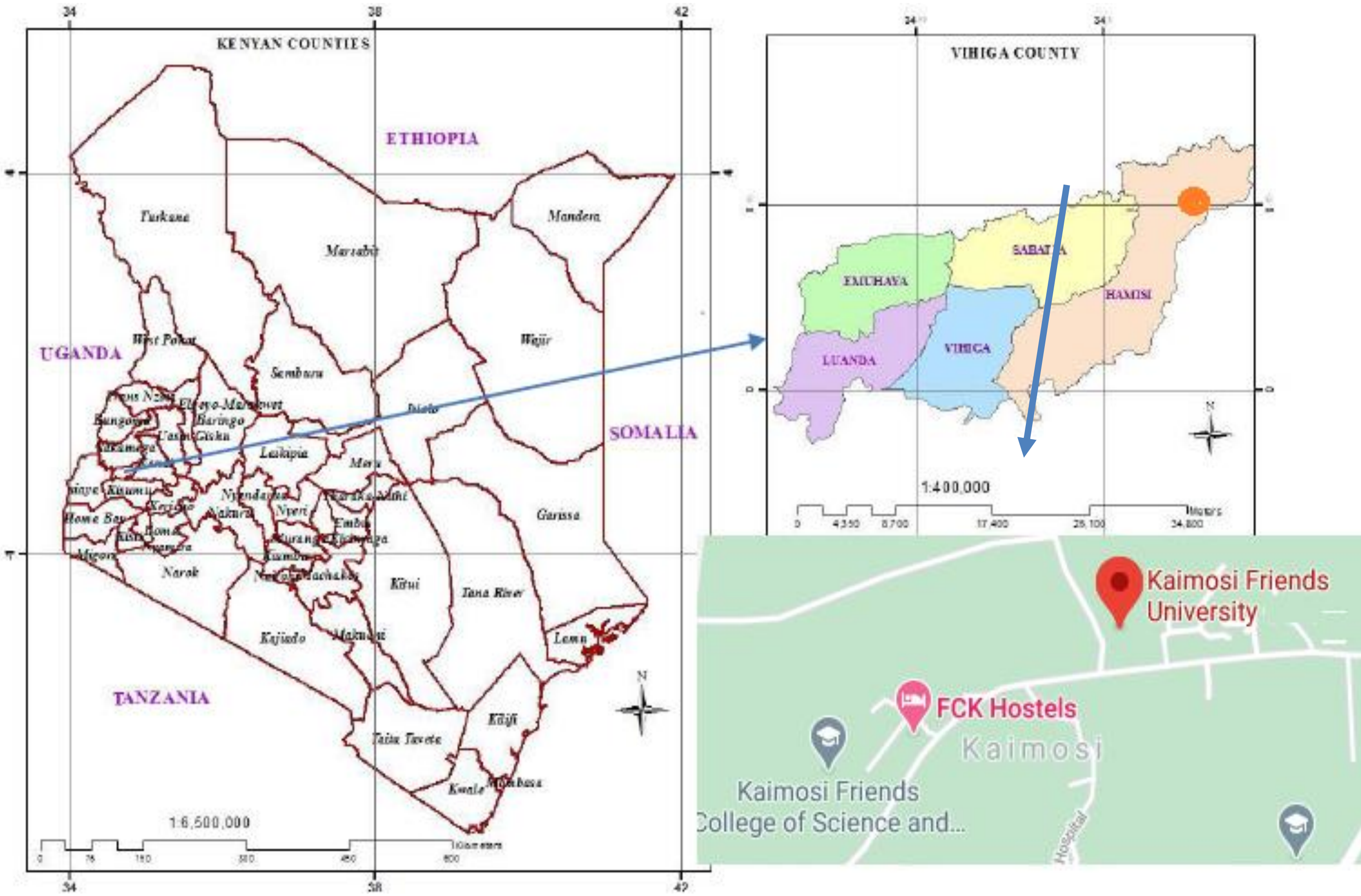

Figure 3. 1: Location of Kaimosi Friends University

Source: Vihiga County Integrated Development Plan, (2018)

3.2 Experimental Design and Treatments

The study was conducted using a randomized complete block design (RCBD) with six treatments and four replicates in an open field setting. The experimental design consisted of six treatment, each representing different combinations of soya beans and maize. These treatments included: sole soya beans, sole maize, one row of maize and one row of soya beans (1M:1S), one row of maize and two rows of soya beans (1M:2S), two rows of maize and two rows of soya beans (2M:2S), and two rows of maize and four rows of soya beans (2M:4S). The four assignments were randomly allocated and subsequently reproduced, as illustrated in Table 3.2.1.

Treatments measuring 3.0m x 3.0m were marked and 1m space left between treatments. In sole soya, a spacing of 45cm by 10cm was used between rows and interplants respectively giving a total of 434 soya bean plants while for sole maize, a spacing of 75cm by 45cm was used between rows and interplants respectively with a total of 70 maize plants. For 1M: 1S pattern spacing used was 75cm by 45cm between maize rows and interplant while spacing between maize and soya beans was 37.5cm while between soya bean interplant was 10cm giving a total of 70 maize plant and 248 soya bean plants. For 1M: 2S pattern spacing was 100cm by 45cm between maize row and between maize and soya beans was 33.3cm and 33.3cm between the two rows of soya beans and 10cm between soya beans interplant with a total of 56 maize plants and 372 soya beans plants. For 2M:2S pattern spacing between two maize rows was 50cm, between maize and soya beans was 33.3cm and between two rows of soya beans was 33.3cm giving a total of 70 and 248 maize and soya beans plants respectively. In 2M:4S pattern spacing between two maize rows was 50cm, between maize and soya beans row was 20cm as well as between soya beans row in both season with a total of 70 and 496 maize and soya beans plants respectively. The spacing used were as per the KARI, (2013) and modifications from Matusso *et al. (*2014)

Table 3.2.1 Treatment and pattern at the site of experiment

Treatment	Cropping pattern
Treatment 1	Sole Soya Bean
Treatment 2	Sole Maize
Treatment 3	Maize-Soya bean (1:1) denoted as ‘1M:1S’
Treatment 4	Maize-Soya bean (1:2) denoted as ‘1M:2S’
Treatment 5	Maize-Soya bean (2:2) denoted as ‘2M:2S’
Treatment 6	Maize-Soya bean (2:4) denoted as ‘2M:4S’

Source: **Modified from Matusso *et al. (*2014)**

3.3 Management of the experiment

3.3.1 Plant varieties

The experiment utilized two crops, specifically maize and soya beans, which were sourced from the Kakamega branch of Kenya Seed Company Limited. The maize variety H513 and the soya bean variety SB19 were sown in the designated plots at the appropriate depth, following the prescribed intercropping pattern, at the beginning of the rainy season. The selection of these particular types was based on their recommended adaptability to the ecological zone of Kaimosi.

3.3.2 Land Preparation and planting

Land preparation commenced before the onset of rains. This started by land clearing followed by ploughing and then harrowing after 2 weeks using a tractor. Planting was done as per the spacing indicated in sub-section 3.2 above with 3 seeds per hole to cater for germination losses.

Thinning of the intercrops was conducted through uprooting two weeks post-sowing, with the practice of retaining two plants per hole. During the process of planting, di-ammonium phosphate (DAP) fertilizer was administered at a rate of 26 kilograms per acre and 75kgs per acre, for soya beans and maize respectively. CAN for top dressing at the rate of 45kg N per acre and 75kg N per acre, for soya beans and maize respectively according to the management practice recommended by KARI (2013).

3.4 Data Collection

3.4.1 Determination of growth parameters

3.4.1.1 Plant height of soya beans

The measurement of height was conducted from the soil level to the base of the shoot apex with a meter rule. Simple random sampling in each treatment was done to select plant for experimentation. The selected plants were randomly tagged in an X-manner for all the replicates, which was 50% of the total population. This process was initiated two weeks subsequent to the seeding of the plants and was then repeated at 14-day intervals until the conclusion of the experiment.

3.4.1.2 Leaf number of soya beans

Counting of green true leaves was done on the 50% randomly tagged plants in an X-manner to determine the leaf number for all the treatments and replicates. This procedure was conducted 14 days following from planting and subsequently repeated every 14 days to the conclusion of the experiment.

3.4.1.3 Leaf Area Index of soya beans

The Leaf Area Index (LAI) was determined by employing the inversion of transmitted Photosynthetic Active Radiation (PAR) across the entire treatment, as outlined in the equation proposed by Goudriaan (1988). The amount of PAR intercepted in a canopy brought by intercropping pattern is inversely proportional to the leaf area index of the plant.

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

In this context, L represents the leaf area index, while K is the extinction coefficient for the canopy. The extinction coefficient is provided in terms of Θ, which represents the zenith angle of the sun. The variable "fb" represents the proportion of incident photosynthetic active radiation (PAR), whereas the variable "τ" denotes the ratio of PAR measured below the canopy to PAR recorded above the canopy. The variable A is provided as

$$A = 0.283 + 0.785a - 0.159a^2$$

The leaf absorbing capacity in the photosynthetic active radiation (PAR) band is commonly seen to be approximately 0.9.

3.4.2 Determination of yield components of soya beans

3.4.2.1 Determination of pod number

The quantification of the amount of pods per plant was conducted through direct physical enumeration, on the 50% plants of the total soya bean population that were selected for sampling in each treatment from 42 Days After Planting.

3.4.2.2 Determination of pod length

The measurement of pod length was conducted by employing a string to assess the 50% sampled plants precisely 42 days after planting. Subsequently, this string was transferred to a meter rule for accurate measurement, and the obtained data was duly recorded. This was done when pods started forming to the time of harvesting (98 DAP).

3.4.2.3 Yield of soya beans

Soya bean was harvested 98 days after sowing in both seasons. This was done through uprooting of the whole plant drying them for a day and then crushing using a stick to break the pods and obtain the seeds. Afterwards, threshing was done to separate chaffs from the grain and measuring of fresh weight was done using a weighing scale. Subsequently, the grains underwent a drying process spanning three days in order to achieve an optimal moisture content of 13%, as verified by the utilization of a moisture-meter, at that point dry weight was taken. Two weeks later, at 112 days after planting maize was also harvested hand shelled dried and weighted. The aforementioned data was subsequently employed to calculate the Land Equivalent Ratio (LER) for intercropping in comparison to mono-cropping.

3.4.2.4 Land Equivalent Ratio (LER)

In order to assess the performance of the intercrop, the land equivalent ratio (LER) was computed using the formula proposed by Ofori and Stern (1987).

The Land Equivalent Ratio (LER) can be calculated using the formula: LER = (Y ij / Y ii) + (Y ji / Y jj).

In this context, Y represents the yield obtained per unit area. Yii and Yjj refer to the individual crop yields of the component crops i (soya bean) and j (maize'), respectively. On the other hand, Yij and Yji represent the yields obtained from intercropping these crops.

The partial land equivalent ratio (LER) values Li and Lj denote the relative yields of crops i and j when cultivated as intercrops. Therefore, the equation for calculating the Partial LER (Li) can be expressed as the ratio of Yij to Yii.

The formula for calculating the Partial LER (Lj) can be expressed as the ratio of the element Yji to the element Yjj.

The Land Equivalent Ratio (LER) is determined by the addition of two partial LER values, denoted as Partial LER (Li) and Partial LER (Lj).

3.4.3 Determination of Photosynthetic active radiation of Soya Beans

The measurement of photosynthetic active radiation (PAR) was conducted using a Sunflex Ceptometer model LP-80 in all treatment groups and replicates. The Sunfleck Ceptometer is a portable photosynthetic active radiation (PAR) sensor that is powered by a battery. It is commonly employed in the field of plant and forestry cover studies for gathering data. This technology facilitates the acquisition and retention of radiation measurements within the wavelength range of 400 to 700 nanometers waveband when placed below the maize canopy at about 30-60cm from the ground. The Ceptometer is equipped with a data logger that effectively records and retains measurements. These measurements are subsequently transmitted to a computer for analysis once the field measurements have been completed. The measurements were conducted between the periods of 11:30 am to 3:00 pm, according to the local time depending with weather of the day; this was also done when the crops height was measuring 2fts and repeated after every 14 days to the end of the experiment. The calculation of the intercepted PAR was performed using the methodology outlined by Goudriaan (1988).

$$\% \, PAR \, intercepted = \frac{(PAR_a - PAR_b)}{PAR_a} * 100$$

In this context, PARa refers to photosynthetic active radiation (PAR) measurements taken above the canopy, while PARb represents PAR measurements taken below the canopy.

3.5 Data analysis

The data pertaining to the height of soya beans, number of leaves, leaf area index, photosynthetic active radiation (PAR), length of pods, number of pods, and yield were analyzed using the analysis of variance (ANOVA) method in the GenStat statistical package version 15.2. This analysis aimed to determine the presence of statistically significant differences across various intercropping patterns. The LSD post hoc test was employed at a 95% confidence level to differentiate between the means. The yield was analyzed using a t-test with a significance level of 5% ($p < 0.05$).

CHAPTER FOUR

RESULTS

4.1 Effect of maize-soya beans intercropping patterns on growth parameters of soya beans

4.1.1 Plant height of soya beans

Soya bean height increased progressively from germination to maturity in all the patterns during data collection period. The height of soya beans was not significantly affected by the intercropping pattern, except for the comparison between sole soya bean and the 1M: 2S pattern at 14 days after planting (DAP). Also, between sole soya bean and both the 1M: 2S and 2M: 2S patterns at 42 DAP as indicated in Table 4.1. The pattern with 1 row of maize and 2 rows of soya bean recorded the tallest plant height with a mean height of 64.50cm at 84 DAP. This was followed by 1 line of maize and 1 line of soya bean and third was 2 line of maize and 2 line of soya bean pattern with an average height of 57.75cm. The pattern with 2 line of maize followed by 4 lines of soya bean had the least height with a mean height of 56.00cm.

Table 4. 1: Mean soya beans height in (cm).

PATTERNS	14 DAP	28 DAP	42 DAP	56 DAP	70 DAP	84 DAP
Sole soya bean	4.95 ^{a}	14.75^{a}	15.80^{b}	27.65^{a}	33.25^{a}	59.50^{a}
1M-1S	4.80 ^{ab}	15.00^{a}	18.90^{ab}	31.00^{a}	42.03^{a}	61.50^{a}
1M-2S	4.73 ^{b}	12.45 ^{a}	20.95^{a}	29.05^{a}	34.40^{a}	64.50^{a}
2M-2S	4.83^{ab}	16.68^{a}	21.10^{a}	31.95^{a}	39.10^{a}	57.75^{a}
2M-4S	4.83 ^{ab}	16.00^{a}	18.40^{ab}	26.90^{a}	32.75^{a}	56.00^{a}
LSD	**0.224**	**4.763**	**4.048**	**5.500**	**10.781**	**9.350**
P-Value (P≤0.05)	**0.358**	**0.725**	**0.078**	**0.262**	**0.251**	**0.395**

Means followed by different letter down the column are statistically different at P≤0.05 by Fisher's protected least significant difference test. Those with more than one letter within a column are intermediates. (1M:1S- one line of maize followed by one line of soya bean, 1M:2S- one line of maize followed by two line of soya bean, 2M:2S- two line of maize followed by two line of soya bean, 2M:4S- two line of maize followed by four line of soya bean)

4.1.2 Leaf number of soya beans

Intercropping pattern of maize and soya bean significantly affected the quantity of leaves at the end of the experimental period (p<0.05) (Table 4.2). At 84 days after planting pattern with 1 line of maize followed by 2 lines of soya bean (1M:2S pattern) recorded significantly the highest number of leaves among the intercrops while sole soya bean had the overall significantly higher number of leave compared to other intercrops but had no statistical significance variation with 1M:2S pattern only. When intercrops were compared at 84 DAP, pattern with 1 line of maize and 2 lines of soya bean had significantly the highest number of leaves of 60.0 leaves. This was followed by conventional pattern of 1 line of maize followed by 1 line of soya bean with a mean number of leaves of 48.25 and 2 line of maize and 2 lines of soya bean with a mean number of 46.5 leaves. The pattern with significantly the least number of leaves was that of two line of maize and four lines of soya bean with an average of 32.75 number of leaves.

The results of the long rain were different from the short rains since in the long season intercropping pattern significantly affected the leaf count and this was not evidenced in the short rain period as intercropping had no significant impact on number of leaves during the duration of the investigation (Table 4.3).

Table 4. 2: Table showing mean number of leaves of soya bean for long rain

PATTERNS	14 DAP	28 DAP	42 DAP	56 DAP	70 DAP	84 DAP
Sole soya bean	2.00^{a}	9.00^{ab}	14.50^{a}	18.75^{b}	26.00^{b}	60.25^{a}
1M-1S	2.00^{a}	8.50^{ab}	14.75^{a}	28.75^{a}	48.25^{a}	48.25^{ab}
1M-2S	2.00^{a}	8.25^{b}	15.25^{a}	22.50^{ab}	33.00^{ab}	60.00^{a}
2M-2S	2.00^{a}	9.50^{a}	14.00^{a}	21.75^{ab}	34.00^{ab}	46.50^{ab}
2M-4S	2.00^{a}	8.50^{ab}	15.25^{a}	23.15^{ab}	30.00^{ab}	32.75^{b}
LSD	**1.0**	**1.215**	**1.707**	**7.705**	**21.825**	**18.560**
***P-Value (P*≤0.05)**	**0.21**	**0.242**	**0.501**	**0.142**	**0.325**	**0.001**

Means followed by different letter down the column are statistically different at P≤0.05 by Fisher's protected least significant difference test. Those with more than one letter within a column are intermediates. (1M: 1S- one line of maize followed by one line of soya bean, 1M: 2S- one line of maize followed by two line of soya bean, 2M: 2S- two line of maize followed by two line of soya bean, 2M: 4S- two line of maize followed by four line of soya bean)

Table 4.3**: Table showing mean number of leaves for the short season**

PATTERNS	14 DAP	28 DAP	42 DAP	56 DAP	70 DAP
Sole soya bean	5.00^{b}	8.75^{a}	11.50^{a}	17.25^{a}	39.50^{a}

PATTERNS	14 DAP	28 DAP	42 DAP	56 DAP	70 DAP
1M-1S	6.00^{ab}	8.75^{a}	12.00^{a}	18.50^{a}	38.50^{a}
1M-2S	6.00^{ab}	9.00^{a}	11.75^{a}	20.00^{a}	39.25^{a}
2M-2S	6.00^{ab}	9.00^{a}	12.00^{a}	18.00^{a}	34.25^{a}
2M-4S	6.75^{a}	8.50^{a}	11.75^{a}	21.50^{a}	36.25^{a}
LSD	**0.933**	**0.826**	**0.613**	**6.838**	**13.448**
P-Value (P≤0.05)	**0.133**	**0.680**	**0.415**	**0.694**	**0.903**

Means followed by different letter down the column are statistically different at P≤0.05 by Fisher's protected least significant difference test. Those with more than one letter within a column are intermediates. (1M:1S- one line of maize followed by one line of soya bean, 1M:2S- one line of maize followed by two line of soya bean, 2M:2S- two line of maize followed by two line of soya bean, 2M:4S- two line of maize followed by four line of soya bean)

4.1.3 Leaf Area Index of soya beans

The leaf area index of soya bean was considerably influenced by the intercropping pattern during the study period (p≤0.05) (Table 4.4). Pattern with 2 lines of maize and 4 lines of soya bean pattern recorded the highest leaf area index of 0.55 than both the sole crop and intercrop patterns. This was followed by pattern with 2 line of maize and 2 line of soya bean, then 1M: 2S pattern and the least was 1M: 1S patterns with the LAI of 0.50, 0.43 and then 0.43 respectively at 84 DAP. 2M: 2S and 2M: 4S pattern indicated a statistical significance difference with sole soya beans, 1M: 1S and 1M: 2S patterns at 84 DAP. The result in the long rain had a similar trend to those of the short rains season.

Table 4. 4: Table showing mean LAI of soya beans

PATTERNS	42 DAP	56 DAP	70 DAP	84 DAP
Sole soya bean	0.08^{b}	0.11^{c}	0.15^{c}	0.33^{b}
1M-1S	0.13^{ab}	0.17^{bc}	0.18^{bc}	0.43^{b}
1M-2S	0.15^{a}	0.17^{bc}	0.22^{b}	0.43^{b}
2M-2S	0.15^{a}	0.20^{b}	0.21^{b}	0.50^{a}
2M-4S	0.19^{a}	0.26^{a}	0.29^{a}	0.55^{a}
LSD	**0.069**	**0.037**	**0.067**	**0.120**
P-Value (P≤0.05)	**0.048**	**0.007**	**0.007**	**0.019**

Means followed by different letter down the column are statistically different at P≤0.05 by Fisher's protected least significant difference test. Those with more than one letter within a column are intermediates. (1M:1S- one line of maize followed by one line of soya bean, 1M:2S- one line of maize followed by two line of soya bean, 2M:2S- two line of maize followed by two line of soya bean, 2M:4S- two line of maize followed by f our line of soya bean**)**

4.2. Effect of maize-soya beans intercropping patterns on yield components of soya beans

4.2.1 Pod Length of Soya Beans

Intercropping pattern of maize and soya bean had a significance effect on the pod length of soya beans ($p \leq 0.05$) during the designated time of data collection as indicated in Table 4.6. By 84 DAP when different intercropping pattern were compared 1M: 2S pattern recorded significantly the longest pods with an average of 3.84cm followed by 1M: 1S, 2M: 2S and 2M: 4S patterns respectively which were all significant. There was statistical significant difference among all the intercrops except between 1M: 1S and 2M: 2S intercropping patterns. 2M: 4S pattern had significantly the least pod length of 2.26 as shown in the table below.

Table 4.6: Table showing mean pod length of soya beans

PATTERNS	70 DAP	84 DAP
Sole soya bean	4.05^{a}	4.35^{a}
1M-1S	2.03^{d}	2.78^{c}
1M-2S	3.05^{b}	3.84^{b}
2M-2S	2.08^{c}	2.65^{c}
2M-4S	2.83^{e}	2.26^{d}
LSD	**0.441**	**0.386**
P-Value (P≤0.05)	**< 0.0001**	**< 0.0001**

Means followed by different letter down the column are statistically different at $P \leq 0.05$ by Fisher's protected least significant difference test. Those with more than one letter within a column are intermediates. (1M: 1S- one line of maize followed by one line of soya bean, 1M: 2S- one line of maize followed by two line of soya bean, 2M: 2S- two line of maize followed by two line of soya bean, 2M: 4S- two line of maize followed by four line of soya bean)

4.2.2 Pod Number of Soya Beans

Intercropping pattern had a significant impact on quantity of pods of soya beans ($p \leq 0.05$) during the study period with sole soya bean treatment recording significantly the highest number at both 70 and 84 DAP (Table 4.7). When intercrops were compared, 2M: 4S treatment had significantly the highest number of soya bean pods with an average of 45.5 pods per plant in the long rain period but with similar trend in the short rain. This was followed by 1M: 2S, 1M: 1S and significantly the fewest pods recorded in 2M: 2S pattern with an average of 36.05, 27.75 and 24.25 pods per plant respectively. All the treatment indicated a statistical difference with each other with similar trends in the short rain season.

Table 4.7: Table showing mean pod number of soya beans

PATTERNS	70 DAP	84 DAP
Sole soya bean	28.50^{b}	56.50^{a}
1M-1S	14.50^{c}	27.75^{d}
1M-2S	13.25^{c}	36.05^{c}
2M-2S	14.00^{c}	24.25^{d}
2M-4S	35.75^{a}	45.50^{b}
LSD	**4.629**	**8.678**
P-Value (P≤0.05)	**< 0.0001**	**< 0.0001**

Means followed by different letter down the column are statistically different at P≤0.05 by Fisher's protected least significant difference test. Those with more than one letter within a column are intermediates. (1M: 1S- one line of maize followed by one line of soya bean, 1M: 2S- one line of maize followed by two line of soya bean, 2M: 2S- two line of maize followed by two line of soya bean and 2M: 4S- two line of maize followed by four line of soya bean)

4.2.3 Effect of maize-soya beans intercropping patterns on yield of soya beans

Intercropping pattern significantly affected the yield of soya during the study period (Table 4.8). At harvesting of soya beans 98 DAP, intercropping significantly affected the fresh weight of soya bean. Sole soya bean recorded the highest fresh weight of 1.64g. However, when intercrops under the study were evaluated 2M: 4S pattern had the greatest fresh weight of 1.408kgs followed by 1M: 2S with 1.013kgs, then 2M: 2S pattern with 0.948kgs and least was 1M: 1S pattern with 0.618kgs respectively. The final yields, which are the dry weight, had sole soya bean recording significantly the highest yield in overall, while 1M: 2S pattern recording significantly the highest weight of 0.913kgs among the intercrops followed by 2M: 4S pattern and 2M: 2S pattern respectively.

Table 4.8: Table showing mean yields of soya beans in kilogram at 98 days after planting

PATTERNS	FRESH WEIGHT(FW)	DRY WEIGHT/YIELDS(DW)
Sole soya bean	1.640[a]	1.015[a]
1M-1S	0.618[c]	0.419[c]
1M-2S	1.013[b]	0.913[a]
2M-2S	0.948[b]	0.703[b]
2M-4S	1.408[a]	0.909[a]
LSD	**0.373**	**0.146**
***P-Value (P*≤0.05)**	**0.0001**	**0.0001**

Means followed by different letter down the column are statistically different at P≤0.05 by Fisher's protected least significant difference test. Those with more than one letter within a column are intermediates. (1M: 1S- one line of maize followed by one line of soya bean, 1M: 2S- one line of maize followed by two line of soya bean, 2M: 2S- two line of maize followed by two line of soya bean and 2M: 4S- two line of maize followed by four line of soya bean).

4.2.3.1 Correlation analysis of maize-soya beans intercropping patterns with the yield of soya beans

During the study, all the parameters showed positive correlation with the yield of soya beans, with significantly strong relationship indicated by pod length and dry weight as shown in table 4.9. In addition, height, leaf area index, photosynthetic active radiation (PAR), pod length and pod number showed a positive relationship with yield ($p<0.05$). However, number of leaves had no significant relationship with the yield of soya ($p>0.05$) and indicated weak positive correlation.

Table 4.9: Table showing correlation analysis of growth parameters, PAR and yield parameters on yield of soya bean

Variables	Height	Leaf no.	LAI	PAR	Pod length	Pod number	Fresh weight	Dry weight
Height	1.000	0.185 *P=0.433*	0.525 *P=0.018*	0.666 *P<0.0001*	0.754 *P=0.0001*	0.828 *P<0.0001*	0.854 *P<0.0001*	0.611 *P=0.004*
Number of leaves	0.185 *P=0.434*	1.000	0.338 *P=0.145*	0.422 *P=0.064*	0.354 *P=0.126*	0.609 *P=0.005*	0.501 *P=0.024*	0.394 *P=0.085*
Leaf area index	0.525 *P=0.018*	0.338 *P=0.145*	1.000	0.501 *P=0.024*	0.551 *P=0.012*	0.609 *P=0.005*	0.501 *P=0.024*	0.535 *P=0.015*
PAR	0.666 *P<0.001*	0.501 *P=0.025*	0.501 *P=0.025*	1.000	0.607 *P=0.005*	0.739 *P=0.0002*	0.792 *P=0.0001*	0.621 *P=0.004*
Pod length	0.754 *P=0.0001*	0.551 *P=0.012*	0.551 *P=0.012*	0.607 *P=0.005*	1.000	0.811 *P<0.0001*	0.756 *P=0.0001*	0.669 *P=0.001*

Pod number	0.828 *P<0.0001*	0.609 *P=0.005*	0.609 *P=0.005*	0.739 *P=0.0002*	0.811 *P<0.0001*	1.000	0.902 P<0.0001	0.669 *P=0.004*
Fresh weight	0.854 *P<0.0001*	0.501 *P=0.024*	0.501 *P=0.024*	0.792 *P=0.0001*	0.756 *P=0.0001*	0.902 *P<0.0001*	1.000	0.669 *P=0.004*
Dry weight	0.611 *P=0.004*	0.394 *P=0.085*	0.535 *P=0.015*	0.621 *P=0.004*	0.669 *P=0.001*	0.669 *P=0.004*	0.669 *P=0.004*	1.000

4.2.4 Effects of maize-soya beans intercropping patterns on land equivalent ratio (LER) of maize and soya beans

Maize soya bean intercropping pattern significantly affected the land equivalent ratio ($p \leq 0.05$) (Table 4.10). Findings from intercropping patterns indicated a more than one mean land equivalent ratio during the study with 1M: 2S pattern recording significantly the highest land equivalent ratio (LER) of 8.84 followed by 2M: 4S with 6.89, and 2M: 2S with 6.45. 1M: 1S pattern recorded significantly the lowest LER of and 4.50 compared to other pattern. These results indicated a similar trend as those of the short rain season.

Table 4. 10: Table showing land use efficiency of maize- soya beans intercropping patterns- Long Season

PATTERNS	LAND EQUIVALENT RATIO(LER) AT WEEK 16
Sole soya bean	< 0.0001^{e}
1M-1S	4.500^{d}
1M-2S	8.840^{b}
2M-2S	6.450^{c}
2M-4S	6.890^{a}
LSD	**0.056**
P-Value (P≤0.05)	**< 0.0001**

4.3. Effect of intercropping pattern on Photosynthetic active radiation of soya beans

The amount of PAR intercepted was significantly ($P<0.05$) affected by the intercropping pattern at different days after planting during the study (Table 4.5). Pattern with 1 line of maize and 2 line of soya bean pattern recorded significantly the highest photosynthetic active radiation (PAR) among intercrop with PAR amounting to 62.75% followed by treatment with. 2 line of maize and 4 lines of soya bean with mean percentage PAR of 55.5%, then 2 lines of maize and 2 lines of soya bean with 48.25%. Pattern with significantly the least PAR interception was conventional treatment with 1 line of maize and 1 line of soya beans with a percentage PAR of 45.5%. The outcome of the extended rainy season exhibited a comparable pattern to that of the short rainy season. When different intercropping patterns were compared 1M: 1S pattern indicated a significant difference with 1M: 2S and 2M: 4S. Also, there was a significant different between 1M: 2S pattern with the rest of the pattern as well as 2M: 4S with similar trend in the short rain period.

Table 4. 5: Table showing mean PAR of soya beans for the long season (%)

PATTERNS	56 DAP	70 DAP
Sole soya bean	64.75[a]	69.00[a]
1M-1S	42.25[d]	45.50[d]
1M-2S	56.25[b]	62.75[b]
2M-2S	49.25[c]	48.25[d]
2M-4S	38.25[e]	55.50[c]
LSD	**3.475**	**6.293**
***P-Value (P*≤0.05)**	**< 0.0001**	**< 0.0001**

Means followed by different letter down the column are statistically different at P≤0.05 by Fisher's protected least significant difference test. Those with more than one letter within a column are intermediates. (1M:1S- one line of maize followed by one line of soya bean, 1M:2S- one line of maize followed by two line of soya bean, 2M:2S- two line of maize followed by two line of soya bean, 2M:4S- two line of maize followed by f our line of soya bean)

CHAPTER FIVE

DISCUSSION

5.1. Effect of maize-soya beans intercropping patterns on growth parameters of soya bean

5.1.1 Plant height of soya beans

Soya bean height increased progressively from germination to maturity with the advancement of growth in all the patterns during data collection period. During the study, longer stems were observed in the intercrops pattern than the sole soya bean. This study shows that intercropping pattern did not significantly affect the height of soya bean. Similar studies by Mutusso *et al. (*2014) and Muoneke *et al. (*2007) yielded similar results, as they did not observe any statistically significant variations in the height of plants when comparing different intercropping systems including maize and soya beans. Similarly, finding by Cai *et al. (*2010), Gao *et al*. (2010), and Salama *et al.* (2022) in other crop combination namely lentil- wheat intercrop, sorghum- cow peas intercrop and maize- cow peas intercropping pattern respectively were similar to the results of this study.

Plant height is taken as a basic parameter employed in morphological analysis, providing insights into the progress and maturation of crop as well as the rate and vigor of plant growth (Wei *et al.*, 2022a). Increased height among the intercrops than sole soya bean can be attributed to degree of cover by maize. For instance, the soya bean plant in 1M: 2S pattern were more shaded and they were the tallest while those in the 2M: 4S pattern were more exposed to light and were the shortest. Thus, soya bean plant exhibited a sequence of shading reaction to acclimate to stress caused by reduced light availability. This led to predominant allocation of soya bean photosynthate to elongation of the stem, thus promoting an increase in soya bean long stature. Furthermore, height increase of soya bean may also have been due to positive phototropism where plants grow towards a light source in order to carry out photosynthesis.

Maize dominate by lengthening their stem more than soya bean and covering them by forming a canopy on the understorey as growth and development period advances. This is because maize, a C4 plant has a more competitive ability for resources like water, light and nutrients compared to soya beans a C3 plant. This is because C4 plants have many chloroplast including in their bundle sheath, can perform photosynthesis even when the stomata are closed, optimum temperature for photosynthesis is high and thus more efficient in photosynthesis compared to C3 plants. Reduction of infra-red radiation of photosynthetic active radiation at the uppermost part of an intercropped soya bean canopy may have contributed to increased soya bean height among other growth parameters due to the accumulation of biomass (Liu *et al.*,2021).

Soya bean under 1M: 2S recorded the tallest plant while the shortest soya bean plants were those found in 2M: 4S pattern. However, the study conducted by Koyejo *et al.* (2021) and Wei *et al.* (2022b) on maize-mung bean intercropping pattern provided contrary result to the current study, whereby they found that intercropping maize and mung beans significantly increased the height of the mung beans contrary to the recent findings. However, the intercropping patterns were fewer in their study consisting of alternate double row pattern and convention system of alternating 1 to 1 row of maize and soya bean.

5.1.2 Leaf number of soya beans

Intercropping pattern significantly increased the leaf numbers of soya bean during the study period. Nevertheless, 1M; 2S pattern among the intercrops had the highest number of leaves. The present study result are also supported by the finding of Baker *et al.* (2021), who reported significantly high number of leaves in both sorghum and cowpeas in sorghum cow peas intercropping pattern. Mohammed *et al*. (2021), also reported more vegetative growth of cow peas under maize intercrop.

The high number of leaves recorded in 1M: 2S pattern could because maize minimizes the amount of infra-red radiation reaching the lower soya bean thus encouraging more branches and leave growth. Soya bean under 1M: 2S pattern favorably adapt to shade brought by the overstorey maize either through tolerance or avoidance mechanism and continued with the normal physiological processes. Soya bean under 1M: 2S pattern could tolerate the shade enabling them to exhibit the ability to withstand reduced light condition while simultaneously enhancing its capacity to capture and utilize light energy enabling continuity in food manufacturing through the process of photosynthesis thus increasing vegetative growth of soya bean. Also, soya bean under 1M: 2S pattern adapted to absorb and capture as much light as possible to optimize the photosynthesis output. This in turn may have help them to accelerate CO_2 fixation as well as accumulate carbohydrates to ensure physiological growth rate such as leaf multiplication is achieved (Wu *et al.,* 2021).

Therefore, intercropping pattern affect the leaf number of soya bean at a specific period of production as shown in the finding of this study when intercropping affected soya leaves quantity at the end of production period but not at the beginning nor at the middle end.

5.1.3 Effect of Maize-Soya bean Intercropping Pattern on Leaf area Index of soya beans

This study shows that intercropping patterns significantly reduced Leaf Area Index (LAI). Leaf Area Index for 2 line of maize and 4 line of soya bean intercropping pattern was the highest while the least LAI was recorded for 1 line of maize and 2 line of soya bean pattern. Similar findings were recorded by Khonde *et al*. (2022), who also studied intercropping patterns of maize and soya beans. These findings are largely attributed to the decrease of infra-red radiation (R:FR) ratio of photosynthetic active radiation above the intercropped soya bean shade that increased LAI of underneath soya bean (Liu *et al.,* 2021). LAI of a canopy is key in forecasting crop growth and yields. Maintaining an optimal LAI is essential for sustaining high photosynthetic rates and maximizing crop output.

According to Brintha and Seran (2010), insufficient light absorption occurs when the index is too low, whereas inadequate light distribution to lower leaves, resulting in their reduced functionality, is observed when the index is excessively high. In the current study soya bean under intercrop pattern recorded the highest LAI than those under monocrop which agrees with reports of Yang *et al*. (2022) who similarly observed bigger leaf areas index in intercropped maize-soya system than sole crops. In contrast to the findings of Raza *et al. (*2021) in strip maize soya bean intercropping, who saw a decrease in leaf area index in maize-soya bean intercrops compared to monocrops, this study presents a different perspective. This phenomenon might be attributed to the potential negative impact of excessive maize shade and water stress in an intercropping system on the growth and development of soya bean plants, leading to reduced dry matter output and altered partitioning. The practice of intercropping maize and soya bean resulted in a notable increase in the Leaf Area Index (LAI) of soya bean across the entire data collection period. This can be attributed to the substantial LAI absorption, which consequently enhanced the absorption of light for photosynthesis.

5.2. Effect of maize-soya beans intercropping patterns on yield parameters of soya beans

5.2.1. Pod Length of Soya Beans

Intercropping pattern significantly increased the pod length of soya bean. The longest pod length was observed in 1M: 2S pattern with the mean pod length of 3.84cm. This was followed by conventional pattern of 1 row of maize and 1 row of soya bean with mean pod length of 2.28cm at 84 DAP. However, sole soya bean recorded the longest pods amongst all patterns. These findings mirror those of Bibi *et al*. (2020) who found that different intercropping treatment of mung bean with maize significantly affected the length of mung bean pods and mung bean pods were also longest in the sole crop treatment. These results may be attributed to sufficient light interception during the reproductive stage that allowed higher rate of photosynthesis generating more biomass that accumulated to lengthen the pods.

The optimum nutrient utilization may also have occurred in this pattern, which led to increases in length of pods of soya bean. The longest pods observed in sole soya bean than intercrop treatment can be ascribed to availability of more nutrients that fostered the apical meristematic activities leading to vegetative growth and pod lengthening and less interspecific competition for available resources (Matusso *et al.*, 2014). As observed earlier (Matusso *et al.*, 2014), canopy which brings about (20-49 %?) of ambient light leads to lengthening of internodes and increased lodging in soya bean plants. In a study conducted by Raza *et al. (*2021), it was shown that the introduction of light enhancement during the early stage of pod formation resulted in a significant increase in seed length in maize-soya bean intercrops. Nevertheless, it should be acknowledged that nutrient absorption through nitrogen fixation processes of the two crops in the intercropping pattern was not quantified in this study, hence a gap for future studies.

5.2.2. Pod Number of Soya Beans

Intercropping pattern significantly increased the quantity pods of soya beans with the highest amount recorded in 2 line of maize and 4 line of soya bean among the intercrop treatment with an average of 45.5 pods per plant. Lyngdoh *et al*. (2020), found that the number of pods per plant of soya beans, groundnut and mung bean were similarly affected by the intercropping pattern. The result also agrees with Matusso *et al. (*2014) who found that the intercropping pattern had a comparable impact on the quantity of pods per plant in soya beans, groundnut, and mung bean. Other studies by Mohammadzadeh *et al.* (2022) and Matusso *et al., (*2014) with mung bean and maize intercrops also found a higher number of pods in sole mung bean than in maize mung bean combination. These findings can be attributed to a combination of factors, including a reduced level of competition between different species and a more efficient consumption of nitrogen through the application of a starter dose and its subsequent fixation by the root nodules.

Nevertheless, the phenomenon of biological nitrogen fixation appears to have a significant impact in soya bean pod production. It was however not determined in this study and should be part of future studies. The high number of pods recorded in 2 line of maize and 4 line of soya bean among the intercrop can be linked to the optimum amount of leaf area index (LAI) reported elsewhere in this paper as it is key in determining the number of pods in soya bean in an intercropping pattern. The pattern also may have allowed for maximum light interception hence mitigating flower abortion and subsequently increasing pod count. It is worth noting that the quantity of flower recorded in soya bean determines the amount of pods per plant. Light improvement at late vegetative or early flowering multiplies the number of pods, which later improves its yield by encouraging more vegetative growth, flowering and increased podding in soya bean plant (Matusso *et al.*, 2014).

5.2.3. Effect of intercropping pattern on Yield of Soya Beans

Intercropping pattern significantly affected the yields of soya bean during the study. The highest fresh and dry yields were found in 2M: 4S and 1M: 2S patterns, respectively. Matusso *et al. (*2014) observed that the yield of soya beans was considerably influenced by the intercropping pattern. The highest yields of soya bean were recorded in sole treatment in this study corroborates those of Mongare *et al.* (2020) and Khonde *et al. (*2022). The decrease in soya bean yields observed in intercropping scenario may be attributed to interspecific competition between the intercrop constituent for essential resources such as water, light, and nutrients. This struggle is further intensified by the vigorous growth characteristics of maize, a C4 species, which has a suppressive effect on soya bean, a C3 species. Furthermore, yield of soya beans could have reduced as a result of maize shadowing effects on soya bean, making the legume component to devote its photosynthates to vegetative growth and height enhancement in order to compete with taller maize plant (Ali *et al.*, 2012).

In addition Papathanasiou *et al.* (2022), also argued that minimal irradiance during flowering stage results in a significant increase in the proportion of flowers that do not develop fully, ultimately leading to a reduced number of pods per plant in common bean cultivation, hence adversely impacting the overall yield. Matusso *et al. (*2014), showed that an increase in leaf area index (LAI) frequently does not result in higher productivity. Instead, it typically leads to a fall in output due to the loss of respiratory CO_2 from severely shadowed leaves and stem. Reduction in dry weight yield of soya bean in 2M: 4S pattern could be because pod did not fill fully at maturity bringing about inferior grains. Poor grain filling could be brought about by low nitrogen concentration and uptake from the soil possibly resulting from the absence of indigenous rhizobia responsible for nodulating the legume which determines pod filling at maturity. Inferior pods can as well be ascribed to suboptimal plant nutrition and several plant stressors that impede nitrogen fixation such as insufficient water, nutrients and light, as they are key factors affecting productivity of a plant.

The finding where 1 row of maize and 2 rows of soya bean (1M:2S) pattern recorded the highest dry weight (yields) was possibly due to mature and healthy pod harvested as a result of availability of nutrients especially nitrogen and water absorption during flowering and maturity stage. The 1M: 2S intercropping pattern allowed for sufficient PAR interception (data not shown). The pattern (1M: 2S) also may have allowed for optimum soil cover that minimized the rate of evapotranspiration thus more water was available from soil for use in primary production.

During the study period, the parameters showed positive relationship with the yield of soya beans, with significantly strong relationship indicated by pod length and fresh weight. These parameters (leaf number, pod number and length) directly influence final yield. Increased vegetative growth allows for proper light interception for photosynthesis thus more flower formation and development. Increase in number of flowers in a plant leads to corresponding increase in number of pods, resulting in augmented yields.

Umesh *et al. (*2023) and Begna *et al. (*2020) established a positive correlation of height with yields parameters indicating that, taller plants produce heavy fruits, long fruit length and heavy grain in cereal-legume combination and maize- soya bean intercropping system respectively.

5.2.4 Effects of maize-soya beans intercropping patterns on land equivalent ratio (LER) of maize and soya beans

Intercropping pattern significantly affected the land equivalent ratio with all the intercrop treatments recording a LER greater than one indicating a balance in material utilization by intercrops and yield advantage among the intercrop treatment. The findings support the result of many other researchers who concluded that intercropping pattern significantly affected the LER of cereal legume combination ((Mudare *et al.*, 2022,; *Matusso et al.* 2014; Yusuf *et al.*, 2012; Dahmardeh *et al*. 2010; Hugar and Palled, 2008) in maize legume intercropping patterns. Land Equivalent Ratio (LER) therefore, is the total land area needed under mono-cropping to provide the yield obtained in intercropping system. Normally it shows combined yield for assessing the efficiency of intercropping (Ofori & Stern, 1987).

A land equivalent ratio above one (LER>1) recorded in the present study were consistent with the findings of earlier done research such as those of Tofa *et al. (*2019); Gong *et al. (*2020) and Muoneke *et al*.(2007) in corn soya bean intercropping system indicating beneficial output in an intercropping than mono-cropping as a result of yield complementarity. A Land Equivalent Ration which is equal to 1 shows that there is no yield benefit in intercropping as the similar yield can be attained in mono-cropping at acclaimed density with mixed cropping, minus altering the entire space. On the other hand, a LER less than 1 indicate that, the yield attained in intercropping can be realized in mono-cropping from a lesser space. However, a LER greater than 1 indicates yield advantage and bigger land is required to harvest an equivalent yield of each crop when grown as a solitary crop at the suggested density compared to intercropping (Ofori & Stern, 1987).

The comparative level of competitiveness exhibited by the constituent crop within an intercropping system is given by the partial LER thus, crops with bigger partial LER are said to have greater competitors for growth restrictive factor compared to those with low partial LER (Justes *et al.*, 2021). The intercrop system exhibited greater productivity in comparison to the solo crop, potentially due to the component crops' ability to effectively and synergistically utilize growing resources, as suggested by Liu *et al.* (2021). For example, the study conducted by Sivakumar & Virmani, (1984), showed that the production of dry matter per unit of photosynthetic active radiation (PAR) intercepted was greater in the maize-pigeon pea intercrop compared to the solo crops. This finding is consistent with the results of our current investigation, which also reported higher levels of light interception in the intercropping treatments. However, it is important to investigate further on the quantity of dry matter formed per the amount of PAR intercepted to ascertain some findings earlier done research. The reduced land equivalent ratio (LER) observed in the traditional 1 row of maize and 1 row of soya bean (1M: 1S) intercropping pattern can be attributed to the research findings of Ofori and Stern (1986). These scientists revealed that light availability plays a crucial role in determining the LER of maize and soya bean intercropping. The LER decreases when the legume component experiences significant shading, as evidenced by measurements of light intensity.

5.3 Effect of maize soya bean intercropping pattern on Photosynthetic active radiation of soya beans

The interception of photosynthetic active radiation (PAR) was found to be significantly influenced by the intercropping pattern at various time points after planting, as indicated by a p-value of less than 0.05. The result obtained in this study align with result reported by Arun (2016) and Matusso *et al. (*2014), who observed a significant difference in light interception as affected by different intercropping patters of maize and soya beans at different time of growing season. The highest PAR recorded in sole soya bean than intercrops were also similar to reports compiled from other studies conducted by Ghanbari *et al. (*2010) and Bibi *et al. (*2020). These researchers also reported higher light interception in monocrop compared to intercrops in maize-cowpea, maize soya bean and maize mung bean intercropping system respectively.

The high percentage of light intercepted in the sole crop was because of lack of shade hence maximum light absorption. However, among the intercrops treatment with 1M: 2S pattern intercepted the highest PAR at 70 Days after planting (70 DAP) than both the conventional pattern (1M: 1S) and mbili mbili pattern of 2line of maize followed by 2 line of soya bean (2M: 2S). In the current study also, mbili mbili (2M; 2S) intercepted much light than conventional pattern (1M; 1S). This disagrees with the findings of Ennin *et al. (*2002) who observed that percentage Photosynthetic Active Radiation captured in maize soya bean combination was 4% more than conventional pattern of maize and soya bean than in intercrops of two lines of maize followed by two line of soya beans (mbili-mbili). Other researchers such as Mongare *et al. (*2020) and Matusso *et al. (*2014) also resolved that mbili mbili pattern intercept high PAR than conventional pattern contrary to the finding of this study where 1M:2S pattern intercepted more light than mbili mbili. Photosynthetic active radiation is the radiation absorbed by the plants to carry out photosynthesis process Goudriaan (1988). Its denotes the spectra range (wave band) of solar radiation from about 400-700 nanometers which is utilized by photosynthetic organisms during the process of photosynthesis.

The greater PAR absorbed by 1M: 2S pattern may be due to high accumulation of biomass in soya beans under the pattern. Additionally, it is worth noting that the increased PAR conversion efficiencies reported in intercropping systems can be attributed to the wider leaf area and more effective distribution of light in their canopies during the early stages of growth, as discussed by Addo-Quaye *et al. (*2011). Variances in vertical arrangement and leaf architecture brought about by 1M: 2S pattern also allowed for greater PAR interception than the rest of the intercrop pattern (Keating and Carberry, 1993). However, this study could not explain how canopy of the intercropping system bring different leaf architecture and how different leaf arrangement and architecture affect PAR interception. Furthermore, the relationship between the amount of biomass accumulated and its effects on the amount of PAR intercepted in an intercropping pattern could not be explained.

According to the study conducted by Feng *et al. (*2019) in an intercropping pattern involving maize and soya bean demonstrated enhanced light interception and radiation usage efficiency compared to solitary cropping. This improvement was attributed to an increase in leaf area index, light interception, and dry matter production. According to a study conducted by Reddy *et al.* (1980), it was found that the millet-groundnut intercrop system exhibited a 28 percent increase in efficiency in light utilization compared to their respective monocrops. This enhanced efficiency was primarily related to the intercrop's approximately 30 percent higher leaf area index (LAI) in comparison to the sole crops. Those results by Reddy *et al. (*1980), were also at variance with findings of our study where sole soya bean intercepted more light than the rest of the patterns (intercrops). It appears from findings of the current study that there is no conclusion on how various intercropping pattern affect PAR and hence productivity of the legume intercrop.

CHAPTER SIX

CONCLUSIONS, RECOMMENDATIONS AND SUGGESTION FOR FURTHER RESEARCH

6.1. Conclusion

This study has established that soya bean height was not significantly influenced by intercropping despite increasing it throughout the period of data collection. Although, plants in intercrop pattern were taller probably due to the shading effect of maize plant which made soya bean plants to undergo series of reaction to adopt to shade stress. This contributed to favourable supply of soya bean photosynthate towards stem elongation. Reduced number of leaves in intercrop was because of adaptation of the understory soya beans to the light. Significantly higher LAI recoded in intercrop pattern than sole crops as in 2 line of maize and 4 line of soya bean may be attributed to low infra-red radiation (R:FR) ratio of photosynthetic active radiation above the intercrop soya bean that increased LAI of underneath soya bean. Significantly, higher PAR intercepted in 1M: 2S pattern was brought about by the greater PAR conversion efficiencies observed in intercropping systems and optimum vegetative growth.

Intercropping pattern of maize and soya bean significantly increased pod length, pod number and final yield of soya bean. This was due to optimum LAI that provided a larger surface area for light interception at flowering fostering stage increase vegetative growth thus high number of pod in 1M: 2S pattern. Also, greater PAR interception possibly led to accumulation of biomass that lengthen pods.

The 2M: 4S pattern appears to have performed better in final fresh weight yield but less effective in dry weight. The higher light exposure contributed to the favourable performance in 1M: 2S pattern and has potential to be adopted. Findings from intercropping patterns indicated a more than one mean land equivalent ration during the study with 1M: 2S pattern having significantly the highest land equivalent ration due to proper utilization of resources.

6.2. Recommendations

Agroecologist to practice the 1M: 2S arrangement of maize and soya bean since it exhibited effectual utilization of materials that led to increased vegetative growth such as height leaves number and LAI. The optimum leaf growth allowed in 1M: 2S pattern decreased the infra-red radiation ratio of PAR above the intercropped soya bean thus increasing the LAI of underneath soya bean. In addition, the optimal vegetative growth observed in in 1M: 2S pattern lead to higher PAR interception than the other pattern. This pattern also gave the best yield compared to other intercrops due to optimal growth and high PAR that promoted high yield of soya bean and effective land utilization due to yield benefits indicated by the highest land equivalent ratio of 8.84 than the rest of the patterns.

6.3. Suggested areas for further research

Several issues are suggested for future research:

1. The phenomenon of biological nitrogen fixation was not determined in this study yet it appear to have a vital role in soya bean pod development and thus should form part of future study.
2. The quantity of nutrient absorbed through nitrogen fixation process of different crop in an intercropping system need to be investigated further as it was not explained in this study.
3. Further research need to be conducted to understand how canopy brought about by intercropping system bring about different leaf architecture and how different leaf arrangement and architecture affect PAR interception.
4. It is important to investigate further on the quantity of dry matter formed per the amount of PAR intercepted to ascertain some findings of earlier done research
5. Further research is required to find out the relationship between the amount of biomass accumulated and how it affects the amount of PAR intercepted in an intercropping pattern

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APPENDICES

APPENDIX 1: TABLES OF ANALYSIS

APPENDIX 1.1: TABLES SHOWING ANALYSIS OF VARIANCE (ANOVA) OUTPUT (SHORT SEASON)

1.1.1 WEEK 2 SHORT SEASON ANALYSIS OF VARIANCE FOR HEIGHT

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	2.967	0.74175	2.43	0.093
Error	15	4.5825	0.3055		
Corrected Total	19	7.5495			

1.1.2 WEEK 4 SHORT SEASON ANALYSIS OF VARIANCE FOR HEIGHT

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	20.315	5.07875	0.95	0.4644
Error	15	80.495	5.3663333		
Corrected Total	19	100.81			

1.1.3 WEEK 6 SHORT SEASON ANALYSIS OF VARIANCE FOR HEIGHT

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	1.262	0.3155	0.71	0.5991
Error	15	6.6875	0.445833		
Corrected Total	19	7.9495			

1.1.4 WEEK 8 SHORT SEASON ANALYSIS OF VARIANCE FOR HEIGHT

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	90.868	22.717	2.03	0.142
Error	15	168.06	11.204		
Corrected Total	19	258.928			

1.1.5 WEEK 10 SHORT SEASON ANALYSIS OF VARIANCE FOR HEIGHT					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	971.443	242.86075	51.82	<.0001
Error	15	70.3025	4.686833		
Corrected Total	19	1041.7455			

1.1.6 WEEK 12 SHORT SEASON ANALYSIS OF VARIANCE FOR HEIGHT					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	269.117	67.27925	2.13	0.127
Error	15	473.1725	31.5448333		
Corrected Total	19	742.2895			

1.1.7 WEEK 2 SHORT SEASON ANALYSIS OF VARIANCE FOR NUMBER OF LEAVES					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	3.2	0.8	2.09	0.1333
Error	15	5.75	0.383333		
Corrected Total	19	8.95			

1.1.8 WEEK 4 SHORT SEASON ANALYSIS OF VARIANCE FOR NUMBER OF LEAVES					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0.7	0.175	0.58	0.6795
Error	15	4.5	0.3		
Corrected Total	19	5.2			

1.1.9 WEEK 6 SHORT SEASON ANALYSIS OF VARIANCE FOR NUMBER OF LEAVES					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0.7	0.175	1.05	0.4146
Error	15	2.5	0.167		
Corrected Total	19	3.2			

1.1.10 WEEK 8 SHORT SEASON ANALYSIS OF VARIANCE FOR NUMBER OF LEAVES					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	46.2	11.55	0.56	0.6944
Error	15	308.75	20.5833333		
Corrected Total	19	354.95			

1.1.11 WEEK 10 SHORT SEASON ANALYSIS OF VARIANCE FOR NUMBER OF LEAVES					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	80.7	20.175	0.25	0.9031
Error	15	1194.25	79.616667		
Corrected Total	19	1274.95			

1.1.12 WEEK 12 SHORT SEASON ANALYSIS OF VARIANCE FOR NUMBER OF LEAVES					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	80.7	20.175	0.25	0.9031
Error	15	1194.25	79.61667		
Corrected Total	19	1274.95			

1.1.13 WEEK 6 SHORT SEASON ANALYSIS OF VARIANCE FOR LEAF AREA INDEX (LAI)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0.02088428	0.00522107	2.64	0.0753
Error	15	0.02966659	0.00197777		
Corrected Total	19	0.05055087			

1.1.14 WEEK 8 SHORT SEASON ANALYSIS OF VARIANCE FOR LEAF AREA INDEX (LAI)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0.07506794	0.01876699	2.83	0.0622
Error	15	0.09942179	0.00662812		
Corrected Total	19	0.17448974			

1.1.15 WEEK 10 SHORT SEASON ANALYSIS OF VARIANCE FOR LEAF AREA INDEX (LAI)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0.13197739	0.03299435	2.09	0.1334
Error	15	0.23719411	0.01581294		
Corrected Total	19	0.3691715			

1.1.16 WEEK 12 SHORT SEASON ANALYSIS OF VARIANCE FOR LEAF AREA INDEX (LAI)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0.109645	0.027411	6.38	0.0033
Error	15	0.064431	0.004295		
Corrected Total	19	0.174076			

1.1.17 WEEK 8 SHORT SEASON ANALYSIS OF VARIANCE FOR POD NUMBER (PN)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	13.3	3.325	3.76	0.0259
Error	15	13.25	0.883333		
Corrected Total	19	26.55			

1.1.18 WEEK 10 SHORT SEASON ANALYSIS OF VARIANCE FOR POD NUMBER (PN)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	178.8	44.7	15.33	<.0001
Error	15	43.75	2.9166667		
Corrected Total	19	222.55			

1.1.19 WEEK 12 SHORT SEASON ANALYSIS OF VARIANCE FOR POD NUMBER (PN)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	410.7	102.675	29.91	<.0001
Error	15	51.5	3.433333		
Corrected Total	19	462.2			

1.1.20 WEEK 8 SHORT SEASON ANALYSIS OF VARIANCE FOR PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	76.5	19.125	4.14	0.0186
Error	15	69.25	4.6166667		
Corrected Total	19	145.75			

1.1.21 WEEK 10 SHORT SEASON ANALYSIS OF VARIANCE FOR PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	1163.5	290.875	212.84	<.0001
Error	15	20.5	1.366667		
Corrected Total	19	1184			

1.1.22 WEEK 12 SHORT SEASON ANALYSIS OF VARIANCE FOR PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	1163.5	290.875	212.84	<.0001
Error	15	20.5	1.366667		
Corrected Total	19	1184			

1.1.23 WEEK 14 SHORT SEASON ANALYSIS OF VARIANCE FOR FRESH WEIGHT					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	2.21148	0.55287	174.22	<.0001
Error	15	0.0476	0.003173		
Corrected Total	19	2.25908			

1.1.24 WEEK 14 SHORT SEASON ANALYSIS OF VARIANCE FOR DRY WEIGHT					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0.83107	0.207768	7.42	0.0017
Error	15	0.41975	0.027983		
Corrected Total	19	1.25082			

1.1.25 WEEK 14 SHORT SEASON ANALYSIS OF VARIANCE FOR LAND EQUIVALENT RATIO					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	180.4229	45.10572	32844	<.0001
Error	15	0.0206	0.001373		
Corrected Total	19	180.4435			

APPENDIX 1.2: TABLES SHOWING LONG RAIN ANALYSIS OF VARIANCE OUTPUT

1.2.1 WEEK 2 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR HEIGHT					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0.105	0.02625	1.18	0.3575
Error	15	0.3325	0.022167		
Corrected Total	19	0.4375			

1.2.2 WEEK 4 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR HEIGHT					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	20.638	5.1595	0.52	0.7248
Error	15	149.8075	9.987167		
Corrected Total	19	170.4455			

1.2.3 WEEK 6 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR HEIGHT					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	75.272	18.818	2.61	0.0777
Error	15	108.21	7.214		
Corrected Total	19	183.482			

1.2.4 WEEK 8 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR HEIGHT					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	73.828	18.457	1.46	0.2619
Error	15	188.99	12.59933		
Corrected Total	19	262.818			

1.2.5 WEEK 10 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR HEIGHT					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	307.802	76.9505	1.5	0.2509
Error	15	767.5075	51.16717		
Corrected Total	19	1075.31			

1.2.6 WEEK 12 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR HEIGHT					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	174.8	43.7	1.09	0.3954
Error	15	599.75	39.9833333		
Corrected Total	19	774.55			

1.2.7 WEEK 2 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR NUMBER OF LEAVES (NL)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0	0	0	
Error	15	0	0		
Corrected Total	19	0			

1.2.8 WEEK 4 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR NUMBER OF LEAVES (NL)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	4	1	1.54	0.2415
Error	15	9.75	0.65		
Corrected Total	19	13.75			

1.2.9 WEEK 6 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR NUMBER OF LEAVES (NL)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	4.5	1.125	0.88	0.5009
Error	15	19.25	1.283333		
Corrected Total	19	23.75			

1.2.10 WEEK 8 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR NUMBER OF LEAVES (NL)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	212	53	2.03	0.1419
Error	15	392	26.13333		
Corrected Total	19	604			

1.2.11 WEEK 10 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR NUMBER OF LEAVES (NL)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	1065.7	266.425	1.27	0.3249
Error	15	3145.5	209.7		
Corrected Total	19	4211.2			

1.2.12 WEEK 12 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR NUMBER OF LEAVES (NL)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	174.8	43.7	1.09	0.3954
Error	15	599.75	39.9833333		
Corrected Total	19	774.55			

1.2.13 WEEK 6 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR LEAVE AREA INDEX (LAI)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0.025952	0.006488	3.09	0.0484
Error	15	0.031492	0.002099		
Corrected Total	19	0.057445			

1.2.14 WEEK 8 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR LEAVE AREA INDEX (LAI)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0.043423	0.010856	17.62	<.0001
Error	15	0.009242	0.000616		
Corrected Total	19	0.052665			

1.2.15 WEEK 10 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR LEAVE AREA INDEX (LAI)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0.042791	0.010698	5.37	0.0069
Error	15	0.029891	0.001993		
Corrected Total	19	0.072681			

1.2.16 WEEK 10 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR LEAVE AREA INDEX (LAI)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	0.104292	0.026073	4.1	0.0193
Error	15	0.095332	0.006355		
Corrected Total	19	0.199623			

1.2.17 WEEK 10 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR POD LENGTH (PL)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	12.687	3.17175	37.1	<.0001
Error	15	1.2825	0.0855		
Corrected Total	19	13.9695			

1.2.18 WEEK 12 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR POD LENGTH (PL)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	20.263	5.06575	77.34	<.0001
Error	15	0.9825	0.0655		
Corrected Total	19	21.2455			

1.2.19 WEEK 10 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR NUMBER OF PODS (PN)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	2513.3	628.325	66.61	<.0001
Error	15	141.5	9.433333		
Corrected Total	19	2654.8			

1.2.20 WEEK 12 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR NUMBER OF PODS (PN)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	13746.5	3436.625	103.67	<.0001
Error	15	497.25	33.15		
Corrected Total	19	14243.75			

1.2.21 WEEK 8 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR PAR					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	1820.8	455.2	85.62	<.0001
Error	15	79.75	5.316667		
Corrected Total	19	1900.55			

1.2.22 WEEK 10 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR PAR					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	1539.7	384.925	22.08	<.0001
Error	15	261.5	17.43333		
Corrected Total	19	1801.2			

1.2.23 WEEK 12 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR FRESH WEIGHT IN KGS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	6.40375	1.6009375	26.13	<.0001
Error	15	0.919025	0.06126833		
Corrected Total	19	7.322775			

1.2.24 WEEK 12 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR DRY WEIGHT/YIELDS IN KGS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	3.674287	0.918572	97.48	<.0001
Error	15	0.141343	0.009423		
Corrected Total	19	3.81563			

1.2.25 WEEK 12 LONG SEASON ANALYSIS OF VARIANCE (ANOVA) FOR LAND EQUIVALENT RATIO (LER)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	4	1.7105	0.427625	5966.86	<.0001
Error	15	0.001075	0.00007167		
Corrected Total	19	1.711575			

APPENDIX 1.3: TABLES SHOWING MEANS OF SOYA BEAN DURING SHORT SEASON

Table 1.3.1: Showing mean soya bean height for the short season

PATTERN	WEEK2	WEEK4	WEEK6	WEEK8	WEEK10	WEEK12
Sole soya bean	11.875[a]	14.850[a]	16.600[a]	27.500[a]	36.250[ab]	37.450[a]
1M-1S	11.875[ab]	14.000[a]	16.000[a]	27.000[a]	30.200[c]	38.500[a]
1M-2S	12.225[a]	14.175[a]	16.375[a]	31.100[a]	39.250[a]	39.750[a]
2M-2S	11.250[b]	13.350[a]	16.000[a]	26.850[a]	30.450[bc]	34.250[a]
2M-4S	11.250[b]	11.875[a]	16.650[a]	31.750[a]	34.750[bc]	39.500[a]
LSD	**0.833**	**3.491**	**1.006**	**5.045**	**7.095**	**13.448**
***P-Value* (*P*≤0.05)**	**0.093**	**0.464**	**0.599**	**0.142**	**0.042**	**0.127**

Treatments with same letter along the columns are not significantly different according to LSD at p≤0.05

Table 1.3.2: Table showing mean PAR of soya beans in % during the short season

PATTERN	WEEK8	WEEK10	WEEK12
Sole soya bean	69.750[b]	74.000[e]	74.000[b]
1M-1S	60.750[c]	58.750[d]	65.000[c]
1M-2S	65.750[b]	69.750[b]	68.750[a]
2M-2S	56.000[d]	65.000[c]	61.500[c]
2M-4S	64.500[a]	52.750[a]	61.500[a]
LSD	**3.464**	**1.762**	**5.431**
***P-Value* (*P*≤0.05)**	**< 0.0001**	**< 0.0001**	**0.0008**

Treatments with same letter along the columns are not significantly different according to LSD at p≤0.05

Table 1.3.3: Table showing mean LAI of soya beans for the short season

PATTERN	**WEEK6**	**WEEK8**	**WEEK10**	**WEEK12**
Sole soya bean	0.077^{b}	0.217^{b}	0.131^{b}	0.114^{c}
1M-1S	0.136^{ab}	0.252^{b}	0.208^{ab}	0.125^{bc}
1M-2S	0.158^{a}	0.273^{b}	0.177^{ab}	0.162^{bc}
2M-2S	0.145^{a}	0.302^{ab}	0.275^{ab}	0.221^{ab}
2M-4S	0.170^{a}	0.397^{a}	0.363^{a}	0.315^{a}
LSD	**0.067**	**2.132**	**0.180**	**0.099**
P-Value (P≤0.05)	**0.075**	**0.062**	**0.133**	**0.003**

Treatments with same letter along the columns are not significantly different according to LSD at p≤0.05

Table 1.3.4: Table showing mean pod length of soya beans during the short season

PATTERN	**WEEK8**	**WEEK10**	**WEEK12**
Sole soya bean	1.500^{c}	1.625^{c}	4.500^{b}
1M-1S	1.900c	1.400^{c}	4.875^{b}
1M-2S	3.450^{b}	4.275^{b}	9.700^{a}
2M-2S	1.925^{c}	1.400^{c}	4.800^{a}
2M-4S	5.300^{a}	7.000^{a}	10.850^{a}
LSD	**1.004**	**1.6791**	**3.760**
P-Value (P≤0.05)	**<0.0001**	**< 0.0001**	**0.004**

Treatments with same letter along the columns are not significantly different according to LSD at p≤0.05.

Table 1.3.5: Table showing mean number of pods of soya beans during short season

PATTERN	**WEEK8**	**WEEK10**	**WEEK12**
Sole soya bean	4.250^{bc}	11.000 ^{a}	16.000 ^{a}
1M-1S	5.250^{b}	5.500 ^{b}	5.750^{c}
1M-2S	6.750^{a}	10.000 ^{a}	11.750 ^{b}
2M-2S	3.750^{c}	5.000 ^{b}	5.500^{c}
2M-4S	8.000^{a}	11.500 ^{a}	11.000 ^{b}
LSD	**1.362**	**2.574**	**2.793**
P-Value (P≤0.05)	**< 0.0001**	**<0.0001**	**<0.0001**

Treatments with same letter along the columns are not significantly different according to LSD at p≤0.05.

Table 1.3.6: Table showing mean Yields of soya beans during 2021 short rain season

PATTERN	FRESH WEIGHT	DRY WEIGHT/YIELDS
Sole soya bean	1.056 [c]	0.816 [b]
1M-1S	0.255 [a]	0.218 [c]
1M-2S	0.943 [b]	0.724 [b]
2M-2S	0.543 [d]	0.311 [c]
2M-4S	1.023 [c]	0.708 [a]
LSD	0.085	0.252
P-Value (P≤0.05)	< 0.0001	0.002

Table 1.3.7: Table showing land use efficiency of maize soya beans intercropping patterns-Short Season

PATTERN	L.E.R
Sole soya bean	< 0.0001[e]
1M-1S	0.326[d]
1M-2S	0.860[a]
2M-2S	0.580[c]
2M-4S	0.620[b]
LSD	**0.013**
***P-Value (P*≤0.05)**	**0.0001**

APPENDIX 2: FIGURES OF LAND PREPARATION, PLANTING AND DATA COLLECTION

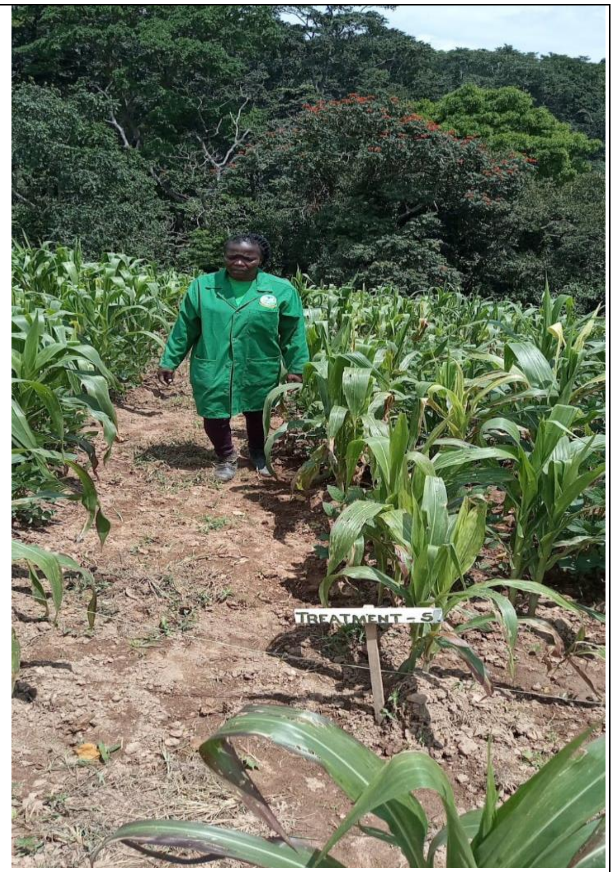
APPENDIX 2.1: FIGURES SHOWING LAND PREPARATION, SETTING UP OF THE EXPERIMENT AND PLANTING

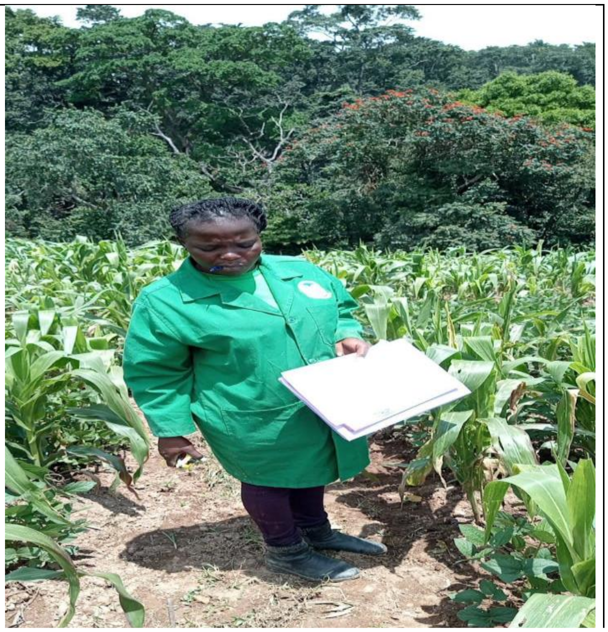
Picture showing land preparation
Source: Photo taken by the Researcher

Picture showing laying down of the experiment
Source: Photo taken by the Researcher

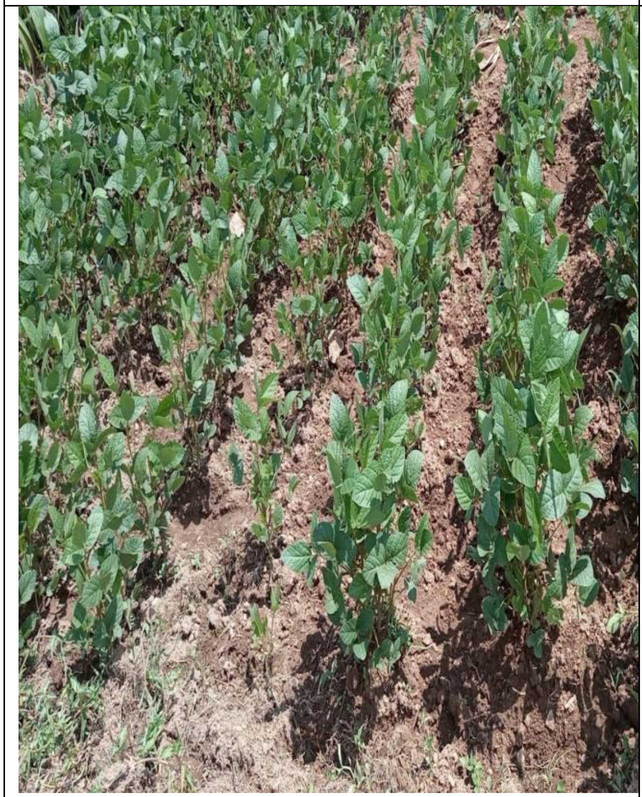
Pictures showing planting at the experimental site. (**Source:** Photo taken by the Researcher)

APPENDIX 2.2: FIGURES SHOWING DATA COLLECTION, HARVESTING AND POST HARVESTING PRACTISES



Pictures showing Data collection at the study sites. (**Source:** Photo taken by the Researcher)




Pictures showing Treatments at the study sites. (**Source:** Photo taken by the Researcher)

Pictures showing Treatments at the study sites. (**Source:** Photo taken by the Researcher)

APPENDIX 3: FIGURE SHOWING SCHEMATIC REPRESENTATION OF THE TREATMENTS

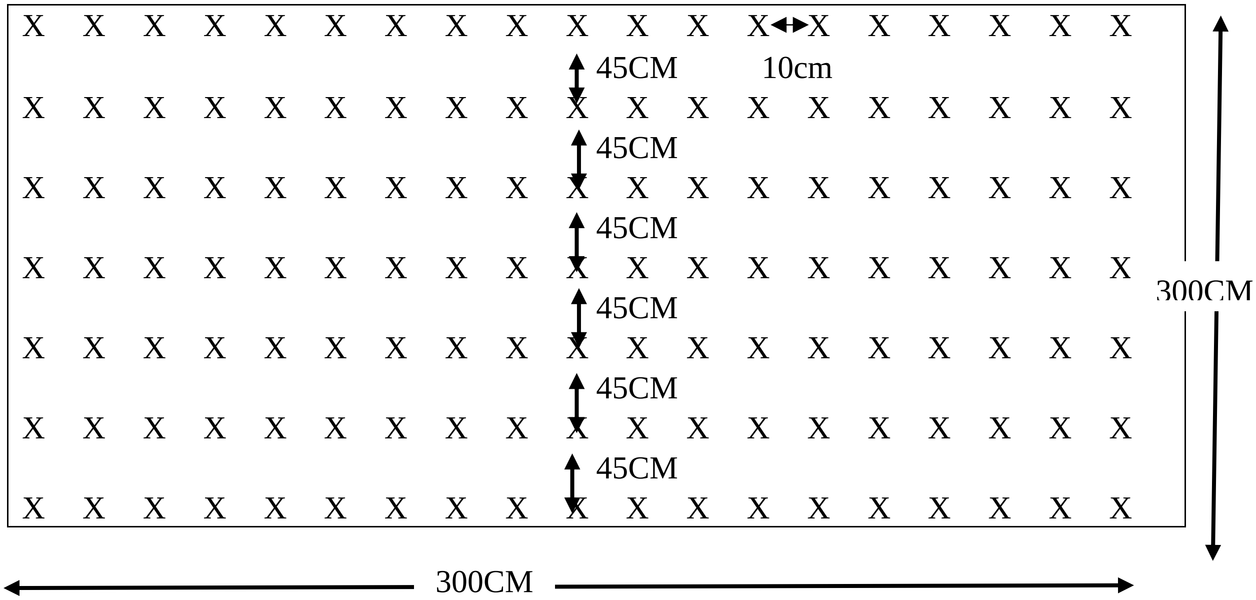


Figure 3.1: Diagrammatic representation of sole bean at spacing of 10cm by 45cm for interplant and inter-row spacing. Key: XXXX- Soya beans row

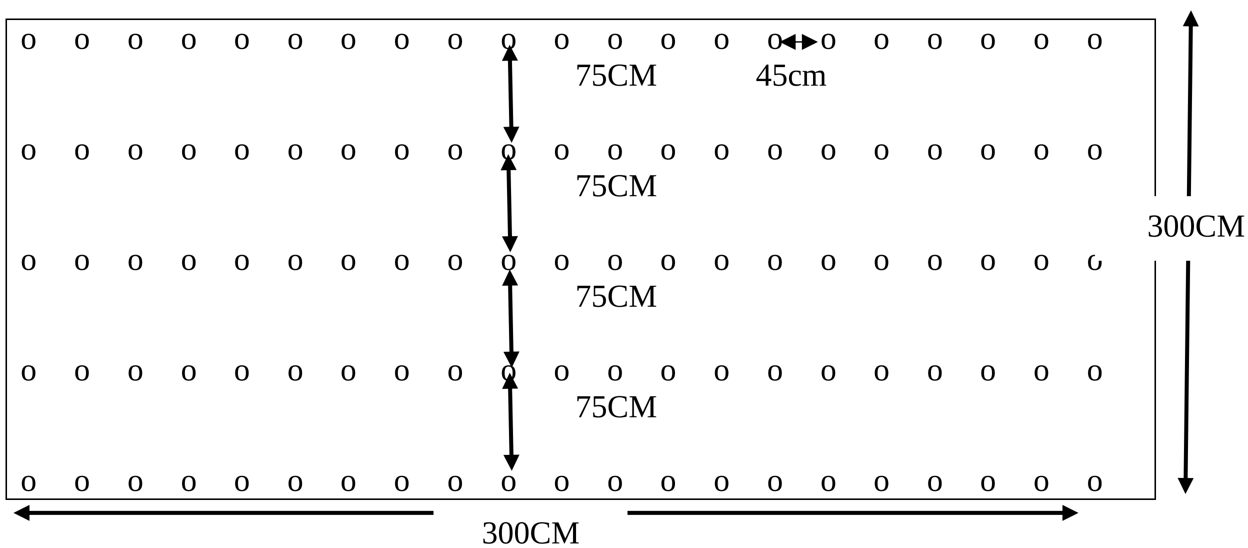


Figure 3.2: Diagrammatic representation of sole maize at a spacing of 45cm by 75cm for interplant and inter-row spacing. Key: ooooo- Maize row

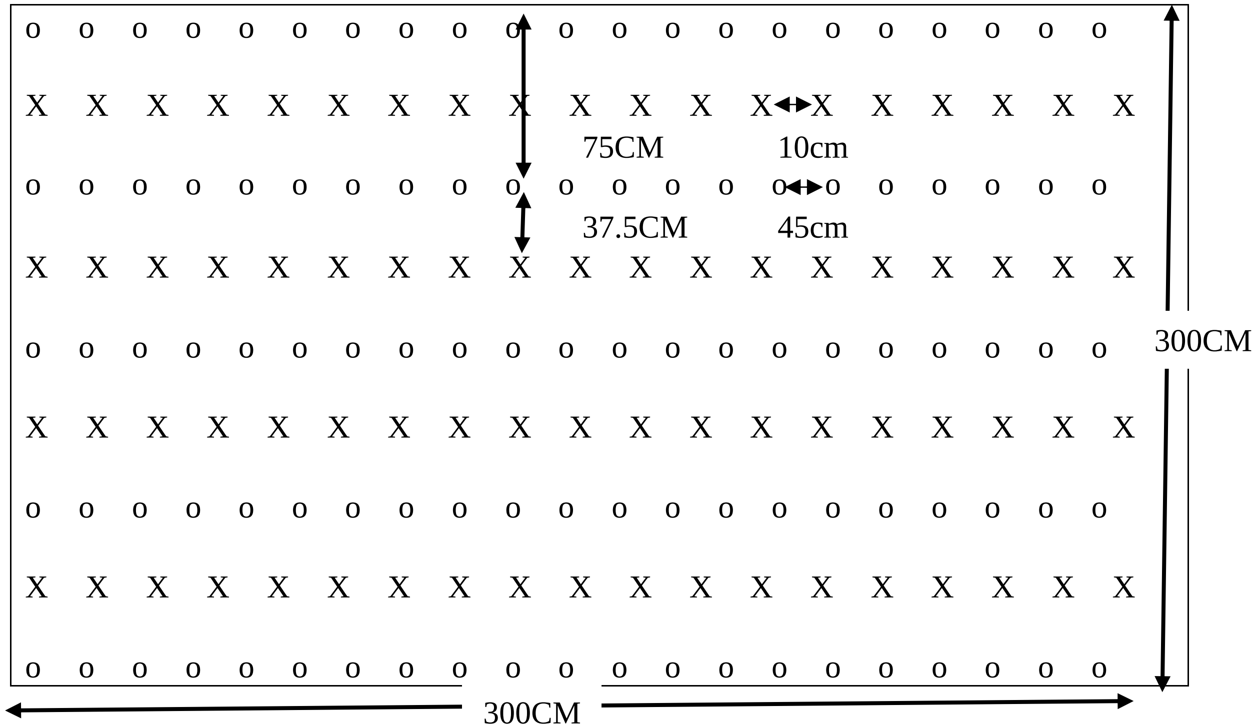


Figure 3.3: Diagrammatic representation of conventional intercropping pattern of maize and soya bean at spacing of 45cm by 75cm between maize and 37.5 inter-row spacing of maize and soya beans (1M:1S) Key: oooooo- Maize row, XXXX- Soya beans row

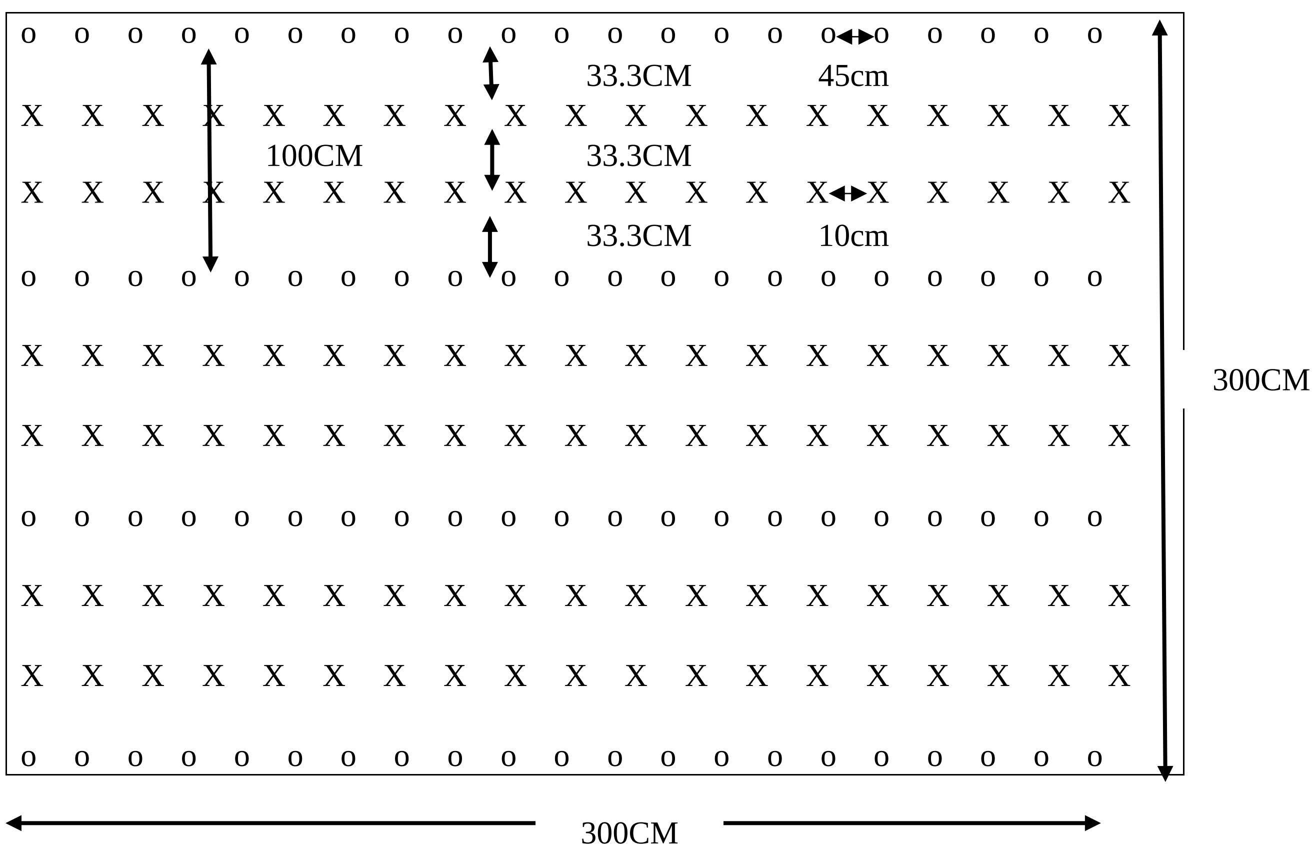


Figure 3.4: Diagrammatic representation of 1M:2S intercropping pattern with two line of soya bean between one line of maize spaced at 100cm and spacing between two lines of soya bean and maize and soya bean being 33.3cm. Key: oooooo- Maize row, XXXX- Soya beans row

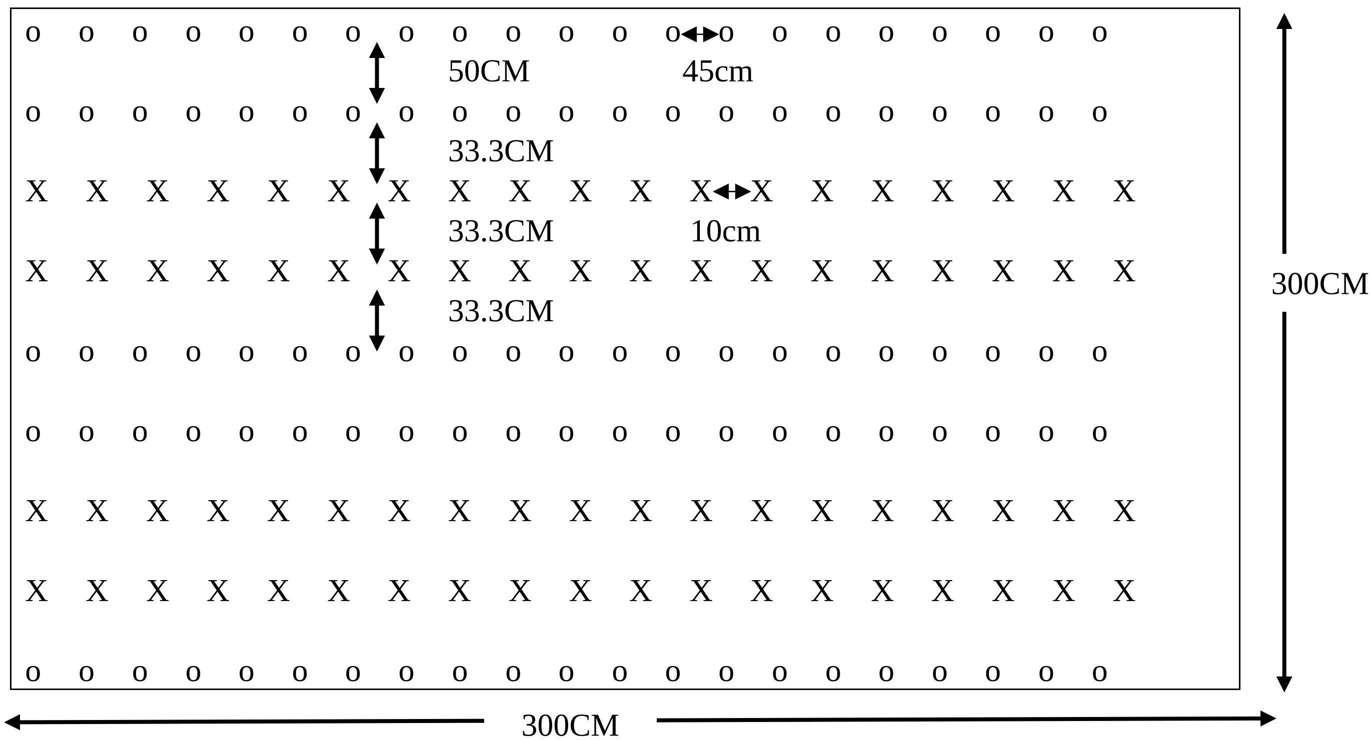


Figure 3.5: Dramatic representation of 2M:2S intercropping with two line of soya bean between two line of maize spaced at 100cm and spacing between two lines of soya bean between two line of maize spaced at 100cm and spacing between two lines of soya bean and maize and soya bean being 33.3 cm and between two lines of maize being 50cm. Key: oooooo- Maize row, XXXX- Soya beans row

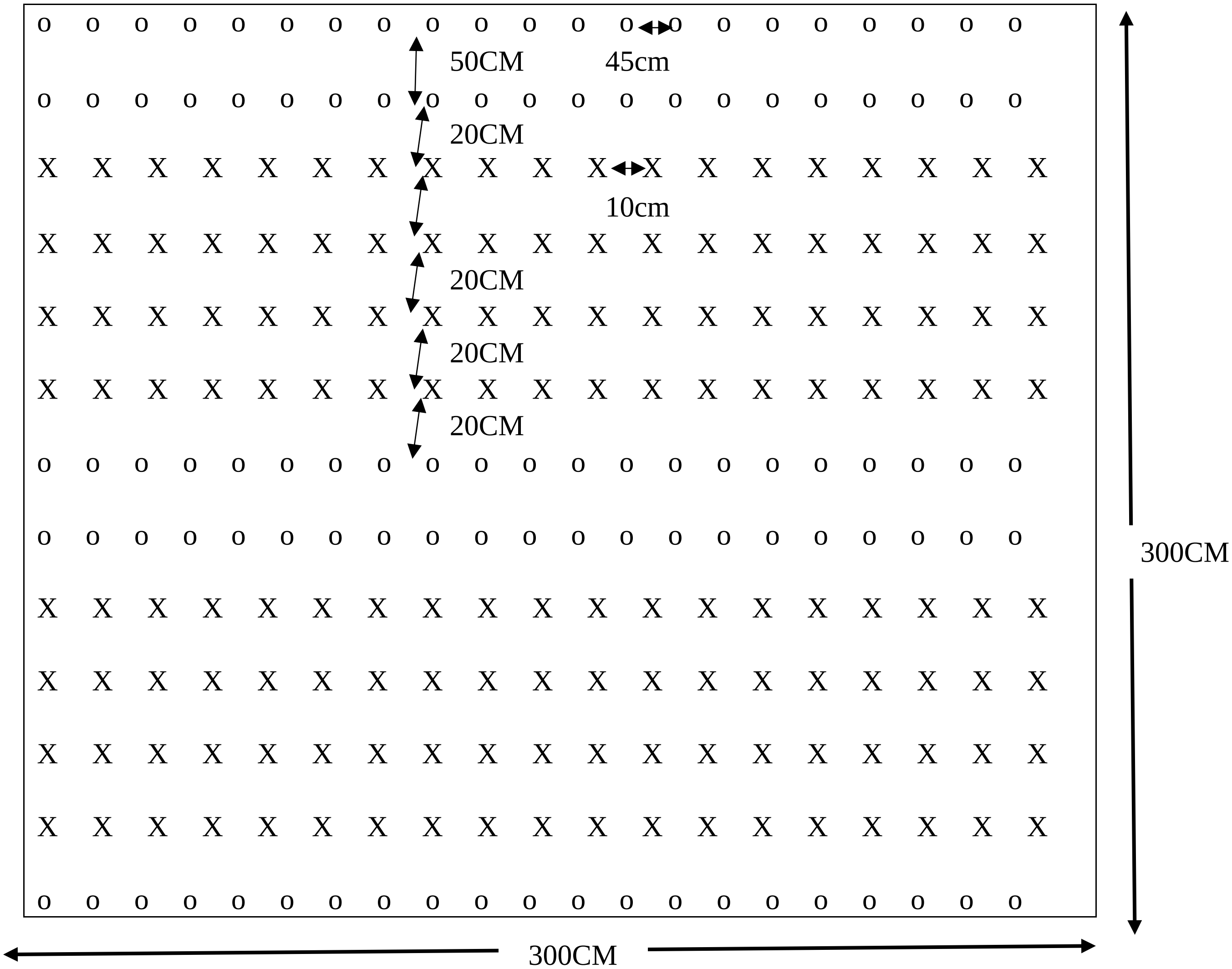


Figure 3.6: Diagrammatic representation of 2M:4S intercropping pattern with four line of soya bean between two line of maize spaced at 100cm and spacing between two lines of soya bean and maize and soya bean being 25cm and between two lines of maize being 50cm.
Key: oooooo- Maize row, XXXX- Soya beans row

APPENDIX 4: TABLE SHOWING CLIMATIC CONDITIONS DURING THE RESEARCH PERIOD (2021)

Longitude	34.7077665
Latitude	0.0767553
Attitude/Elevation	1594.28m (5230.58ft)
Annual high temperature	28.15ºC (82.67ºF)
Annual low temperature	17.36ºC (63.25ºF)
Average annual rainfall.	276.22mm (10.87in)
Warmest month	February (31.77ºC / 89.19ºF)
Coldest Month	July (16.41ºC / 61.54ºF)
Wettest Month	May (544.89mm / 21.45in)
Driest Month	January (80.88mm / 3.18in)
Number of days with rainfall (≥ 1.0 mm)	296.46 days (81.22%)
Days with no rain	68.54000000000002 days (18.78%)
Humidity	73.84%

APPENDIX 5: FIGURE SHOWING NACOSTI RESEARCH APPROVAL

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

National Commision for Science, Technology and Innovation

Ref No: **199554**

Date of Issue: **07/June/2021**

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This is to Certify that Ms.. MILLICENT AUMA OTHIENO of Maseno University, has been licensed to conduct research in Vihiga on the topic: EFFECT OF MAIZE (Zea mays L.)- SOYABEAN (Glycine max (L.) Merrill) INTERCROPPING PATTERNS ON GROWTH, POD FORMATION AND YIELD OF SOYABEAN (Glycine max (L.) Merrill) IN KAIMOSI, VIHIGA COUNTY KENYA for the period ending : 07/June/2022.

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