EFFECT OF PLANT SPACING AND RHIZOBIAL INOCULATION ON GROWTH, NODULATION AND YIELD OF SELECTED GREENGRAM VARIETIES IN KIBOKO AND ITHOOKWE IN LOWER EASTERN KENYA

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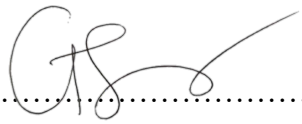
Signed  …… Date 01/08/2022

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This work is dedicated to my late dad and mum - John Mulika and Lucia Nzula, my husband - Cornelius Kyalo and my children - Collins Muuo, Joy Ndumi and Stephanie Nzula.

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Collins Muuo and my daughter Joy Ndumi, all my classmates and my colleagues at KEPHIS; Ms. Caroline M. Kavu, Bernard Onkonda and Joshua M. Maluli for their words of encouragement throughout the study period as well as for any form of support they gave me in one way or the other during my project.

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ABBREVIATIONS AND ACRONYMS

AVRDC	World Vegetable Centre
ASAL	Arid and Semi-Arid Lands
CBS	Central Bureau of Statistics
FAO	Food and Agriculture Organization of the United Nations
KALRO	Kenya Agricultural and Livestock Research Organization
TSBF	Tropical Soil Biology and Fertility
URT	United Republic of Tanzania

GENERAL ABSTRACT

Diseases, pests, inappropriate agronomic practices and drought are the most important constraints to grain legumes production in Sub-Saharan Africa. Low green gram *Vigna radiata* (L) Wilczek yields in eastern Kenya is attributed to lack of adequate knowledge of agronomic practices like fertilization, appropriate spacing and use of available high yielding varieties. Therefore, the current study was established in Kiboko and Ithookwe to evaluate the influence of intra row spacing and microbial inoculation and varieties on growth and yield of selected green gram varieties. Five levels of plant spacing (5 cm x 45 cm, 10 cm x 45 cm, 15 cm x 45 cm, 20 cm x 45 cm, 25 cm x 45 cm), two inoculation treatments (inoculated with rhizobia and not inoculated with rhizobia) and three green gram varieties (KS20, KAT 00308 and KAT 00309) which were laid out in a randomized complete block design with a factorial arrangement and replicated three times. Data was collected on growth and yield parameters and analysed using GenStat Version 15.1 and means separated using Fischer's Protected LSD test at $p \leq 0.05$. Plant height, shoot dry weight, number of effective nodules, weight of nodules and the ground cover were significantly influenced by the intra-row spacing in both sites but no significant differences observed on the parameters due to rhizobial inoculation. The days to maturation were significantly different between the intra-row spacing treatments in both sites where the narrowest spacing led to earlier maturation of green grams. The varieties differed significantly on plant height, shoot dry weight, number of effective nodules, dry weight of nodules and the ground cover in both sites. Variety KS20 matured the earliest in Kiboko while KAT00309 matured within the shortest period in Ithookwe where the two sites had a difference of >11 days. There were significant differences between the intra-row spacing treatments in growth parameters where the highest grain yield at Kiboko (3,114 kg ha^{-1}) was observed in the 20 cm by 45 cm spacing while the same treatment had the highest grain yield at Ithookwe (1,583 kg ha^{-1}). The lowest grain yield was exhibited in the narrowest spacing of 5 cm by 45

cm spacing in both sites. Inoculation significantly increased the number of effective nodules compared to those that were not inoculated in both sites at 3, 5 and 7 weeks after sowing (WAS) but it did not have a significant influence on the yield of green gram. The varieties differed significantly in the growth and yield parameters tested in both sites where variety KAT00309 had the highest grain yield with 2,898 kg ha^{-1} and 1,568 kg ha^{-1} in Kiboko and Ithookwe respectively. The local variety, KS20 had the lowest number of pods per plant in both sites with only 22 and 14 pods per plant for Kiboko and Ithookwe respectively compared to 33 and 20 pods per plant on the other varieties in Kiboko and Ithookwe respectively. Moreover, the local variety had the lowest 100-seed mass at the two study sites with more than 14% compared to KAT00308 and KAT00309. From these results, it is recommended that variety KAT00309 is the best variety in both sites planted at an intra-row spacing of 20 cm by 45 cm with or without inoculation.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Production of green gram (*Vigna radiata* L.) is mainly situated in Asia (90%) with India producing the largest quantities (more than 50% of world production) and consuming almost its entire production. The main exporter of green grams is Thailand and had its production increase by 22% every year between 1980 and 2000 (Lambrides *et al.*, 2006). Green gram is not a major crop in Africa though it is produced in many African countries (Mogotsi, 2006). In Kenya, an increase in production of green grams from 680,528 bags in 2010 to 1,345,294 bags in 2014 was recorded as well as an increase in the area under production of the same crop over the years from 147,352 ha in 2010 to 259,167 ha in 2014. Both consumption and production have consistently increased over time (ERA, 2015). This data shows that the increase in production is more associated with an increase in the production area than it is with the productivity per hectare.

Green gram has a range of uses. It can be used to make green manure, as a cover crop, and it is a N-fixing legume that can provide large amounts of biomass (7.16 t biomass/ha) and N to the soil (ranging from 30 to 251 kg N/ha) (Hoorman *et al.*, 2009). Green gram is a very important crop in the warm and dry parts of Eastern Kenya where it is grown for both subsistence and as a cash crop (Shakoor *et al.*, 1984). Dry grain is used for food, though in Asia where we have the largest number of people consuming green grams it is cooked as split grain (Dhal). Mature green gram grains provide an invaluable source of digestible protein for humans in regions where meat is not available or where people are mostly vegetarian (AVRDC, 2012). Demand for plant and non-animal proteins in the East African region is increasing over the years mainly due to the growing population. The supply of proteins from the available animal sources is less than the demand. Therefore, there is need to improve production of

proteins from alternative sources such as legumes. Since green gram is drought tolerant, it becomes an excellent alternative. Green gram has gained popularity among smallholder farmers in the East African region especially in the dry marginal areas (Hargrave 2007; Purseglove, 2003). The grains are easily cooked and do not cause much flatulence like is the case with other pulses (Pursglove, 2003).

Green gram is able to survive in harsh conditions escaping drought due to its early maturing ability (Rowe, 1980). Most green gram varieties mature within a short period of approximately 60 days giving reasonable yields even when the rains are as little as 650 mm of rainfall (CBS Kenya Govt, 2003; URT, 2003). Additionally, green gram forms associations with mycorrhiza hence the ability to adapt to poor soils (Kasiamdari *et al*., 2002) and it can be used as a relay crop, hence playing environmental conservation and food security roles respectively. Green gram protein content varies from 21 to 29% based on the variety and environment where the crop was grown (AVRDC, 2012). Green gram production is constrained by several factors including poor soil fertility, inappropriate agronomic practices such as lesser or wider than optimal spacing and unsuitable varieties. The average green gram yields in Kenya are as low as 300-700 kg ha^{-1} while yields as high as 1250 kg ha^{-1} have been obtained under irrigation and proper agronomic practices and yields above 3000 kg ha^{-1} have been obtained in trials (Mogotsi, 2006). The reasons for low yields of green grams in most countries have been stated by Begum (2009) to be manifold: some as poor soil fertility, varietal and some as agronomic management issues. Mogotsi (2006) reported that in Kenya, especially in ASAL like Ithookwe and Makueni where green gram production has been practiced, women have participated in majorly providing casual labour. In Ithookwe, green gram production has been done on small scale with women being in the front row in doing all the labour from land preparation to harvesting. As a result of this, the level of production and the output therein has been dismal. Research on green grams in Kenya has been minimal but due to changing climate patterns and

increasing global warming there is need for more research on green grams since it is one of the drought tolerant crops that does well in the lower Eastern part of Kenya where other crops like maize do not do very well necessitating this study.

1.2 Problem statement

The most important challenges and constraints that legume farmers encounter include issues of diseases, pests, inappropriate agronomic practices low soil fertility and drought in the Sub-Saharan Africa. Crop failures are frequent in the climatically marginal areas, making occasional reliance on relief food supplies a reality in affected populations. The gap between actual and realizable yields (300-700 kg/ha and 1000-1500 kg/ha) needs to be bridged up with appropriate technologies that are either totally lacking or limited (Swaminathan *et al.,* 2012). There is need to develop and promote drought tolerant crops such as the green gram, *Vigna radiata* (L) Wilczek, that yield reasonably with little rainfall and are resistant to pests and diseases. According to a survey by Kimiti *et al*., (2009) in the semi- Arid Eastern Kenya, there is need to increase legume grain yields through the introduction of drought tolerant, early maturing or high yielding legume varieties and need to improve soil fertility through interventions, such as use of integrated soil fertility management. Biological nitrogen fixation by use of rhizobia is one of the options to increase nitrogen uptake and use by plants but limited knowledge and research remains a major challenge. Postel. (2000) indicates that there will be an increase in size of water-stressed areas of the world and production of green gram will continue to worsen.

1.3 Justification

Drylands in Kenya occupy about 80% of Kenya's land surface and because of their vastness, they have an immense scientific, economic and social value. They are the habitat and source of livelihood for about one quarter of Kenya's population. Furthermore, dry lands of eastern Kenya, cover about 6 percent of the land mass of the country (GoK, 2009). Drylands face

increasing threats of further degradation and loss of biodiversity, especially with the looming climatic change and reduction in household incomes (Nguluu et al., 2014). Due to crop failure in ASAL areas, food shortage often leads to low plant protein intake and results into human malnutrition problems and reduced household income. There is need to put efforts towards producing grain legumes high in protein and grown in the dry lands of Kenya such as the lower eastern Kenya. Green gram is one of the crops that does well in drought prone areas and fixes Nitrogen in the soil but there is lack of knowledge on proper agronomic practices for Kenyan dry land conditions (Kamiti *et al.,* 2009). Keeping in view the fact that there is climate change and lesser rainfall, this study aimed at determining the optimum plant spacing and microbial inoculation on three green gram genotypes in order to produce optimum good quality green gram under the present agro-climatic conditions of Ithookwe and Kiboko. In the successful completion of the current study, researchers, academicians, farmers and policy makers would benefit in their respective programs in adoption of information generated.

1.4 Objectives of the study

1.4.1 General objective

The study was carried out to improve green gram productivity in lower eastern Kenya using optimum plant spacing, rhizobial inoculation and high yielding varieties of green gram.

1.4.2 Specific objectives

i. To evaluate the effect of plant spacing on growth, root nodulation and yield of three green gram varieties in lower Eastern Kenya.
ii. To determine the effect of rhizobia inoculation on growth, root nodulation and grain yield of three green gram varieties in lower Eastern Kenya.
iii. To determine the effect of varietal differences on growth, root nodulation and yield of green grams in lower Eastern Kenya.

1.5 Hypotheses

i. Increasing plant spacing to a given range increases growth, root nodulation and grain yield of green gram.

ii. Inoculation with rhizobia increases growth, root nodulation and grain yield in green gram.

iii. Recently released improved varieties are superior to the traditionally grown varieties in growth, root nodulation and yield.

CHAPTER TWO: LITERATURE REVIEW

2.1 Botany, ecology and importance of green gram

Green gram (*Vigna radiata* (L.) R. Wilczek), also known as mung bean, was previously known as *Phaseolus aureus* Roxb before it was moved to the *Vigna* genus alongside other *Phaseolus* spp. (Lambrides *et al*., 2006). It is a legume grown for its edible grains; it is an annual plant which grows up to a height of 0.15-1.25m (FAO, 2012; Lambrides *et al*., 2006; Mogotsi, 2006). The plant has branches which may twine at the tips (Mogotsi, 2006). It has alternate leaves which are trifoliate with elliptical to ovate leaflets. The plant bears pale yellow to greenish flowers which give rise to long cylindrical pods that are hairy. Green gram varieties can be distinguished by the colour of the seeds and the presence or absence of a rough or smooth layer (Lambrides *et al*., 2006; Mogotsi, 2006).

Green gram is a warm-season legume which grows fast and does well mainly within a temperature range of 20-40°C with the optimum temperature being 28-30°C. Waterlogging is not favorable for green gram growth while high moisture levels at maturity spoil the grains by enabling them to sprout before being harvested. Green gram does well on a wide range of soils but is best in loams or sandy loams that are well-drained with a pH of 5 to 8. The crop is generally tolerant to saline soils (Mogotsi, 2006). Green gram grows best at an altitude of 0 to 1600 m above sea level and under warm climatic conditions (temperature range of 28 to 30°C). Green grams are not tolerant to wet, poorly drained soils (Kinama, 2005). They are drought tolerant and will give reasonable yields with as little as 650 mm of yearly rainfall. Heavy rainfall results in increased vegetative growth with reduced pod setting and development (CBS Kenya Govt, 2003; URT, 2003). Additionally, it is adapted to poor soils because it forms associations with mychorrhiza (Kasiamdari *et al*., 2002) and is a relay crop, hence plays an important role in environmental conservation and food security. (Machocho *et al*., 2012).

Green grams play a key role in the economy of arid and semiarid regions as well as being a major source of protein in these regions (Singh and Patal, 1996). A variety of dishes can be made from mature green gram seeds. These include soups, porridge, snacks, bread, noodles and even ice-cream. Green gram grain in Kenya is commonly consumed whole after boiling with cereals such as maize or sorghum. The whole grains can as well be boiled and fried with meat or vegetables and eaten as stew with thick maize porridge ('ugali') and pancakes ('chapatti'), whereas people of Asian descent commonly consume green gram as split grains (dhal). In Ethiopia the grains are used in sauces. In Malawi the seed coat of the grains is removed by grinding and the rest of the grain is cooked as a side dish. In India and Pakistan, the dried grains are consumed whole or split into dhal. Split seeds are eaten as a snack after being fried and salted. The seeds can as well be parched and ground into flour after removing the seed coat; this flour is used to make various Indian and Chinese dishes. The flour can as well be processed further into starch noodles, biscuits, bread, extract for the soap industry and vegetable cheese. Sprouted green gram seeds are eaten raw or cooked as a vegetable. Immature pods and young leaves are eaten as a vegetable. Plant residues and cracked or weathered grains are fed to livestock. Green gram is also grown for fodder, green manure or as a cover crop. The grains are also said to be a traditional source of cures for coughs, paralysis, rheumatism, liver ailments and fevers (Mogotsi, 2006). Green gram is a source of high-quality protein which is easily digestible making it suitable for vegetarians and sick persons. It contains 24 % protein. Green gram grains are suitable for children and older people since they are highly digestible and low in anti-nutritional factors. They cause less flatulence than the grains of most other pulses, its starch is considered to have a low glycaemic index, i.e. raises the blood sugar level slowly and steadily. Extracts from green gram grains and husks have shown anti-oxidative effects (Swaminathan *et al.,* 2012). The crop is referred to as a 'wonder' or 'super' food (Mogotsi, 2006). The health benefits of green grams are increasingly exploding with more

research on the crop. Weight loss is achieved because green grams are low in calories and rich in fibre. The insoluble fibres present in the seeds help to keep the digestive system healthy and reduce the problem of constipation. Eating a small cup of green grams' soup therefore gives the feeling of fullness. It therefore helps to curb hunger pangs and bring body weight to healthy levels. Regular consumption of the seeds helps to reduce unhealthy cravings for sweet artificial foods thus regulate blood sugar level. Its high potassium content lowers blood pressure by counteracting the effect of sodium (Mogotsi, 2006).

Green grams have an awesome and acceptable taste no matter the preparation. In India, the bean is cooked for sick people who may have lost appetite for food. Its healing properties have therefore been found to be gaining undisputable popularity. The potassium and magnesium components of the seeds are important for a healthy heart, while its folic acid is important for pregnant women and women of child bearing age. Other minerals present in the crop include zinc, iron and phosphorus. Vitamins are essential to maintain good health and prevent diseases. Green grams sprouts are rich in Vitamin C which improves the immune system and keeps common fever, sore throat and cold away. Eating green gram thus brings the benefit of fruit and vegetable consumption. A host of benefits of consuming green gram was outlined by beneficiaries as: it helps to reduce weight and fight obesity, lowers blood pressure, controls cholesterol and heart disease risk, helps fight cancer, boosts immunity and protects against infections, improves skin health and possesses anti-toxic properties. In China and India, green grams are frequently recommended to detoxify the blood and get rid of chronic illnesses. It is an anti-inflammatory food and helps to heal the body through improved body metabolism (Tang *et al*., 2014).

2.2 Constraints to green gram production in Kenya

Common challenges faced by farmers practicing green gram production include poor soils in terms of fertility, lack of adequate farm inputs such as seeds, fertilizers, chemicals, labour at the right time, pests and diseases and noxious weeds (Kimiti *et al*., 2009).

Soils in the dryland regions of Kenya are commonly deficient of nutrients especially Nitrogen (N) and phosphorus (P) hence the production of legumes is very low. The nutrient deficiency is caused by continuous cropping with low or no use of external inputs (Mc. Cown *et al*., 1992). Many farmers know and appreciate the benefits of manure hence they use it but only in small quantities due to unavailability. The available manure is also of poor quality (Probert *et al*., 1995). Green gram is one of the legumes grown in lower Eastern Kenya. In addition to poor soil fertility, low rainfall and increasing temperatures impact negatively on productivity of crops hence reduced crop yield, poor quality produce or even total crop failure. Low grain legume yields in eastern Kenya are also attributed to lack of adequate knowledge of agronomic practices like good land preparation, fertilization, appropriate spacing and weeding (Van de Steeg *et al*., 2009). These constraints lead to yields below the potential grain legume yields documented by the Kenya Agricultural and Livestock Research Organization (KALRO). According to KALRO, the potential grain yield of green gram ranges from 1,000-1,500kg ha^{-1} (Audi *et al*., 1996) compared to the actual yield of 300 -700kg ha^{-1}.

The major constraint to current legume yields in parts of East Africa is pest infestation, either as vectors of diseases or destroyers of seedlings, foliage or fruiting bodies (Seif *et al*., 2001). Incidences of diseases and pests are comparatively low during the dry months when the crop escapes rain damage. It has been established that in order to achieve high crop yields, even with the potentially high yielding varieties grown in the United States of America, plants must be adequately protected from insect pests. Leguminous crops generally attract insect pests because of their high nutritive value (Mogotsi, 2006). Their protein and vitamin content are a

source of nourishment to insects, just as humans. In Uganda both yield and seed quality are significantly reduced (ranging from 80-100%) by damage due to insects, if no control is undertaken (Emmanuel *et al*., 2017). Adamu *et al*. (2001) recorded up to 92% seed losses in green gram due to damage by the pod weevil, *Piezotrachelus varius* in the northern guinea savanna zone of Nigeria. Whiteflies (*Bemisia tabaci* and *Aleurodicus dispersus*), blister beetles (*Mylabris spp*) and stink bug (*Nezara viridula*) were also found in the area.

2.3 Effects of rhizobia inoculation on biomass production, nodulation and yield of Legume crops

Declining soil fertility, high fertilizer costs and intensification of agriculture coupled with reduction in farm sizes are major limitations to crop production in smallholder farms in Kenya (Chemining'wa *et al.,* 2007). As a result, cheaper sources of nitrogen (N) need to be sought if yields are to be sustained and food security attained (Otieno *et al.*, 2009). Grain legumes contribute more than 20 million tons of fixed N to agriculture each year. Such fixation of N can only be achieved in the presence of efficient rhizobial strains, which can be native to the soil or introduced in the form of commercial inoculants. Inoculation with effective rhizobia strains substantially increases the nitrogen fixing potential and yields of legumes, including green gram.

Responses of legumes to rhizobia inoculation have been investigated by various authors. In a study conducted in Ghana, some native strains of cowpea rhizobia gave higher symbiotic effectiveness than inoculated strains (Fening and Danso, 2002). Meghvansi *et al*., (2010) reported nodulation specificity of certain strains of *Bradyrhizobium japonicum* towards some soybean genotypes. Rhizobia inoculation enhanced seed yield of cowpea in Mbeere, Kenya (Onduru *et al*., 2008). In contrast, Chemining'wa *et al*., (2007) reported that cowpea rhizobia inoculation did not enhance nodule numbers, shoot biomass or yield of cowpea in Kabete. The reason could be due to abundance and nodulation efficiency of native cowpea rhizobia, or

sufficient soil nitrogen. Similarly, Mathu *et al.,* (2012) observed that there were no significant differences when rhizobia inoculation was applied on nodulation, biomass production and shoot N content in cowpea and green gram grown on soils from Chonyi at the Kenyan Coast. Pea inoculation gives a response in soils with low soil nitrogen, pH close to neutral, low population of native rhizobia, and in soils with no previous legume cultivation history (Vargas *et al*., 2000; Chemining'wa *et al*., 2007; Erman *et al*., 2009). Response of pea to inoculation may not be attained in soils with a history of pea cultivation as the population of indigenous rhizobia could be high (McKenzie *et al*., 2001). Environmental factors like soil pH, moisture stress and salinity also affect populations of pea rhizobia in soil (Hansen, 1994). Chemining'wa *et al*., (2011) observed that low pH and deficient levels of P adversely affected rhizobia cell numbers and nodulation while the commercial inoculant was more effective in terms of shoot biomass improvement than soil inoculants in cowpea and common bean in central Kenyan soils.

Grain legumes can meet most of the soil needs on nitrogen by contributing to soil N through symbiotic nitrogen fixation as well as an important source of income and cheap protein in many rural and urban households in Kenya. Estimates indicate that legumes can fix up to 200 kg N /ha/year under optimal field conditions. It is widely acknowledged that inoculation of legumes with effective rhizobia can improve yields and provide a substitute to inorganic fertilizers. Inoculation however, does not always elicit positive responses. Inoculation of legumes is necessary in the absence of compatible rhizobia and when rhizobial populations are low or inefficient in fixing N. Awareness and use of rhizobia inoculants in legume production in Kenya is limited. Most of the rhizobia inoculation studies done in Kenya have concentrated on common bean with little focus on underutilized grain legumes such as green gram, lima bean, cowpea, and lablab which have the potential to broaden the food base and thereby improve food security.

The ability of legumes to fix atmospheric nitrogen in association with rhizobia gives them the capacity to grow in much degraded soils. But do we have to systematically inoculate legumes? For example, our results suggested that the systematic inoculation of both cowpea and green gram in Kenya with commercial inoculants to improve yields is not really justified, native strains performing better than inoculated strains. But when native rhizobia nodulating legumes are not naturally present, application of rhizobial inoculants is very commonly used. Our results showed that the utilization of effective good-quality rhizobial inoculants by farmers have a real potential to improve legume yields in unfertile soils requesting high applications of mineral fertilizers. For example, an effective soybean commercial inoculant was tested in different locations in Kenya (in about 150 farms in three mandate areas representing different soil characteristics and environmental conditions). Application of the rhizobial inoculant significantly increased the soybean yields in all mandate areas (about 75% of the farms). Nodule occupancy analysis showed that a high number of nodules occupied by the inoculated strain did not obviously lead to an increase of soybean production. Soil factors (pH, P, C, N) seemed to affect the inoculant efficiency whether the strain is occupying the nodules or not (Hansen, 1994).

Lesueur *et al*. (2000) in their studies showed that soil pH significantly affected nodulation and yield, though the effect was variable depending on the region. They concluded that the competitiveness of rhizobial strains might not be the main factor explaining the effect (or lack of) of legumes inoculation in the field. In another study by TSBF-Kenya on green grams, the results showed that nodulation was not significantly affected by the different factors except N fertilization, regardless of the season. Nodule occupancy revealed only three main profiles representing 93.6% and 92.5% of all the RFLP profiles obtained from 2008 and 2009 nodules respectively. This suggested a low diversity of native rhizobial strains capable to nodulate the promiscuous variety. The cropping system, Nitrogen and Residue applications didn’t increase

the diversity of the rhizobia but results indicated an effect on the distribution of the three profiles within the nodules of the plants. Within same treatments, significant differences were found between the two seasons in terms of strains occupying the nodules. It could be explained by the shorter rainfall received in 2008 compared to 2009. Results suggest that cropping systems and both N and crop residues applications affect more specifically plant growth and grain yields than the diversity of the native rhizobia nodulating promiscuous soybean variety. In various other studies, inoculants were varied whereas 95% of the farmers were familiar with root nodules, only 26% considered nodules to have beneficial effects and less than 1% of farmers use inoculants in Kenya (Karanja *et al*., 2000) thus necessitating the need for the current study.

2.4 Effects of plant spacing on legume production

With optimum spacing, plants are able to grow in their both aerial and underground parts by efficiently utilizing nutrients and solar radiation thus increasing grain yield (Miah *et al.*, 1990). Crop yield is adversely affected by too low or too high plant population beyond a given limit due to various limitations including soil deterioration fertility as a result of continuous cropping with nominal inputs or lacking rotation to restock soil nutrients and poor agronomical practices in a broad sense. Plant size, yield components and grain yield are highly affected by the number of plants per unit area (Beech and Leach, 1989). Aeration and light penetration into the plant canopy are also affected by plant spacing hence affecting the rate of photosynthesis. Both low and high plant densities resulted in significant yield decrease. So, optimum seed rate should be ensured for the plant to grow properly in order to give higher yields Research studies show that growth and yield contributing attributes are significantly and positively correlated with the grain yield of many crop plants viz., green gram (Khan *et al.,* 2010). Corroborating findings were reported on chickpea (Arshad *et al*., 2004), soybean (Malik *et al*., 2006-07) and sunflower (Vahedi *et al*., 2010). Large differences exist in yield among green gram varieties and the

maximum yield potential can only be achieved if optimum spacing is used. Experiments on spacing of green gram have been carried out in Bangladesh, and in other countries to find out the most appropriate plant population to get maximum yield (Mondal, 2007). Improper spacing reduced the yield of green gram up to 20-40% (AVRDC, 2014) due to competition for water, light, space and nutrition. Recommended spacing for sole crop of green gram in Kenya is 45 cm between rows and 15 cm within the row, with a seed rate of 6–10 kg/ha and a sowing depth of 4–5 cm (Mogotsi, 2006). Production of green gram is getting worse with the rapid expansion of water-stressed areas of the world (Postel, 2000).

2.5 Effects of variety on legume production

Green gram (*Vigna radiata* L.) commonly known as golden gram is one of the most important short duration pulse crops in India. It ranks third among all the pulse crops grown in Kenya. Green grams are annual legume crops grown for their seed. Grams could be green, black or yellow in color (Adamu, 2001). The green grams are the most commonly grown in Kenya. Grams are native crops of India. Often called green gram or golden, it is cultivated in several countries of Asia, Africa, and the Americas. The dried beans are prepared by cooking or milling. They are eaten whole or split. The seeds or the flour may be used in a variety of dishes like soups, porridge, snacks, bread, noodles and even ice cream. Green gram also produces great sprouts, which can be sold in health food shops or eaten at home. Even though pulses production increased significantly during the last decade but continuing the rapid growth is a challenge for researchers, extension agencies and policy makers to fulfil the domestic demand. The productivity of pulses in Kenya (360 kg ha^{-1}) is lower than most of the major pulse.

Green gram varieties give low seed yield mainly due to poor management and low soil fertility (NRC, 2006). Green grams usually mature in 60 to 90 days. The early maturing varieties can often produce before drought destroys many bean species.

Although grain legumes occupy about 21 per cent of World's total area planted to food crops, their contribution to the total food grains supply is only 12 per cent. Low yields of grain legume crops account for this inadequacy. A comparison of the average yields of some pulses with those obtained in experimental plots suggests that very little of their existing potential is actually realized by farmers. Moreover, less research on pulses is done compared with cereals or other commercial crops. The legume cultivars used as planting materials are poor-yielding, less responsive to inputs and susceptible to pests and diseases, e.g., the groundnut cv TMV-2 which has been in use for more than 20 years now is highly susceptible to leaf spots and rust, although some legumes yield substantial dry matter, their grain yield is low because of a poor harvest index. Green gram represents an extreme case where the grain yield of late and medium-maturing cultivars is only 10-20 per cent of the total dry matter. The late-maturing cultivars of green gram are grown only once a year (Adamu, 2001).

Variety development and release is only one step in the impact pathway of legumes. Even more critical is the adoption of varieties for large-scale production. This is still relatively poor in Eastern Africa where it is hampered mainly by limited availability of high-quality seed of these new varieties. Farmers tend to keep their own seed, which is mostly self-pollinated, and recycle the seed over several generations. The variety replacement rate is as much a problem as the seed replacement rate. Therefore, reported variety adoption levels may refer to very old varieties, while new varieties with the potential to revolutionize production, productivity and profitability remain on the shelf. It is not uncommon for researchers to cite yield gaps between the farmers' fields and the research station data. While this is mostly with reference to crop management practices adopted by the farmers, the difference between the average national yields and potential yields could be a complex problem that may be a combination of use of poor varieties, poor quality seed, poor agronomic practices - including non-use of inputs such as fertilizers, rhizobia inoculants, fungicides and insecticides - as well as agro-ecological and

edaphic factors. There is an urgent need to develop short-season and high-yielding varieties of grain legumes like green grams to enable them to compete well with other crops and be appropriate for multiple cropping systems. In the case of genotypes meant for intercropping, specific plant characters and growth patterns advantageous to the legume crop need to be considered. Improvement in plant type for higher harvest index, response to management and resistance to pests and diseases also need to be incorporated in the development of new legume varieties (NRC, 2006). Agricultural technologies play immense role in increasing food productivity. As a result, it is useful to examine the adoption of technologies among farmers. Agricultural technologies are said to include all kinds of improved techniques and practices which affect the growth of agricultural output. The most common areas of technology development and promotion for crops include new varieties and management regimes; soil as well as soil fertility management; weed and pest management; irrigation and water management but they are usually hindered by the ever high rising cost incurred in creation of the technologies as well as the time aspect it takes to complete and implement (Mulwa and Nguluu, 2003).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study sites

The study was carried out in two sites namely; Kiboko in Makueni and Ithookwe in Kitui. At Kiboko, the experiment was carried out at the KALRO centre-Kiboko. The site is located at 2° 28'S, 37° 83'E and 975 meters above sea level with an annual rainfall of 595 mm coming in two seasons and a mean annual temperature of 25.7°C (Njarui *et al*., 2004). The site is in the dry low midland (LM) Zone V with soils that are generally low in organic matter (0.1-0.5% C content), thus highly vulnerable to degradation through physical erosion as well as chemical and biological degradation (El Beltagy, 2002).

The Ithookwe site is located1^{o} 37'S, 38^{o} 02' E and 1160 meters above sea level with an annual rainfall of 1080 mm coming in two seasons and a mean annual temperature of 22.5°C (Njarui *et al*., 2004). The site is in Lower Midland (LM) to Upper Midland (UM) Zone III to IV (ALRMP, Machakos District., 2009) with soils that are sandy clay loam. (Jaetzold *et al*., 2006).

3.2 Soil Sampling and Analysis

3.2.1 Soil sampling

At the start of the experiment after demarcation of the experimental units, soil sub-samples were collected using a soil auger in a zigzag pattern from 3 spots on the three furrows at a depth of 0-30 cm from each. The 3 sub-samples were considered to be representatives of the soil chemical condition of the trial field. The sub-samples were mixed to obtain a composite sample which were air-dried in a well-ventilated room for 3 days then grounded and passed through a 2-mm sieve. They were packed in plastic bags, labelled and analyzed at the Kenya Plant Health Inspectorate Service Analytical Chemistry Laboratory, Nairobi.

3.2.2 Soil Analysis

The soil samples were analyzed for the following chemical properties using the described procedures:

i. Soil pH

The pH of soil samples was determined electrometrically both in water (pH water) and in 0.01 M CaCl2 (pH CaCl2) at a (1: 2) soil: solution ratio (weight /volume) as outlined by Okalebo *et al*, (1993). About 10g of air – dry soil samples were added to 25 ml of distilled water and the mixture shaken at 260 reciprocations per minute for 10 minutes and allowed to settle for 30 minutes. The pH of the soil suspension was recorded thereafter, using a pH meter (Model SG78) on a glass electrode.

ii. Nitrogen

Nitrogen was obtained by modified Kjeldahl method (Ryan *et al*., 2001). The procedure involved digestion and distillation. The fraction of Nitrate N (NO3 –N) in the soil was reduced and subsequently distilled. Finely ground soil sample (15 mm) was uniformly mixed and spread in a thin layer on a sheet of paper. A representative sample containing 3 g of N was taken. 0.01 g of the sample was placed into a 250 ml digestion tube that was calibrated and10 ml distilled water added and thoroughly swirled and let to stand for 30 minutes.

Blank digest was prepared and 0.1 g EDTA (Ethylene-Diamine-Tetraacetic Acid) standard digest weighed to 0.1 g with each batch. Potassium permanganate (10 ml) solution was added and swirled well, left to stand for 30 seconds, and the digestion tube held at 45o angle while 20 ml 50% sulphuric acid was slowly and carefully added so that it washed down material adhering to the tube neck. It was left to stand for 15 minutes then swirled. A few pumice boiling granules was added to the blank, EDTA, and sample digest tubes. Reduced iron (2.5 g) was added through a long-stem funnel and a 5 cm internal diameter glass funnel with a removed stem was immediately placed in tube neck, and swirled. Excessive frothing at this stage was

halted by pouring 5 ml distilled water through the 5 cm glass funnel. The tubes were allowed to stand overnight. The samples were pre-digested by placing them on the cold block and heating at 100°C for an hour. After 45 minutes from removing the samples from the block-digester, the samples were swirled and left to cool. A mixture catalyst of about 5 g was added through a long stem funnel and 25 ml concentrated sulphuric acid added to each tube, and swirled. The tubes were pre-heated on the block-digester to 100°C, and block temperature setting increased to 240°C, and funnels removed. Funnels were systematically arranged so as to be placed afterwards into the same digestion tube. Water was boiled for 1 hour after reaching 240°C. Funnels were replaced after removing the water and the temperature raised to 380°C. The tubes were removed from the block-digester after digestion for 4 hours and 50 ml of DI (De-Ionized) water added mixed with a vortex mixture. A glass rod was used to break the solid precipitate remaining in the tubes. After cooling, DI water was added to the 250 ml mark.

For the distillation procedure, the digestion tube was shaken thoroughly and 50 ml pipetted into a 250 ml distillation flask. Acid digests were distilled with excess NaOH. One ml distilled water and 1 ml saturated boric acid solution were dispensed into a 100-ml Pyrex evaporating dish and placed underneath the condenser tip with the tip touching the solution surface. Volume of 10 N NaOH was then carefully dispensed on the flask with the digest at a 50° angle. The flask was attached to the distillation unit and the distillation started until 3 minutes elapsed. The dish was lowered and distillate let to drain freely into the dish.

After 4 minutes, when about 35 ml distillate was collected, steam supply was turned off and tip of the condenser washed into the evaporating dish with a small amount of DI water. The distillate was titrated to pH 5.0 with standardized 0.01 N H_2SO_4 using the Auto-Titrator. After titration, the Teflon-coated magnetic stirring bar, the burette tip and the combined electrode were washed into the dish. Distillations between different samples were steamed out. Distillation flasks containing the digest sample and NaOH were disconnected, a 100-ml empty

distillation flask attached to distillation unit, and a 100 ml empty beaker placed underneath the condenser tip, cooling water supply turned off and steamed out for 90 seconds. Each distillation contained at least two standards and two blanks.

iii. Total Organic Carbon

Organic carbon content was determined using modified Walkley and Black wet oxidation procedure described by Ryan *et al.* (2001). Half a gram of air dried soil passed through 0.5 mm sieve were weighed into 500 ml wide mouth conical flasks and 10 ml of 1 N potassium dichromate added into the flasks using a burette. In a fume cupboard, 15 ml concentrated sulphuric acid was rapidly added directing the stream into the suspension. The flasks were swirled gently at first until all soil and reagents mixed and then more vigorously for about one minute. They were then allowed to stand for exactly 30 minutes. About 150 ml of distilled water was added and allowed to cool, after which 10 ml 85% orthophosphoric acid and finally 10 drops diphenylamine indicator were added. The solutions were titrated with 0.5 N ammonium ferrous sulphate.

iv. Phosphorus

The analysis of P was done by the Olsen P method as described by Olsen and Sommers (1982). A strong acid was used to digest the soil sample where P determination involved digestion and the dissolution of all insoluble inorganic minerals and organic P forms. In the digestion chamber, 2 g air-dry soil was weighed into a 250 ml calibrated digestion tube, 30 ml 60% perchloric acid and a few pumice-boiling granules were added and mixed well. Tubes rack was placed in the block-digester and gently heated to about 100°C. Block-digester temperature was slowly increased to 180°C and the samples digested until dense white fumes of acid appeared. If necessary, perchloric acid was the medium used in washing the sides of the digestion tube. The total digestion with perchloric acid lasted about 40 minutes.

The mixture was cooled and distilled water added to obtain a volume of 250 ml, contents mixed and filtered through Whatman No. 1 filter paper. About 5 ml of the sample digest was pipetted into a 50 ml volumetric flask, 10 ml ammonium-vanadomolybdate reagent added, and diluted to volume with DI water. A blank was made with ten ml of ammonium-vanadomolybdate reagent was used to make the blank, and preceded as for the samples. Standards, absorbance of blank and samples were read after 10 minutes. A calibration curve was prepared for standards, plotting absorbance against the respective P concentrations.

v. Potassium

The method used was flame photometer (Ryan *et al*., 2001) whereby a neutral salt solution replaced cations present on the soil exchange complex. Air-dry 5 g soil (< 2 mm) was weighed into a 50 ml centrifuge tube, 33 ml ammonium acetate solution added, and shaken for 5 minutes on a shaker. The tubes were fitted with a clean rubber stopper and centrifuged until the supernatant was clear and the extract collected in a 100 ml volumetric flask through a filter paper to exclude any soil particles. The process was repeated two more times and extract collected each time. Hundred ml with 1 N ammonium acetate solution was diluted to the combined ammonium acetate extracts. Standards were run for the suitable potassium and a calibration curve drawn.

vi. Extractable nutrients (Ca, Mg, Mn, Cu, Fe, Zn, and Na)

The Diethylenetriamine Penta acetic Acid (DTPA) method as described by Lindsay and Norvell (1978) was used. Ten-gram soil samples were mixed with 20 ml DTPA (0.005 M, adjusted to pH 7.3 with Triethanolamine), then shaken for 2 hours before filtering. The micronutrients were then measured with an AAS (Atomic Absorption Spectrophotometer).

vii. Electrical Conductivity (EC)

Soil samples weighing 50-g were placed in a 100-ml disposable plastic cups; 50 ml of deionized water was added to each. The slurry was shaken on a reciprocating shaker for 45 minutes, and

then filtered. Electrical conductivity of the filtrate was then read with a conductivity bridge (Beckman RC 1682 model).

Table *3:1:* The mean soil chemical properties at Kiboko and Ithookwe sites

Parameter analyzed	Ithookwe	Kiboko	Guide Low	Guide High
pH	5.0	7.3	6.0	7.0
Electrical conductivity (EC) µS/cm)	-	0.7		<800
Sodium (Na) (mg/kg)	158.7	345.0		<175
Potassium (K) (mg/kg)	163.8	624.0	179	595
Calcium (Ca) (mg/kg)	696.0	3224.0	1830	2140
Magnesium (Mg) (mg/kg)	165.6	541.2	183	330
Manganese (Mn) (mg/kg)	515.7	240.3	30	250
Phosphorus (P) ppm	57.6	243.9	50	100
Nitrogen (N) %	0.9	0.8	0.2	0.5
Carbon (C) %	18.2	11.0	10	25
Exchangeable acidity (Hp) (mg/kg)	567.0	-	150	300
Copper (Cu) ppm	1.3	1.1	2.0	10.0
Iron (Fe) ppm	BDL	BDL	50	350
Zinc (Zn) ppm	2.2	17.7	2	20

Source: FAO, 2006

The soil reaction was slightly alkaline in Kiboko and moderately acidic in Ithookwe. Exchangeable Sodium (Na) was adequate for green gram cultivation in both sites while Potassium (K), Calcium (Ca) and Magnesium (Mg) were at low moderately available levels at Kiboko while in Ithookwe they were adequate for green gram cultivation. Available Phosphorus (P) was high and adequate in both sites while Total Nitrogen (N) was found to be adequate in both sites. Organic Carbon (C) content was moderate in the field for both sites. Micronutrients Manganese (Mn), Copper (Cu) and Zinc (Zn) were adequate for green gram cultivation in both sites except for Zinc (Zn) which was deficient in Ithookwe while Iron (Fe) was found to be below the Machine Detectable Levels (BDL) in both sites.

3.3 Experimental design, treatments and crop husbandry

The experiment was carried out during the October–December short rains of 2016. The treatments comprised: five levels of spacing (5 cm x 45 cm, 10 cm x 45 cm, 15 cm x 45 cm, 20 cm x 45 cm, 25 cm x 45 cm) two inoculation treatments (Inoculated with rhizobia and not inoculated with rhizobia) and three green gram varieties (KS20, KAT 00308 and KAT 00309). The plant to plant spacing treatments were selected based on what has been recommended by KALRO (15cm X45cm) as well as what farmers commonly practice while rhizobia has been widely cited to be of greater importance in improving yield of legumes. These treatments were laid out in a randomized complete block design with a factorial arrangement and replicated three times. The experimental plot size was 1.35 m x 3 m with spacing of 1 m between plots and 2 m between blocks. One of the green gram varieties (KS20) is already in use by farmers, while the other two (KAT 00308 and KAT 00309) are newly released and being bulked for use by farmers. The field was ploughed and prepared to a fine tilth and pegged to divide it into three blocks made up of 30 plots of four rows each. Planting was done in moist soils (while the rains were already on) on 4th November 2016 in Ithookwe and 17th November 2016 in Kiboko. Two seeds were planted per hole in 45 cm spaced rows in both sites. For the inoculated treatment, non-treated seeds were dressed with the inoculant shortly before planting by mixing the inoculant with water in three labelled basins and putting the seeds of each variety and mixing gently in one basin to ensure even coating of the seeds by the inoculant. Seedlings were thinned to have one plant per hole. The experimental field was kept weed free throughout the growth period by manual weeding. No fertilizer application was done in both sites because soil phosphorous (P) and Potassium (K) were adequate. The rainfall pattern as in Table 3.3 was consistent in both sites where rainfall was highest in the months of November and December with no rainfall experienced in January. The November rainfall in Kiboko was early in the month before planting hence supplementary irrigation was done in the month of November and

December (25mm of water twice per week) for proper establishment of the crop then withdrawn on the 31st December 2016.

Table 3:2: Daily weather Data in Kiboko and Ithookwe for November and December 2016

Date	Rainfall **(mm)** Kiboko	Rainfall **(mm)** Ithookwe	R.H % Kiboko	R.H % Ithookwe	Max. Temp **(ºC)** Kiboko	Max. Temp **(ºC)** Ithookwe	Min. Temp **(ºC)** Kiboko	Min. Temp **(ºC)** Ithookwe
November, 2016								
1	0	60.3	82	73	34	30.6	15	19
2	16	1.6	82	89	32	31.3	19.5	17.3
3	11.5	37.7	95	87	32	29.3	18	18.7
4	14.8	8.6	91	88	32	27	19	17.2
5	0	8.9	91	93	32	27.6	19	17.4
6	0	0.8	91	82	31.5	28.2	19	18
7	0	0	82	72	31.5	28.5	19	14.8
8	0	0	91	70	32	28.4	18.5	17.9
9	0	0.6	82	71	32	29	20	18
10	12	0	82	82	32	29	19	18.2
11	4	0	91	79	31	28	19	18.4
12	0	0	91	64	32	29.5	19	17.8
13	4.5	3.5	95	78	28	29	19	19.1
14	6.5	13	99	88	28	29	19	18.9
15	15.5	30.5	86	100	28	28.5	19	18.5
16	14.5	53	87	97	29	26.4	19	16.8
17	4	1	91	99	28	26.6	18	17.5
18	0	43.2	82	82	28	27.2	19	18.3
19	0	18.8	91	100	29	27	17.5	18.9
20	0	15.7	91	100	29	26.5	19	18.4
21	0	20.4	83	96	29	26.3	18	18.7
22	0	4	87	74	29	26.5	17.5	18.2
23	0	9.6	91	89	29	25.8	20	17.8
24	84	6.6	91	98	29.5	26.3	19	18.9
25	0	0	95	81	29	27.3	18	18.4
26	0	0	91	72	29	27	19	17.8
27	0	21.1	82	87	29	27	17	18.7
28	0	69.4	87	97	29	26.5	19	17.5
29	0.3	6.5	95	90	28.5	27.1	20	18
30	0	3.1	83	100	29	25	19	19
Mean	**6.25**	**14.6**	**85.9**	**85.9**	**30**	**27.7**	**18.7**	**18.1**

Date	Rainfall **(mm)** Kiboko	Rainfall **(mm)** Ithookwe	R.H % Kiboko	R.H % Ithookwe	Max. Temp **(ºC)** Kiboko	Max. Temp **(ºC)** Ithookwe	Min. Temp **(ºC)** Kiboko	Min. Temp **(ºC)** Ithookwe
December, 2016								
1	0	0	91	83	29	25.6	19	18.2
2	0	0	91	80	31	26.6	19.5	18.2
3	0	5.6	87	88	30	27.3	19	19.6
4	4	0	83	87	29	26.7	17	18.6
5	0	0	83	77	29	25.8	16	17
6	0	1.4	82	82	31	26.5	17	16.6
7	0	2.4	91	86	29	26.5	19	17.7
8	0	0	83	83	32	26.5	19	17.4
9	0	5.1	83	82	32	26	17.5	18.4
10	0	0	82	81	32	27	17	18.4
11	0	9	83	89	31	27	18	18.7
12	8.5	5.2	91	89	32	27.2	17.5	18.7
13	0	2.1	95	89	29	25.5	19	17.6
14	0	0	95	85	29	25.4	16	18.2
15	0	0	91	85	29	25.6	16	17.2
16	0	0.7	91	97	29	26.6	17	17
17	0	0	75	72	32	27.8	15	16.2
18	0	0	87	82	32	27.6	16	16.4
19	0	0	75	81	32.5	28	15	16.4
20	0	0	82	86	32	27.6	14	16.3
21	0	1.4	91	80	32	28	18.5	18.6
22	8	6.8	95	100	29	27.3	18	18.5
23	0	0	95	94	29	28.3	18	18.6
24	0	0	91	96	32	25.1	17	15.6
25	0.8	0	91	98	31	27.1	17	17.4
26	0	0	75	83	32	25.4	18	15.4
27	0	0	67	78	31.5	25.8	15	17.5
28	0	0	66	73	30	27	14	15.8
29	0	0	74	76	29	27	16	16.7
30	0	0	82	72	32	28	15	18.2
31	0	0	82	77	32	27.2	14	18.9
Mean	**0.7**	**1.3**	**84.8**	**84.2**	**30.7**	**26.7**	**16.9**	**17.6**

KEY: Max – Maximum temperature, Min – Minimum temperature and RH %- Relative humidity percentage.

3.4 Data collection

Growth parameters, phenological aspects, yield and yield components were determined with harvesting being done on 7th January 2017 in Ithookwe and on the 24th January 2017 in Kiboko. Data was recorded for the following parameters:

3.4.1 Growth parameters

a) Plant height

Plant height was determined at 21 DAS (Days after Sowing) and fortnightly up to pod stage. The plant height of three randomly selected and tagged plants was measured using a standard ruler from the stem base to the top node where the leaves segregate and the average value of plant height from each plot was computed.

b) Shoot dry matter

Shoot dry matter was determined at 21 DAS (Days after sowing) and fortnightly up to pod stage. Three to five plants were randomly sampled and cut at the base from each plot and oven dried at 70^{o}C till constant weight. Average dry matter per plant was recorded.

c) % Ground cover

The % ground cover was determined at 21 DAS (Days after sowing) and fortnightly up to pod stage. Three areas of 0.25 m^2 were randomly selected in each plot and a sampling frame (50 cm x50 cm) used to estimate the % ground cover in each of the selected 0.25 m^2 areas. Average % ground cover per plot was recorded.

3.4.2 Phenological parameters

a) Time to 50% flowering

Number of days to 50% flowering was counted from the effective date of sowing up to the time when half of the plant population per plot had flowered**.**

b) Time to maturity

Number of days to maturity was counted from the effective date of sowing up to the time when 80% of the pods per plot had turned black or brown in color depending on the variety.

3.4.3 Nodulation parameters

a) Number of effective and dry nodule weight

Numbers of effective nodules and nodule dry weight were determined at 21 DAS (Days after sowing) and thereafter fortnightly up to pod stage. Little water was applied to the base of three randomly selected plants. The three plants were then dug out carefully, the roots washed with clean water in a bucket to remove adhered soil particles and nodules plucked. The nodules were then cut open to check their color. Those with pink pigmentation were counted and recorded as effective nodules. The nodules were later oven dried at 70^0C up to a constant weight and the nodule dry weight determined.

3.4.4 Yield and Yield components

a) Number of pods per plant

The total number of pods from five randomly selected plants in each plot was counted and an average value computed and recorded.

b) Number of seeds per pod

Grains from five randomly selected pods from tagged selected plants per plot were counted and an average value computed then recorded.

c) Pod length

The pod length was measured using a standard ruler from the petiole of the pod to the pod apex on five pods tagged per plot and the average recorded.

d) Pod harvest index

This was calculated from the total grain weight harvested from a net plot divided by the total pod biomass of the pods from a net plot.

e) 100 seed weight

One hundred seeds were counted randomly from each net plot's (1 m^2 within the middle rows in each plot) yield and their weight in grams recorded as 100 seed weight per plot.

f) Grain yield

The grain produced from a randomly selected net plot in each plot was harvested and recorded separately. The grain yield per m^2 was then converted into kilograms per hectare (kg ha^{-1}).

g) Biological yield (kg ha^{-1})

Total dry matter (above ground) or biological yield was determined by weighing completely dried plants harvested at physiological maturity from each net plot (1m^2 within the middle rows of each plot). The plants were harvested by cutting the whole plant from the point where it touches the ground and all its components put carefully in a paper bag for drying (at 70^0 C) and the dry matter computed into kg ha^{-1}.

h) Harvest Index (%)

The harvest index was calculated by using the formula below given by Donald and Hambling (1976).

$$\text{Harvest Index} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Total dry matter (kg ha}^{-1}\text{)}} \times 100$$

3.5 Data analysis

Data collected in the study were entered in Excel spread sheets and subjected to analysis of variance (ANOVA) using GenStat Version 15.1. Where mean differences were found to be significant, the means were separated using Fisher's Protected Least Significant Difference (LSD $p<0.05$) test at 95% Confidence level. Regression and correlation analysis were performed to estimate quantitative relationships between the parameters.

CHAPTER FOUR: RESULTS

4.1 Effect of intra-row spacing on growth, root nodulation and yield of three green gram varieties in lower Eastern Kenya

4.1.1 Effect of intra-row spacing on plant height (cm)

There were significant differences (P≤0.05) between the treatments in plant height for both sites at 3, 5 and 7 weeks after sowing (Table 4.1). At Kiboko, the narrowest intra row spacing (5cm x 45cm) had the tallest plants at 3 weeks and 5 weeks after sowing while spacing of 25cm x 45cm had the shortest plants. At Ithookwe 10cm x 45cm and 5cm x 45cm had taller plants than other spacing while no differences were noted among 15cm, 20cm, and 25cm x 45cm in plant height at all sampling stages. Plant spacing had no effect at 7WAS.

Table 4:1: Influence of intra-row spacing on the plant height (cm) of green gram in Kiboko and Ithookwe

Treatments	**Kiboko**			**Ithookwe**		
Spacing	**3 WAS**	**5 WAS**	**7 WAS**	**3 WAS**	**5 WAS**	**7 WAS**
10 cm x 45 cm	11.3b	31.1b	57.8a	10.1ab	19.4a	32.0ab
15 cm x 45 cm	10.6bc	28.2c	52.5bc	9.5b	16.6b	29.5b
20 cm x 45 cm	10.3cd	28.9c	54.6ab	9.2b	17.9b	30.4ab
25 cm x 45 cm	9.6d	26.4d	50.6c	9.2b	17.0b	30.2ab
5 cm x 45 cm	12.6a	33.6a	55.5a	11.1a	21.2a	32.3a
P Value	**<.001**	**<.001**	**<.001**	**0.006**	**0.011**	**0.026**
LSD	**0.704**	**1.37**	**3.256**	**1.166**	**2.662**	**3.752**

Means followed by different letters in a column are significantly different at 95% confidence level, WAS-Weeks after Sowing, LSD-Least significant difference

4.1.2 Effect of intra-row spacing on shoot dry weight

The shoot dry weight of green gram was significantly influenced (P≤0.05) by the intra-row spacing in Ithookwe and Kiboko as shown in Table 4.2. In Kiboko, the differences were pronounced at 5 and 7 weeks after sowing where the wider intra row spacing 15cm, 20cm and 25cm x 45cm had higher shoot dry weight than 10cm x 45cm and 5cm x 45cm. In Ithookwe

the only significant differences (P≤0.05) were observed at 7 weeks after sowing where the wider intra row spacing of 20cm x 45cm and 25cm X 45cm had higher shoot dry weight than of 5cm x 45cm and 10cm x 45cm.

Table 4:2: Influence of intra-row spacing on the shoot dry weight (g) of green gram in Kiboko and Ithookwe at 3, 5 and 7 weeks after sowing

Treatments		**Kiboko**			**Ithookwe**	
Spacing	**3 WAS**	**5 WAS**	**7 WAS**	**3 WAS**	**5 WAS**	**7 WAS**
10 cm x 45 cm	1.9ab	18.1b	44.6c	0.9a	4.9a	16.2bc
15 cm x 45 cm	2.0a	22.7a	58.8b	0.8a	4.5a	19.9abc
20 cm x 45 cm	2.0a	23.3a	75.6a	0.9a	5.5a	21.6ab
25 cm x 45 cm	1.8ab	22.3a	84.8a	0.9a	5.5a	25.2a
5 cm x 45 cm	1.4b	11.8c	29.5d	0.9a	4.1a	14.9c
P Value	**0.008**	**<.001**	**<.001**	**0.822**	**0.164**	**0.018**
LSD	**0.3566**	**2.993**	**9.19**	**NS**	**NS**	**6.099**

Means followed by different letters in a column are significantly different at P≥0.05, LSD-Least significant difference, WAS-Weeks after Sowing, NS-Not significant.

4.1.3 Effect of intra-row spacing on number of days to 50% Flowering and Maturity

The number of days to flowering and maturity were significantly influenced (P≤0.05) by the intra-row spacing in Kiboko and Ithookwe (Table 4.3). At Kiboko the number of days to 50% flowering was significantly higher at 20cm x 45cm and 25cm x 45cm than the other spacing treatment. No significant differences were recorded in the number of days to maturity among intra row spacings. At Ithookwe, the number of days to 50% flowering were not significantly different among the intra row spacing treatments. The days to maturity were significantly highest and lowest at intra row spacing of 25cm x 45cm and 5cm X 45cm respectively.

Table 4:3: Days to 50% flowering and days to maturity of green gram in Kiboko and Ithookwe as influenced by different intra-row spacing treatments

Treatments	Kiboko		Ithookwe	
Spacing	Days to 50% Flowering	Days to Maturity	Days to 50% Flowering	Days to Maturity
10 cm x 45 cm	35b	59a	40a	71b
15 cm x 45 cm	35b	59a	41a	71b
20 cm x 45 cm	36a	59a	41a	71b
25 cm x 45 cm	36a	59a	41a	73a
5 cm x 45 cm	35b	58b	40a	69c
P Value	**0.008**	**0.022**	**0.499**	**<.001**
LSD	**0.658**	**0.1933**	**NS**	**1.094**

Means followed by different letters in a column are significantly different at 95% confidence level, NS-Not Significant

4.1.4 Effect of intra-row spacing on the number of effective nodules

The number of effective nodules per plant were significantly ($P \leq 0.05$) influenced by the within-row spacing treatments in Kiboko at all sampling stages while no significant differences were observed in Ithookwe at all sampling stages (Table 4.4a). At Kiboko, 20cm x 45cm had a higher number of effective nodules than 5cm x 45cm at all sampling stages. No difference in nodules were noted between plant spacing of 15cm, 20cm, and 25cm x 45cm and between 10cm x 45cm and 5cm x 45cm.

Table 4:4a: Intra-row spacing influence on the number of effective nodules of green gram in Kiboko and Ithookwe during different weeks

Treatments Spacing	Kiboko			Ithookwe		
	3 WAS	5 WAS	7WAS	3 WAS	5 WAS	7 WAS
10 cm x 45 cm	19b	26a	13c	2a	7a	6a
15 cm x 45 cm	19b	29a	20a	2a	5a	5a
20 cm x 45 cm	25a	31a	16ab	3a	9a	6a
25 cm x 45 cm	21ab	28a	19a	2a	6a	5a
5 cm x 45 cm	16b	23a	11c	2a	5a	3a
P Value	**0.013**	**0.073**	**0.008**	**0.39**	**0.195**	**0.108**
LSD	**5.015**	**NS**	**5.595**	**NS**	**NS**	**NS**

Means followed by different letters in a column are significantly different at 95% confidence level, WAS-Weeks after Sowing, NS-Not Significant

Table 4:4b: Interactions between intra-row spacing, rhizobial inoculation and variety on the number of effective nodules of green gram at Kiboko

Spacing	Inoculation	KAT00308	KAT00309	KS20
10 cm x 45 cm	Inoculated	9.2c	15.7c	14.8c
	Non-Inoculated	8.2c	14.2c	14.3c
15 cm x 45 cm	Inoculated	20.0b	22.9b	22.4b
	Non-Inoculated	9.1c	16.6bc	29.8ab
20 cm x 45 cm	Inoculated	11.2c	8.7c	22.0b
	Non-Inoculated	8.4c	7.2c	37.2a
25 cm x 45 cm	Inoculated	17.9b	10.8c	42.9a
	Non-Inoculated	14.4c	14.2c	16.1c
5 cm x 45 cm	Inoculated	6.0c	7.2c	19.6b
	Non-Inoculated	6.7c	14.9c	14.4c
P-Value			**0.022**	
LSD			**13.706**	

Means followed by different letters in a column are significantly different at 95% confidence level

4.1.5 Effect of intra-row spacing on nodules dry weight (g)

The dry weight of nodules per plant were significantly affected ($P \leq 0.05$) by spacing at Kiboko at 5 and 7 weeks after sowing (Table 4.5). No significant differences in nodule dry weight at 3 WAS in Kiboko and at all sampling stages in Ithookwe. At 5 weeks after sowing in Kiboko, the wider row spacing, 15cm, 20cm and 25cm x 45cm showed higher nodule dry weight while the other Spacing of 5cm x 45cm had lower nodule number than 10cm x 45cm at 5WAS.

Table 4:5: Intra-row spacing influence on the dry weight of nodules of green gram in Kiboko and Ithookwe during different weeks

Treatments	Kiboko			Ithookwe		
Spacing	**3 WAS**	**5 WAS**	**7 WAS**	**3 WAS**	**5 WAS**	**7 WAS**
10 cm x 45 cm	0.07a	0.41a	0.28b	0.014a	0.049a	0.056a
15 cm x 45 cm	0.06a	0.47a	0.47a	0.016a	0.044a	0.043a
20 cm x 45 cm	0.08a	0.39ab	0.41a	0.022a	0.054a	0.060a
25 cm x 45 cm	0.14a	0.44a	0.44a	0.015a	0.039a	0.041a
5 cm x 45 cm	0.06a	0.25b	0.23b	0.016a	0.042a	0.030a
P Value	**0.156**	**<.001**	**0.003**	**0.385**	**0.863**	**0.253**
LSD	**NS**	**0.0981**	**0.1392**	**NS**	**NS**	**NS**

Means followed by different letters in a column are significantly different at 95% confidence level, WAS-Weeks after Sowing, NS-Not Significant

4.1.6: Effect of intra-row spacing on ground cover (%)

The intra row spacing had significant effects (P≤0.05) on the ground cover of green grams in Kiboko and Ithookwe (Table 4.6). At Kiboko, the narrowest plant spacing 5cm x 45cm had the highest ground cover at 3, 5 and 7 weeks after sowing while the lowest ground cover was observed in the widest row spacing of 25cm x 45cm at 3 and 5 WAS stage. The same trend was observed in Ithookwe at the different sampling stages except that there were no differences in ground cover between 15x 45cm and 20x 45cm at all sampling stages and 10x45cm and 5x45cm at all sampling stages.

Table 4:6: Intra-row spacing influence on the ground cover (%) of green gram in Kiboko and Ithookwe at 3, 5 and 7 weeks after sowing

Treatments	**Kiboko**			**Ithookwe**		
Spacing	**3 WAS**	**5 WAS**	**7 WAS**	**3 WAS**	**5 WAS**	**7 WAS**
10 cm x 45 cm	50.6b	50.6b	82.8b	34.7ab	66.1a	74.5a
15 cm x 45 cm	42.8c	42.8c	73.3c	28.3b	56.9b	65abc
20 cm x 45 cm	35.6d	35.6d	72.2c	26.7bc	55.6b	70.0ab
25 cm x 45 cm	28.9e	28.9e	67.2c	20.0c	42.8c	57.2c
5 cm x 45 cm	66.1a	66.1a	91.4a	37.8a	68.9a	76.4a
P Value	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.026**
LSD	**3.244**	**3.244**	**6.87**	**7.59**	**11.48**	**12.68**

Means followed by different letters in a column are significantly different at 95% confidence level, WAS-Weeks after Sowing

4.1.7 Effect of intra-row spacing on pod harvest index

There were no significant differences between the treatments in the pod harvest index. Pod harvest index ranged from 60% to 70%. (Fig. 4.1) in both sites.

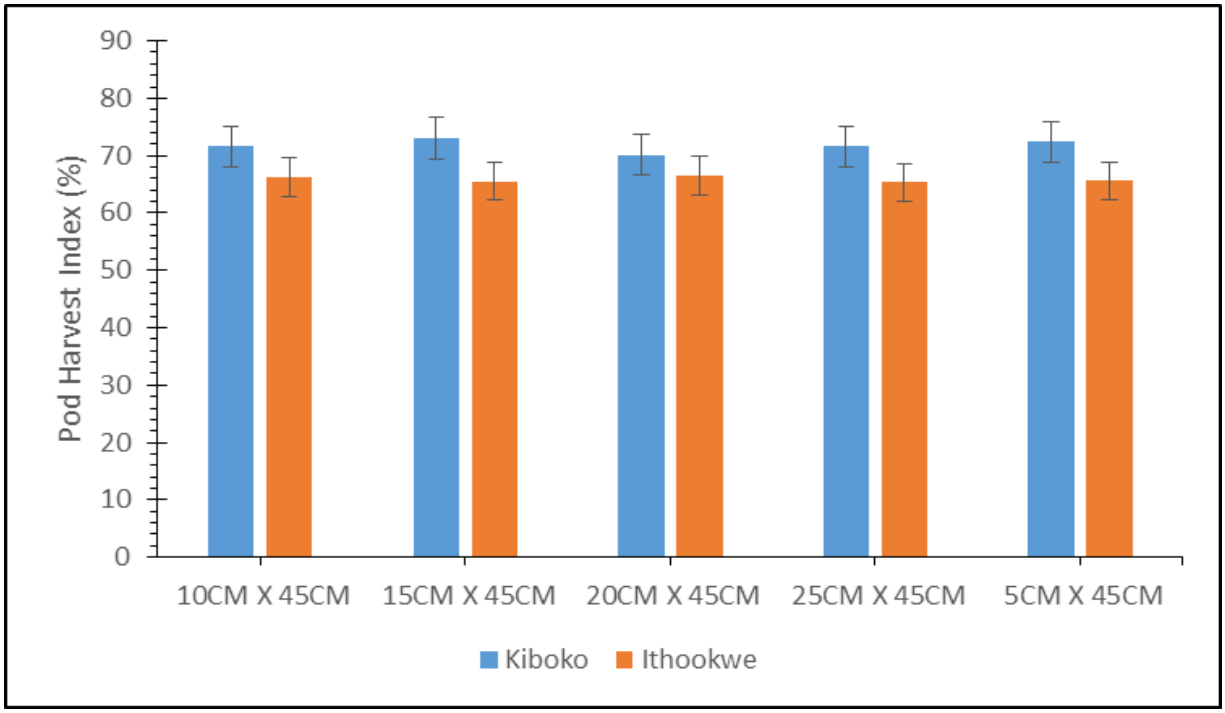

Figure 4:1: Influence of intra-row spacing on the pod harvest index of green gram in Kiboko and Ithookwe. Error bars represents least significant difference (LSD) at P = 0.05. Treatment means are significantly different where error bars do not overlap.

4.1.8 Effect of intra-row spacing on yield components

The number of pods per plant in Kiboko and Ithookwe were significantly influenced (P≤0.05) by the different intra-row spacing treatments as shown in Table 4.7. At Kiboko, the highest number of pods per plant (43) was recorded in the widest row spacing (25cm x 45cm) while the lowest number of pods per plant (16) was observed under the narrowest row spacing (5cm x 45cm). Therefore, increase in plant spacing led to increase in number of pods per plant. In Ithookwe, similar results were made but there was no difference among 15cm x 45cm, 20cm x 45cm and 25cm x 45cm. At Kiboko, 5cm x 45cm spacing had significantly shorter pods than 20cm x 45cm and 25cm x 45cm spacing. No difference was noted among 10cm, 15cm, 20cm and 25cm x 45. The same trend was recorded in Ithookwe except that 5cm x 45cm had shorter pod length than 10cm x 45cm. The number of grains per pod were not significantly different among the different spacing in both sites.

Table 4:7: Intra-row spacing influence on the number of grains per pod, number of pods per plant and the pod length of green gram in Kiboko and Ithookwe

Treatment	Kiboko			Ithookwe		
Spacing	Grains/ Pod	Pods/ Plant	Pod Length	Grains/ Pod	Pods/ Plant	Pod Length
10 cm x 45 cm	12a	22d	10.5b	12a	15b	9.89b
15 cm x 45 cm	12a	27c	10.6b	12a	19ab	9.74b
20 cm x 45 cm	12a	35b	10.9a	12a	21a	10.2a
25 cm x 45 cm	12a	43a	10.9a	12a	21a	10.4a
5 cm x 45 cm	12a	16e	10.1c	12a	13c	9.4b
P Value	**0.304**	**<0.001**	**<0.001**	**0.567**	**<0.001**	**<0.001**
LSD	**NS**	**3.835**	**0.2532**	**NS**	**4.373**	**0.4067**

Means followed by different letters in a column are significantly different at 95% confidence level, NS-Not significant

4.1.9 Effect of intra-row spacing on yield

The 100-grain mass and grain yield of green gram were significantly influenced ($P \leq 0.05$) by the intra-row spacing (Table 4.8a) in both sites. At Kiboko, the grain yield was highest under 20cm x 45cm treatment while 25 cm x 45 cm, 15 cm x 45, 15 cm x 45 cm intra-row spacing treatments were not significantly different from each other but lower than the 20cm x 45cm treatment. At Ithookwe, the grain yield was significantly influenced by the intra-row spacing treatments where the highest was recorded on the narrowest spacing which was however not significantly different from the 10 cm x 45 cm and the 20 cm x 45 cm treatments. The lowest grain yield at Ithookwe was observed on the widest intra-row spacing treatment. No significant differences were noted among the intra-row spacing treatments at Ithookwe on the 100-grain weight treatments. However, the highest 100-grain weight was recorded on the widest intra-row spacing treatment of 25 cm x 45 cm while the lowest 100-grain weight was on the narrowest intra-row spacing treatment of 5 cm x 45 cm which is the same trend observed in Kiboko. At Kiboko, 100-grain weight was significantly lower at 5cm x 45cm than all the other plant spacing except 10cm x 45cm.

Table 4:8a: Intra-row spacing influence on the 100-grain weight (g) at Kiboko and Ithookwe and grain yield (Kg ha^{-1}) of green gram at Ithookwe

	100-Grain Weight		Yield kg/ha	
Spacing	**Kiboko**	**Ithookwe**	**Kiboko**	**Ithookwe**
10 cm x 45 cm	7.36ab	6.485a	2673b	1456ab
15 cm x 45 cm	7.58a	6.441a	2537b	1323b
20 cm x 45 cm	7.51a	6.265a	3114a	1583ab
25 cm x 45 cm	7.40ab	6.559a	2542b	1242b
5 cm x 45 cm	7.10b	6.251a	2503b	1731a
P Value	**0.03**	**0.436**	**<.001**	**0.047**
LSD	**0.3037**	**NS**	**219.6**	**387**

Means followed by different letters in a column are significantly different at 95% confidence level, NS-Not significant

Interaction effect were exhibited between row spacing and inoculation on the three varieties at Kiboko where the highest biological yield was recorded on KAT00309 variety which was inoculated at the 20 cm x 45 cm intra-row spacing which was however not significantly different from the Non-inoculated varieties of KAT00308 and KS20 with the same intra-row spacing and the inoculated KAT00308 at the same spacing treatment. The lowest biological yield was recorded on the least intra-row spacing of the inoculated KAT00308 seed variety of green grams at Kiboko (Table 4.8b).

Table 4:8b: Interaction effect of intra-row spacing, rhizobial inoculation and variety on the biological yield at Kiboko

Spacing	**Inoculation**	**KAT00308**	**KAT00309**	**KS20**
10 cm x 45 cm	Inoculated	5086c	5470c	6959a
	Non-Inoculated	5965b	7028a	5886b
15 cm x 45 cm	Inoculated	5702b	6069b	5833b
	Non-Inoculated	4917c	5963b	5097c
20 cm x 45 cm	Inoculated	7575a	7808a	5994b
	Non-Inoculated	7147a	6234b	7425a
25 cm x 45 cm	Inoculated	6097b	5626b	5551c
	Non-Inoculated	5600b	4990c	5241c
5 cm x 45 cm	Inoculated	4596c	5920b	5542c
	Non-Inoculated	6552a	6083b	5540c
P-Value			**<.001**	
LSD				

Means followed by different letters in a column are significantly different at 95% confidence level

Table 4:8c: Interaction effect of rhizobial inoculation and variety on the biological yield at Ithookwe

Inoculation	KAT00308	KAT00309	KS20
Inoculated	4330a	3719ab	4787a
Non-Inoculated	3677ab	4245a	3308b
P-Value		**0.039**	
LSD		**1086.6**	

Means followed by different letters in a column are significantly different at 95% confidence level

There were significant interactions between variety and inoculation treatments where the highest biological yield was recorded on KAT00308 and KS20 on the inoculated treatments while the lowest biological yield on variety KAT00309 under the non-inoculated treatment at Ithookwe (Table 4.8c).

There were significant differences on the grain yield of green grams which realized under the interaction between intra-row spacing, inoculation and varieties at Kiboko (Table 4.8d). The intra-row spacing of 20 cm x 45 cm of inoculated treatments of varieties KAT00308 and KAT00309 exhibited the highest grain yield. The lowest grain yield was exhibited on the narrowest intra-row spacing of 5 cm x 45 cm under variety KAT00308 which was inoculated.

Table 4:8d: Interaction effect of intra-row spacing, rhizobia inoculation and variety on the grain yield at Kiboko

Spacing	Inoculation	KAT00308	KAT00309	KS20
10 cm x 45 cm	Inoculated	2281c	2583b	2826b
	Non-Inoculated	2600b	3321a	2426c
15 cm x 45 cm	Inoculated	2566b	2834b	2522c
	Non-Inoculated	2292c	2832b	2178c
20 cm x 45 cm	Inoculated	3402a	3614a	2579b
	Non-Inoculated	2930b	2987b	3172a
25 cm x 45 cm	Inoculated	2818b	2678b	2469c
	Non-Inoculated	2577b	2395c	2315c
5 cm x 45 cm	Inoculated	2022c	2734b	2228c
	Non-Inoculated	2692b	2999b	2346c
P-Value			**0.006**	
LSD			**538**	

Means followed by different letters in a column are significantly different at 95% confidence level

4.2 Effect of rhizobia inoculation on growth, root nodulation and grain yield of three green gram varieties in lower Eastern Kenya

4.2.1 Effect of rhizobia inoculation on plant height

There were no significant differences between the inoculated and non-inoculated green grams in plant height in both sites (Fig. 4.2 & 4.3). However, there were significant interactions (P=0.026) revealed between inoculation treatments and varieties where the tallest plants on KAT00308 and KS20 were inoculated while KAT00309 was tallest on the non-inoculated treatment at 5 WAS

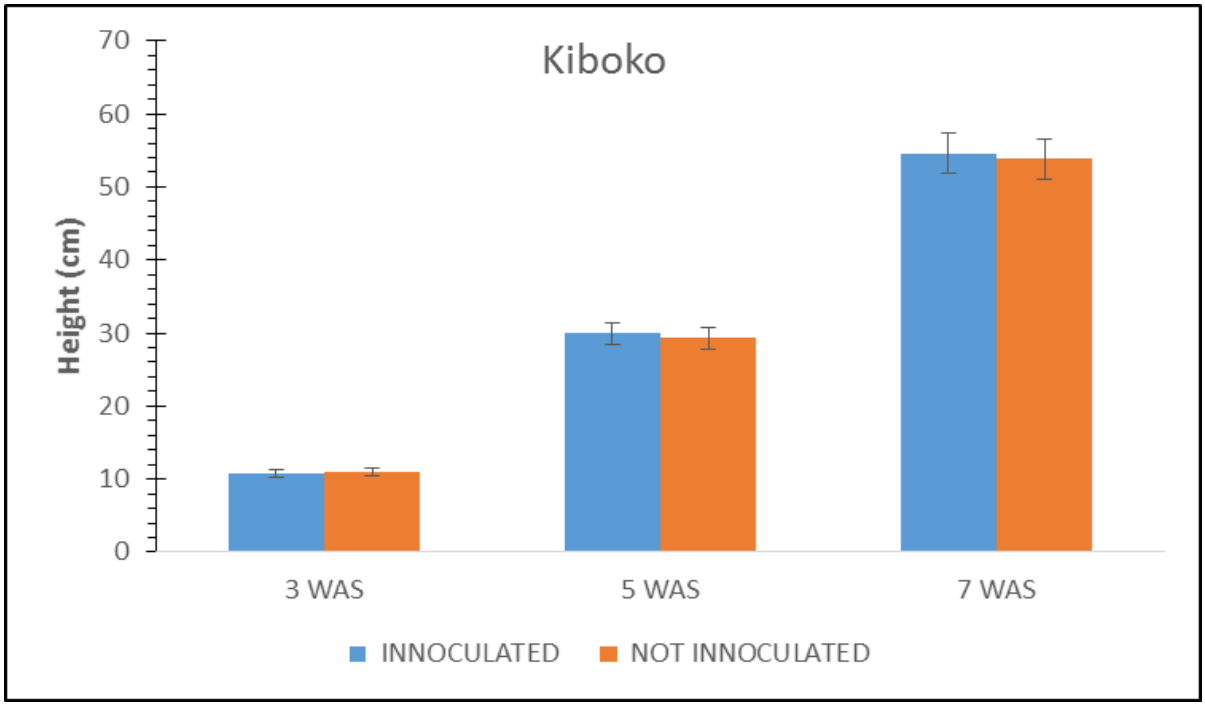

Figure 4:2: Effect of rhizobia inoculation on the plant height (cm) of green gram varieties in Kiboko at 3, 5 and 7 weeks after sowing (WAS). Error bars represents least significant difference (LSD) at P = 0.05. Treatment means are significantly different where error bars do not overlap.

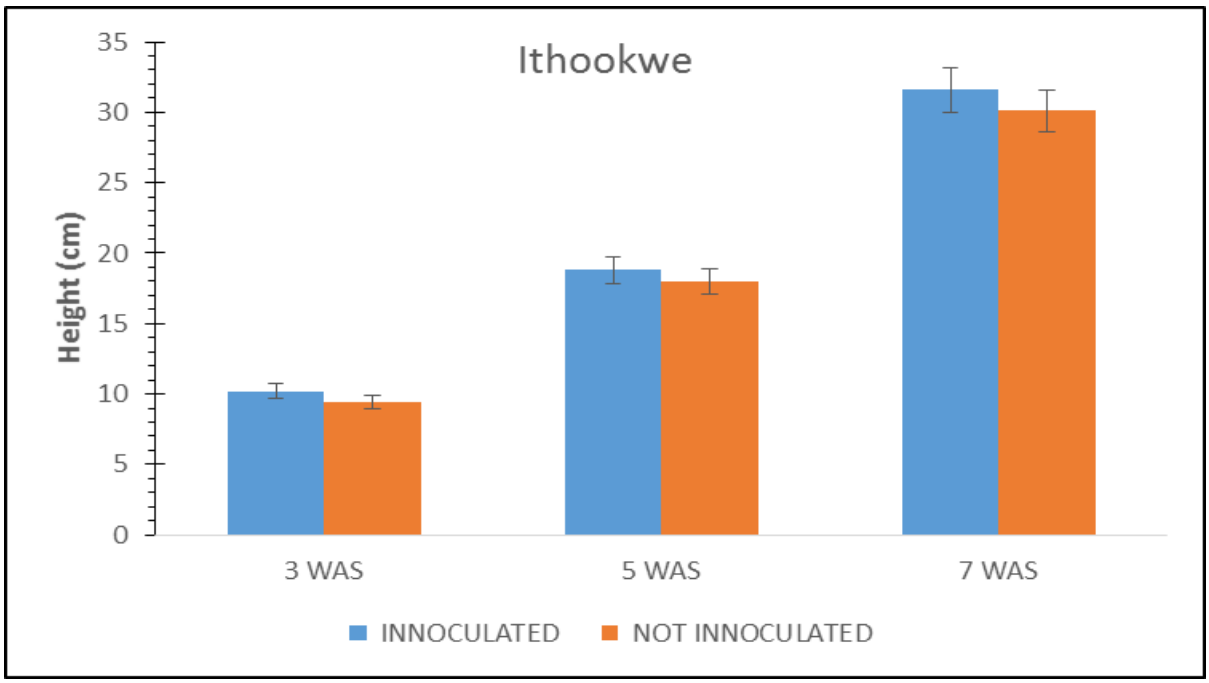

Figure 4:3: Effect of rhizobia inoculation on the plant height (cm) of green gram varieties in Ithookwe at 3, 5 and 7 weeks after sowing (WAS). Error bars represents least significant difference (LSD) at P = 0.05. Treatment means are significantly different where error bars do not overlap.

4.2.2 Effect of rhizobia inoculation on shoot dry weight

The shoot dry weight showed significant differences (P≤0.05) between the treatments only in Ithookwe at 3 weeks after sowing (WAS). No significant differences were observed at Kiboko at all the stages (Table 4.9).

Table 4:9: Effect of rhizobia inoculation on the shoot dry weight (g) of green gram in Kiboko and Ithookwe during different weeks after sowing

	Kiboko			Ithookwe		
Treatment	**3 WAS**	**5 WAS**	**7 WAS**	**3 WAS**	**5 WAS**	**7 WAS**
Inoculated	1.884a	20.0a	57.8a	0.945a	4.88a	20.93a
Non-Inoculated	1.789a	19.3a	59.5a	0.825b	4.93a	21.01a
P Value	**0.402**	**0.508**	**0.576**	**0.029**	**0.914**	**0.968**
LSD	**NS**	**NS**	**NS**	**0.1075**	**NS**	**NS**

Means followed by different letters in a column are significantly different at 95% confidence level, WAS-Weeks after Sowing, NS-Not Significant

4.2.3 Effect of rhizobia inoculation on days to 50% flowering and maturity

There were significant differences between the treatments on the days to 50% flowering in Ithookwe but not in Kiboko (Fig. 4.4). At Ithookwe the number of days to 50% flowering increased with inoculation by 2 days. There were no significant differences in the number of days to maturity between the treatments in both sites (Fig 4.5).

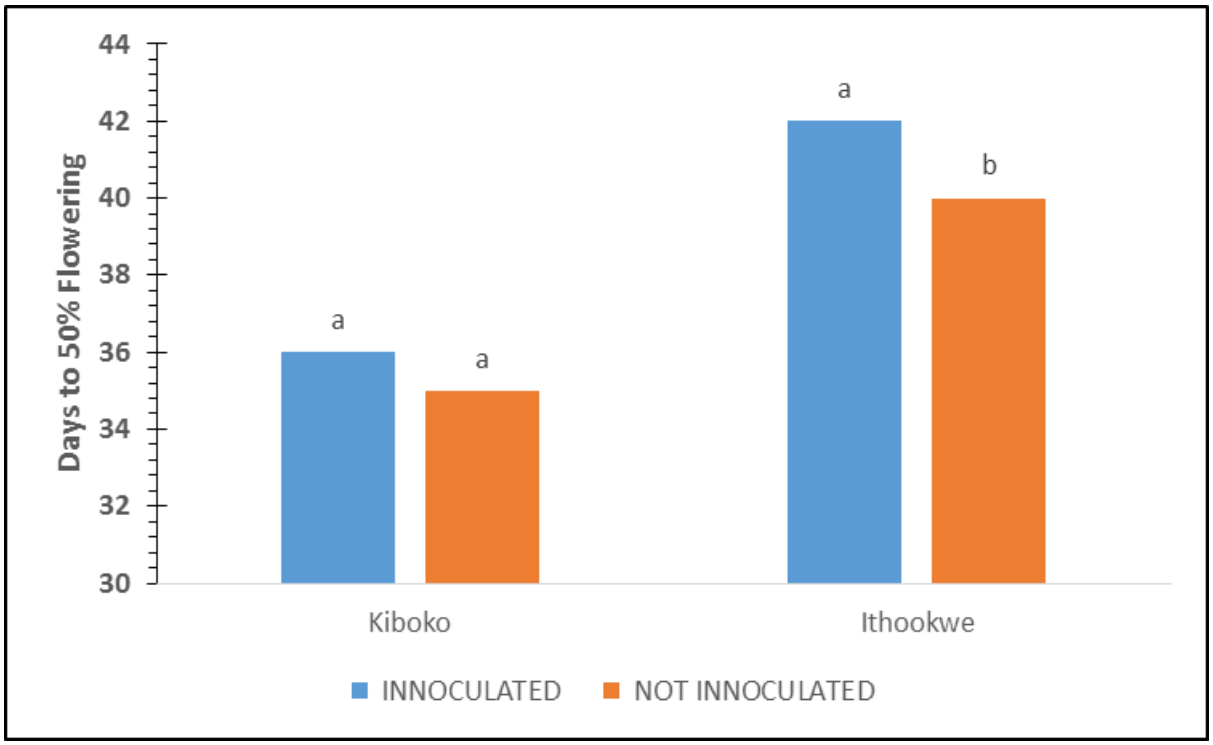

Figure 4:4: Days to 50% flowering of green gram varieties as influenced by inoculation treatment at Ithookwe and Kiboko. Bars with different letters at each site show no significant differences between treatments at p<0.05.

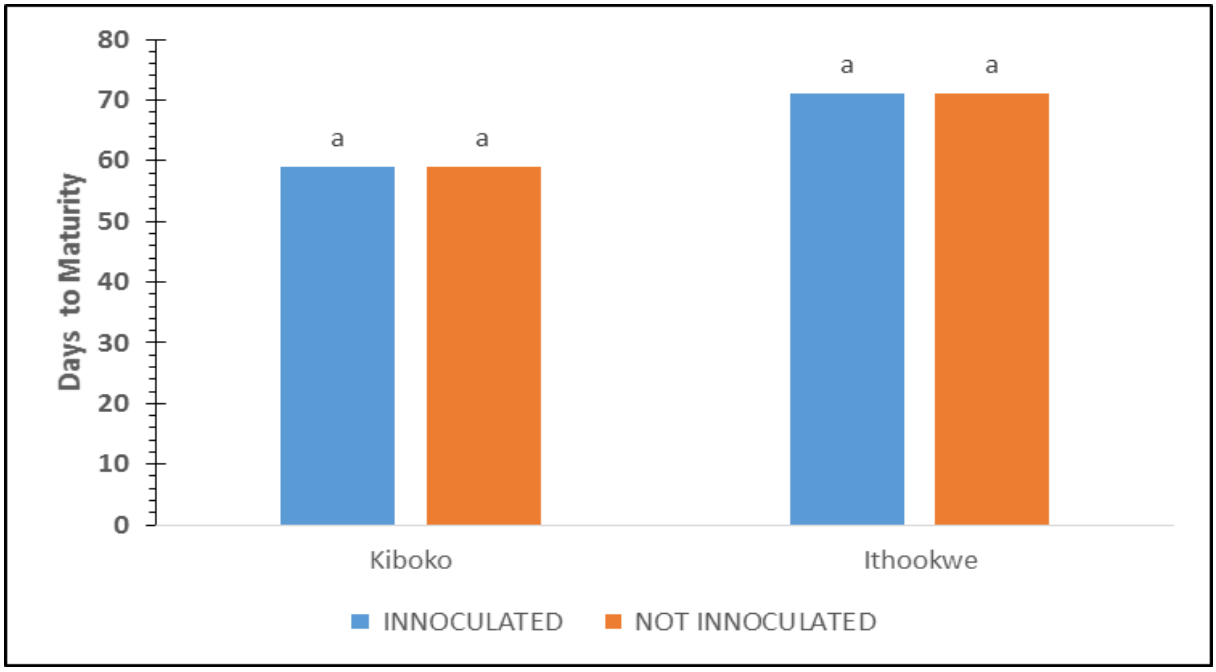

Figure 4:5: Days to maturity of green gram varieties as influenced by inoculation treatment at Ithookwe and Kiboko. Bars with different letters at each site show no significant differences between treatments at p<0.05.

4.2.4 Effect of rhizobia inoculation on ground cover

The ground cover of green gram increased exponentially with time but it was not affected by inoculation with rhizobia in both sites (Fig. 4.6 & Fig 4.7). No interactions between inoculation and varieties were revealed on ground cover of green gram in both sites.

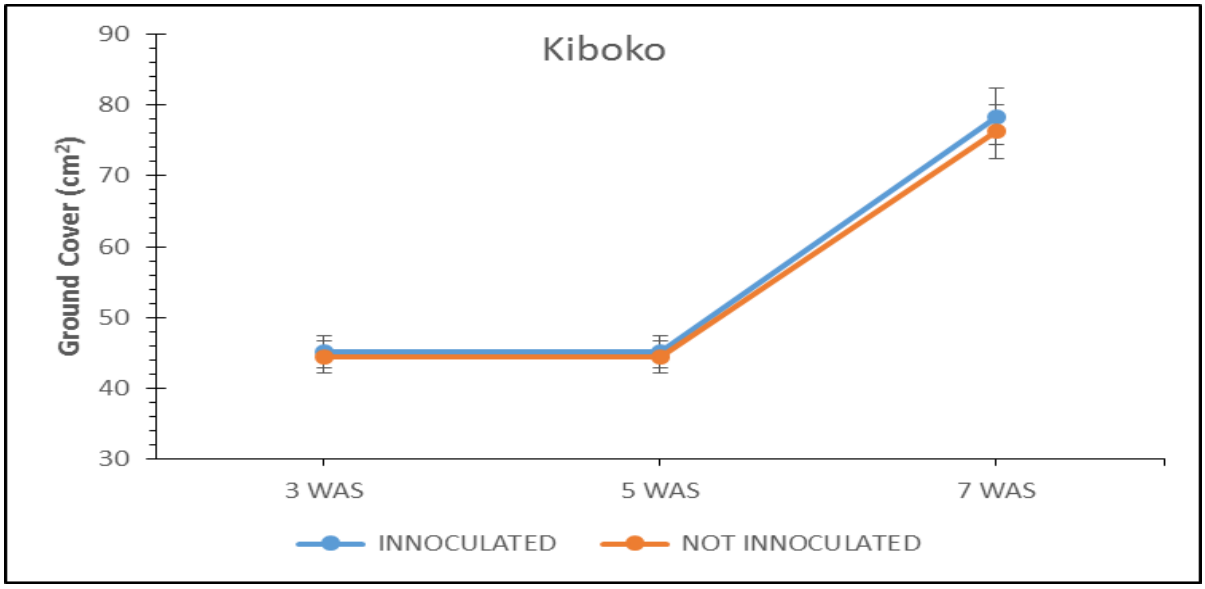

Figure 4:6: Influence of rhizobia inoculation on the ground cover of green gram in Kiboko. Error bars represents least significant difference (LSD) at P = 0.05. Treatment means are significantly different where error bars do not overlap.

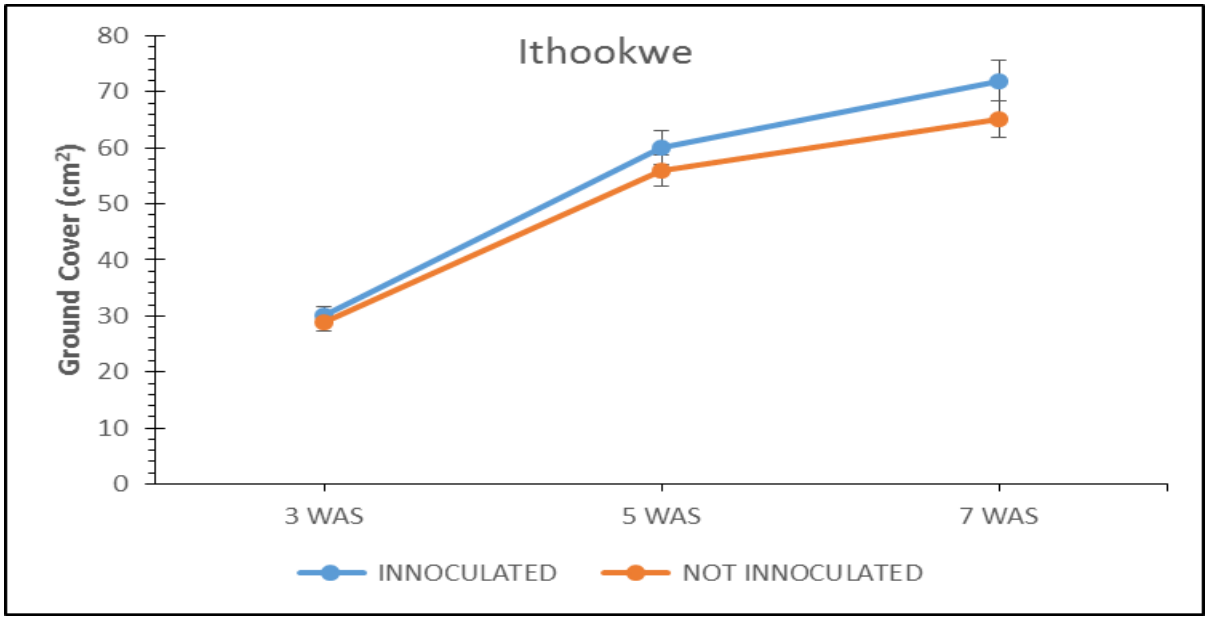

Figure 4:7: Influence of rhizobia inoculation on the ground cover of green gram in Ithookwe. Error bars represents least significant difference (LSD) at P = 0.05. Treatment means are significantly different where error bars do not overlap.

4.2.5 Effect of rhizobia inoculation on number of effective nodules

The number of effective nodules showed non-significant differences between the inoculated and non-inoculated treatments at all stages of sampling in both sites except at 3WAS in Ithookwe where the inoculated treatment had significantly more effective nodules than the no-inoculated treatment (Table 4.10). Interaction between inoculation and varieties were revealed on the number of effective nodules at Ithookwe 3 weeks after sowing where the highest on inoculated treatment was on varieties KAT00308 and KS20 while highest nodules on KAT00309 was on the non-inoculated treatment.

Table 4:10: Number of effective nodules in green gram at Kiboko and Ithookwe as influenced by rhizobia inoculation

	Kiboko			Ithookwe		
Treatment	**3 WAS**	**5 WAS**	**7 WAS**	**3 WAS**	**5 WAS**	**7 WAS**
Inoculated	21a	28a	17a	3a	7a	4a
Non-Inoculated	20a	27a	15a	2b	7a	5a
P Value	**0.54**	**0.815**	**0.343**	**0.033**	**0.879**	**0.101**
LSD	**NS**	**NS**	**NS**	**0.937**	**NS**	**NS**

Means followed by different letters in a column are significantly different at 95% confidence level, WAS-Weeks after Sowing, NS-Not Significant

4.2.6 Effect of rhizobia inoculation on yield components

There were significant differences (P≤0.05) between the number of grains per pod in Kiboko where the inoculated treatment had the highest number of grains per pod (12) compared to the non-inoculated treatment (11) (Table 4.11). There were no significant differences on the number of grains per pod in Ithookwe. There were also no significant differences between the treatments on the number of pods per plant and the pod length in both sites except for the pod length in Kiboko where the inoculated pods were longer (10.72 cm) than the non-inoculated (10.55cm). Interaction between inoculation and green gram varieties was revealed in both sites on the number of grains per pod and on pod length in Ithookwe where only variety KS20 had a positive influence of inoculation and vice-versa for KAT00308 and KAT00309.

Table 4:11: Influence of rhizobia inoculation on number of grains per pod, number of pods per plant and the pod length (cm) of green gram in Kiboko and Ithookwe

	Kiboko			Ithookwe		
Treatment	**Grains /pod**	**Pods /plant**	**Pod length**	**Grains /pod**	**Pods /plant**	**Pod length**
Inoculated	12a	29a	10.72a	12a	19a	9.95a
Non-Inoculated	11b	29a	10.55b	12a	17a	9.88a
P Value	**0.05**	**0.887**	**0.037**	**0.931**	**0.274**	**0.577**
LSD	**0.2883**	**NS**	**0.08**	**NS**	**NS**	**NS**

Means followed by different letters in a column are significantly different at 95% confidence level, Variety, NS-Not Significant

4.2.7 Effect of rhizobia inoculation on yield

The biological yield and 100-grain mass of green gram were not significantly influenced by inoculation treatments at Kiboko and Ithookwe (Table 4.12). There were however significant differences between the treatments on the grain yield at Ithookwe where the inoculated treatment had higher grain yield (1,587 kg ha^{-1}) than the non-treated plots (1,347 kg ha^{-1}).

Table 4:12: Influence of rhizobia inoculation on the biological yield, 100-grain weight and grain yield of green gram in Kiboko and Ithookwe

	Kiboko			Ithookwe		
Treatment	**Biological Yield kg ha^{-1}**	**100-Grain Weight**	**Yield Kg ha^{-1}**	**Biological Yield kg ha^{-1}**	**100-Grain Weight**	**Yield Kg ha^{-1}**
Inoculated	5989a	7.34a	2677a	4278a	6.37a	1587a
Non-inoculated	5978a	7.45a	2671a	3743a	6.43a	1347b
P Value	**0.941**	**0.252**	**0.929**	**0.093**	**0.635**	**0.05**
LSD	**NS**	**NS**	**NS**	**NS**	**NS**	**244.7**

Means followed by different letters in a column are significantly different at 95% confidence level, NS-Not Significant

4.2.8 Effect of rhizobia inoculation on harvest index and pod harvest index

The pod harvest index and harvest index were not significantly influenced by the inoculation treatment for both sites (Fig. 4.8). The pod harvest index among the treatments in Kiboko varied between 71-72% while that of Ithookwe varied from 65-67%. The harvest index in Kiboko was between 44-45% while that of Ithookwe varied from 36-37%.

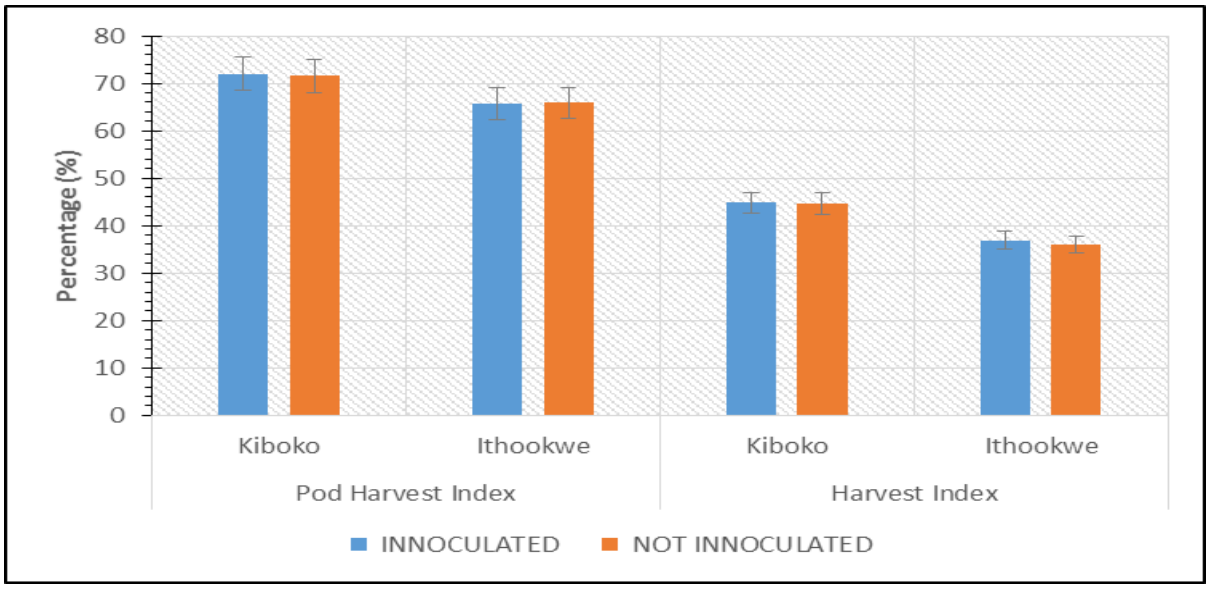

Figure 4:8: Influence of rhizobia inoculation on the pod harvest index and harvest index of green gram in Ithookwe and Kiboko. Error bars represents least significant difference (LSD) at P = 0.05. Treatment means are significantly different where error bars do not overlap.

4.3. Effect of varietal differences on growth, root nodulation and yield of green grams in lower Eastern Kenya

4.3.1 Effect of varietal differences on plant height

The varieties differed significantly (P≤0.05) in both sites in plant height at all the sampling stages from 3 to 7 weeks after sowing (Table 4.13). At both sites KS20 was taller than KAT00308 and KAT00309 at all stages except at 7WAS in Kiboko where KAT00308 was equally tall. No differences were noted between KAT00308 and KAT00309 in both sites at all stages except at 7WAS at Kiboko where KAT00308 was taller than KAT00309.

Table 4:13: Plant height of different green gram varieties in Kiboko and Ithookwe at different stages of growth

	Kiboko			Ithookwe		
Variety	**3 WAS**	**5 WAS**	**7 WAS**	**3 WAS**	**5 WAS**	**7 WAS**
KAT00308	10.0b	28.3b	55.1a	8.8b	17.7b	30.4b
KAT00309	9.6b	27.9b	52.2b	9.1b	17.4b	29.2b
KS20	13.0a	32.6a	55.3a	11.4a	20.2a	33.7a
P Value	**<.001**	**<.001**	**0.031**	**<.001**	**0.016**	**0.004**
LSD	**0.545**	**1.061**	**2.522**	**0.903**	**2.906**	**2.906**

Means followed by different letters in a column are significantly different at 95% confidence level, WAS-Weeks after Sowing, NS-Not Significant

4.3.2 Effect of varietal differences on shoot dry weight

The shoot dry weight differed significantly (P≤0.05) between the varieties at 5 weeks after sowing (WAS) only in Ithookwe as shown in Table 4.14. No significant differences were observed at Kiboko at all stage. At Ithookwe, KS20 had significantly higher shoot dry weight than KAT 308 and KAT00309 but the latter two were not significantly different in shoot dry weight.

Table 4:14: Shoot dry weight (g) of different varieties in Ithookwe and Kiboko at different weeks after sowing

	Kiboko			Ithookwe		
Variety	**3 WAS**	**5 WAS**	**7 WAS**	**3 WAS**	**5 WAS**	**7 WAS**
KAT00308	1.763a	20.00a	59.3a	0.884a	4.15b	18.59a
KAT00309	1.805a	20.26a	54.8a	0.928a	4.78b	22.26a
KS20	1.942a	18.69a	61.9a	0.842a	5.79a	22.05a
P Value	**0.404**	**0.354**	**0.14**	**0.433**	**0.015**	**0.227**
LSD	**NS**	**NS**	**NS**	**NS**	**1.093**	**NS**

Means followed by different letters in a column are significantly different at 95% confidence level, WAS-Weeks after Sowing, NS-Not Significant

4.3.3. Effect of varietal differences on number of effective nodules

There were significant differences (P≤0.05) between the varieties in the number of effective nodules in Kiboko and Ithookwe (Table 4.15). The highest number of nodules in both sites was observed on variety KS20. At all sampling stages in both sites no differences were noted between KAT00308 and KAT00309 except at 3WAS at Kiboko where KAT00309 had significantly higher number of nodules than KAT00308.

Table 4:15: Influence of varietal differences on the number of effective nodules of green gram in Kiboko and Ithookwe

	Kiboko			Ithookwe		
Variety	**3 WAS**	**5 WAS**	**7 WAS**	**3 WAS**	**5 WAS**	**7 WAS**
KAT00308	13c	19c	11b	1b	3b	2b
KAT00309	18b	25b	13b	2b	5b	4b
KS20	29a	39a	23a	4a	11a	8a
P Value	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
LSD	**3.884**	**4.333**	**4.334**	**1.147**	**2.778**	**1.846**

Means followed by different letters in a column are significantly different at 95% confidence level, WAS-Weeks after Sowing, NS-Not Significant

4.3.4 Effect of varietal differences on nodules dry weight

The dry weight of nodules differed significantly (P≤0.05) among the varieties at all stages in Kiboko and at 3WAS and 5WAS in Ithookwe. At Kiboko, KAT00309 had higher nodule dry weight than KAT308 at all stages and KS20 at 3 and 5WAS. At Ithookwe KS20 had higher nodule dry weight than KAT00309 while KAT00309 had higher nodule dry weight than KAT308 at 3 and 5WAS. No significant differences were noted among varieties at 7 WAS.

Table 4:16: Varietal differences on the dry weight of nodules of green gram in Kiboko and Ithookwe

	Kiboko			Ithookwe		
Variety	**3 WAS**	**5 WAS**	**7 WAS**	**3 WAS**	**5 WAS**	**7 WAS**
KAT00308	0.051b	0.283b	0.252b	0.0106c	0.03c	0.0366a
KAT00309	0.124a	0.494a	0.424a	0.0181b	0.0477b	0.0429a
KS20	0.071b	0.399b	0.423a	0.0208a	0.0583a	0.0582a
P Value	**0.016**	**<.001**	**0.002**	**0.009**	**0.044**	**0.172**
LSD	**0.0508**	**0.076**	**0.1078**	**0.0066**	**0.02236**	**NS**

Means followed by different letters in a column are significantly different at 95% confidence level, WAS-Weeks after Sowing, NS-Not Significant

4.3.5 Effect of varietal differences on ground cover

The ground cover differed significantly between the varieties in both sites as shown in Fig.

4.9. Variety KS20 had significantly higher ground cover than the other varieties at both sites.

At the same time, KAT00309 had higher ground cover than KAT00308 except at 5WAS in Kiboko.

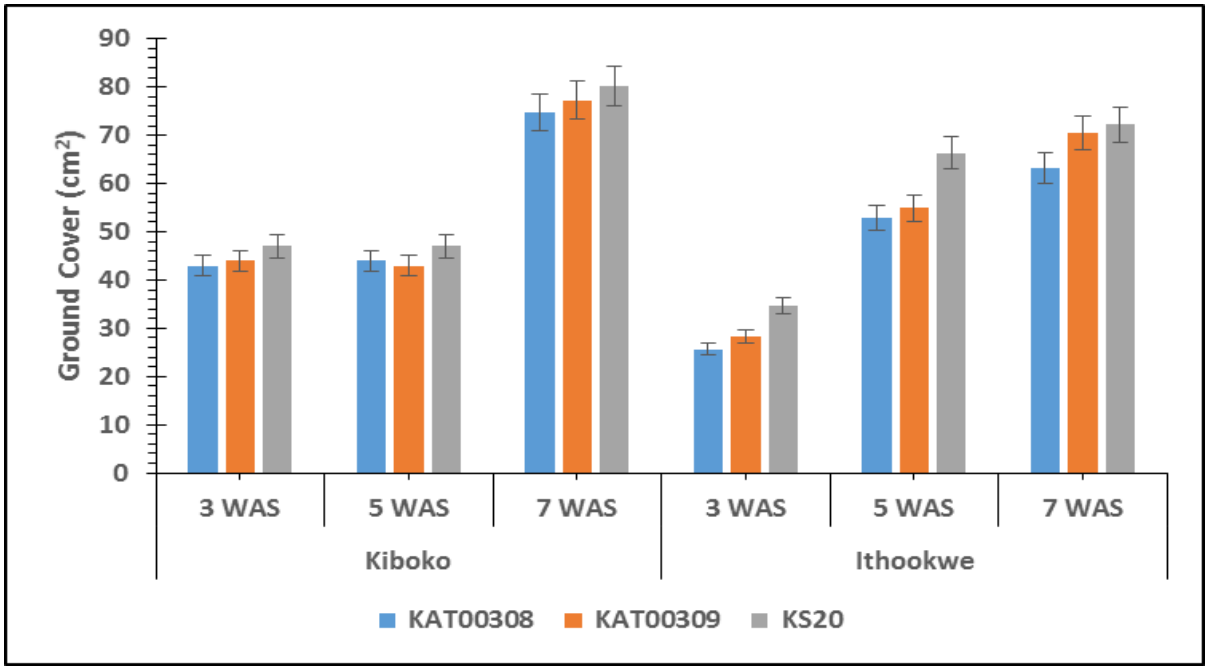

Figure 4:9: Ground cover as influenced by different green gram varieties in Kiboko and Ithookwe. Error bars represents least significant difference (LSD) at P = 0.05. Treatment means are significantly different where error bars do not overlap.

4.3.6 Effect of varietal differences on the Number of days to 50%flowering and maturity

The number of days to 50% flowering differed significantly (P≤0.05) between the varieties of green gram at Kiboko but not at Ithookwe. (Table 4.17). The time to 50% flowering was shorter in varieties KAT00309 and KS20 than in variety KAT00308. The number of days to maturity were significantly different in both sites where variety KS20 had the shortest period to maturity (58 days) compared to the other varieties in Kiboko. At Ithookwe variety KAT00309 took shorter time to reach maturity than variety KAT00308 and KS 20. Time to maturity ranged from 58days at Kiboko to 72 days at Ithookwe.

Table 4:17: Varietal differences on the days to 50% flowering and maturity of green gram in Ithookwe and Kiboko

	Kiboko		Ithookwe	
Variety	**Days to 50% Flowering**	**Days to Maturity**	**Days to 50% Flowering**	**Days to Maturity**
KAT00308	36a	59a	41a	72a
KAT00309	35b	59a	41a	70c
KS20	35b	58b	41a	71b
P Value	**0.017**	**<.001**	**0.987**	**<.001**
LSD	**0.51**	**0.1497**	**NS**	**0.847**

Means followed by different letters in a column are significantly different at 95% confidence level, NS-Not Significant

4.3.7 Effect of varietal differences on yield components

The number of grains per pod, number of pods per plant and pod length differed significantly (P≤0.05) between the varieties at both sites (Table 4.18). The highest number of grains per pod (13) was exhibited by variety KS20 in both sites while the other two varieties (KAT00308 and KAT00309) had equal number of grains per pod in Kiboko with KAT00309 having the lowest number of grains per pod (11) in Ithookwe. In both sites, Varieties KAT00308 and KAT00309 had higher number of pods per plant than KS20. There was no significant difference in the number of pods per plant between KAT308 and KAT00309.

The pod length of KS20 and KAT00309 varieties were significantly different in both sites. At Kiboko KAT00309 had longer pods than KAT00308 where the longest pods in Kiboko were

in variety KAT00309 which were however not significantly different from that of variety KS20 while the shortest were on variety KAT00308. In Ithookwe, the longest pods were on variety KS20 while the shortest were on variety KAT00308 and KAT00309 which were not significantly different.

Table 4:18: Varietal differences on the number of grains per pod, number of pods per plant and the pod length of green gram in Kiboko and Ithookwe

	Kiboko			Ithookwe		
Variety	**Grains /Pod**	**Pods /Plant**	**Pod Length**	**Grains /Pod**	**Pods /Plant**	**Pod Length**
KAT00308	11b	32a	10.14b	12b	20a	9.63b
KAT00309	11b	33a	10.95a	11c	19a	9.94b
KS20	13a	22b	10.82a	13a	14b	10.17a
P Value	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**0.004**
LSD	**0.3531**	**2.97**	**0.1961**	**0.4525**	**3.388**	**0.315**

Means followed by different letters in a column are significantly different at 95% confidence level, NS-Not Significant

4.3.8 Effect of varietal differences on yield

The 100-grain mass and grain yield were significantly ($P \leq 0.05$) influenced by varietal differences in both sites. However, the difference in the biological yield was not significant due to varietal differences in both sites (Table 4.19).

At Kiboko, variety KAT00309 had significantly higher grain yield than KS20 but it was not significantly different from KAT00308 in this parameter. In Ithookwe, variety KAT00309 had higher grain yield than KAT00308 but it was not significantly different from KS20. The differences among varieties in the 100-grain mass of green gram were significant in both sites. KAT00309 had significantly higher 100-grain weight than KAT00308 which in turn had significantly higher 100-grain weight than KS20.

Table 4:19: Varietal differences on the biological yield, 100-grain weight (g) and grain yield (Kg ha^{-1}) of green gram in Kiboko and Ithookwe

	Kiboko			Ithookwe		
Variety	Biological Yield kg ha^{-1}	100-Grain Weight	Yield Kg ha^{-1}	Biological Yield kg ha^{-1}	100-Grain Weight	Yield Kg ha^{-1}
KAT00308	5924a	7.399b	2618ab	4003a	6.40b	1404b
KAT00309	6119a	7.833a	2898a	3982a	6.88a	1568a
KS20	5907a	6.943c	2506b	4047a	5.90c	1429ab
P Value	**0.416**	**<.001**	**<.001**	**0.985**	**<.001**	**0.032**
LSD	**NS**	**0.2353**	**170.1**	**NS**	**0.306**	**149.7**

Means followed by different letters in a column are significantly different at 95% confidence level, NS-Not Significant

4.3.9 Effect of varietal differences on pod harvest index

There were no significant differences between the pod harvest indices in the different green gram varieties (Fig. 4.10). There were marginal differences on the varieties where the highest in Kiboko and Ithookwe was on varieties KAT00309 and KS20 respectively. The pod harvest index percentage ranged from 64-67% in Ithookwe and 71-72% in Kiboko

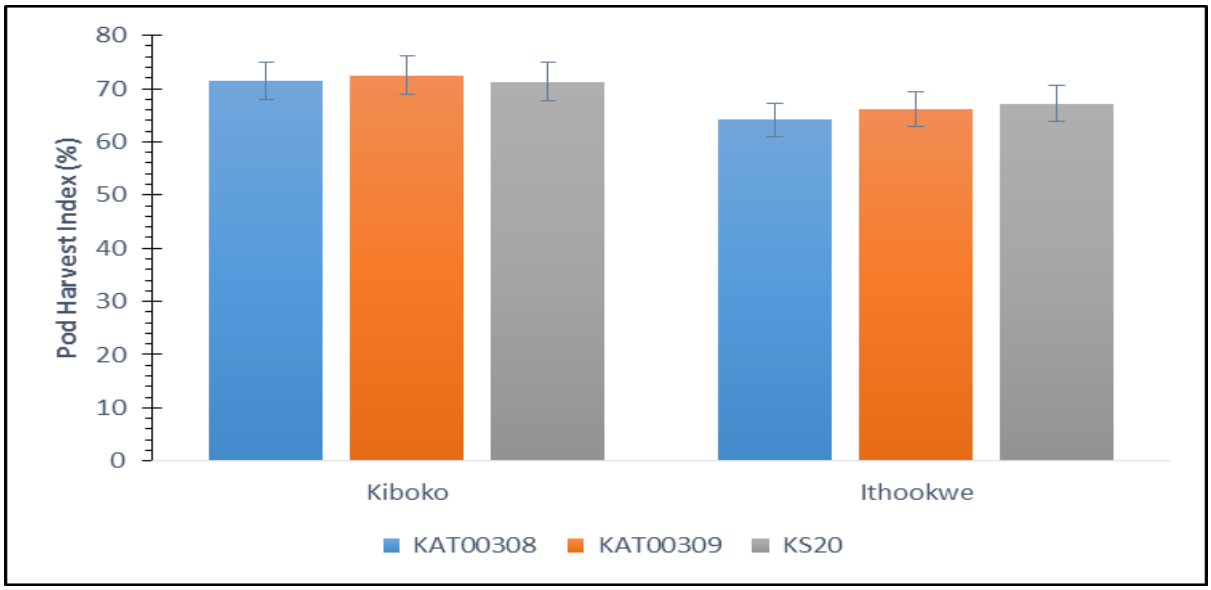

Figure 4:10: Influence of varieties on the pod harvest index of green gram in Kiboko and Ithookwe. Error bars represents least significant difference (LSD) at P = 0.05. Treatment means are significantly different where error bars do not overlap.

4.3.10 Effect of varietal differences on harvest index

The harvest index differed significantly (P≤0.05) between the varieties in Kiboko and Ithookwe (Fig.4.11). The highest harvest index was observed on variety KAT00309 with 47.4% and 39.1% in Kiboko and Ithookwe respectively while the lowest was on variety KS20 with 42.5% and 34.9% in Kiboko and Ithookwe respectively. Harvest indices ranged from 35 to 39% in Ithookwe and 43 to 47% in Kiboko.

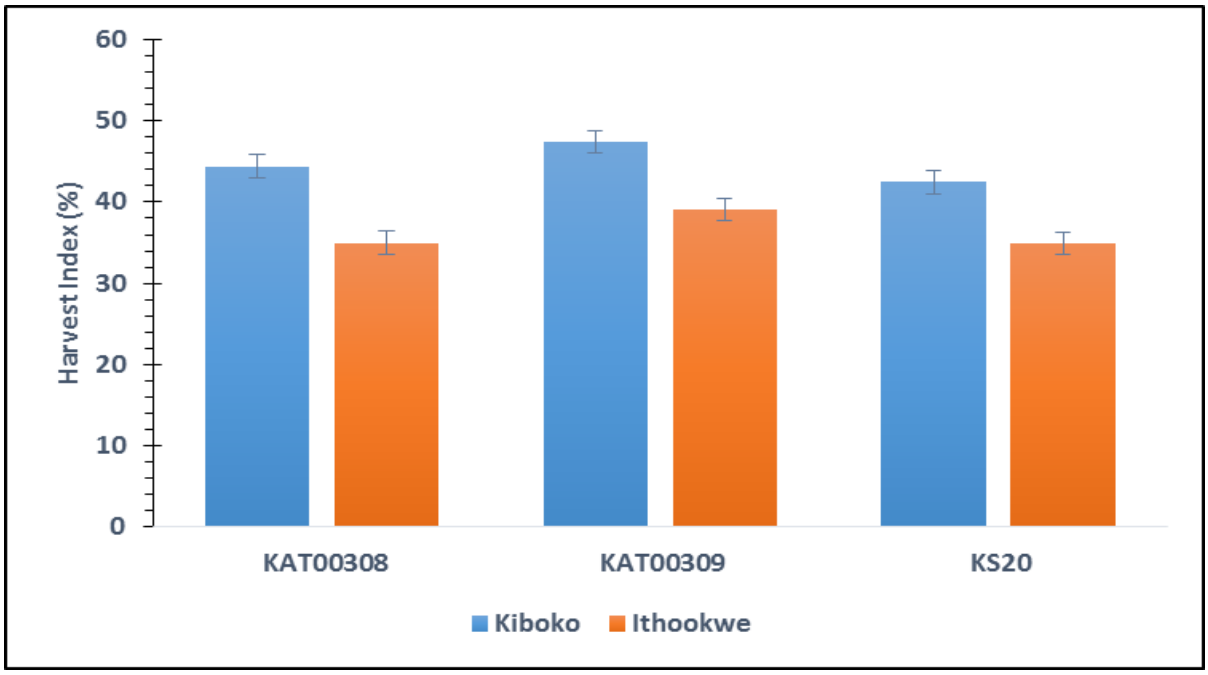

Figure 4:11: Influence of varieties on the harvest index of green gram in Kiboko and Ithookwe. Error bars represents least significant difference (LSD) at P = 0.05. Treatment means are significantly different where error bars do not overlap.

4.4 Association analysis

There were significant positive and negative correlations between selected parameters of green gram in both sites. The number of grains per pod were significantly and positively correlated with the plant height (r=0.384) while the number of pods per plant and the ground cover were significantly and positively correlated (r=0.7544) as well as the number of pods per plant and the plant height (0.6548) at Kiboko (Table 4.20).

Table 4:20: Spearman's correlation analysis of selected parameters of green gram in Kiboko

	1	2	3	4	5	6	7	8
1	-							
2	-0.2298	-						
3	0.3843*	0.6548*	-					
4	-0.0566	0.5610*	-0.4304*	-				
5	-0.1898	0.2935*	-0.1218	0.217	-			
6	0.4738*	-0.2085*	0.1943	0.0547	-0.1096	-		
7	-0.0316	0.7544*	0.6318*	-0.6014*	0.1757*	0.016	-	
8	0.0941	0.1477	-0.2274	0.2780*	0.1062	0.5142*	-0.3113*	-

*=Significant, 1=Grains per pod, 2=pods per plant, 3=Plant height, 4=Shoot dry weight, 5=Yield (Kg/ha), 6=Number of effective nodules, 7=Ground cover, 8=Dry nodules weight. The grain yield of green gram was positively and significantly correlated with the ground cover (0.6908), pods per plant (0.5226), plant height (0.6688) and shoot dry weight (0.5711) at Ithookwe. The dry weight of nodules was also positively and significantly correlated with the plant height (0.3551) and shoot dry weight (0.5842) (Table 4.21).

Table 4:21: Spearman's correlation analysis of selected parameters of green gram in Ithookwe

	1	2	3	4	5	6	7	8
1	-							
2	0.0632	-						
3	0.4588*	0.1843	-					
4	0.3998*	0.4548*	0.5267*	-				
5	0.2879*	0.5226*	0.6688*	0.5711*	-			
6	0.5096*	0.0026	0.339*	0.643*	0.2871	-		
7	0.4356*	0.1841	0.746*	0.5431*	0.6908*	0.4095*	-	
8	0.2897	0.0927	0.3551*	0.5842*	0.3374	0.8207*	0.3507*	-

*=Significant, 1=Grains per pod, 2=pods per plant, 3=Plant height, 4=Shoot dry weight, 5=Yield (Kg/ha), 6=Number of effective nodules, 7=Ground cover, 8=Dry nodules weight

The number of nodules per plant was significantly influenced by the intra-row spacing in both sites but stronger relationships were recorded in Kiboko (r^2=0.6857) compared to that of Ithookwe (r^2=0.2449) as shown in Figures 4.12 and 4.13.

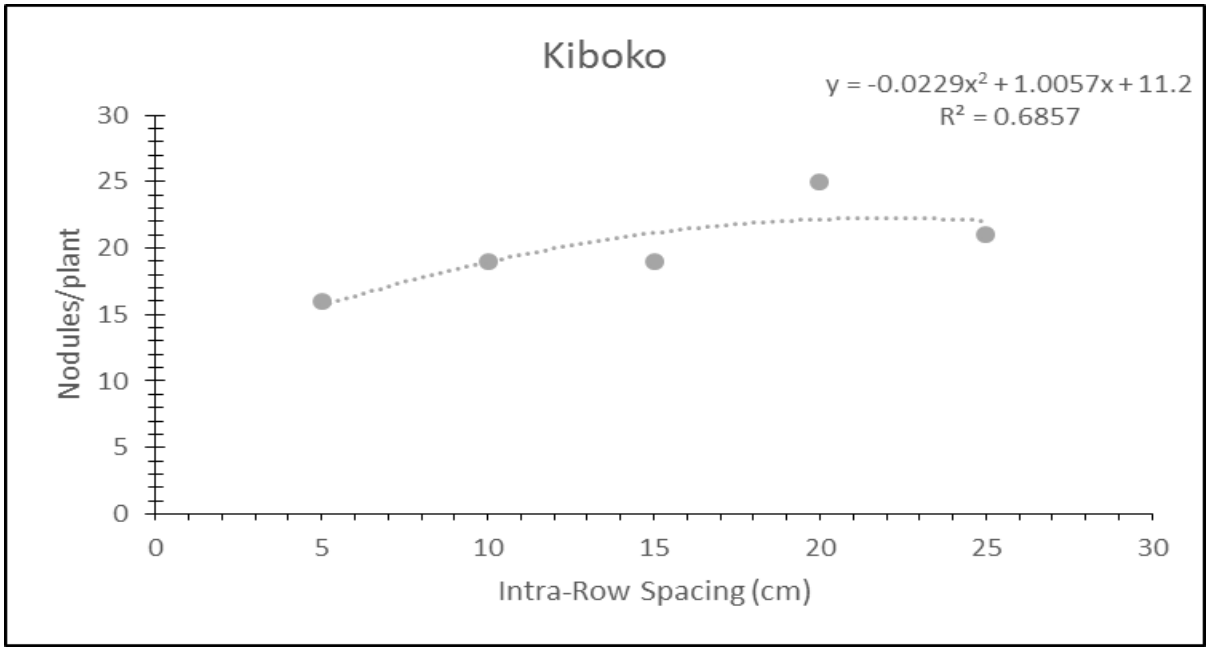

Figure 4:12: Polynomial regression relationship between the intra-row spacing and number of nodules per plant at Kiboko

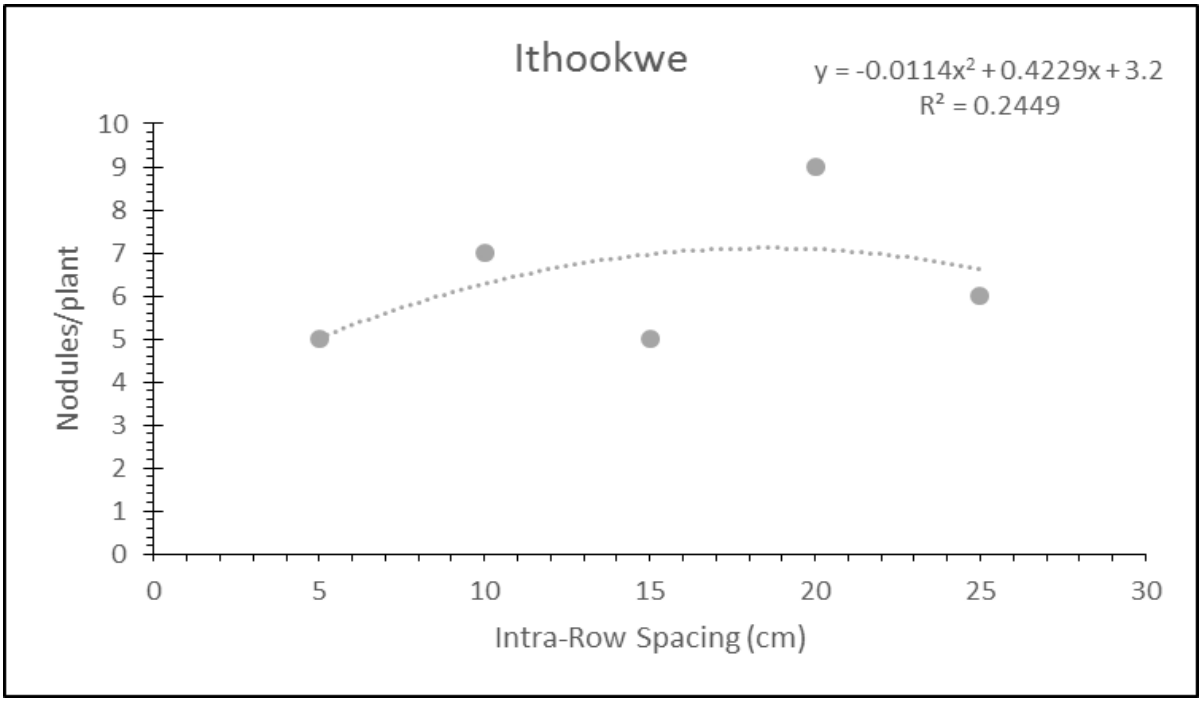

Figure 4:13: Polynomial regression relationship between the intra-row spacing and number of nodules per plant at Ithookwe

There was a polynomial increase on the number of nodules per plant as the plant spacing increased with a maximum recorded at 20 cm then a tail off was observed in both sites as the intra-row spacing increased to 25 cm (Fig. 4.12).

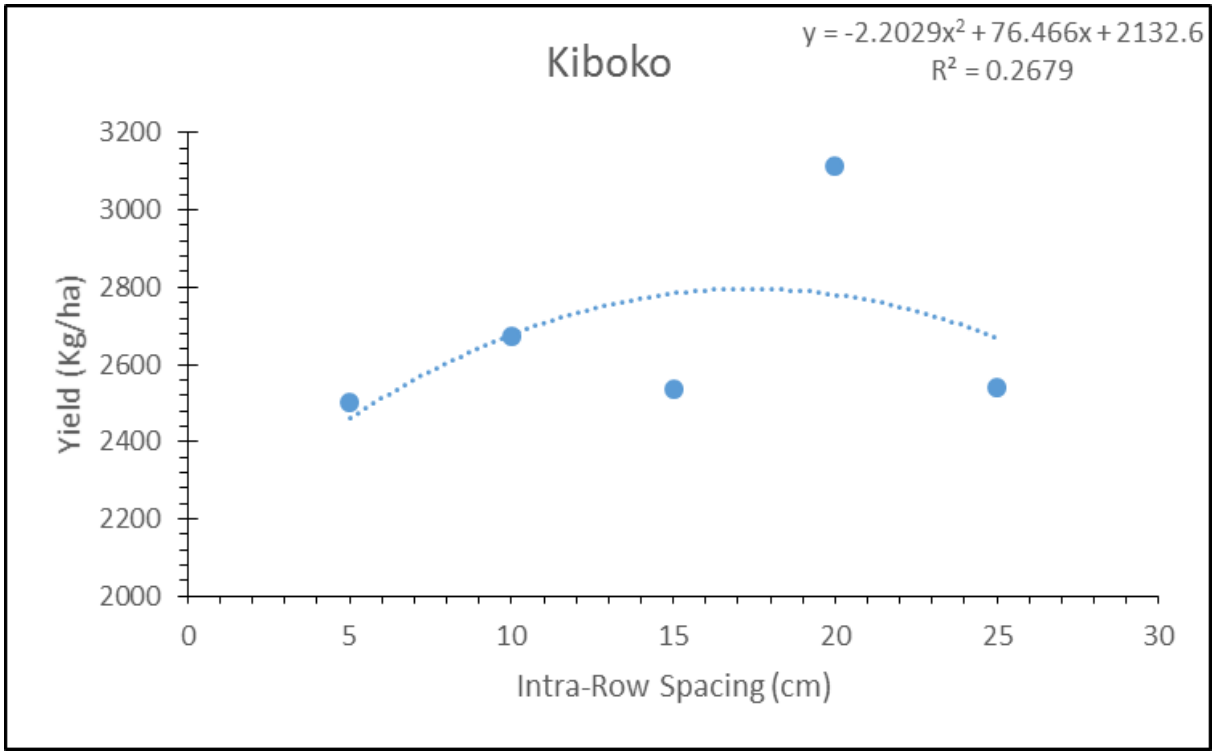

Figure 4:14: Polynomial regression relationship between the intra-row spacing and grain yield of green gram at Kiboko

The trend on the yield as influenced by the intra-row spacing was different in Kiboko and Ithookwe respectively whereby the increase in the intra-row spacing led to a polynomial increase of yield at Kiboko while at Ithookwe the yield was highest at the least spacing and significantly reduced thereafter with the lowest recorded at the highest intra-row spacing (Fig. 4.15). The regression coefficient was however higher at Ithookwe (r^2=0.4998) compared to that of Kiboko (r^2=0.2679). At Ithookwe, the differences in the row spacing probably modified the dynamics of mass accumulation by respective organs of the green grams, and a decrease in the row spacing resulted in an increase in the yield.

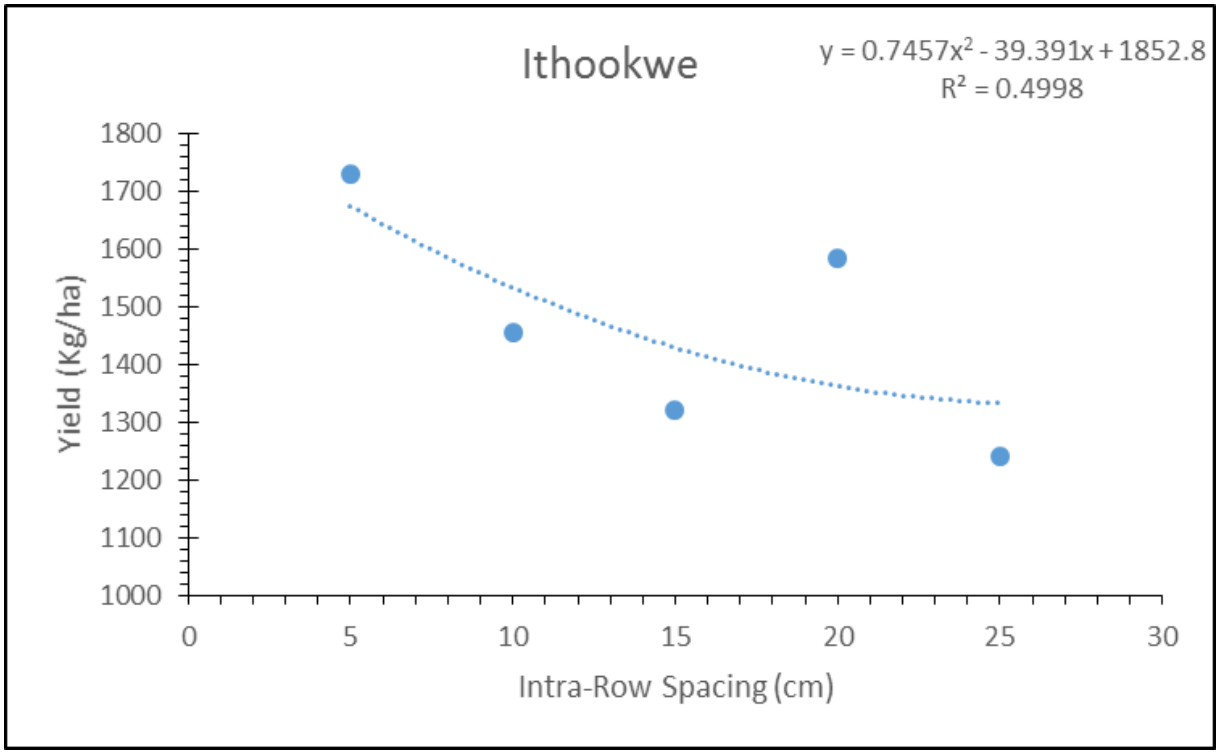

Figure 4:15: Polynomial regression relationship between the intra-row spacing and grain yield of green gram at Ithookwe

CHAPTER FIVE: DISCUSSION

5.1 Plant spacing effect on growth, root nodulation and yield of green gram

5.1.1 Growth

A decrease in within-row spacing increased plant length in both sites. This was apparently because individual plants from the plots with the narrow spacing did not get an opportunity to proliferate laterally due to the less lateral space. Hence, plants were compelled to grow more in upward direction for the fulfillment of light requirement for photosynthesis. This result is in accordance with the findings of Kachare *et al.,* (2019) in green gram, Dhanjal *et al.,* (2001) in French bean, and Nimje *et al.,* (2003) in soybean with respect to plant height, which all found that a wider spacing created a larger surface area for plant photosynthesis to take place hence increasing the number of nodules per plant.

The maximum dry weight of nodules per plant was observed with the plots having wider spacing. This might be due to the fact that plants grown with wider spacing got better opportunity of availing maximum space, light and nutrients which increased the rate of photosynthesis hence maximizing the number of nodules per plant.

Green gram gives low seed yield and poor growth performance mainly due to poor spacing management and low soil fertility. The beneficial effect of different levels of spacing on number of branches of green gram were evident during active growth and maturity which directly impacts on plant shoot weight and height as observed in both sites where highest weights were recorded in the wider intra-row spacing.

The narrowest intra row spacing of 5cm x 45cm led to shorter periods to 50% flowering and maturity which might be due to the fact that narrow intra row spacing had a better light interception through competition as compared to the wider intra-row spacing resulting in less number of days to flower as green gram needs direct sunlight coverage for its various

physiological processes. Further, more nutritional area available in wider intra-row spacing might have caused the crop to flower and mature late than the closer spacing because of more availability of nutrients especially N which delays maturation of crops. On the other hand, in narrower intra row spacing due to competition for nutrients, moisture and space, the crop revealed faster flowering. Besides moisture and nutrient utilization was more luxurious in the wider spaced plants as compared to the narrower spaced plants. In disagreement to this, the wide plant spacing of 50 cm reduced number of days to flowering in broad bean than 40 cm plant spacing (Farag and El-Shamm, 1994).

Similarly, it has been found that the denser plant population hastened days to flowering in lentil while other researchers found no significant effect of plant population on days to flowering in common bean (Abdel, 2008). Similarly, in the narrower intra row spacing, the plants attained 50% flowering earlier than the wider spacing. But works on safflower reported that intra- row spacing did not affect significantly the number of days to 50% flowering (Oad *et al*., 2002). Therefore, it seemed that the influence of plant population on days to flower initiation varies from crop to crop as well as the prevailing environmental conditions under which the crops are grown.

This result might be due to the fact that as the spacing among plants decreased, the interplant competition for light increased while sparsely populated plants intercepted sufficient sunlight that enhanced the lateral growth. In agreement with this, it was reported that plant height of chickpea and green bean was taller in higher plant population treatments due to more competition for light (Felton, 1996).

Similarly, others indicated that plant height significantly increased with the increase in plant density primarily because of lower amount of light intercepted by a single plant resulting into increased inter node length (Parvez, 1989). More competition for light in narrow spacing resulted in taller plants while at wider spacing light distribution was normal (Tuba, 2008).

Moreover, spacing experiment on soybean observed that increasing the density of plants led to significant increases in plant height (Shamsi, 2009). In contrast with this, plant height was not affected by increasing plant density of faba bean reported by Shahein (1995).

On the contrary, other researchers (Holshouser and Joshua, 2002) argue that in wider intra row spacing, there existed a lower competition for resources like moisture and essential nutrients than in narrower intra row spacing. In addition, light would be intercepted better in the wider intra row spacing as compared to the narrower intra row spacing and also the better free air circulation in the canopy of the wider spaced rows could have its own contribution for shorter days to maturity. They state that prolonged days to maturity in the case of narrower intra row spacing could be because of high competition for available resources in the soil, poor light interception and air circulation in the canopy as compared to the wider intra row spacing.

But in disagreement with the report, no significant effect of intra row spacing on maturity of soybean was reported (Holshouser and Joshua, 2002). In general, the difference in days to flowering and physiological maturity was very small which may not be practically important though statistically significant.

The differential responses among the interaction of inter- and intra- row spacing might be due to differences in the access to growth factors by the plants grown under their respective environments. The increased dry shoot weight under lower plant densities could be attributed to higher sunlight interception for photosynthesis. In contrast, the decreased shoot dry weight in the narrower plant spacing might be due to the high competition for the resources and with the overlapped plant canopy, the crop might have been subjected to lower interception of sunlight which led to lower photo assimilation. This also indicated the plasticity response of plants to various plant spacing. This result was in agreement with the finding of increased number of branches at the wider plant spacing for soybean and the reason for this was more interception of sunlight for photosynthesis, which may have resulted in production of more

assimilate for partitioning towards the development of more branches (Mehmet, 2008). In addition, others reported that the number of primary branches decreased with the increase in density of chickpea (Togay, 2005). Moreover, similar findings also reported faba bean, soybean and common vetch, respectively, reduced the number of branches with increased plant population (Aydogdu, 1995).

For all of the intra row spacing, the highest number of above ground dry biomass were recorded as the intra row spacing decreased. The highest total dry biomass at the highest density of plants might be due to a greater number of plants per unit area. However, if the number of plants per unit area keeps on increasing, the aboveground dry biomass will reduce as there is lodging problem and lower photosynthetic efficiency in highly crowded plant population. In agreement with this study, an author reported that dry biomass per ha was significantly increased with increased plant density on haricot bean (Solomon, 2003). Similar report revealed increment of total dry biomass with increasing plant population of soya bean up to a certain point and subsequently no addition in biological yield can be obtained thus decrease in economic yield (Singh and Singh, 2002). In line with this, lower plant densities of 5 and 7 plants m^{-1} resulted in a greater aboveground DM biomass and number of pods per plant of the common bean; grain yield was not decreased (Soratto, *et al*., 2017).

The reduction in harvest index in narrower spacing might be due to the higher plant population per unit area which might have increased the flower abortion due to competition for nutrients, moisture and solar radiation. Similar result reported by other authors indicated maximum harvest index in the highest intra row spacing (45cm) of chickpea than 15cm intra row spacing (Khan *et al*., 2010).

5.1.2 Root nodulation

The number of root nodules and dry weight of root nodules are determined by crop geometry and is therefore one of the most important crop management activities which improves the performance and productivity of plants. Moreover, plant spacing in the field is also very important to facilitate aeration and light penetration in to plant canopy for optimizing rate of photosynthesis. The differences in root nodulations might be due to less competition for space, moisture and nutrients which accelerate normal photosynthetic activity and provide sufficient photosynthates for developed root system. These results are in conformity with the findings of Sathe and Patil (2012a) in pigeon pea.

5.1.3 Yield

The yield attributing characters *viz.* number of pods per plant, number of grains per pod and pod length were significantly highest at widest plant spacing of 25 x 45 cm over other spacing under investigation. It can thus be seen that, the total yield per unit area depended not only on the performance of individual plants but also on the number of plants per unit area as confirmed in this study. Further, other reason for seed-yield enhancement under narrow planting could be attainment of sufficient ground cover to produce maximal light interception during the grain formation. But in the wide inter- and intra-row spacing even though the yield per individual plant was higher, since the plant population reduced, the grain yield showed decrement. In the same manner, at narrow-row planting seed yield enhancement in determinate soybean was due to greater light interception during pod filling, and not greater leaf area development and dry matter production before this time (Ball, 2000).

Medium intra row spacing provided optimum condition for individual plant growth because of minimum inter and intra plant competition. The yield of crop sown at wider spacing 25 cm was significantly low because of less than optimum plant population per hectare. These results are

in conformity with the findings reported by Kaul and Sekhon (1976) and Rana and Ahuja (1986).

In agreement to the present result, higher number of pods plant^{-1} were reported in the wider intra row spacing of chickpea (Khan, 2010). Similarly, researchers who worked on faba bean reported that the development of more and vigorous leaves on low plant density helped to improve the photosynthetic efficiency of the crop and supported higher number of pods (Hodgson, 2005).

As the number of plants within a row increased, intra row plant competition got increased while light interception reduced and resulted in decreased number of seeds pod^{-1}. In agreement with the present result, the number of seeds per pod reportedly increased with decreased plant density of faba bean (Ayaz, 2001). Moreover, in safflower higher number of seeds per pod was reported in association with wider inter and intra-row spacing (Oad, 2002).

Decreasing inter and intra-row spacing might have increased inter specific competition which eventually caused reduction in weight of seeds. Moreover, decreasing plant density might have caused more sunlight to penetrate the canopy that made plants to benefit more from the natural environment. Thus, this might have caused an increase in number of branches and the increased level of photosynthesis resulting in more assimilates translocated and stored in seeds. In agreement with the result obtained, hundred seed weight that decreased was reported as plant density increased in haricot bean (Solomon, 2003). Similarly, other authors also reported that hundred seed weight of faba bean was negatively related with plant density (Matthews, 2008). Moreover, higher hundred seed weight was reported in the wider intra row spacing of 45cm than 30cm intra row spacing of chickpea (Khan, 2010). However, the result of this experiment was not in line with other authors who reported that individual seed weight is rarely affected by growth factors except in case of severe water stress and hot desiccating winds that caused

forced maturity (Turk, 2002). Similarly, no significant effect of plant density was obtained on hundred seed weight of soya bean (Lemlem H/Giorgis, 2011).

5.2 Rhizobia inoculation effect on growth, root nodulation and grain yield of three green gram varieties in lower Eastern Kenya

5.2.1 Growth

The low number of nodules in the un-inoculated treatment could be attributed to the indigenous rhizobial strains specific for green gram in the soils of the current study. This could be the consequence of a legume absence on investigated field locations because rhizobial soil count gradually decreases in parallel with the increase of the time elapsed from the presence of host plants in crop rotation. Many researches confirmed that inoculation of mung bean with effective rhizobial strains increase plant height and dry matter production as well as seed yield. The present results of increased plant height agree with those reported by Tahir *et al*. (2009) in soybean and Ravikumar (2012) in mung bean. Inoculation with *Rhizobium* resulted in the higher rate of Nitrogen fixation. This might have reflected on the growth of the plant and its maximum height over that recorded under no inoculation. Biofertilizer application did not exert significant effect on most of the characters. But it has beneficial effect on number of branches per plant, dry weight of root nodules per plant and stover yield. Similar result was reported by Bhat *et al*. (2010), Patel *et al*. (2016).

Podder *et al.* (1999) carried out a field experiment at Brahmaputra Floodplain Soil to evaluate the effect of seed inoculation with 8 bradyrhizobial strains on shoot length of soybean. They reported significantly higher shoot length in the inoculated treatments than the uninoculated control. Solaiman (1999) carried out an experiment and found higher plant height and root length of mung bean due to *Bradyrhizobium* inoculant over control. Solaiman *et al.* (1999) reported that the inoculation of chickpea significantly increased the plant height. Alam *et al.*

(1999) conducted an experiment and obtained higher shoot and root length due to inoculation of *Rhizobium* over control.

Sultan (2001) conducted a field experiment on lentil inoculated with *Rhizobium* inoculums and observed that inoculated plants produced significantly tallest plant than uninoculated plants. Bhuiyan (2008) reported from a field experiment that *Rhizobium* inoculation increased nodule number, nodule weights, shoot weights and pod yield significantly.

5.2.2 Root nodulation

The results indicated that all the rhizobial inoculants tested significantly increased the number of nodules per plant as well as dry weight of the nodules at certain sampling stages. The present results of increase in nodulation due to *Rhizobium* inoculation are similar to those of Tahir *et al*., (2009) in soybean, Solomon *et al*., (2012) and Lamptey *et al*., (2014). Chatterjee and Bhattacharjee (2002) studied the effects of inoculation with *Rhizobium* sp. on the nodulation of mung bean cv. B-l and found that the plants inoculated with *Rhizobium* strains showed higher nodulation. Islam *et al.,* (1999) conducted an experiment to study the performance of some bradyrhizobial inoculants on soybean at B1NA experimental farm. Mymensingh. They found that the total nodule numbers were significantly higher in inoculated treatments. The results of present investigation also revealed significant increase in nodule dry weight of green gram due to inoculation with isolates of *Rhizobium.* These results agree with those reported by Solomon *et al*., (2012) and Lamptey *et al*., (2014) in soybean.

The highest nodulation with *Rhizobium* inoculation also matches with the findings of Shukla and Dixit (1996). It might be due to the fact that application of NPK caused increase in the initial root growth which would have formed larger domain for bacteroids in host cell to fix N and stimulated growth of nodules.

The goal of inoculation is to introduce a large number of viable host-specific Rhizobia in order to increase infection rates, which ultimately leads to higher yields (Deaker *et al*., 2004). In this case, the addition of an inoculant with the host-specific Rhizobia can increase the BNF of the legume. The increase of rhizobia numbers in the rhizosphere is a response to the release of nutrients by the host legume. Use of rhizobia inoculants coupled with phosphorous supplements on legumes plays a great role in cropping systems which in return increase plant productivity and soil fertility. Rhizobia inoculation and phosphorus among the factors that contribute to soybean success have shown prominent effects on nodulation, growth, and yield (Shahid *et al*., 2009). Deaker *et al*. (2004), reported that significant yield increases were obtained by inoculation of soybean with appropriate bacteria. *Bradyrhizobium* inoculation increased soybean seed yield by 85 % over control. Similarly, Egamberdiyeva *et al*. (2004) and Okereke *et al*. (2004) reported that nodule number, nodule dry weight, and soybean shoot yield were increased when seeds were inoculated with *Bradyrhizobium*. However, inoculation may not be required in fields where soybeans have been previously grown and inoculated for many years. Seeds inoculation with beneficial rhizobia bacteria could be an alternative for use of expensive commercial nitrogen fertilizers and realization of optimal productivity in legumes.

5.2.3 Yield and yield components

Inoculation increased the number of grains per pod. Singh *et al.* (1993) also observed the importance of seed inoculation on green gram and black gram. Sarker *et al.* (2013) reported that *Rhizobium* inoculation along with P application and inoculation with *Azotobacter chroococcum* were equally effective in enhancing grain yield of green gram. Combined applications of N and P along with *Rhizobium* inoculation also performed better than other treatments. Singh and Tilak, (1992) observed that Rhizobium inoculant might increase the nodulation, which ultimately increased the N fixation in soil and thus the yield of cowpea.

Tahir *et al.*, (2009) reported that combination of *Rhizobium* inoculation and P fertilizer application resulted in 21% increase in grain yield. Fatima *et al.* (2006) observed similar findings and concluded that combined application of P with *Rhizobium* inoculation increased growth, yield and nitrogenase activity as well as improved soil fertility. Kumaga and Ofori (2004), however, reported that P fertilizer additions did not result in significant increases in shoot growth and seed yield against the inoculated soybean variety; significant differences were only observed on the un-inoculated variety.

Rahman (1989) observed significantly higher number of nodules per plant, root and shoot dry weight per plant, 1000 seed weight and grain yield due to inoculation over control in soybean. Similar to results reported by Kamara *et al.* (2007), there were no significant differences ($P < 0.05$) in harvest index between the inoculated and the fertilized plus inoculated soybean varieties in both promiscuous and specific varieties. There was remarkable effect of *Rhizobium* inoculation on number of pods per plant. The yield parameter like pods per plant was significantly influenced by seed treatment with *Rhizobium*. This may be due to synergistic effect of inoculants. It is also important to note that the higher yield and yield parameters observed in Kiboko as compared to Ithookwe may have been influenced by the even distribution of soil moisture (which directly influences the activity of rhizobia) throughout the active growth period due to supplemental irrigation (on average in Ithookwe the soil moisture was 15.9mm per day but much of which was realized early in the first month of growth (table 3.2) while in Kiboko the soil moisture on average both rainfall and supplemental irrigation was 13.51mm per day and evenly distributed since irrigation was done at 25mm twice a week for six weeks). Similar results were also reported by Tahir *et al*. (2009) Solomon *et al*. (2012) in soybean and Sajid *et al*. (2010) in groundnut. These results agree with the earlier findings of Tahir *et al*. (2009) and Lamptey *et al*. (2014) in soybean.

5.3 Effect of varietal differences on yield and yield Components of green gram varieties in lower Eastern Kenya

The higher yield in variety KAT00309 in the study sites might be due to its inherited genetic makeup as evidenced by comparatively higher number of pod plant^{-1}, pod dry weight, seed yield plant^{-1} and 100-seed weight. The total dry matter production in the variety indicates the potential for yield but its mobilization towards the seed yield is an important factor for economic yield. It is the function of crop growth rate in total growth period and is related with seed yield. The capacity of a plant to produce dry matter depends upon the size and duration of the photosynthetic apparatus, i.e. leaf but it also depends upon the genetic potential of the varieties to translocate assimilates towards economic yields due to differential response of different varieties. Differential response of different varieties was also observed by Singh *et al.* (2005). Kabir (2000) reported that the shoot dry weight of soybean increased significantly due to the sowing of large sized seeds. In another experiment, Kabir (2000) found that seed size (small, medium and large) had significant effect on total dry weight showing the highest dry weight from using the large sized seeds.

The highest number of pods plant^{-1} was obtained from using the large sized seeds when sown in 2 cm depth. Similar result was also found by Islam (2004) in mung bean.

There were differences between the growth characteristics between treatments which probably was due to the difference in weather patterns during the crop growth cycle. Higher moisture levels were recorded at Ithookwe compared to Kiboko albeit the last month of the crop cycle when no rainfall was experienced in each site. It is important to note that the rainfall distribution was very poor in Ithookwe compared to Kiboko where due to supplemental irrigation the distribution was more even over the active growth period. Temperatures vary between 20-35^{0}C with pan evaporation rates of 4-9mm per day. It is well documented that dry lands suffer from annual moisture deficits of greater than 50% and are considered the most threatened by land

degradation (Mugagga et al., 2010) due to their fragile soils that have poor nutrient content and weak structure prone to soil erosion.

Green gram, being one of the most important pulse crops of Kenya, requires scrutiny of the varieties for their suitability under the existing agro- climatic conditions of the lower Eastern. Thus, it was important to identify their production potential in addition to their growth behavior, yield attributes, maturity period including seed yield per hectare under rain fed conditions. The significant variations in plant height among the varieties may be due to their genetic variability for this trait. The similar results have also been reported by Goswami *et al*. (2010).

Genetic variation and environment were the object of investigation of some researchers (Atta and Shah, 2009). In addition, there were differences between inoculated treatments with and without N mineral fertilizer as in research of Atta and Shah (2009). In combined treatments on the both soil types, grain and shoot fixed N were mainly significantly lower in respect to inoculation alone since plants prefer mineral N in respect to N_2 from the air.

Kabir (2000) in his study with mung bean showed that the highest 1000 seeds weight was obtained when large sized seeds were sown. Similar result was also obtained by Islam (2004) who worked with mung bean with 1000-seed weight though others have indicated some varieties have bigger seeds thus weighed on 100-seed weight. The wide differences among the green gram varieties with respect to branches formation may be owing to inheritance of genetic divergence of the varieties. The present findings have been supported by many workers (Parameswarappa and Lamani 2003, Rao *et al.* 2006, Goswami *et al.* 2010 and Verma *et al.* 2011).

Rao *et al*. (2006) evaluated 180 germplasm lines of mung bean comprising both indigenous and exotic collections along with checks. The ANOVA for yield indicated highly significant

differences among test varieties and the check. The traits plant height and number of clusters per plant recorded highly significant and positive association with grain yield, while number of seeds per pod showed negative association with seed yield.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The green gram sown at the intra-row spacing of 20 cm X 45 cm produced better yield over other treatments tried during the season. Inoculation had no effect on most of the parameters studied in both sites with only several stages showing significant differences which were however marginal. The varieties differed significantly on the growth, nodulation and yield parameters in both sites with KS20 being superior on growth and nodulation than the other varieties but variety KAT00309 had the highest grain yield.

There were significant differences between treatments in the row spacing on green gram therefore accepting the null hypothesis of positive correlation between row spacing and growth, nodulation and yield components of green gram to a given point. The same trend was recorded on the varietal selection where yield was highest under the new released variety KAT00309 on grain yield but the study rejects the hypothesis of improved varieties will have higher growth and nodulation. Lastly, the study rejects the hypothesis that inoculation improves growth, nodulation and yield of green grams.

6.2 Recommendations

i. The intra-row spacing of 20 cm X 45 cm is recommended in the production of green gram based on the grain yield from this study in Kiboko, Ithookwe and all other similar areas

ii. The application of the green gram inoculant in this study is not recommended for green gram growing in Ithookwe, Kiboko and other similar areas.

iii. From this study, it is recommended that Variety KAT00309 be grown in Kiboko, Ithookwe and other similar areas for the potential grain yield of green gram to be attained.

It should be noted that, farmers select crops and varieties using different criteria – some strains will be selected because they are high yielding in optimum conditions, others because they are

tolerant to drought and others due to their resistance to storage pests. Considering the prevailing moisture conditions in both sites, variety KAT 00309 was the best in terms of yield at the spacing of 20cmX45cm.

6.3 Further Research

 More studies should be conducted to find out the main reasons for low adoption and uptake of existing inoculation technologies.

CHAPTER SEVEN: REFERENCES

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CHAPTER EIGHT: APPENDICES

ANOVA TABLES

Appendix I. Analysis of variance Kiboko

Variate: Biological_yield_kg_ha^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum					
	2	1141285	570642	1.22	
REP.*Units* stratum					
SPACING	4	27845714	6961429	14.83	<.001
INOCULATION	1	2616	2616	0.01	0.941
VARIETY	2	835376	417688	0.89	0.416
SPACING.INOCULATION	4	5695295	1423824	3.03	0.024
SPACING.VARIETY	8	6610486	826311	1.76	0.104
INOCULATION.VARIETY	2	625564	312782	0.67	0.517
SPACING. INOCULATION. VARIETY					
	8	15922048	1990256	4.24	<.001
Residual	58	27224673	469391		
Total	**89**	**85903056**			

Variate: Days_to_50%_flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum					
	2	8.8667	4.4333	4.55	
REP.*Units* stratum					
SPACING	4	15.0444	3.7611	3.86	0.008
INOCULATION	1	1.8778	1.8778	1.93	0.17
VARIETY	2	8.4667	4.2333	4.35	0.017
SPACING.INOCULATION	4	1.6222	0.4056	0.42	0.796
SPACING.VARIETY	8	8.0889	1.0111	1.04	0.418
INNCOLATION.VARIETY	2	0.1556	0.0778	0.08	0.923
SPACING. INOCULATION.VARIETY					
	8	13.5111	1.6889	1.73	0.11
Residual	58	56.4667	0.9736		
Total	**89**	**114.1**			

Variate: Days_to_maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum					
	2	0.46667	0.23333	2.78	
REP.*Units* stratum					
SPACING	4	1.04444	0.26111	3.11	0.022
INOCULATION	1	0.17778	0.17778	2.12	0.151
VARIETY	2	12.8	6.4	76.27	<.001
SPACING.INOCULATION	4	0.15556	0.03889	0.46	0.762
SPACING.VARIETY	8	1.08889	0.13611	1.62	0.138
INOCULATION.VARIETY	2	0.08889	0.04444	0.53	0.592
SPACING. INOCULATION.VARIETY					
	8	0.91111	0.11389	1.36	0.235
Residual	58	4.86667	0.08391		
Total	**89**	**21.6**			

Variate: Harvest_index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum					
	2	32.993	16.496	2.24	
REP.*Units* stratum					
SPACING	4	60.79	15.198	2.06	0.097
INOCULATION	1	0.011	0.011	0	0.969
VARIETY	2	358.85	179.425	24.38	<.001
SPACING.INOCULATION	4	7.073	1.768	0.24	0.914
SPACING.VARIETY	8	54.023	6.753	0.92	0.509
INOCULATION.VARIETY	2	31.086	15.543	2.11	0.13
SPACING. INOCULATION.VARIETY					
	8	37.994	4.749	0.65	0.736
Residual	58	426.864	7.36		
Total	**89**	**1009.684**			

Variate: No_of_grains_per_pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum					
	2	13.1449	6.5724	14.08	
REP.*Units* stratum					
SPACING	4	2.3173	0.5793	1.24	0.304
INOCULATION	1	1.764	1.764	3.78	0.057
VARIETY	2	68.3796	34.1898	73.26	<.001
SPACING.INOCULATION	4	0.9893	0.2473	0.53	0.714
SPACING.VARIETY	8	1.7893	0.2237	0.48	0.866
INOCULATION.VARIETY	2	3.464	1.732	3.71	0.03
SPACING. INOCULATION.VARIETY					
	8	2.6693	0.3337	0.71	0.677
Residual	58	27.0684	0.4667		
Total	**89**	**121.5862**			

Variate: Number_of_pods_per_plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	2				
REP stratum					
		10.76	5.38	0.16	
REP.*Units* stratum					
SPACING	4	8076.58	2019.14	61.13	<.001
INOCULATION	1	0.68	0.68	0.02	0.887
VARIETY	2	2050.98	1025.49	31.05	<.001
SPACING.INOCULATION	4	149.38	37.34	1.13	0.351
SPACING.VARIETY	8	442.6	55.33	1.68	0.124
INOCULATION.VARIETY	2	24.53	12.27	0.37	0.691
SPACING. INOCULATION.VARIETY					
	8	500.16	62.52	1.89	0.078
Residual	58	1915.64	33.03		
Total	**89**	**13171.29**			

Variate: Plant_Height_3_WAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.091	0.045	0.04	
REP.*Units* stratum					
SPACING	4	90.818	22.704	20.39	<.001
INOCULATION	1	0.344	0.344	0.31	0.58
VARIETY	2	207.42	103.71	93.14	<.001
SPACING.INOCULATION	4	4.732	1.183	1.06	0.383
SPACING.VARIETY	8	17.444	2.181	1.96	0.068
INOCULATION.VARIETY	2	4.314	2.157	1.94	0.153
SPACING. INOCULATION.VARIETY	8	11.475	1.434	1.29	0.268
Residual	58	64.585	1.114		
Total	**89**	**401.223**			

Variate: Pod_length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.3082	0.1541	1.07	
REP.*Units* stratum					
SPACING	4	6.2983	1.5746	10.94	<.001
INOCULATION	1	0.6554	0.6554	4.55	0.037
VARIETY	2	11.473	5.7365	39.84	<.001
SPACING.INOCULATION	4	0.6023	0.1506	1.05	0.392
SPACING.VARIETY	8	1.5266	0.1908	1.33	0.249
INOCULATION.VARIETY	2	0.3754	0.1877	1.3	0.279
SPACING. INOCULATION.VARIETY	8	0.9268	0.1159	0.8	0.601
Residual	58	8.3507	0.144		
Total	**89**	**30.5166**			

Variate: X100_GRAIN_WT_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3.5514	1.7757	8.57	
REP.*Units* stratum					
SPACING	4	2.3949	0.5987	2.89	0.03
INOCULATION	1	0.2778	0.2778	1.34	0.252
VARIETY	2	11.8749	5.9375	28.66	<.001
SPACING.INOCULATION	4	0.743	0.1857	0.9	0.472
SPACING.VARIETY	8	1.742	0.2177	1.05	0.41
INOCULATION.VARIETY	2	1.11	0.555	2.68	0.077
SPACING. INOCULATION.VARIETY	8	0.8915	0.1114	0.54	0.823
Residual	58	12.0165	0.2072		
Total	**89**	**34.6019**			

Variate: Yield_kg_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	107930	53965	0.5	
REP.*Units* stratum					
SPACING	4	4661727	1165432	10.76	<.001
INOCULATION	1	880	880	0.01	0.929
VARIETY	2	2440237	1220119	11.26	<.001
SPACING.INOCULATION	4	1317978	329494	3.04	0.024
SPACING.VARIETY	8	1216674	152084	1.4	0.214
INOCULATION.VARIETY	2	12159	6079	0.06	0.945
SPACING. INOCULATION.VARIETY	8	2660833	332604	3.07	0.006
Residual	58	6284244	108349		
Total	**89**	**18702661**			

Appendix II. Analysis of variance Ithookwe

Variate: Biological_yield_kg_ha

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		43630686	21815343	9.88	
REP.*Units* stratum						
SPACING	4		30520817	7630204	3.46	0.013
INOCULATION	1		6440884	6440884	2.92	0.093
VARIETY	2		67068	33534	0.02	0.985
SPACING.INOCULATION	4		5964448	1491112	0.68	0.612
SPACING.VARIETY	8		16857938	2107242	0.95	0.48
INOCULATION.VARIETY	2		15228233	7614117	3.45	0.039
SPACING. INOCULATION.VARIETY	8		19656843	2457105	1.11	0.369
Residual	57	-1	1.26E+08	2208351		
Total	**88**	**-1**	**2.64E+08**			

Variate: Days_to_50%_flowering

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		9.298	4.649	2.07	
REP.*Units* stratum						
SPACING	4		7.642	1.91	0.85	0.499
INOCULATION	1		29.865	29.865	13.29	<.001
VARIETY	2		0.057	0.028	0.01	0.987
SPACING.INOCULATION	4		24.929	6.232	2.77	0.035
SPACING.VARIETY	8		18.603	2.325	1.04	0.421
INOCULATION.VARIETY	2		6.61	3.305	1.47	0.238
SPACING. INOCULATION.VARIETY	8		26.237	3.28	1.46	0.192
Residual	57	-1	128.051	2.247		
Total	**88**	**-1**	**250.449**			

Variate: Days_to_maturity

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		14.873	7.436	2.77	
REP.*Units* stratum						
SPACING	4		91.705	22.926	8.54	<.001
INOCULATION	1		0.153	0.153	0.06	0.812
VARIETY	2		49.29	24.645	9.18	<.001
SPACING.INOCULATION	4		3.454	0.863	0.32	0.862
SPACING.VARIETY	8		31.905	3.988	1.49	0.183
INOCULATION.VARIETY	2		8.372	4.186	1.56	0.219
SPACING. INOCULATION.VARIETY	8		31.272	3.909	1.46	0.194
Residual	57	-1	152.989	2.684		
Total	**88**	**-1**	**382.09**			

Variate: Harvest_index

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		165.889	82.944	9.14	
REP.*Units* stratum						
SPACING	4		133.569	33.392	3.68	0.01
INOCULATION	1		22.426	22.426	2.47	0.121
VARIETY	2		371.103	185.552	20.46	<.001
SPACING.INOCULATION	4		34.182	8.545	0.94	0.446
SPACING.VARIETY	8		85.123	10.64	1.17	0.331
INOCULATION.VARIETY	2		14.95	7.475	0.82	0.444
SPACING. INOCULATION.VARIETY	8		88.825	11.103	1.22	0.302
Residual	57	-1	517.014	9.07		
Total	**88**	**-1**	**1431.51**			

Variate: Number_of_pods_per_plant

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		790.39	395.2	9.21	
REP.*Units* stratum						
SPACING	4		1120.66	280.16	6.53	<.001
INOCULATION	1		52.46	52.46	1.22	0.274
VARIETY	2		678.2	339.1	7.9	<.001
SPACING. INOCULATION	4		78.41	19.6	0.46	0.767
SPACING.VARIETY	8		111.23	13.9	0.32	0.954
INOCULATION.VARIETY	2		123.38	61.69	1.44	0.246
SPACING. INOCULATION.VARIETY	8		601.14	75.14	1.75	0.106
Residual	57	-1	2446.97	42.93		
Total	**88**	**-1**	**6002.75**			

Variate: Plant_Height_3_WAS

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		3.557	1.778	0.58	
REP.*Units* stratum						
SPACING	4		49.208	12.302	4.03	0.006
INOCULATION	1		11.753	11.753	3.85	0.055
VARIETY	2		121.098	60.549	19.83	<.001
SPACING.INOCULATION	4		27.112	6.778	2.22	0.078
SPACING.VARIETY	8		9.53	1.191	0.39	0.921
INOCULATION.VARIETY	2		9.457	4.729	1.55	0.221
SPACING.INOCULATION.VARIETY	8		13.881	1.735	0.57	0.799
Residual	57	-1	174.042	3.053		
Total	**88**	**-1**	**417.673**			

Variate: Pod_length

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		1.8831	0.9415	2.54	
REP.*Units* stratum						
SPACING	4		10.8296	2.7074	7.29	<.001
INOCULATION	1		0.1168	0.1168	0.31	0.577
VARIETY	2		4.494	2.247	6.05	0.004
SPACING.INOCULATION	4		1.1661	0.2915	0.79	0.539
SPACING.VARIETY	8		3.1627	0.3953	1.07	0.4
INOCULATION.VARIETY	2		3.1634	1.5817	4.26	0.019
SPACING. INOCULATION.VARIETY	8		2.9587	0.3698	1	0.449
Residual	57	-1	21.1565	0.3712		
Total	**88**	**-1**	**48.9073**			

Variate: X100_GRAIN_WT_g

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		0.3907	0.1954	0.56	
REP.*Units* stratum						
SPACING	4		1.346	0.3365	0.96	0.436
INOCULATION	1		0.0797	0.0797	0.23	0.635
VARIETY	2		14.3065	7.1533	20.42	<.001
SPACING.INOCULATION	4		0.7912	0.1978	0.56	0.689
SPACING.VARIETY	8		1.4918	0.1865	0.53	0.827
INOCULATION.VARIETY	2		1.1107	0.5553	1.58	0.214
SPACING. INOCULATION.VARIETY	8		1.1856	0.1482	0.42	0.903
Residual	57	-1	19.9717	0.3504		
Total	**88**	**-1**	**40.27**			

Variate: Yield_kg_ha

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
REP stratum	2		5379753	2689877	8	
REP.*Units* stratum						
SPACING	4		2775585	693896	2.06	0.097
INOCULATION	1		1294266	1294266	3.85	0.055
VARIETY	2		464686	232343	0.69	0.505
SPACING.INOCULATION	4		734795	183699	0.55	0.702
SPACING.VARIETY	8		2884195	360524	1.07	0.395
INOCULATION.VARIETY	2		2458714	1229357	3.66	0.032
SPACING. INOCULATION.VARIETY	8		3430788	428849	1.28	0.274
Residual	57	-1	19158322	336111		
Total	**88**	**-1**	**38480896**			

Appendix III. Average Rainfall Data

Kiboko				
Month	**Rainfall in mm**	**R.H %**	**Temperature in ^{0}C**	
			Max	**Min**
November, 2016	187.6	85.9	30	18.7
December, 2016	21.3	84.8	30.7	16.9
January, 2017	0	80.7	32.7	16.2
Ithookwe				
November, 2016	437.9	85.9	27.7	18.1
December, 2016	39.7	84.2	26.7	17.6
January, 2017	0	78.8	28.4	16.5