EVALUATION OF GREEN GRAM GENOTYPES FOR AGRONOMIC PERFORMANCE UNDER REDUCED LIGHT INTENSITY AND MICROCATCHMENTS IN MACHAKOS AND MAKUENI COUNTIES, KENYA

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Evaluation of green gram genotypes for agronomic performance under reduced light intensity and micro-catchments in Machakos and Makueni Counties, Kenya

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DECLARATION

This Thesis is my original work and has not been presented for a degree in any University

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DEDICATION

This work is dedicated to my nuclear and extended families who supported and encouraged me to this level of education. Special dedication goes to my husband Mr. Lawrence Masaku Kimilu, our daughters Dr. Rhoda Ndinda Masaku, Rachael Ngina Masaku, Rabecca Ndunge Masaku and Ruth Ndanu Masaku, my parents Mr. John Muli Nziu and Mrs Sarah Mbaika Muli for teaching and showing me the fruits of hard work and commitment.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	Agro-ecological Zones
ASALs	Arid and Semi-Arid Lands MOA-CPPMU
ASL	Above sea level
C4	Carbon 4 plants
CPPMU-MOA	Central Project Planning and Monitoring Unit-Ministry of Agriculture
FAO	Food and Agriculture Organization
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KALRO	Kenya Agricultural and Livestock Research Organization
LSD	Least Significant Difference
MKS ATC	Machakos Agricultural Training Centre
MOA	Ministry of Agriculture (Kenya)
NACOSTI	National Commission for Science, Technology and Innovation
PAR	Photosynthetically Active Radiation
RCBD	Randomized Complete Block Design
SSA	Sub-Sahara Africa

DEFINATION OF TERMINOLOGIES

2011 short rain season	November to December 2011 rains
2012 long rain season	March to May 2012 rains
2012 short rain season	November to December 2012 rains
2013 long rain season	March to May 2013 rains

ABSTRACT

Green gram (*Vigna radiata* L.) is a hardy pulse crop, well adapted to marginal areas. In pursuit of strategies to evaluate agronomic performance of green grams in Machakos and Makueni Counties, Kenya, the study was carried out in Machakos Agricultural Training Centre in Machakos County and Kiboko sub-station of KALRO Katumani in Makueni County to: a) evaluate 40 green gram genotypes for agronomic performance at two locations, b) assess the effect of reduced light intensity on the agronomic performance of four green gram genotypes c) evaluate the effect of micro-catchments on the agronomic performance of four green gram genotypes, and d) evaluate the effects of reduced light intensity and micro-catchments (open and tied ridges) on the productivity of four green gram genotypes. Data was collected on several growth variables and subjected to Analysis of variance using Genstat statistical package, the means were separated using Least Significant Difference (LSD). The trial to evaluate 40 green gram genotypes for agronomic performance was laid out in Randomized Complete Block Design (RCBD). Accession GBK-022494A had the highest (103) number of pods per plant while Nylon-2 recorded the least number (19 pods) per plant in Machakos ATC during the 2011 short rain season. GBK-022501A had the highest seed yield (4.7 ton ha^-1) followed by GBK-022494A with 4.5 ton ha^-1. In Kiboko GBK-022494A had 115 pods per plant as compared to GBK-018633A with 27 pods per plant. Accession GBK-022494A attained 7.4 ton ha^-1 and Nylon with 5.8 ton ha^-1. It was concluded that GBK-022494A was the best performer in Kiboko while GBK-022501A was the best performer in Machakos ATC. To assess the effect of reduced light intensity on agronomic performance, four green gram genotypes; GBK-022494A, GBK-022501A, GBK-022502A and Nylon-1 were used. The experiment was laid in a split-plot arrangement with shading as the main plot at two levels; shaded and non-shaded while the 4 accessions were the sub-plots. The green gram accessions revealed significant ($P \leq 0.05$) differences in their response to shading as measured by number of seeds per pod and number of days to maturity at Machakos ATC and number of seeds per pod at Kiboko during the 2012 short rain season. The values of the variables were higher under shade net during the 2012 short rain season while the values of the variables were higher under direct solar radiation in both sites as during 2013 long rain season at both sites. In order to evaluate the effect of micro-catchments on the agronomic performance of green grams, the trials were laid out in split-plot arrangement. The accessions had better agronomic performance under tied ridges. To evaluate the effects of integrated packages incorporating reduced light intensity and micro-catchments on productivity of four green gram genotypes the experiment was laid out in Split-split plot Design and replicated three times. The results indicated that agronomic performance was better under the direct solar radiation than under the shade net and that these traits performed better under the tied ridges at both sites.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Food legumes have been grown by farmers since millennia providing nutritionally balanced food to the people of many countries in the world (Swaminathan- *et al.*, 2012). Green grams (*Vigna radiata*) is considered to be the hardiest of all pulse crops (Chhidda *et al.*, 2011) and is said to be better than other pulses in terms of food quality (Nene, 2006). Green gram is sometimes specifically grown for hay, green manure or as a cover crop (Kimiti *et al*, 2009). It is the most suitable pulse for Arid and Semi-Arid areas as it is adapted to a wide range of soil and altitudes (0-1600 meters above sea). It also withstands high temperatures ranging between 28°C and 30°C and yields well in low rainfall areas (650 mm per annum) (MOA, 2002). The crop gives high yields, as long as all agronomical practices are carried out as recommended, thus contributing to food security, employment creation and income generation (MOA-CPPMU, 2010).

Machakos and Makueni Counties are characterized by low and unreliable rainfall, frequent droughts and high temperature. The high temperature is related to the solar radiation hitting directly on the ground surface. The high solar radiation coupled with unsaturated air lead to high rates of evaporation and evapotranspiration leading to water losses from both the plants and the earth surface (Tom, 2005). This in effect reduces the amount of water available to the plants. Inadequacy of water affects transmission of nutrients from the soil to the plant cells and leaves the plant cells less turgid thus contributing to stunted plant growth (Tom, 2005). This eventually culminates into low crop yield (Shisanya *et al*., 2011) or total crop failure.

Therefore, there is need to reduce the amount of light intensity falling directly on plant and ground surfaces in order to enhance crop yield. It has been observed that high temperatures are recorded between 12.00hrs and 1400hrs (Kenyan time) ranging from

32°C to 36°C and that the light intensities decline as the afternoon advances (Guenni *et al.*, 2008). Shading reduces air and soil temperature (Makus, 2001, Makus and Lester, 2002) thus reducing water loss through evaporation and evapo-transpiration from plants and this leads to better agronomic performance of crops in Machakos and Makueni Counties. According to Hashem *et al.*, (2006), shade, irrespective of its source, reduces the irradiance especially so in the photosynthetically active radiation (PAR) at 400-700nm. Guenni *et al.*, (2008) indicated that three major physiological responses to shade have been observed, that is; a reduction in the respiration rate, an increase in the shoot to root partitioning and an increase in the specific leaf area with a relatively low leaf mass ratio. This corroborates the finding by Humphreys (1994) and Lambers *et al*., (2008) while working on tropical pastures and their role in sustainable agriculture and plant physiology ecology respectively. Guenni *et al.*, (2008) indicated that areas where water and nutrients are limited, there is increasing evidence that substantial improvements in herbage yield and forage nutrient quality can be obtained when C4 grasses are grown under tree shade in tropical and subtropical grasslands. Shade can provide many environmental benefits including acting as insulators for the undergrowth environment providing cool microclimate (better soil moisture) during very warm weather (Souza *et al.*, 2012; Santos *et al.*, 2012) leading to a higher soil organic matter breakdown and, therefore, more available N in the soil. As a result of this, it has been shown that mature leaves show very little adaptation to shade or sun as opposed to the whole plant of some species that adapt very well to either condition during development especially so to shade (Hashem *et al.*, 2006). Therefore, it is important to introduce shading at the early stages of the crop in order to achieve good agronomic performance.

Adugna and Paul (2010) found that shading coffee plants against adverse environmental stresses such as high soil temperatures and low relative humidity led to improved photosynthesis and increased leaf area index, resulting in better performance in terms of larger and heavier fruits with better bean quality than those grown in direct solar radiation. According to Makus, (2001) reducing the light intensity by 30% did not affect the yield of snap beans and that light reduction tended to decrease pod size, plant biomass and leaf greenness, while leaf area and chlorophyll contents were increased with increased shading. Also incidences of powdery mildew occurred late in the season and were linearly increased by reduced light.

Arid and semi-arid areas receive rainfall amount of less than 650 mm per annum. This amount could be enough to achieve good green gram agronomic performance if distributed evenly through the plant growing period. However, sometimes, the rain is quite erratic, such that, the total amount is received within a very short time (Rosegrant *et al*., 2002). This quite often results in runoff and causes soil erosion (Moges, 2004). In such cases, irrigation would be the best option for crop production. However, irrigation is expensive and it is not available in most parts of ASALs area of Kenya (Moges, 2004). This calls for practical measures, which can increase the availability of water to the crops for high agronomic performance. One of the measures that can be used is to construct micro-catchments, which would collect water and direct it to the root areas for immediate use and/or store for use during the dry periods (Seleshi *et al*., 2009).

1.2 Statement of the Problem

Food and nutritional insecurity are increasingly becoming a major threat to livelihoods among communities living in the Machakos and Makueni Counties of Kenya. The problem is exacerbated by climate change which is now a matter of global concern (Herrero *et al.*, 2010). Important effects of climate change are alteration of global rainfall patterns, increased evaporation and runoff, and reduced soil moisture storage (Fidelibus and Bainbridge, 1994). The ultimate result is moisture stress which is detrimental to the crop growth particularly when it occurs at the critical periods of the crop's life cycle (MOA, 2002). The rise in temperature is projected to increase with time and is expected to lead to increased water loss resulting from transpiration and evaporation (Itabari *et al.*, 2003). The uncertainty of rainfall forces farmers to adopt low input crop management practices serving as a major impediment for improving crop yield. Therefore, in semi-arid areas, the effect of erratic rainfall on crop yield is apparent and efficient rainwater management (Gicheru *et al*, 2004) seems to be one of the solutions.

1.2 Justification

Green gram is an important pulse crop in the Machakos and Makueni Counties of Kenya. The crop is tolerant to the adverse conditions of these Counties. The crop is grown both as a food and cash crop. Green grams can be consumed as whole grains either cooked or milled; the grains or flour can be used to prepare a variety of dishes such as snacks, porridge, noodles and soups. The grains can also be used to produce sprouts. Green gram is rich in nutrients and minerals. .

The drought tolerance and adaptation of green gram to a wide range of ecological zones makes it possible for the crop to be grown by most resource poor farmers in the arid and semi-arid areas leading to both food and nutrition security as well as adapting to climate change. Besides, green gram genotypes take relatively short time to mature (60-90 days) depending on the variety (MOA, 2010) leading to enhance food security. The green gram can be stored for a long time thus enabling the producer to sell them when prices are high. Production of green grams will contribute to the achievement of Vision 2030 which envisages Kenya being food secure both quantitatively and qualitatively (GOK, 2007).

It has been observed that high temperatures ranging from $32^{\circ}C$ to $36^{\circ}C$ are commonly recorded in the ASALs and may cause high evapo-transpiration rates leading to excess water loss from plants. In order to mitigate against this, green gram genotypes could be grown under reduced light intensity (shade) in order to reduce the amount light reaching the soil. This is expected to lower the rate of evaporation from the soil as well as transpiration from the plant thus saving more water to the plants. Therefore, the plants grown under reduced light intensity would have better agronomic performance as compared to those under direct solar radiation.

Due to the fact that higher and more stable yields require better availability and management of water to crops, it is evident that some more effective practices are necessary not only for utilizing light rains, but also concentrating surface water and storing it in the crop root zone (through use of micro-catchments) and reducing the rate of evaporation and evapotranspiration by plants during dry and hot periods.

Micro-catchments are soil and water conservation structures which direct water to the plant root area for plant's use. They include open ridges and tied ridges. Green gram genotypes can be grown in the micro-catchment in order to ensure that much rain water is directed to the crop area. This is expected to increase the agronomic performance even when there is variation in weather. The effects of integrated packages incorporating reduced light intensity and micro-catchments are expected to increase the agronomic performance even when there is variation in weather

1.3 Objectives

1.3.1Main objective

The main objective of this study was to evaluate the agronomic performance of green gram accessions under reduced light intensity and micro-catchments in the Machakos and Makueni Counties of Kenya.

1.3.2 Specific objectives:

1. To evaluate 40 green gram genotypes for agronomic performance in Machakos and Makueni Counties, Kenya.
2. To assess the agronomic performance of selected green gram genotypes grown under reduced light intensity
3. To determine the effect of two micro-catchments on the agronomic performance of four green gram genotypes

4. To evaluate the effects of integrated packages incorporating reduced light intensity and micro-catchments on productivity of four superior green gram genotypes

1.4 Hypotheses

1. There is no variation in agro-morphological traits among 40 green gram genotypes grown in Machakos and Makueni Coutnies , Kenya

2. Reduced light intensity does not affect the agronomic performance of the selected green gram genotypes

3. Micro-catchments have no effect on agronomic performance of the selected green gram genotypes.

4. Integrated packages incorporating reduced light intensity and micro-catchments have no effect on the agronomic performance of selected green gram genotypes

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction of green gram

Vigna radiata (L.) Wilczek which is also referred to as mung bean, green gram or/and golden gram is a native of India and is widely grown throughout Asia including Pakistan, Bangladesh, Sri Lanka, Thailand, Laos, Cambodia, Vietnam, Indonesia, Malaysia, South China, and Formosa. Greengram has been grown in these areas since pre-historic times (Swaminathan *et al.*, 2012). According to Nene (2006), the progenitor of green gram is believed to be *Vigna trilobata*. The genus *Vigna* comprises about 80 species and occurs throughout the tropics. *Vigna radiata* belongs to the sub- genus *Ceratotropis*, a relatively homogenous and morphologically and taxonomically distinct group, primarily of Asian distribution. These are divided into wild and domesticated varieties with wild varieties having smaller seeds than the cultivated. The cultivated types of mung bean are grouped as *Vigna radiata var. radiata.* Cultivation of *Vigna radiata* later spread to Australia, the Americas, the West Indies and many tropical African countries. In certain areas of Kenya, especially the Eastern Province, mung bean is the principal cash crop (Mogosti, 2006).

2.2 Agro-ecological requirements of green gram production in Kenya

Green gram grows well in a wide range of soil types, however, it does well in well drained loams or sandy loams with a pH range 5-8 with 5.5- 7 being the optimal (Mogosti, 2006). Saline and alkaline soils are not suitable for green gram cultivation (Chhidda *et al.*, 2011) and it is susceptible to waterlogging (Mogosti, 2006). Green grams are well adapted to red sandy loam soils, but also do reasonably well on relatively low fertile sandy soils. Heavy rainfall normally results in increased vegetative growth thus reducing pod setting and development. This makes the crop suitable for the arid and semi-lands (ASALs) of Kenya. According to Kimiti *et al.*, (2009), green gram (mung bean) is an important crop in the warm dry parts of eastern Kenya where it is grown for use as a subsistence crop and as a cash crop. The ASALs cover 80% of Kenya's total area (MOA-CPPMU, 2012; Herrero *et al.*, 2010) mostly in coastal, eastern and northern regions of the country (MOA-CPPMU, 2013). These regions receive a bimodal rainfall; short rains from October to December and long rains from March to May (Herrero *et al.*, 2010). The crop requires water/rain during the critical periods of germination, flowering and grain filling (MOA, 2002). Unfortunately, the rains in these regions are normally erratic, sporadic and quite unreliable, presenting unfavourable distribution (Fidelibus and Bainbridge, 1994). According to Herrero *et al*., (2010) this has led to low yield as compared to the potential yield (Table 2.1). According to MOA, (2002) the potential yield of green gram in Kenya is between 1.2 and 1.5 tons per hectare.

In order to mitigate against these low yields, some measures need to be put in place, such as reduction of evapo-transpiration in order to increase the amount of water available to the crop (Fidelibus and Bainbridge, 1994; Wang *et al.*, 2008). The water from the available precipitation should be directed to the root region of the plant (Moges, 2004) for immediate use by the plant and effectively "stored" below the soil surface where it is available for the plant use, but is also protected from evaporation (Fidelibus and Bainbridge, 1994).

2.3.1 Uses and nutritive value of green gram

Green gram is considered to be better than other pulses in terms of food quality (Nene, 2006). Green gram can be used when whole and dry, cooked or milled and can be prepared into a variety of dishes such as snacks, porridge, noodles, soups and even bread (Nene, 2006; Swaminathan *et al.*, 2012). Immature pods and young leaves are eaten as a vegetable (Swaminathan *et al.*, 2012). The Asian community in Kenya is the largest consumer of the crop, and normally cooks it as split grains (Dhal). Green gram is sometimes grown for hay or cover crop (Kimiti *et al.*, 2009; and Swaminathan *et al.*, 2012).

Green gram also acts as a green manure crop (Kimiti *et al.*, 2009) through enriching the soil fertility by fixing atmospheric nitrogen in the root nodules and improves the soil structure as the tap root system opens the soil into deeper strata and heavy leaf protein increases the soil organic matter. Being a short duration crop, it fits well in many intensive crop rotation systems (Kywe *et al.*, 2008). Green gram can also be used as feed for cattle; the plants can be harvested when green through cutting at the base or uprooting, chopped and fed to cattle. After harvesting and threshing the crop, the husks are also stored and feed to cattle during periods of forage shortage. The husks can be soaked in water and fed to cattle (Chhidda *et al.*, 2011).

2.3.2 Green gram sprouts and their nutritive values

Sprouting is a process of soaking, draining and rinsing till the seed germinate. Any whole gram but small one like green gram, horse gram, chick peas and black gram needs little effort and time to sprout. Green grams are soaked in sufficient water by completely immersing it. They are soaked overnight in order to allow them to bloat and use up all the water. They are then drained and rinsed with water several times. The green grams are placed in a big bowl and kept in a warm place and allowed to stay overnight, at this time the green grams are all sprouted and ready for consumption. Sprouted green gram is used as green salad and vegetables (Adsule, *et al.*, 2009).

Sprouts are considered as good enzyme-rich food and when allowed to sprout, ascorbic acid (Vitamin C) is synthesized (Chhidda *et al.*, 2011). They are good source of B vitamins, proteins and minerals. They are rich in digestive enzymes, easy to digest, as a result of which they are fed to children and sick people (Chhidda *et al.*, 2011; Adsule *et al.*, 2009; Choon *et al.*, 2010). Raw green gram seeds are rich in trypsin-inhibitors that block the effects of protein digesting enzymes in the gut. Sprouted green gram has lower amounts of these inhibitors.

Table 2. 1: Green gram production in Kenya during the period 2006 - 2014

Year	Unit	2006	2007	2008	2009	2010	2011	2012	2013	2014
Area (Ha)		102,882	82,784	91,452	112,997	147,352	159,910	188,416	258,407	259,167
Production	90kgs bag	482,212	688,363	296,808	470,372	680,528	780,283	1,020,270	1,075,554	1,345,294
	Tons	43,399	61,953	26,715	42,333	61,248	70,225	91,824	96,799.86	121,076.5
Average yield	Bags (90kg) /hac	5	5.5	3.2	4.16	4.62	4.88	5.41	4.2	5.2
	Tons/hac	0.42	0.75	0.29	0.37	0.41	0.44	0.49	0.37	0.47

Source: CPPMU-MOA, 2010; CPPMU-MOA, 2011; CPPMU-MOA, 2013; and CPPMU-MOA, 2015

Table 2. 2: Nutritive value per 100g of edible portion of green gram

Raw or cook vegetable	Food Energy (calories/ % Daily value*	Carbohydrates (g % DV)	Fat (g/ % DV)	Protein (g/%DV)	Calcium (g/% DV)	Phosphorus (mg/%DV)	Iron mg/%DV)	Potassium (mg/%DV)	Vitamin A (I.U)	Vitamin C (I.U)	Vitamin B 6 (I.U)	Thiamine (mg/% DV)	Riboflavin (mg/%DV)	Ash (g/% DV)
Green gram cooked	105/ 5%	19.2 / 6%	0.4 / 1%	7.0 / 14%	27.0 / 3%	99.0 / 10%	1.4 / 8%	266 / 8%	24.0 IU /0%	1.0 / 2%	0.1 / 3%	0.2 / 11%	0.1 / 4%	0.8
Green gram raw	347 / 17%	62.6 / 21%	1.2 /2%	23.9 / 48 %	132.0 / 13%	367 / 37%	6.7 / 37 %	1246 / 36%	114 IU / 2%	4.8 / 8%	0.4 / 19 %	0.1 / 6%	0.1 /7%	0.4
Green gram sprouted raw	30.0 / 2 %	5.9 /2%	0.2 / 0%	3.0 / 6%	13.0 / 1%	54.0 /5%	0.9 / 5%	149 / 4 %	21.0 IU / O%	13.2 / 22%	0.1 / 4%	0.1 / 6%	0.1 / 7%	0.4

*Percent Daily Values are based on a 2000 calorie diet. Your daily values may be higher or lower, depending on your calorie needs

Source: AVRDC, (2012), accessed on 25th April 2019.

2.3.3 Farming in dry lands

Inadequate soil moisture is the most limiting constraint to productivity in the semi-arid areas of Kenya (Itabari *et al.,* 2003). Improvements in on-farm water management through water harvesting may prove key to up-grade smallholder farming systems in dry sub-humid and semi-arid areas. The low yield is ascribed to the limited crop water availability due to rainfall variability, soil water loss through evaporation and inherently low soil nutrient levels. To meet an increased food demand with less use of water and land in the region requires farming systems with high water efficiency in the future. The rainwater harvesting technologies that have been tested and found suitable for increasing crop productivity are those that retain rainwater in situ in the farms for crops. They also allow rainwater to be retained on open furrows for longer duration as the water infiltrates the soil through the tied and open ridges. These water-harvesting techniques favour prolonged rainwater infiltration and retention, thus raising the overall soil moisture and soil water holding capacity (Itabari *et al.*, 2003).

Farmers in the drylands incorporate different technologies to improve *in-situ* water infiltration capacity. Examples are soil conservation technologies such as ridging and zai pits. Improved strategies incorporating *in-situ* water harvesting together with fertility management are also suggested (Gicheru *et al.*, 2004). Although these structures improve soil infiltration and crop water availability, the efficiency for mitigation of dry spell effects may be limited depending on soils inherent water holding capacity. Surface runoff is a resource as important as the rain, and it can be used to improve crop production. Consequently, there has been a major development in a diverse range of technologies in water harvesting and conservation. Rain Water Harvesting (RWH) systems are also applicable over a wide range of conditions in areas where average annual rainfall is insufficient to meet the crop water requirement, with seasonal rainfall being as low as 100 to 350 mm.

Table 2. 3: Green gram commercial varieties grown in Kenya, and Tanzania

Variety	Maturity Days	Potential yield t/ha	Remarks
"KVR 22" (N 22) (Kenya)	80-90	1.0-1.3	.Golden yellow seed colour .Tolerant to aphids .Resistant to yellow mosaic .Moderately resistant to powdery mildew .In the driest areas will perform poorly due to its lateness .Performs well between 50 and 1600 m above sea level
"KVR 26" (N 26) (Kenya)	60-65	0.3-1.5	.Shiny green seed colour .Best performer in dry areas due to its earliness .Performs well between 0 and 1600 m above sea level
"Nuru" (Tanzania)	50	1.5	.Resistant to mosaic disease .Moderately resistant to bacterial blight .Performs well between 50 and 1350 m above sea level
"Imara" (Tanzania)	50	1.5	.Resistant to mosaic disease .Moderately resistant to bacterial blight .It has wide adaptability .Performs well between 0 and 1350 m above sea level

Source: AIC Field Crops Technical Handbook

Publications and Fact Sheets on Mungbean. AVRDC Extension Materials. www.avrdc.org LLs (4th November 2014)

2.3.4 Green gram varieties/germplasm

Green grams also known as mung bean has many varieties, however only a few have been adopted. For example in Kenya and Uganda only 2 commercial varieties are grown (Table 2.2). These are "KVR 22" ("N 22") and "KVR 26" ("N 26") (MOA, 2002). In Tanzania there are also two main commercial green gram varieties ("Nuru" and "Imara") as indicated on Table 2.3 which have different characteristics. These include different days to maturity, yields and colour. Some varieties are susceptible to various diseases while others are resistant to the same. Some varieties are tolerant to some pests while other pests infest some other varieties.

2.4 Rain water-harvesting technologies – micro-catchments.

In the Arid and Semi-Arid Lands (ASALs), rainfall is usually lower than the potential evaporation, unevenly distributed eventually resulting in frequent drought periods during the crop growing season (Oweis and Hachum, 2009). Consequently, the ASALs experience significant problems in securing adequate amounts of water for rain-fed crop production (Abu-Zanat *et al*., 2004). According to Fidelibus and Bainbridge (1994), low annual rainfall and unfavorable distribution throughout the year (Boers, 1997) limit soil moisture in arid and semi-arid zones. However, these areas, may receive enough annual rainfall to support crops but it is unevenly distributed in time and space that make rain-fed agriculture not viable (Rosegrant *et al*., 2002). As human population increases, land pressure also rises, as a result more and more marginal areas that are located in ASALs are being used for agriculture. In order to establish and maintain plants, Fidelisbus and Bainbridge (1994), noted that techniques for improving, capturing and utilization of local water supplies should be developed. Therefore, this calls for practical ways to harvest rainwater during the rainy seasons. Rainwater harvesting is a method of inducing, collecting, storing and conserving local surface run-off for use during water scarcity. The water could also be used for agricultural production especially so in ASALs. Many a times, much of this water is soon lost as surface runoff (Hatibu and Mahoo, 1999).

Limited and erratic rainfall in ASALs often results in low crop yields and sometimes in total crop failure. While irrigation may be the most appropriate measure to mitigate against this situation, the irrigation water is also not available everywhere and construction of irrigation infrastructure has proved to be expensive, and only benefit the fortunate few (Hatibu and Mahoo, 1999). Therefore, any intervention to increase the quantity of water available to crops could lead to increased yields. The water availability for crop production can be improved through various soils and water management practices (Xiao-Yan *et al.*, 2000). Water harvesting is one of the options that increase the amount of water per unit cropping area, reducing drought incidences and enabling efficient use of run-off (Oweis *et al.,* 1999). On-farming rainwater harvesting technologies/micro-catchments aim at directing rainwater to the root area of the crops (Moges, 2004). This enhances food security even in the areas where rainfall is very low. These micro-catchments include semi – circular bunds, contour ridges, open and tied ridges and furrows/flatbeds (Mati *et al.*, 2006).

2.4.1 Semi-Circular Bunds

This is a network of earthen bunds shaped as half – circles with tips facing upslope and on the contour (Moges, 2004; Mati *et al.*, 2006). According to Moges (2004), semi-circular bunds, of varying dimensions, are used mainly for rangeland rehabilitation or fodder production. This technique is also useful for growing trees and shrubs and, in some cases; it has been used for growing crops. These bunds are normally used in areas where the rainfall ranges between 200 -700mm with deep soil (Ibraimo and Munguamba, 2007, and Sotirakkou964, 2011). These structures are normally constructed on a low slope ranging from 2 – 5% and are suitable for uneven terrain as the structures are free standing. (Anschütz *et al.,* 2003). According to Anschütz *et al.*, (2003) the bunds are also used for tree planting as they collect the run-off water in the infiltration pit. The bunds are made in such a manner that those on one row, are not directly above the ones on the row below it. Also the tips of adjacent bunds do not touch each other as the tips are meant to discharge excess water which is trapped by a series of bunds below it (Anschütz *et al.*, 2003 and Mati *et al*., 2006). The semi- circular bunds act as a micro- catchment that harvests rainwater and retains it in the planting pit. This ensures water availability to the root zone even after the rains. The stored moisture is adequate to support the plant through the dry spell, if the semi- circular bunds are well designed. According to Mutunga (2001), the semi-circular bunds are used for collecting and holding water for crop production in the Machakos, Kitui and Makueni Counties

2.4.2 Open and tied ridges

Open and tied ridges are a network of continuous earth bump parallel to each other with a fuurow in between them. Just like in the case of semi-circular bunds, ridge and furrows are normally constructed where rainfall range between 200mm and 700mm per annum (Hatibu and Mahoo, 1999; Ibraimo and Munguamba, 2007; Sotirakkou964, 2011) and where the land is relatively flat. They are graded in such a manner that when full it feeds to the furrow below (open ridges), however in most cases, the end points of the furrows are normally blocked (tied/closed ridges) in order to concentrate the water within the root areas of the plant (Anschütz *et al.*, 2003, Moges, 2004). Many studies have indicated that rainwater-harvesting furrow/Ridges system in addition to improving soil moisture and extending the period of water availability, it also boots growth of plants and forest plant, hence been suitable for arid and semi-arid regions suffering from irrigation shortage and high irrigation costs (Anschütz *et al.,* 2003; Xiaolong *et al.,* (2008). Regardless of the type of ridge used, closed end ridge (tied ridges) gave the highest yield, while planting in flatbed (normal furrows) produced the lowest grain yields (Heluf, 2003; Hailemariam, 2016). Feng *et al.,* (2012) worked on effects of ridge and flatbeds rainfall harvesting system on *Elymus sibiricus* yield, and found that the effects of the ridge-flatbed on *E. sibiricus* were significant since those in the ridge- grew more rapidly and robustly than those planted on flatbeds. Wang *et al.,* (2008) found out that yield of potatoes grown on furrow and ridges were significantly higher than those in the flatbeds planting. In addition, Abu-Zanat *et al.*, (2004) found out that overall survival of transplants after three growing seasons averaged 67% under strictly rainfed conditions compared to 95% survival with additional rainwater harvest.

The crop is normally planted along the furrow; therefore, the distance from one ridge to the other depends on the inter-row spacing of the crop (Feng *et al.*, 2012). When constructing ridges and furrows, the height at which the crop starts bearing should be taken into account so that the pods/fruits/leaves do not come into contact with water or soil.

2.5 Reduced light intensity

Light plays an important role in the development of a plant and in that processes such photosynthesis and phototropism depend on the availability of light sources for plants (Long 2011). Light as a primary source of energy, is one of the most important environmental factors for plant growth (Benvenuti *et al.*, 2001). The intensity of light is essential for the growth, morphogenesis and other physiological responses of plants. The structure of plants is regulated, in part, by light signals from the environment. Light intensity affects various characteristics of plants. In order to adjust the various light environments, plants have evolved many mechanisms, including morphological and physiological changes in the leaves.

Normally during periods of low erratic rainfall, crops under shades perform better than those under direct solar radiation. On realizing this, farmers create artificial shades over fruits of tomatoes, pumpkins, cabbage heads among others in order to reduce the light intensity thus reducing the rate of evaporation and sunburns on the produce (AIC, 2002; AVRDC, 2012)). According to Hashem *et al.*, (2006) regardless of the source, shade reduces the irradiance predominantly in the Photosynthetically Active Radiation (PAR) of the spectrum (400-700nm).

Shading reduces air and soil temperature (Makus, 2001) thus reducing water loss through evaporation and transpiration from plants and this leads to better agronomic performance of crops in ASALs. It has been shown that mature leaves show very little adaptation to shade or sun as opposed to the whole plant of some species that adapt very well to either condition during development, especially so to shade (Hashem *et al.*, 2006). However, Adugna and Paul, (2010) indicated that shading delays the maturation of coffee berries resulting in a better bean filling and larger bean size resulting in better coffee quality. According to Makus, (2001), light reduction tended to decrease pod size, plant biomass, and leaf greenness, while leaf area and chlorophyll contents were increased with increased shading. Polthanee *et al.*, (2011) reported that when soyabean cultivars were grown under light intensity at 30% of the natural light in both wet and dry seasons; dry matter, total pod number per plant and thousand grain weight were significantly ($p<0.05$) decreased. Adugna and Paul, (2010) asserted that shade, trigger differences in physiological behaviour of the coffee plants, such as improved photosynthesis and increased leaf area index, resulting in better performance than in direct sun light. Venkateswarlu, (1977) reported that the number of rice tillers, tiller weight, dry matter production and grain yield of rice were significantly reduced under low light intensity. Restrepo and Garcés (2013) reported that low irradiance (LI) during the reproductive and/or ripening stages has an adverse effect on potential yield as the photosynthetic activity in the leaves of rice cultivars decreases. Also incidences of powdery mildew occurred late in the season and were linearly increased by reduced light.

CHAPTER THREE

EVALUATION OF 40 GREEN GRAM GENOTYPES FOR AGRONOMIC PERFORMANCE IN MACHAKOS AND MAKUENI COUNTIES, KENYA.

3.1 Abstract

Green gram (*Vigna radiata* L.) is a hardy pulse serviving in harsh conditions. To evaluate agronomic performance of green grams in the Machakos and Makueni Counties of Kenya, a study involving 40 green gram accessions was carried out at two locations; Machakos ATC in Machakos County and Kiboko, KALRO Katumani in Makueni County. At each location, the experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Data was recorded on various traits including plant height, number of pods per plant, 100 seed weight, seed yield. During the 2011 short rain season the accessions differed significantly on plant height with Ndengu-2 attaining a height of 66 cm as compared to 40 cm of GBK-017437A in Machakos ATC. In Kiboko, Ndengu-2 attained the highest plant height (66.1 cm) and GBK-017437A was the shortest (39.5 cm). Further, the results indicated that number of leaves per plant and plant height were positively correlated to number of pods and seed yield per plant; number of pods per plant was positively correlated with number of leaves per plant, plant height and seed yield and, was negatively correlated to pod length, pod girth and 100 seeds weight. Seed yield positively correlated to number of leaves per plant, plant height and number of pods per plant were negatively correlated to pod girth. Seed yield was positively correlated to number of pods per plant, plant height and number of leaves per plant. Hence improving any of the three parameters would result in increased seed yield.

3.2 Introduction

Green gram is the hardiest legume (Nene, 2006), adapted to a wide range Agro-Ecological Zones (AIC, 2002), however, the unfavourable climatic factors, unreliable rainfall coupled with increased prevalence and severity of pests and diseases lead to increased crop losses.

Carolina *et al.,* (2006) indicated that maintaining crop yield under adverse environmental conditions is probably the major challenge facing modern agriculture. As land pressure rises, more marginal areas in the Arid and Semi-Arid Lands (ASALs) in the world are being used for agriculture (Moges, 2004). Unfortunately, most ASALs predominantly depend on rain-fed agriculture (Cooper *et al.,* 2008; Jones and Thornton, 2009). As a result, food security has been identified as a major area of concern especially in view of the limited resources for adaptation to the ASALs.

In Kenya, agriculture remains the backbone of the economy with 80 % of the country's population living in the rural areas and deriving their livelihood from agriculture and related activities (CPPMU-MOA, 2008). In addition, ASALs cover 80% of Kenya's total area (CPPMU-MOA, 2012, Herrero *et al.*, 2010; CPPMU-MOA, 2013). Some of these regions receive a bimodal rainfall; short rains from October to December and long rains from March to May (Jaetzold *et al*,, 2006; Herrero *et al.*, 2010). Unfortunately, the rains received in these regions are low in amount and are unreliable ((Fidelibus and Bainbridge, 1994). Drought tolerant crops such as green gram are the most suitable for the ASALs. However, the grain yields realized by the farmers are quite low as compared to those reported from research stations (MOA, 2002; Mondal *et al.*, 2012; Narasimhulu *et al.*, 2013; Hussain *et al.*, 2011). For instance, the potential yield of green gram in Kenya is 1.2 - 1.5 ton ha^{-1} (MOA, 2002) as compared to the actual 0.29 – 0.49 ton ha^{-1} realized between 2008 and 2012 (CPPMU-MOA, 2011; 2013).

According to Herrero *et al.,* (2010) low and erratic rainfall coupled with low quality seeds lead to low yield (0.29 - 0.75 ton ha^{-1}) as compared to the potential yields (1.2 - 1.5 ton ha^{-1}). Farmers just buy grain from the market place, whose seed quality is not known, and use it as seed. In order to enhance green gram performance in the country, there is need to identify high yielding genotypes for specific environments. However, no study has been conducted on germplasm characterization to inform the selection of the best accessions for particular areas in Kenya, and hence the need for this study. The objective of this study was to evaluate green gram accessions for agronomic performance in the Machakos and Makueni Counties, Kenya.

3.3 Materials and Methods

3.3.1 Site description

The study was carried out in two sites; Machakos Agricultural Training Centre (Machakos ATC) in Machakos County and Kiboko sub-station of KALRO Katumani in Makueni County during the 2011 short (November – December rains) and 2012 long rain (March – May rains) seasons. Machakos ATC is located at1° 54'S; 37° 24'E and at 1,614 m asl (Figure 3.2). It is about 66 km South East of Nairobi (Figure 3.1). Machakos ATC lies in agro-ecological zone (AEZ) IV, with a bimodal pattern of rainfall, with a mean annual rainfall of 655 mm. The long rains fall between March and May, with the peak in April with an average of 273 mm while the short rains fall in October and December with the peak in November with an average of 382 mm. The mean maximum temperature is 24.7°C while the mean minimum temperature is 13.7°C. The main type of soil is luvisols (Jaetzold *et al.*, 2006).

Kiboko is situated about 3° 15’S; 37° 50’E and 975 m above sea level (asl). It is approximately 160 km South East of Nairobi along the Nairobi- Mombasa Highway. The turn-off at Kiboko Market is about 15 km before Makindu town (Figure 3.2). Kiboko is located in agro-ecological zone V and is representative of a typical ASAL in Kenya. The centre receives bimodal rainfall with an annual average of 386.4 mm. The short rains are received between March - May with an average of 295.3 mm and long rain which occur between October and December with an average of 91.1 mm (Kamau *et al.*, 2010). The area has a monthly average temperature range from 26.9°C to 30.8°C and evaporation of 2000 mm. It has ferric luvisols type of soil (Jaetzold *et al.*, 2006).

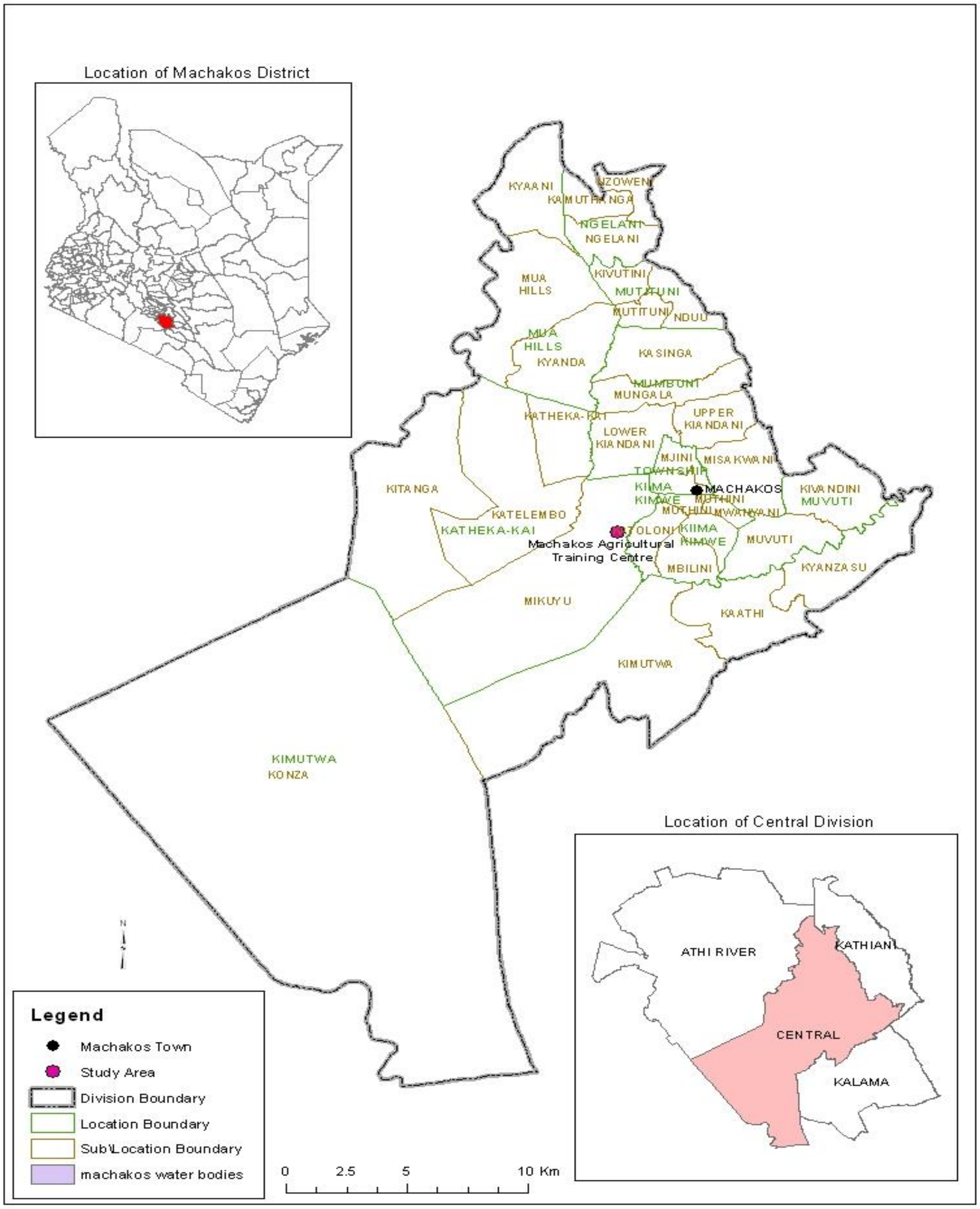

Figure 3.1: Location of Machakos Agricultural training Centre

Source: Kenya National Bureau of Statistic (2009)

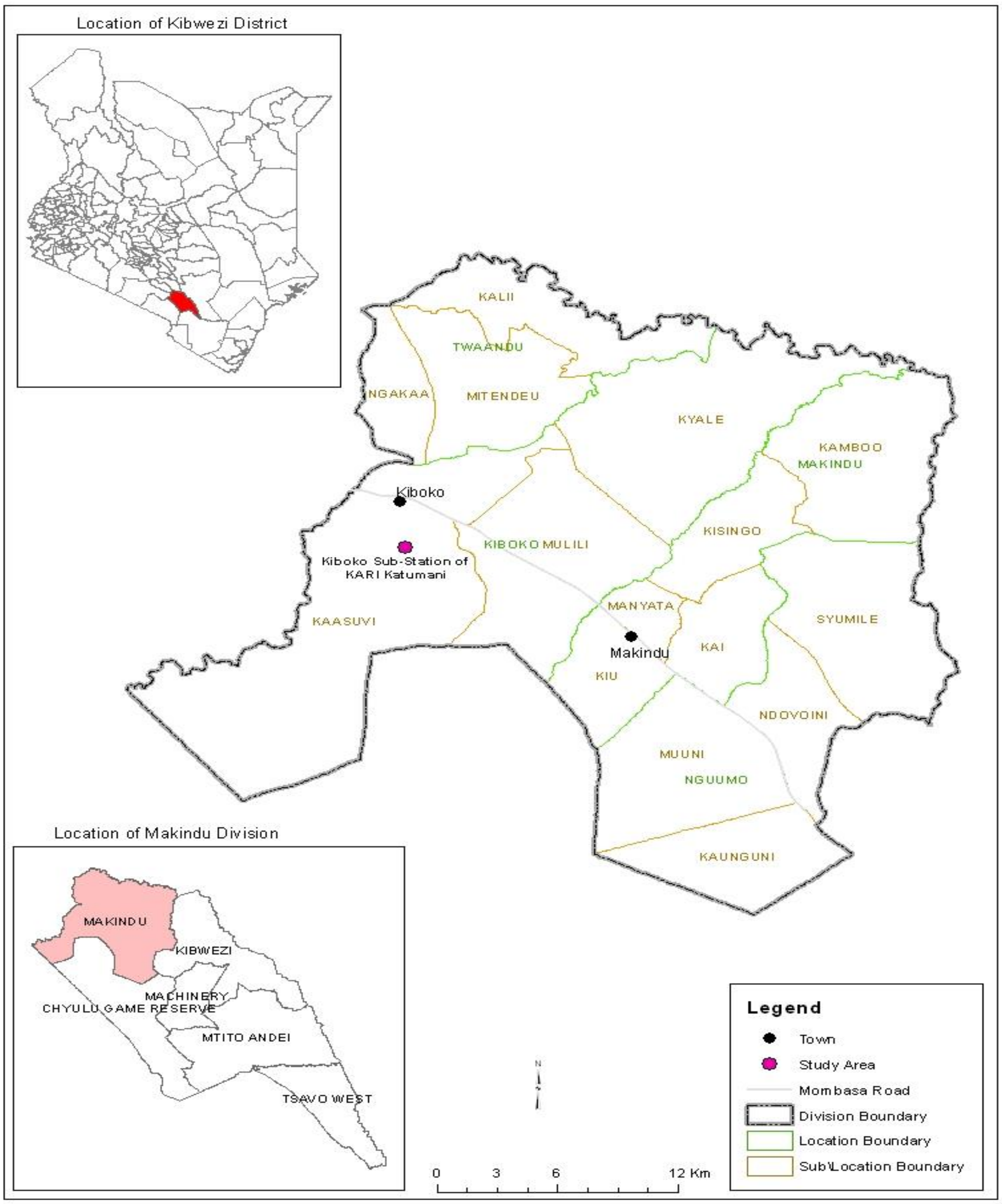

Figure 3.2: Location of Kiboko Sub-Station KALRO Katumani –
Source: Kenya National Bureau of Statistic (2009)

3.3.2 Planting materials

The green gram evaluated included 40 accessions (29 accessions obtained from the National GeneBank of Kenya (GBK) and 11 landraces collected from farmers' fields (Appendix 1). Nylon-1 has been released for cultivation in the region and was included as the commercial check.

3.3.3 Experimental layout and treatments

The experiment was laid out in a randomized complete block design (RCBD) with three replications. Each block measured 9 m x 39 m and contained 40 plots (one for each of the 40 accessions) each measuring 1.5 m x 3 m and separated by one metre pathway. In every plot, four furrows spaced at 0.5 m width and 1.5 m length were made. Seeds were sown at intra-row spacing of 0.15 m. At Kiboko, planting took place on 25th November 2011 (2011 short rains) and on 4th April 2012 (2012 long rain season); At Machakos ATC, planting took place on 3rd December 2011 (2011 short rains) and on 28th March 2012 (2012 long rain season).

3.3.4 Agronomic practices

The field was ploughed and harrowed to medium tilth [Plate 3.1 (A)]. Diammonium Phosphate (DAP) fertilizer was applied along the flatbeds at rate of 100 kg/ha (MOA, 2002; Karanja *et al.*, 2006) [Plate 3.1 (B)]. String marked at a spacing of 0.15 cm to guide in planting [Plate 3.1 (C)]. The fertilizer was mixed with soil before placing two seeds per hill at a spacing of 0.15m and depth of 5 cm) [Plate 3.1 (D)]. The seeds were covered thinly with soil. First weeding was done two weeks after germination followed by thinning to leave one seedling per hill. During the growing period, irrigation was used to keep the soil moist whenever rainfall was inadequate. Insect pests such as pod sucking bugs and aphids were controlled using Duduthrin (Lambdacyhalothrin 17.5g/l at rate of one litre per ha) and Dimethoate (Dimethoate at a rate of one litre per ha) insecticides (PCPB, 2007), respectively. Powderly mildew and rust were controlled using Ridomil –

(Mefenoxam at a rate one kg per ha) and Score 250 SC (Difenoconazole 250 g/l at rate of one litre per ha) fungicides (PCPB, 2007), respectively.

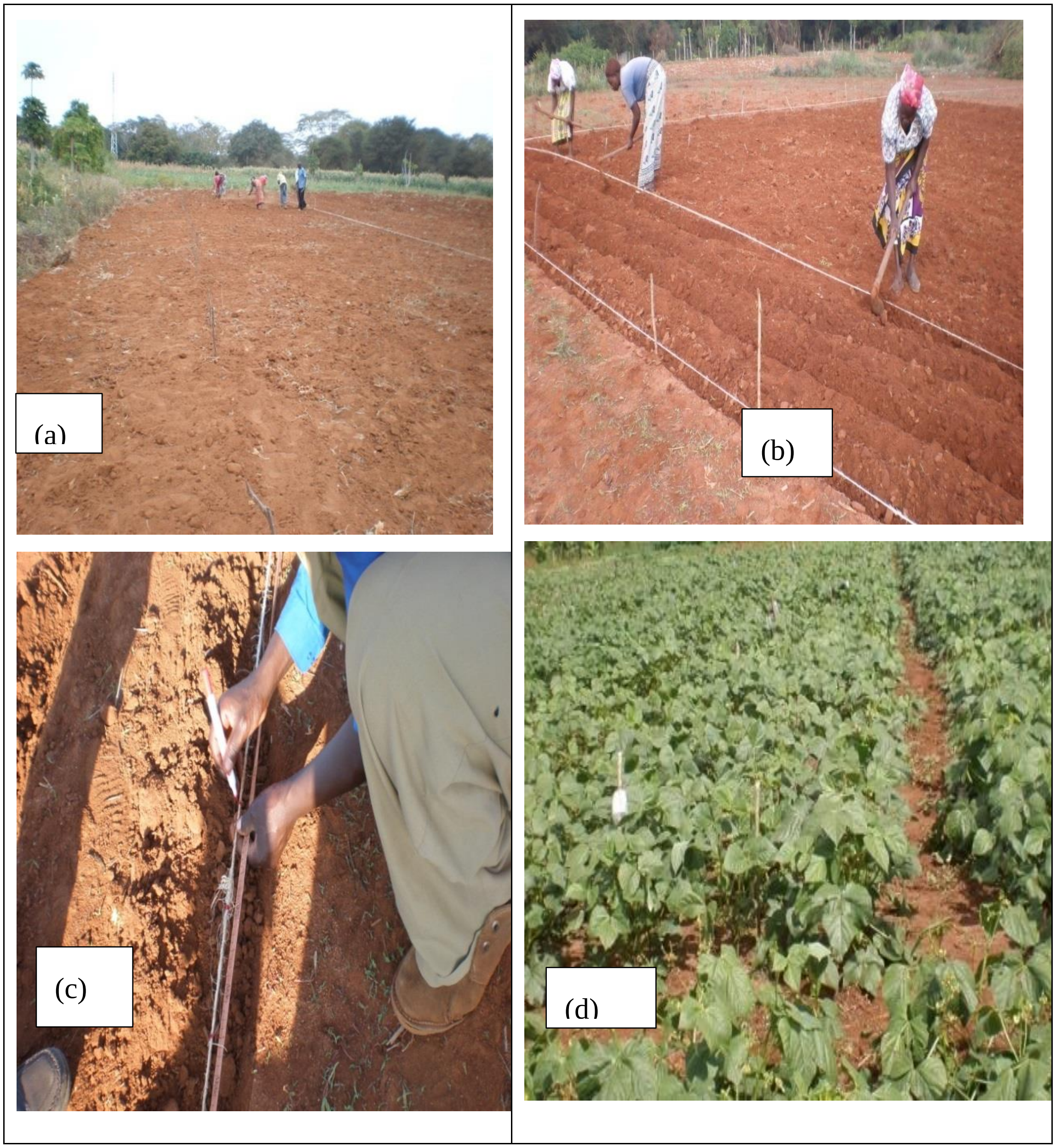

Plate 3.1: Agronomic practices undertaken in the field showing (a) land leveling to medium tilth, (b) making of planting furrows, (c) making of the spacing on a string and (d) green gram crop

3.3.5 Data collection

Five plants were randomly selected and tagged in each plot. From these plants data for various traits was collected as follows;. Plant height was measured as the height (cm) between the soil surface and the tip of the central shoot of mature plants. Number of days to flowering was calculated from germination to when the first flower opened. Number of pods per plant was obtained by counting pods on the plant at maturity. Number of days to maturity was calculated from the day of planting to the date when seventy five percent of the pods per plant were dry. Number of pods per plant was obtained by counting all the pods on a plant. Number of seeds per pod was obtained by randomly selecting 10% of the pods per plant, splitting the pods, followed by counting the number of seeds per pod, summing them up, and then dividing by the number of pods. Weight of 100 seeds was obtained through threshing all the pods from each plant and winnowing after which, 100 seed were randomly selected and weighed using a digital balance. Seed yield was obtained by extrapolating the weight of 100 seed weight through the following process; i) the number of seeds per plant which was obtained by multiplying the number of seeds per pod by the number of pod per plant ii) The weight of one seed was obtained by dividing 100 seed weight by 100 (iii) Multiplying the number of seeds per plant by the weight of one seed.

3.4 Data analysis.

The data was subjected to analysis of variance (ANOVA) using GenStat Ver. 12 statistical software (Payne *et al.*, 2006) (Appendix 3.2). Fisher's least significant difference (LSD) test was used to compare the means ($P \leq 0.05$. SPSS was used to cluster accessions based on similarities in agronomical traits. Correlation analyses were done to determine associations between different agronomics variables.

3.5 Results from Machakos ATC, Machakos County

3.5.1 Weather records

Monthly rainfall (mm), monthly mean temperature (˚C) and Relative humidity (%) data collected is presented in Figure 3.3 and 3.4.

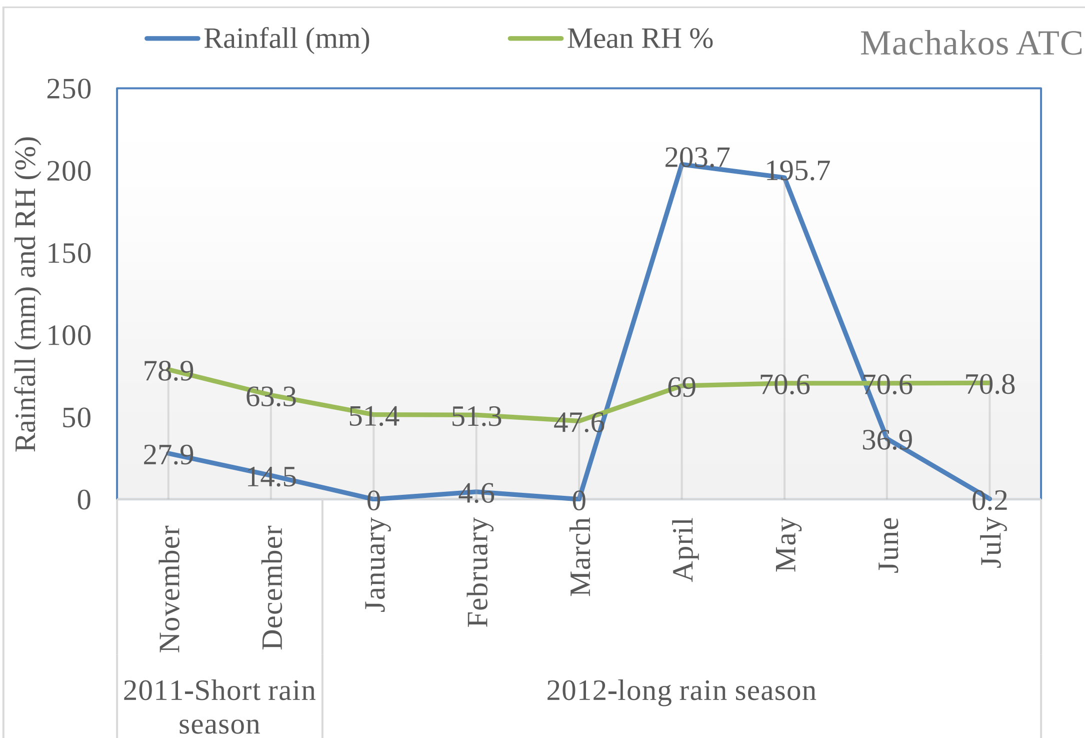

Figure 3.3: Rainfall and RH% data recorded during the growing period of green gram in 2011 short and 2012 long rains-Machakos ATC

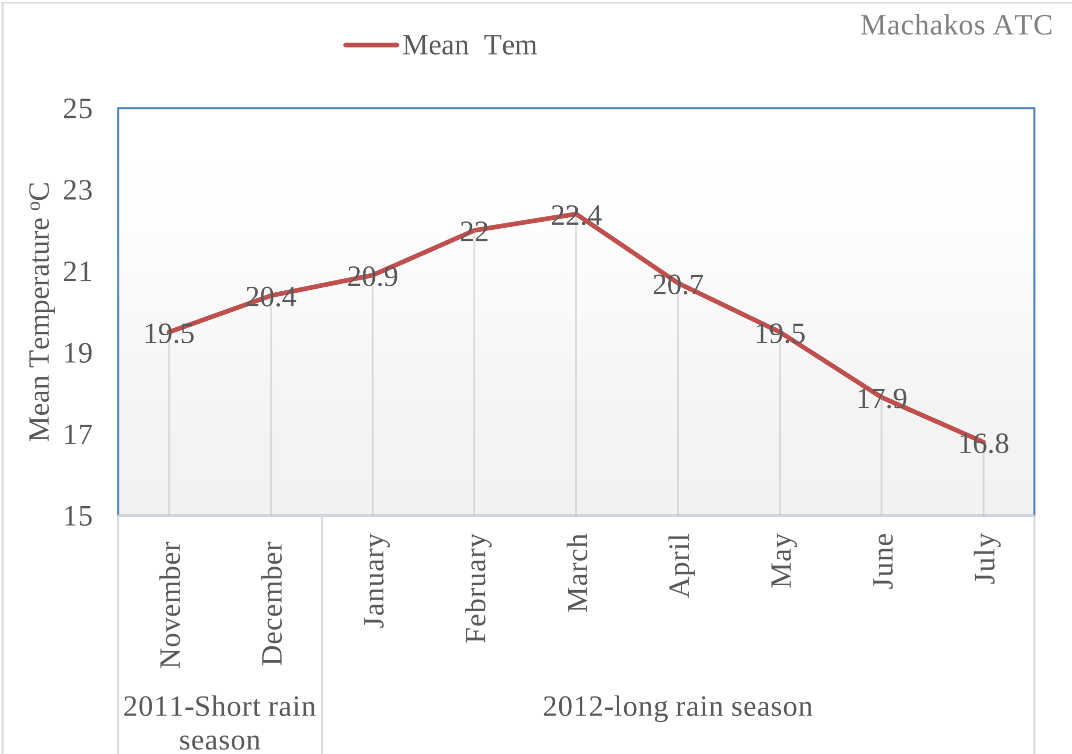

Figure 3.4: Mean Temperature data recorded during the growing period of green gram in 2011 short and 2012 long rains-Machakos ATC

3.5.2 Plant height

Results indicated that accessions had significant ($P \leq 0.05$) effect on the accessions' plant height during the 2011 short and 2012 long rain seasons (Table 3.1). In 2011 short rain season the accessions were found to have plant height ranging from 34.4 cm to 55 cm. Accession GBK-022500A and N26 had the tallest plant height (55 cm each) but they were not significantly different from GBK-022506 (53.7 cm), Ndengu-3 (53.0 cm), GBK-022497A (52.0 cm) and GBK-022498A (51.3 cm). Accession GBK-017437A had the shortest plant height (34.4 cm) although it was not significantly different from GBK-022499A (37 cm), Nylon-2 (38.3 cm), Olayo (38.7 cm), Uncle-1 (39 cm), GBK-022508A (39.1 cm) and Ndengu (39.3 cm). In the 2012 long rain season the accessions' plant height ranged from 39.9 cm to 74.3 cm. Accession GBK-022497A had the tallest plants (74.3

cm) although it was not significantly different from GBK-022492A which was 73.9 cm tall, GBK-022499A (73.1 cm), GBK-022539A (71.5 cm) and GBK-022537A with a plant height of 68.6 cm. Accession GBK-017437A had the shortest (39.9 cm) plants although it was not significantly different from Ndengu-1 (44.9 cm), Olayo (51.8 cm), GBK-022532A (52.1 cm) and GBK-022493A (52.7 cm).

3.5.3 Number of days to flowering

The accessions had significant ($P \leq 0.05$) effect on the number of days to flowering during the 2012 long rain season (Table 3.1). The number of days to flowering ranged from 38 to 42 days. Accessions Uncle-1, Cotton, Uncle-2 and GBK-017437A were the earliest (38 days) to flower although they were not significantly different from Ndengu-1, Olayo and GBK-022491A which took 39 days to flower. Accessions GBK-022493A and N26 were the latest (42 days) to flower although they were not significantly different from Ndengu-3, GBK-022492A and GBK-022500A which took 41 days to flowering. The number of days to flowering was not significantly influenced by the accessions during the 2011 short rain season at Machakos ATC.

Table 3.1: Agronomic traits of 35 green gram genotypes at Machakos ATC during the 2011 short and 2012 long rain seasons.

	Leaves		Plant height (cm)		Days to flowering		Days to maturity		Pod length (cm)	
Accessions	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Cotton	8.7	8.3	43.3	55.8	48.7	38.2	77.7	89.3	9.3	9.6
GBK-017437A	9.0	9.0	34.4	39.9	45.7	38.9	75.0	88.2	8.5	8.9
GBK-022491A	9.7	10.3	48.7	63.0	49.3	39.1	78.0	91.5	8.6	9.1
GBK-022492A	10.3	11.0	44.3	73.9	48.3	41.7	75.3	93.3	8.0	8.5
GBK-022493A	9.3	9.0	43.9	52.7	50.7	42.1	77.5	90.8	8.2	8.6
GBK-022494A	9.7	11.0	46.0	58.7	48.7	40.6	77.5	92.4	9.7	8.1
GBK-022495A	11.0	11.7	45.1	65.0	49.3	41.5	78.0	90.7	8.3	8.6
GBK-022497A	11.0	10.0	52.0	74.3	48.7	40.4	76.3	93.8	8.9	9.0
GBK-022498A	12.7	14.0	51.3	58.9	47.7	41.3	76.7	91.3	8.6	8.9
GBK-022499A	10.3	10.3	37.0	73.1	50.3	41.2	78.3	92.4	8.6	9.7
GBK-022500A	11.0	11.0	55.0	66.7	48.0	41.5	76.3	94.4	8.3	8.3
GBK-022501A	11.3	11.7	45.3	59.3	49.0	40.1	77.7	91.2	8.7	8.3
GBK-022502A	10.3	11.3	44.3	62.4	47.0	41.0	77.0	89.5	8.4	8.6
GBK-022504A	11.7	12.7	50.0	55.5	48.7	40.7	76.7	92.1	8.7	8.7
GBK-022505A	11.3	12.7	44.7	55.3	49.3	41.0	77.0	92.1	8.0	8.4
GBK-022506A	11.3	13.0	53.7	63.9	47.7	40.3	76.7	90.6	8.7	8.3
GBK-022507A	11.3	12.0	49.7	55.8	48.0	39.9	77.7	91.6	8.5	8.5
GBK-022508A	7.3	10.0	39.1	59.5	49.7	40.5	77.5	92.7	8.3	8.8
GBK-022509A	11.3	11.0	45.7	63.7	47.0	41.1	77.0	90.3	8.4	8.4
GBK-022531A	10.7	12.0	43.7	61.9	48.0	40.5	77.7	91.1	8.1	9.7
GBK-022532A	10.7	11.3	45.7	52.1	49.0	41.2	78.3	89.3	8.4	8.4
GBK-022534A	8.7	11.0	49.3	55.9	47.3	40.1	76.3	88.9	8.2	7.8
GBK-022536A	11.3	10.3	44.0	57.5	48.7	40.6	79.0	91.0	8.4	9.3
GBK-022537A	11.0	13.3	42.0	68.6	48.3	40.8	78.0	94.1	8.3	8.8
GBK-022539A	10.7	12.3	46.0	71.5	48.0	41.1	76.7	91.4	8.8	10.0
N26	9.7	10.3	55.0	60.9	50.3	42.0	78.7	84.2	8.6	9.2
Ndengu-1	10.3	9.3	45.7	44.9	47.3	39.1	75.3	89.3	9.0	9.3
Ndengu-2	11.7	10.7	39.3	53.3	52.3	39.8	78.3	89.3	8.4	9.5
Ndengu-3	7.7	9.7	53.0	59.9	52.7	41.9	81.1	92.9	8.8	9.3
Ndengu-4	10.0	11.0	50.3	66.6	47.7	39.8	76.7	90.4	9.5	9.4
Nylon-1	11.0	11.0	47.0	67.3	49.0	40.8	77.7	93.7	8.4	8.4
Nylon-2	9.0	9.3	38.3	63.1	49.0	39.9	77.0	94.6	8.6	9.5
Olayo	11.3	10.0	38.7	51.8	48.3	39.1	76.7	92.2	8.0	8.7
Uncle-1	9.7	8.7	39.0	56.4	49.3	38.2	78.7	92.0	10.1	10.8
Uncle-2	8.3	7.7	46.3	61.0	47.7	38.7	77.3	91.1	10.3	10.0
Mean	10.3	10.8	45.6	60.3	48.7	40.4	77.4	91.3	8.7	9.0
Minimum	7.3	7.7	34.4	39.9	45.7	38.2	75.0	84.2	8.0	7.8
Maximum	12.7	13.3	55.0	74.3	52.7	42.1	81.1	94.8	10.3	10./8
LSD ($P \leq 0.05$)	3	3.3	9.1	13.1	3.8	2.3	2.8	4.8	0.9	0.8
P value	0.143	0.056	<.001	<.001	0.373	0.031	0.157	0.11	<.001	<.001
CV%	8.8	11.3	11.9	4.9	0.8	1.4	2.4	2.7	0.7	1.6

3.5.4 Pod length

The study results indicated significant ($P \leq 0.05$) differences among the accessions' pod length during the 2011 short and 2012 long rain season (Table 3.1). During the 2011 short rain season, pod length of the green gram accessions ranged from 8.0 to 10.3 cm**.** Accession Uncle-2 had the longest (10.3 cm) pod length but was not significantly different from Uncle-1 with a length of 10.1 cm, GBK-022494A (9.7 cm) and Ndengu-4 which had a pod length of 9.5 cm. Accessions GBK-022505A, GBK-022492A and Olayo had the shortest (8.0 cm) pod length though they were not significantly different from GBK-022531A (8.1 cm), GBK-022493A, GBK-022534A and GBK-022537A each with a pod length of 8.3 cm . In 2012 long rain season accession Uncle-1 had the longest (10.8 cm) although it was not significantly different from Uncle-2 and GBK-022539A which were 10 cm long each. Accession GBK-022534A had the shortest (7.8 cm) pod length but was not significantly ($P \leq 0.05$) different from GBK-022494A (8.1 cm), GBK-022500A, GBK-022506A and GBK-022501A which had a pod length of 8.3 cm each.

3.5.5 Pod Girth

The results had significant ($P \leq 0.05$) differences among the accessions' pod girth during the 2011 short rain and long rain seasons (Table 3.2). During 2011 short rain season, pod girth ranged from 1.4 to 2.2 cm. Accession Uncle-1 had the widest (2.2 cm) pod girth although it was not significantly different from Uncle-2 and Nylon-2 each with a pod girth of 2.1cm. Accession GBK-022501A had the smallest (1.4 cm) pod girth and was not significantly different from GBK-022494A with a pod girth of 1.6 cm, followed by N26, Ndengu-2, GBK-022497A and GBK-022492A, which had a pod girth of 1.7 cm each. In 2012 long rain season the accessions had an average pod girth of 1.7 to 2.4 cm. Accession Nylon-2 had the widest (2.4 cm) pod girth and was significantly different from Uncle-2 (2.3 cm) and Uncle-1 with a pod girth of 2.2 cm. Accessions GBK-022494A, N26 and GBK-022504A had the least (1.7 cm) pod girth each.

Table 3. 2: Agronomic traits of 35 green gram genotypes at Machakos ATC during the 2011 short and 2012 long rain seasons

	Pod girth (cm)		Pods per plant		Seeds per pod		100 seeds weight (g)		Seed yield (g)	
Accessions	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Cotton	1.9	2.0	25.3	27.6	11.7	11.9	5.0	6.9	15.0	23.0
GBK-017437A	1.9	2.0	27.0	32.6	9.0	10.3	4.8	6.1	12.4	21.1
GBK-022491A	1.8	1.8	44.2	25.4	10.3	10.4	5.1	6.0	25.0	16.7
GBK-022492A	1.7	1.9	33.0	45.6	9.7	11.7	4.1	5.3	13.0	27.3
GBK-022493A	1.8	1.8	37.0	35.0	10.0	10.1	5.5	5.9	20.9	22.2
GBK-022494A	1.7	1.7	102.5	43.3	10.0	11.0	4.4	5.4	45.7	25.7
GBK-022495A	1.8	1.8	44.3	37.8	10.3	10.6	5.1	5.4	24.5	21.3
GBK-022497A	1.7	2.0	43.0	43.4	11.0	10.7	4.8	6.1	23.1	29.0
GBK-022498A	1.8	1.9	61.0	49.7	10.7	12.2	5.0	4.9	33.1	28.8
GBK-022499A	1.8	1.9	29.7	45.8	10.0	10.4	4.2	5.6	15.2	26.9
GBK-022500A	1.8	1.8	48.7	50.5	10.3	10.1	4.8	5.4	23.3	27.8
GBK-022501A	1.4	1.8	50.8	37.7	11.7	11.1	7.9	5.7	46.9	23.8
GBK-022502A	1.8	1.9	43.0	36.5	9.8	10.8	5.0	5.2	19.9	21.1
GBK-022504A	1.8	1.8	45.3	38.7	10.7	11.2	4.8	5.5	23.0	25.2
GBK-022505A	1.8	1.8	33.7	32.6	10.4	10.8	4.6	5.1	16.1	17.6
GBK-022506A	1.8	1.8	45.3	53.2	10.7	11.3	5.1	5.1	26.1	32.7
GBK-022507A	1.8	1.8	43.7	50.4	10.3	10.4	4.5	5.2	20.4	27.6
GBK-022508A	1.9	1.9	32.5	52.9	9.0	10.7	3.2	5.6	10.5	31.6
GBK-022509A	1.8	1.9	49.0	38.7	10.3	10.2	5.2	5.2	27.6	21.6
GBK-022531A	1.8	2.0	46.3	46.8	9.5	10.7	4.9	5.7	21.2	29.2
GBK-022532A	1.8	1.8	40.7	31.8	10.0	10.9	4.2	5.3	17.3	18.2
GBK-022534A	1.9	1.9	43.0	40.0	10.7	9.9	5.0	5.0	22.8	21.1
GBK-022536A	1.8	1.9	43.0	42.3	9.7	10.7	4.1	6.1	18.0	27.2
GBK-022537A	1.9	1.9	28.0	61.2	10.0	11.3	4.5	4.7	12.9	33.1
GBK-022539A	1.8	1.9	42.0	42.2	10.7	11.0	5.1	5.2	24.1	24.0
N26	1.7	1.7	58.3	34.3	12.3	12.1	4.3	4.9	31.7	20.3
Ndengu-1	1.8	2.0	25.3	2.05	10.7	11.7	5.7	5.4	15.3	16.2
Ndengu-2	1.7	2.0	23.7	27.6	10.3	12.0	3.9	6.3	10.1	22.4
Ndengu-3	1.8	1.8	44.7	40.3	12.3	11.9	4.8	3.4	26.7	16.8
Ndengu-4	1.9	2.0	34.0	30.8	11.0	10.7	5.9	5.7	21.9	18.8
Nylon-1	2	2.0	45.7	35.0	9.3	11.7	6.6	5.3	28.1	21.6
Nylon-2	2.1	2.5	18.7	29.1	8.3	7.5	7.5	10.7	11.7	23.0
Olayo	1.9	1.9	37.7	44.7	11.3	11.0	4.7	6.0	19.0	28.6
Uncle-1	2.2	2.3	23.0	27.4	10.7	9.7	5.9	7.7	16.7	21.6
Uncle-2	2.1	2.3	39.3	25.6	10.7	9.9	7.7	6.5	31.9	16.4
Mean	1.8	1.9	40.9	38.9	10.4	10.8	5.1	5.7	22.0	23.7
Minimum	1.4	1.7	18.7	25.0	8.2	7.5	3.2	3.4	10.1	16.2
Maximum	2.2	2.5	102.5	61.2	12.3	12.2	7.9	10.7	46.9	33.1
LSD ($P \leq 0.05$)	0.3	0.2	23.6	19.9	1.3	1.1	2	0.9	16.4	13.3
P value	<.006	<.001	<.001	<.036	<.001	<.001	0.006	<.001	0.003	0.471
CV%	5.7	1.9	35.3	10.4	0.7	3.2	3.4	7.8	13.1	15.3

3.5.6 Number of pods per plant

The results of the study had significant ($P \leq 0.05$) differences among the accessions' number of pods per plant during the 2011 short and 2012 long rain seasons (Table 3.2). In the 2011 short rain season the average number of pods per plant ranged from 18 to 102 pods. Accession GBK-022494A had the highest (102) number of pods per plant and was significantly different from GBK-022498A (61 pods), N26 (58 pods each), GBK-022501A (50) and GBK-022509A (48). Accessions Nylon-2 had the least (18) number of pods per plant but were not significantly different from Ndengu-2 and Uncle 1(23 pods), Ndengu – 2 (25 pods) and GBK-017437A which had 27 pods per plant. Significant ($P \leq 0.05$) differences were observed among the accessions. During the 2012 long rain season GBK-022537A with 61pods per plant but was not signgicantly different from GBK-022506A (53 pods), GBK-022508A (52 pods); GBK-022500A and GBK-022507A each having 50 pods per plant. Accessions Ndengu-1 had the least (2 pods) and was significantly different from GBK and 022491A, Uncle-2 each with 25 pods per plant; Uncle-1, Ndengu 2 and Cotton each which had 27 pods per plant.

3.5.7 Number of seeds per pod

The study results indicated significant ($P \leq 0.05$) differences among the accessions' number of seeds per pod during the 2011 short and 2012 long rain seasons (Table 3.2). During the 2011 short rain season the average number of seeds per pod ranged from 8 to 12 seeds per pod. Accessions N26 and Ndengu-3 had the highest (12) number of seeds per pod although they were not significantly different from cotton, GBK-22501A, Olayo, GBK-022497A and Ndengu-4 each with 11 pods per plant. Accession Nylon-1 had the least (8) number of seeds per pod although it was not significantly different from GBK-017437A, GBK-022508A, Nylon-1, GBK-022531A, GBK-22536A and GBK-022502A all with 9 seeds per pod each. In 2012 long rain season the average number of seeds per pod ranged from 7 to 12 seeds per pod. Accessions GBK-022198A, N26 & Ndengu-2 had the highest (12) number of seeds per pod although they were not significantly different from Ndengu-3, Cotton, GBK-022492A, Nylon-1 and Ndengu-1 with 11 seeds per pod each. Nylon-2 had the least (7) number of seeds per pod and was significantly different from Uncle-1, GBK-022534A and Uncle-2 with 9 seeds per pod each.

3.5.8 Weight of 100 seeds

The study results indicated significant ($P \leq 0.05$) differences among the accessions' 100 seed weight during the 2011 short rain and 2012 long rain seasons (Table 3.2). In 2011 short rain season the average 100 seed weight ranged from 3.2 to 7.9 g. Accession GBK-022501A had the highest (7.9 g) 100 seed weight and was significantly different from Uncle-2 with a 100 seed weight of 7.7 g, Nylon-2 with a 100 seed weight of 7.5 g and Nylon-1 which had a 100 seed weight of 6.6 g. Accession GBK-022508A had the least (3.2 g) 100 seed weight and was not significantly different from Ndengu-2 (3.9 g), N26 and GBK-022492A and with a 100 seed weight of 4.1 g each and GBK-022499A which had a 100 seed weight of 4.2 g. During the 2012 rain season the accessions had an average 100 seed weight ranging from 3.4 to 10.7 g. Accession Nylon-2 had the highest (10.7 g) 100 seed weight and was significantly different from Uncle-1 with a 100 seed weight of 7.7 g and Cotton with a 100 seed weight of 6.9 g. Ndungu-3 had the least (3.4 g) 100 seed weight and was significantly different from GBK-022537A (4.7 g), N26 and GBK-022498A with a 100 seed weight of 4.9 g each and GBK-022534A which had a 100 seed weight of 5.0 g.

3.5.9 Seed Yield

The study results indicated significant ($P \leq 0.05$) differences among the accessions' seed yield during the 2011 short and long rain seasons (Table 3.2). In 2011 short rain season the accessions' average seed yield ranged from 10.1 to 46.9 g. Accession GBK-022501A had the highest (46.9 g) and was not significantly different from GBK-022494A with a seed weight of 45.7 g and GBK-022498A which had a seed yield of 33.1 g. Ndengu-2 had the least (10.1 g) seed yield was not significantly different from GBK-022508A with a seed weight of 10.5 g, Nylon-2 which had a seed yield of 11.7 g and GBK-017437A which had a seed yield of 12.4 g. Seed yield was not influenced significantly ($P \leq 0.05$) by accessions during the 2012 long rain season.

3.5.10 Cluster analysis

The 35 accessions were divided into 2 main clusters (Figure 3.5). One cluster consisted of only one accession- GBK-022494A, which recorded the highest number of pods per plant, while the other cluster had 2 sub-clusters each comprising 2 sub-sub-clusters. There were 2 minor clusters; one of which consisted of 3 accessions; GBK-022508A, N26 and GBK-022498A while the other minor cluster consisted of 5 accessions; Cotton, Ndengu-2, GBK-017437A, Uncle-1 and Ndengu-1 (Figure 3.5).

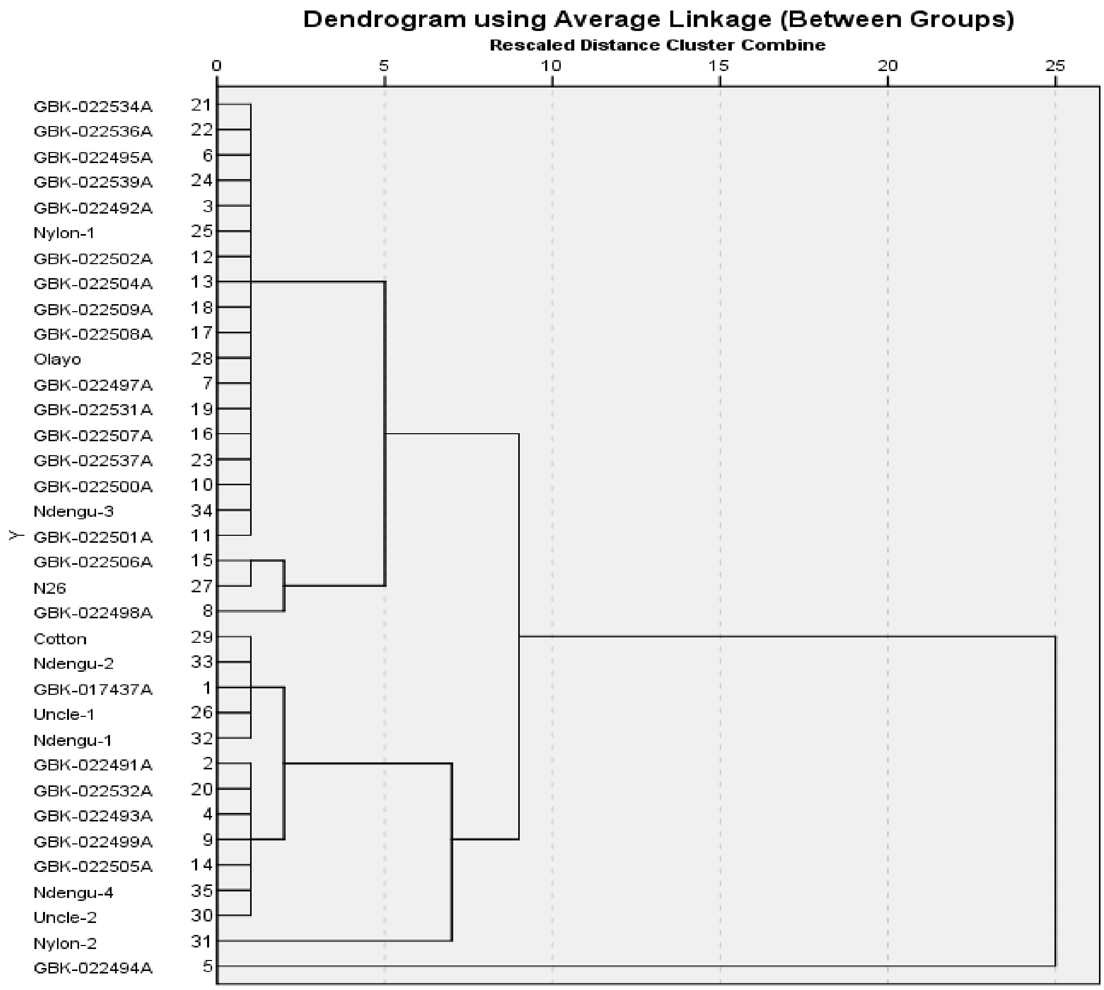

Figure 3.5: Dendrogram based on agronomic variables recorded on green gram accessions evaluated at Machakos ATC

3.5.11 Correlation among agronomic traits recorded at Machakos ATC

Results of correlation analysis in Table 3.3 indicated that the number of leaves per plant were positively correlated to number of pods per plant (0.461) and seed yield (0.369), while it was negatively correlated to pod length (-0.450), pod girth (-0.484) and 100 seed weight (-0.349). Number of days to flowering was positively correlated to number of days to maturity (0.393) (Table 3.3). It was negatively correlated to pod girth (-0.436). Plant height was positively correlated with number of pods per plant (0.463) and seed yield

(0.449). Number of pods per plant were positively correlated with number of leaves (0.461), plant height (0.463), and seed yield (0.831), while it was negatively correlated to pod length (-0.424), pod girth (-0.615) and 100 seed weight (-0.486). Number of seeds per pod was negatively correlated with pod girth (-0.495) and 100 seed weight (-0.531). Pod length was found to be positively correlated to pod girth (0.623) and 100 seed weight (0.439), while it was negatively correlated to number of leaves per plant (-0.450), and number of seeds per pod (-0.424); Pod girth was positively correlated to pod length (0.623) and 100 seed weight (0.678) while it was negatively correlated to number of leaves per plant (-0.484), days to flowering (-0.436), number of pods per plant (-0.615), number of seeds per pod (-0.495), and seed yield (-0.459). Number of days to maturity was positively correlated to days to flowering (0.393). Hundred (100) seed weight was positively correlated to pod length (0.439) and pod girth (0.678) while it was negatively correlated to number of leaves per plant (-0.349) and number of pods per plant (-0.486) and number of seeds per pod (-0.531). Seed yield was positively correlated to number of leaves per plant (0.369), plant height (0.449) and number of pods per plant (0.831). It was negatively correlated to pod girth (-0.459).

Table 3. 3: Correlation coefficients among agronomic traits recorded on green gram accessions at Machakos ATC

	L.WK6	DF	PH	PP	PS	PL	PG	DM	SW	SY
No.of Leaves										
No_of_days_to_flowering	.119									
Plant_height	.291	.323								
No_of_pods_per_plant	.461**	.181	.463**							
No_of_seeds_per_pod	.181	.293	.216	.231						
Pod length	-.450**	-.208	-.059	-.424*	.038					
Pod girth	-.484**	-.436**	-.246	-.615**	-.495**	.623**				
No.of days to maturity	-.077	.393*	.246	.269	-.223	.013	.022			
100 seeds weight	-.349*	-.325	-.188	-.486**	-.531**	.439**	.678**	.060		
Seed Yield	.369*	.062	.449**	.831**	.280	-.166	-.459**	.219	-.081	

L-WK6=Number of leaves at week 6, DF=No. of days to flowering, PH=Plant height, PP= Number of pods per plant, SP=Number of seeds per pod, PL=Pod length, PG=Pod girth, DM=Number of days to maturity' SW=100 seeds weight, SY=Seed yield

3.6 Results from Kiboko, Makueni County

3.6.1 Weather records

The daily rainfall (mm), daily mean temp (ºC) and daily RH (%) data are presented in Figure 3.6 and 3.7

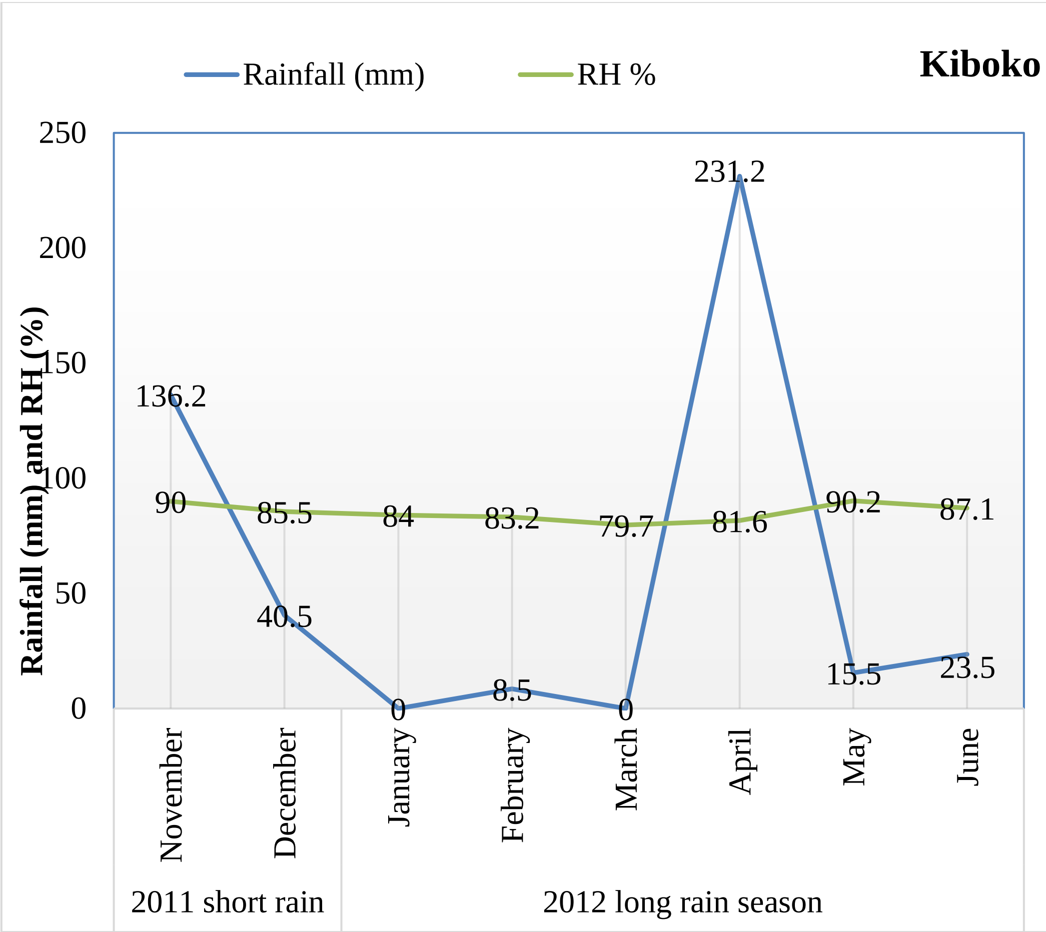

Figure 3.6: Rainfall (mm) and RH (%) data recorded during the growing period of green gram in 2011 short and 2012 long rains-Kiboko

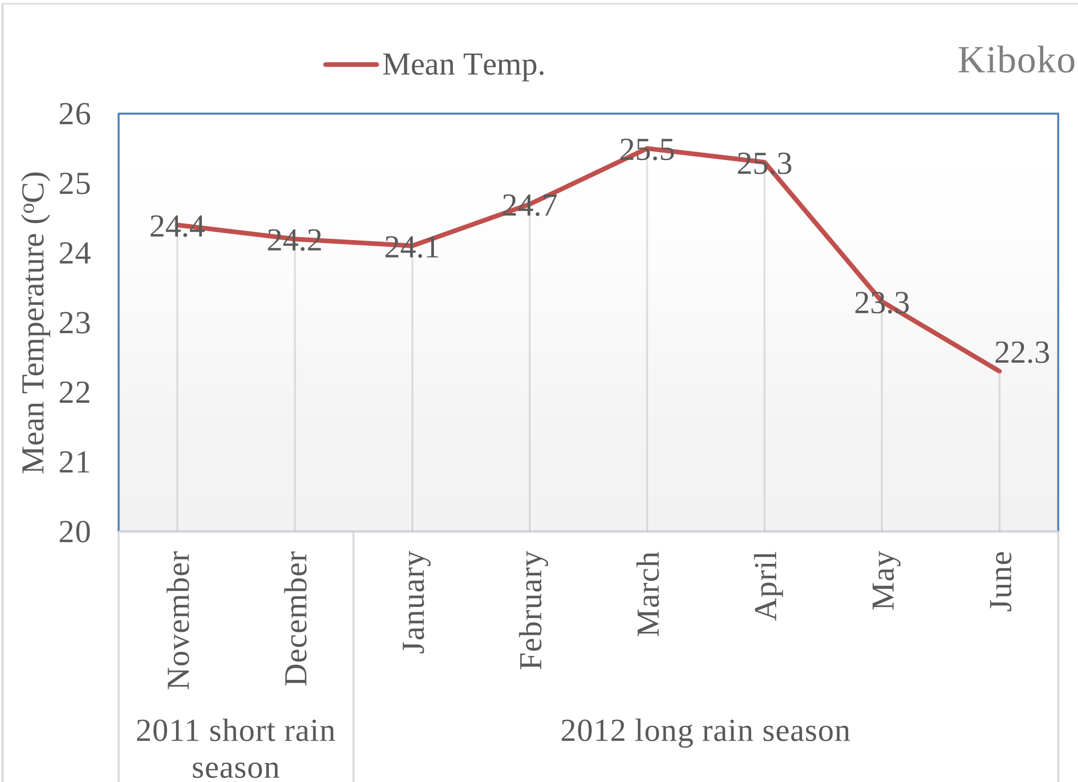

Figure 3.7: Temperature data recorded during the growing period of green gram in 2011 short and 2012 long rains-Kiboko

3.6.2 Plant height

The study results indicated significant ($P \leq 0.05$) differences among the accessions plant height during the 2011 short rain season (Table 3.4). The accessions had plant height ranging from 39.5 cm to 66.1 cm. Accession Ndengu-2 had the highest (66.1 cm) plant height and it was significantly different from GBK-022497A (63.0 cm), Ndengu-3 (61.7 cm) and GBK-022501A (60.8 cm). Accession GBK-017437A was the shortest (39.5 cm) and was significantly different from Olayo (46 cm), GBK-022534A (48.4 cm), Uncle-1 (48.5 cm) and GBK-022531A (50.2 cm). Plant height was not influenced significantly ($P \leq 0.05$) by accessions during the 2012 long rain season.

3.6.3 Number of days to maturity

The study results indicated significant ($P \leq 0.05$) differences among the accessions' number of days to maturity during 2011 short rain season (Table 3.4). Number of days to maturity ranged from 69 to 79 days. Accessions GBK-022502A, Nylon-2 and Ndengu-1 were the earliest (69 days) to mature and were not significantly different from GBK-022532A, GBK-022501A and GBK-022505A, which took 70 days to mature. Accession GBK-022536A was the latest (79 days) to mature although it was not significantly different from Ndengu-3 and GBK-022495A that took 78 days each to mature.

3.6.4 Pod length

The study results indicated significant ($P \leq 0.05$) differences among the accessions' pod length during the 2012 long rain season (Table 3.4). Pod length ranged from 8.0 to 9.4 cm. Accession Ndengu-4 had the longest (9.4 cm) pod length but was not significantly different from Uncle-2 with a pod length of 9.3 cm, Uncle-1 and Ndengu-1 that had a pod length of 9.2 cm each. Accessions GBK-018633A and GBK-022493A had the shortest (8.0 cm) pod length though they were not significantly different from GBK-022500A, GBK-022499A, GBK-022492A and GBK-022495A (8.1 cm each), GBK-022532A & GBK-022537A with a pod length of 8.2 cm long each. The pod length was not significantly ($P \leq 0.05$) affected by the accessions during the 2011 short rain season.

3.6.5 Pod girth

The study results indicated significant ($P \leq 0.05$) differences among the accessions' pod girth during the 2012 long rain season (Table 3.5). The pod girth ranged from 1.6 to 1.9 cm. Accessions GBK-022539A, Uncle-1, GBK-022491A, Nylon-2 and GBK-022502A had the widest (1.9 cm) pod girth while GBK-022499A and GBK-022498A had the least (1.6 cm) pod girth.

Table 3. 4: Various agronomic traits recorded on green gram genotypes at Kiboko during the 2011 shorts and 2012 long rain seasons

	Leaves		Plant height (cm)		Days to flowering		Days to maturity		Pod length (cm)	
Accessions	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Cotton	9.7	12.0	50.4	41.7	39.3	37.4	70.4	69.0	10.1	9.1
GBK-017437A	8.7	13.3	39.5	43.3	42.3	36.3	72.2	68.3	9.6	8.7
GBK-018633A	9.7	13.7	55.2	52.7	46.7	43.5	73.5	72.4	9.2	8.0
GBK-022491A	10.0	13.0	53.3	54.8	44.3	42.1	71.3	70.6	9.3	9.1
GBK-022492A	9.7	12.7	53.1	54.0	44.7	38.3	74.3	70.3	9.5	8.1
GBK-022493A	9.7	12.0	55.6	49.9	42.7	40.6	71.6	69.5	8.9	8.0
GBK-022494A	10.4	14.0	54.2	49.7	41.3	39.1	70.3	69.5	9.5	8.7
GBK-022495A	9.7	13.3	52.5	54.8	44.3	41.4	78.1	69.5	8.4	8.1
GBK-022497A	10.3	12.3	63.0	48.9	42.3	42.6	72.7	68.7	9.6	8.5
GBK-022498A	9.3	12.3	55.7	53.6	43.3	38.0	72.0	69.7	9.5	8.4
GBK-022499A	10.0	13.3	59.2	45.2	42.7	40.5	72.6	68.5	9.6	8.1
GBK-022500A	10.0	14.3	56.1	54.1	43.4	40.1	75.3	67.9	9.9	8.1
GBK-022501A	10.7	12.7	60.8	50.5	41.0	38.8	70.1	70.1	8.8	8.5
GBK-022502A	9.7	12.3	54.3	51.5	43.7	41.7	69.0	69.3	8.9	9.0
GBK-022504A	9.7	11.3	55.6	51.6	43.0	41.1	70.6	70.1	9.1	9.0
GBK-022505A	10.3	12.0	53.1	51.5	45.3	44.0	70.3	70.9	9.1	8.4
GBK-022506A	10.3	14.0	53.9	55.4	43.3	40.3	73.4	69.1	9.7	8.9
GBK-022507A	9.7	12.3	57.5	46.9	40.7	42.6	71.1	70.0	9.1	8.5
GBK-022508A	9.3	13.0	55.0	51.5	44.7	40.4	73.0	69.3	8.8	8.3
GBK-022509A	9.7	14.0	55.4	53.7	43.3	39.9	73.1	69.3	9.7	8.3
GBK-022531A	9.9	12.7	50.2	52.7	45.3	40.6	75.6	69.2	9.2	8.6
GBK-022532A	10.0	11.7	56.4	49.6	43.3	40.1	69.7	69.5	9.1	8.2
GBK-022534A	10.0	12.7	48.4	46.9	47.3	39.7	76.2	71.2	9.5	8.3
GBK-022536A	10.0	12.3	52.6	52.3	46.0	41.7	79.7	68.7	9.4	8.4
GBK-022537A	10.3	10.3	53.1	41.3	45.3	41.9	72.7	71.1	9.1	8.2
GBK-022539A	9.3	12.7	56.8	56.7	44.0	38.3	73.0	69.5	9.6	8.9
N26	9.7	12.7	58.9	49.1	46.3	41.5	75.3	68.7	9.4	8.5
Ndengu-1	10.0	12.3	51.1	41.4	41.3	39.5	69.1	69.1	9.6	9.2
Ndengu-2	10.3	14.7	66.1	49.2	44.7	42.3	76.2	71.6	9.1	8.5
Ndengu-3	10.0	12.3	61.7	50.9	46.0	41.2	78.3	66.0	9.2	8.8
Ndengu-4	10.0	12.7	55.8	54.9	42.0	41.5	73.8	68.1	9.8	9.4
Nylon-1	9.7	13.3	53.7	49.1	43.3	37.9	72.7	69.3	9.1	8.3
Nylon-2	10.0	12.0	52.8	47.6	39.7	37.5	69.1	70.1	9.7	9.0
Olayo	9.7	12.3	46.2	37.8	41.7	38.7	71.5	69.2	19.2	8.4
Uncle-1	10.0	11.3	48.5	44.5	40.7	39.2	71.9	69.1	9.7	9.2
Uncle-2	10.0	11.7	52.5	49.8	41.7	35.9	70.5	69.9	10.0	9.3
Mean	9.9	12.7	54.4	49.2	43.4	40.2	72.8	69.5	9.6	8.6
Minimum	7.3	7.7	34.4	39.9	45.7	38.2	75.0	84.2	8.0	7.8
Maximum	12.7	13.3	55.0	74.3	52.7	42.1	81.1	94.6	10.3	10.8
LSD ($P \leq 0.05$)	1.1	2.2	8.9	10.2	4.5	4.7	5.9	3.2	5	0.7
P value	0.466	0.159	0.001	0.051	0.052	0.139	0.038	0.499	0.65	<.001
CV%	2.7	5.9	5.1	10.7	0.6	5.9	2.8	1.3	5.3	5.9

3.6.6 Number of pods per plant

The study results indicated significant ($P \leq 0.05$) differences among the accessions' number of pods per plant during the 2011 short rain season (Table 3.5). The average number of pods per plant ranged from 26 to 115 pods. Accessions GBK-022494A had the highest (115) number of pods per plant and was significantly different from Ndengu-2 (92 pods), GBK-022502A which had 76 pods per plant and GBK-022501A with 66 pods. Accession GBK-018633A had the least (26) number of pods per plant although it was not significantly different from Cotton (29), Ndengu-1 with 31 pods per plant and Uncle-1 which had 33 pods per plant.

3.6.7 Number of seeds per pod

The study results indicated significant ($P \leq 0.05$) differences among the accessions' number of seeds per pod during the 2012 long rains season (Table 3.5). The average number of seeds per pod ranged from 9 to 11 seeds per pod. Accession Uncle-2, Ndengu-1, Ndengu-4 and GBK-022506A had the highest (11) number of seeds per pod each. Accessions Nylon-1, GBK-022495A and GBK-022492A had the least (9) number of seeds per pod each.

3.6.8 Weight of 100 seeds

The study results indicated significant ($P \leq 0.05$) differences among the accessions' 100 seed weight during the 2011 short and 2012 long rain seasons (Table 3.5). During 2011 short rain season the accessions had an average 100 seed weight ranging from 3.5 to 10.6 g. Accession Nylon-1 had the highest (10.6 g) 100 seed weight and was not significantly different from GBK-017437A with a 100 seed weight of 8.7 g. Accession Ndengu-2 had the least (3.5 g) 100 seed weight and was not significantly different from GBK-022497A (5.2 g), GBK-022504A and N26 with a 100 seed weight of 5.5 g each and also Ndengu-3 with 5.8g. During the 2012 long rain season the accessions had an average 100 seed weight ranging from 5.6 to 8.0 g. Accession Uncle-1 and Nylon-1 had the highest (8.0 g each) 100 seed weight and were not significantly different from Nylon-2 (7.8 g) and Uncle-2

Table 3. 5: Various agronomic traits recorded on green gram genotypes at Kiboko during the 2011 shorts and 2012 long rain seasons

	Pod girth (cm)		Pods per plant		Seeds per pod		100 seeds weight (g)		Seed yield (g)	
Accessions	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Cotton	1.9	1.8	29.5	16.3	12.1	11.1	6.3	7.5	23.0	12.2
GBK-017437A	1.8	1.9	35.5	27.0	11.8	11.1	8.8	6.8	36.5	19.4
GBK-018633A	1.8	1.7	26.8	20.5	12.1	10.1	6.0	6.1	19.9	12.1
GBK-022491A	1.7	1.9	51.8	20.9	11.0	11.3	7.1	6.0	42.4	14.5
GBK-022492A	1.7	1.7	45.6	31.4	11.2	9.7	6.7	6.0	35.2	18.4
GBK-022493A	1.7	1.8	57.5	22.6	11.3	10.7	6.6	7.0	43.6	17.1
GBK-022494A	1.8	1.8	115.0	29.9	11.0	10.9	7.5	6.3	91.1	20.0
GBK-022495A	1.8	1.7	48.4	23.6	11.6	9.9	7.3	6.5	41.1	14.4
GBK-022497A	1.8	1.7	54.7	25.7	11.9	10.7	5.2	7.5	33.3	18.7
GBK-022498A	1.7	1.6	46.2	23.3	12.0	10.6	6.5	6.0	36.6	15.0
GBK-022499A	1.7	1.6	57.5	18.5	11.6	10.4	6.4	5.7	44.4	11.5
GBK-022500A	1.8	1.7	50.7	32.1	11.9	10.4	6.8	6.4	40.7	20.1
GBK-022501A	1.7	1.8	66.8	30.2	10.7	10.7	6.1	6.0	43.7	20.3
GBK-022502A	1.7	1.9	76.8	19.5	13.7	11.5	6.8	6.6	75.3	15.0
GBK-022504A	1.7	1.8	63.2	21.2	11.0	11.5	5.5	6.7	38.5	15.0
GBK-022505A	1.6	1.7	44.0	20.5	10.7	10.5	6.2	5.9	30.4	12.3
GBK-022506A	1.8	1.8	47.6	21.9	10.7	11.5	7.5	6.3	37.9	15.4
GBK-022507A	1.6	1.8	53.4	21.5	9.8	10.7	6.8	6.6	34.9	16.1
GBK-022508A	1.8	1.7	44.6	26.9	11.9	10.4	7.3	5.8	38.6	14.4
GBK-022509A	1.8	1.7	49.3	28.9	11.1	11.0	7.1	6.7	41.6	20.3
GBK-022531A	1.8	1.8	38.9	24.4	11.4	10.8	6.4	6.7	29.4	17.5
GBK-022532A	1.8	1.9	38.3	17.9	11.0	10.3	6.0	7.1	27.8	13.1
GBK-022534A	1.8	1.8	47.2	22.2	12.1	10.4	7.2	6.0	40.7	14.5
GBK-022536A	1.8	1.8	43.9	24.9	11.2	11.3	6.1	6.1	29.4	17.9
GBK-022537A	1.7	1.8	63.4	14.1	11.6	10.5	6.8	6.5	48.3	9.7
GBK-022539A	1.7	1.9	36.0	24.5	11.7	11.4	7.1	7.2	30.5	20.1
N26	1.7	1.7	61.3	18.7	11.6	10.8	5.5	5.7	41.2	11.5
Ndengu-1	1.8	1.8	31.0	14.0	11.2	11.8	8.0	7.2	28.0	12.2
Ndengu-2	1.7	1.8	92.8	25.7	11.9	10.9	3.5	5.6	38.7	14.9
Ndengu-3	1.7	1.8	57.5	20.7	11.7	11.2	5.8	5.9	39.0	13.5
Ndengu-4	1.8	1.8	57.7	24.9	11.7	11.8	7.6	6.7	50.9	19.6
Nylon-1	1.7	1.8	54.5	27.1	10.6	9.9	10.6	8.0	65.4	22.2
Nylon-2	1.8	1.9	51.5	20.9	10.6	11.1	6.2	7.8	33.4	18.0
Olayo	1.8	1.9	34.8	24.3	11.0	10.3	6.6	7.3	26.5	18.4
Uncle-1	1.8	1.9	33.3	18.5	11.3	11.2	6.9	8.0	25.7	17.4
Uncle-2	1.9	1.9	62.6	26.5	10.8	11.9	7.8	7.5	47.3	25.0
Mean	1.8	1.8	51.9	23.1	11.4	10.8	6.7	6.6	39.7	16.3
Minimum	1.4	1.7	18.7	25.0	8.3	7.5	3.2	3.4	10.1	16.2

Maximum	2.2	2.5	102.5	61.2	12.3	12.2	7.9	10.7	46.9	33.1
LSD (P≤0.05)	0.2	0.2	21	10.3	70	1.2	2.4	1.2	24	6.6
P value	0.092	0..018	<.001	0.068	0.142	0.02	0.021	<.001	<.001	0.003
CV%	3	2.1	13.1	18.5	3.5	5.9	4.3	4.8	5.9	19.6

(7.5 g). Accession Ndengu-2 had the least (5.6 g) 100 seed weight and was not significantly different from GBK-022499A and N26 both of had 5.7 g each.

3.6.9 Seed yield

The study results indicated significant (P≤0.05) differences among the accessions' seed yield during the 2011 short rain season (Table 3.5). The accessions had an average seed yield ranged from 19.9 g to 91.1 g. Accession GBK-022494A had the highest (91.1 g) seed yield and was not significantly different from GBK-022502A with a seed yield of 75.3 g. Accession GBK-018633A had the least (19.9 g) seed yield and was not significantly different from Cotton (23.0 g), Uncle-1 (25.7 g) and Olayo (26.5 g).

3.6.10 Cluster analysis

The 36 accessions were clustered into 2 major clusters (Figure 3.8). One cluster consisted of only one accession – GBK-022494A which recorded the highest number of pods per plant and seed yield as compared to the other accessions (Table 3.5), while the other cluster had 2 sub-clusters each, which were further sub-divided into 2 sub-sub clusters. There were two minor clusters each consisting of 2 accessions: Ndengu-4 and Uncle-2, while the other one consisted of Nylon-1 and GBK-022502A.

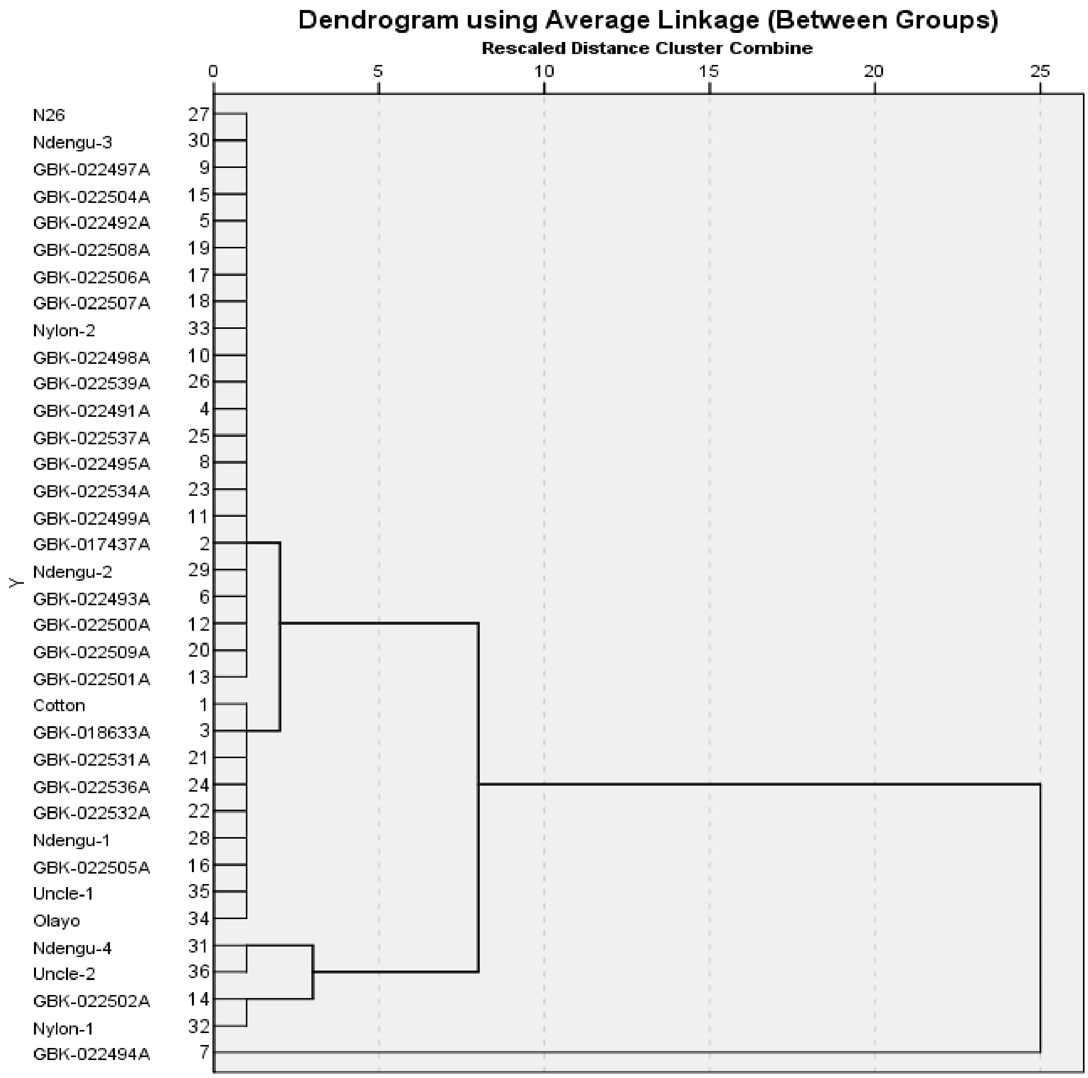

Figure 3.8: Dendrogram based on agronomic variables recorded on green gram accessions evaluated at Kiboko

3.6.11 Correlation among agronomic traits recorded at Kiboko

Results on correlation analysis are given in Table 3.6 indicated that the number of leaves per plant was positively correlated to plant height (0.404), number of pods per plant (0.511) and seed yield (0.341). Number of days to flowering was positively correlated to plant height (0.426), and days to maturity (0.649). It was negatively correlated to pod girth (-0.349), number of seeds per pod (-0.478) and 100 seed weight (-0.562); Plant height was found to be positively correlated to number of leaves per plant (0.404), number of days to flowering (0.426) and number of pods per plant (0.407) while it was negatively correlated to pod girth (-0.504), number of seeds per pod (-0.519) and 100 seeds weight (-0.468). Number of pods per plant was positively correlated to number of leaves per plant (0.511), plant height (0.407) and seed yield (0.803); pod girth was positively correlated to 100 seed weight (0.552) while it was negatively correlated to number of days to flowering (-0.349) and plant height (-0.504). Number of seeds per pod was found to be negatively correlated to the number of days to flowering (-0.478) and plant height (-0.519). Number of days to maturity was positively correlated to days to flowering (0.649) and was negatively correlated to 100 seed weight (-0.403). Hundred (100) seed weight was positively correlated to pod girth (0.552) and was negatively correlated to the number of days to flowering (-0.562), plant height (-0.468), and days to maturity (-0.403). Seed yield was positively correlated to the number of leaves per plant (0.341) and the number of pods per plant (0.803).

Table 3. 6: Correlation coefficients among agronomic traits recorded at Kiboko

	L-WK6	DF	PH	PP	SP	PL	PG	DM	SW	SY
No. of leaves at week 6			-	-	-					
No. of days to flowering	0.161	-								
Plant height	.404*	.426**								
No of pods per plant	.511**	0.015	.407*							
Pod length cm	-0.092	0.034	0.025	0.037						
Pod girth cm	-0.13	-.349*	-.504**	-0.18	0.019					
No of seeds per pod	-0.162	-.478**	-.519**	-0.21	0.258	0.328				
No.of days to maturity	0.294	.649**	0.287	0.034	-0.1	-0.246	-0.26			
100 seeds weight	-0.211	-.562**	-.468**	-0.23	-0.1	0.171	.552**	-.403*		
Seed yield	.341*	-0.179	0.161	.803**	0.115	-0.115	0.036	-0.2	0.309	

L-WK6=No. of leaves at week 6, DF=No. of days to flowering, PH=Plant height, PP= No. of pods per plant, SP=No. of seeds per pod, PL=Pod length, PG=Pod girth, DM=No. of days to maturity’ SW=100 seeds weight, SY=Seed yield

3.7 Discussion

Plant height of the green gram accessions at Machakos ATC was 37cm-63cm and 41cm-45cm at Kiboko. Plant height is a central part of plant ecological strategy (Moles *et al*, (2009). It is strongly correlated with life span, seed mass and time to maturity, and is a major determinant of a species' ability to compete for light. This corroborates the findings of Canci and Toker (2014), that plant height is an important agronomic trait that directly affects the yield a crop and that unless, the height leads to lodging of the crop, it is essential to increase plant height in order to increase yield as it also strongly correlated to the number of pods per plant (Canci and Toker, 2014), this implies that, the taller the plant the higher yields.. The variation in plant height can be attributed to their inherent genes (Romana *et al*, 2013) as well as the environmental conditions. In connection with this, it can be explained that the accessions performed better under Machakos ATC conditions as compared to Kiboko due to the different environmental conditions. Other studies reported comparable results, for instance, Romana *et al.,* (2013); Narasimhulu *et al.*, (2013); Raturi *et al.,* (2012); Hussain *et al*, (2011); Machikowa and Laosuwan, (2009);Khajudparn and Tantasawat (2011); and Mondal *et al.*, (2009). The results were in disagreement with Bekheta and Talaat (2009) who reported a mean plant height of 92cm, Gadakh *et al.*, (2013), reported a green gram plant height of 65.0 cm – 80.1 cm; which is quite high as compared to this study and Ganguly and Bhat (2012), reported a very wide plant height range of 14 cm – 88 cm.

The accessions took 42 - 47 days from emergence to flowering at Machakos ATC and 38-45 days at Kiboko. These results were comparable to those of other scientists working on *Vigna radiata* such as; Romana *et al.*, (2013) while evaluating mungbean (*Vigna radiata*) genotypes under rainfed conditions; Raturi *et al.*, (2012) working on Indian *Vigna radiata* genotypes under arid conditions; Ganguly and Bhat (2012); and Khajudparn and Tantasawat (2011). The reason why the accessions at Machakos ATC took relatively more days to flower as compared to Kiboko could be due to the relatively higher temperature

(24.3^0C) at Kiboko as compared to Machakos ATC (20.1^0C). However, the varied number of days taken by different accessions to flower can be attributed to the inherent genes (Romana *et al*, 2013).

The accessions took 81-87 days to mature at Machakos ATC and 69 - 74 days at Kiboko. The maturity period of a crop is a very important factor considered in the choice of planting material (Abadassi, 2015). Crop varieties are bred according to the agro-ecological zones (AEZ). Low altitude areas with relatively high temperatures and low, erratic rainfall are normally suited for crop varieties which are drought escaping. Such varieties should also be early maturing in order for them to bear fruits before terminal drought as well as pests and diseases damage which normally sets in later in the cropping season (Mortimore *et al.*, 1997) which characterize the ASALs. Early maturity in a plant is a combination of early flower initiation and short grains filling period (Abadassi, 2015; Adeyanju and Ishiyaku, 2007. The early maturing provide first food sooner than any other crop, thus shortening the hunger period (Ayo-Vaughao *et al.*, 2011) and can also be used for rotational purposes with cereals (Pswarayi and Vivek, 2007). Other researchers reported comparable results such as; Machikowa and Laosuwan, (2009), who reported 82 - 89 days to mature. The results were not comparable to those of other researchers; Khajudparn and Tantasawat (2011), who reported 53 - 62 days to mature, and Romana *et al.*, (2013) 47 – 50 days to maturity. The varied number of days to maturity among the different accessions could be attributed to the inherent genes (Rehman *et al.*, 2009; Romana *et al.*, 2013).

Pod length was 8.0cm -10.5 cm at Machakos ATC and 8.3 cm-13.8 cm at Kiboko. The longer the pod the more the number of seeds per pod, which would contribute to higher seed yield. Therefore breeding for longer pod length could lead to increased seed yield (Canci and Toker, 2014; Adewale *et al.*, 2013). Other researchers reported comparable results such as Raturi *et al.*, (2012) who reported a pod length range of 6 cm – 10 cm; (Gadakh *et al.*, 2013) 7.1 cm – 10.3 cm; Khajudparn and Tantasawat (2011) 6.9 cm – 9.9

cm; Rozina *et al.*, (2007) 6.4 cm – 9.1 cm and the differences among the tested accessions could be attributed to different genetic background (Rozina, *et al.*, 2007).

Pod girth was 1.6 cm - 2.3 cm at Machakos ATC 1.6 cm - 1.9 cm at Kiboko. Pod girth (width) is positively corrected to both 100 seeds weight and seed yield (Canci and Toker, 2014) as well as pod length (Adewale *et al.*, 2013). This is because the big the pod girth, the bigger the size of the grain inside the pod and hence the heavier the grain. Therefore improving pod girth would lead to increased seed yield. Other researchers reported non-comparable results such as; Ganguly and Bhat, (2012) who reported a pod girth range of 0.2 cm-0.4 cm. According to Rehman *et al.*, (2009); Romana *et al.*, 2013). The varied size of pod girth attained by different accessions can be attributed to the inherent genes.

The number of pods per plant at Machakos ATC ranged from 24 - 67 and 23 - 72 in Kiboko. Number of mature pods per plant is strongly correlated to seed yield (Mondal *et al.*, 2011; Canci and Toker, 2014). This implies that for increased seed yield, a producer or breeder should focus on aspects which increase the number of pods per plant. The values obtained in this study were comparable to those reported by Machikowa and Laosuwan, (2009; Rozina *et al*, (2007);, but quite high compared to those reported by other researchers, for instance; Ramana *et al.*, (2013); Narasimhulu *et al.*, (2013); (Gadakh *et al.*, 2013); Raturi *et al.*, (2012); Hussain *et al.*, (2011); Khajudparn and Tantasawat (2011); Bekheta and Talaat (2009).

The number of seeds per pod was 8 – 12 seeds at Machakos ATC and 10 – 13 seeds at Kiboko. Number of seeds per pod is correlated to the seed yield (Canci and Toker (2014) implying that the higher the number of seeds per pod, the higher the seed yield. Therefore for increased seed yield, factors contributing to increased seeds per pod were considered. Other Researchers reported comparable results, for instance Ter and Ugase (2009); Raturi *et al.,* (2012); Narasimhulu *et al.,* (2013); Gadakh *et al.,*(2013); Khajudparn and Tantasawat (2011); Hussain *et al.*, (2011); Rozina *et al.*, (2007). The varied number of seeds per pod among the different accessions could be attributed to the inherent genes Rehman *et al*., (2009); Romana *et al*., (2013).

The 100 seed weight was 4.1 - 9.1 g at Machakos ATC and 4.9 - 9.3 g at Kiboko. The size of seed determines the weight of 100 seed, implying that bigger seeds will give a higher 100 seed weight as compared to smaller sized seeds. Therefore, breeding for larger sized seeds or providing a conducive production environment would lead to higher seed yield. Different green gram genotypes attain different 100 seed weight, which corroborates with Rehman *et al*., (2009) Romana *et al*., (2013), who stated that varied 100 seed weight among the different accessions, could be attributed to the inherent genes. Comparable results were reported by; Khajudparn and Tantasawat (2011); Machikowa and Laosuwan, (2009); Rozina *et al.*, (2008); Rozina *et al*., (2007); and Ganguly and Bhat (2012).

Seed yield was 15.8 - 35.4 g per plant in Machakos ATC and 16.1 - 55.6 g per plant at Kiboko. Seed yield is the total sum of the weight of the individual seeds from one plant. Application of good agronomic practices could lead to improved seed yield. Different varieties could produce different seed yields which according to Rehman *et al.*, (2009) Romana *et al.*, (2013) is brought about by inherent genes as well as the prevailing agro-ecological conditions. Seed yields in this study were higher than those reported by other researchers; Gadakh *et al.*, (2013); Mondal *et al.*, (2014); Narasimhulu *et al.,* (2013); and Rozina *et al.,* (2007). The varied plant seed weight among the different accessions could be attributed to the inherent genes (Rehman *et al*., 2009; Romana *et al*., 2013). Hence the accessions' inherent genes performed better under the conditions of 2012 rain season.

Cluster analysis categorized the accessions into groups which are more similar to each other than to those in other groups implying that the accessions which are clustered together may be containing similar germplasm. Some accessions were clustered into different groups at Kiboko compared to Machakos ATC which could imply that some of the green gram accessions' parameters were suited differently in different agro-ecological zones (AEZs).

This could explain why some accessions had different values in the different sites hence clustered in different groups. This corroborates with FAO (1996) and Hermann and Toth (2011) who indicated that different crops perform differently different AEZs. Therefore, for better performance, the accessions should be grown where they are best suited. The cluster analysis revealed that GBK-022494A stood out in both sites and also had the highest number of pods per plant in both sites, hence this genotype should be emphasized.

Positive correlation between any two growth parameters implies that improving one parameter leads to the increased growth of the other parameter. However, negative correlation implies that when one growth parameter is improved, the other one decreases. Therefore, when leaves are found to be positively correlated to certain growth parameter, it implies that, by increasing the number of leaves as well as leaf area of the said growth parameters will also be improved. In this case, increasing the number of leaves led to increased plant height, number of pods per plant and seed yield. Green leaves are the principal part of a plant which carries out photosynthesis (Stewart *et al.*, 1974) in daylight hours. To achieve high yield, maximization of leaf area is an important factor (Morteza *et al.*, 2011). Improving plant height led to increased number of leaves per plant, number of pods per plant, pod length and seed yield.Improving plant height led to decrease in 100 seed weight. The higher the plant height combined with higher number of leaves led to a more the surface area for photosynthesis resulting in more pods per plant enventually leading to higher seed yield. Therefore, when selecting for high yielding green gram accessions, plant height parameter would be a good trait.

Improving number of pods per plant led to increased seed yield, however, improved number of pods per plant led to decreased, pod girth and 100 seeds weight, improving the number of seeds per pod led to increased seed yield and decreased pod girth and 100 seed weight. Improvement in the pod length led to an increase in 100 seed weight and seed yield. However, improving 100 seed weight led to increased pod length. However, improving number of days to flowering, plant height, number of pods per plant and number of seeds per pod led to decreased pod girth, and that improving number of leaves per plant, number of days to flowering, plant height, number of seeds per pod, pod girth, and number of pods per plant led to decreased 100 seed weight, improving the number of leaves per plant, plant height, and number of pods per plant, number of seeds per pod led to increased seed yield, while improving the pod girth led to decreased seed yield.

Conclusion.

Accessions were found to significantly vary in plant height, pod length, pod girth, number of pods per plant, number of seed per pod, and hundred seeds weight during the 2011 short and 2012 long rain season in Machakos ATC.. Seed yield varied among the accession during the 2011 short rain season while the number of days to flowering significantly varied among accessions during the 2012 long rain season in Kiboko.

Recommendation

For better, green gram production, genotypes should be grown in the enviroments, where they are best suited. For instance GBK-022494A and Nylon-1 should be grown in Kiboko and its environs. In Machakos, GBK-022501A and GBK-022494A are the most suited.

CHAPTER FOUR

AGRONOMIC PERFORMANCE OF GREEN GRAM ACCESSIONS GROWN UNDER REDUCED LIGHT INTENSITY IN MACHAKOS AND MAKUENI COUNTIES, KENYA

4.1 Abstract

Green gram is well adapted to Arid and Semi-Arid Areas (ASALs). However, the high solar radiation and temperature in these areas lead to high evapo-transpiration rates, which may result in depressed crop yield. To address this, a study was conducted to evaluate the effect of reduced light intensity on the agronomic performance of four green gram accessions. The study was carried out at Machakos ATC, Machakos County and Kiboko in Makueni County, (shade net used reduced light intensity by 35 percent), Kenya during the 2012 short and 2013 long rain seasons. The trial was laid out in a split-plot arrangement. Data collected on various growth and yield parameters was subjected to analysis of variance using GenStat Ver. 12 software. In Machakos, days to maturity were 86 under the shade and 81 days under the direct solar radiation during the 2012 rain season. During the 2013 long rain season, plant height was 23.2 cm under the shade and 37.4 cm under direct solar radiation. At Kiboko, each pod had attained 9 seeds under shade and 8 seeds under direct solar radiation during the 2012 short rains season. During the 2013 long rain season, plants had a height of 54.7 cm under shade and 50cm under direct solar radiation. Traits values were higher under shade during the 2012 short rains and higher under direct solar radiation during the 2013 long rains in both sites. This study concludes that, green gram performed better under shade net than under direct solar radiation when rainfall amounts were below normal.

4.2 Introduction

Green gram also known as mung bean originated from India dating back in 1,500 – 1,000 BC. Its cultivation has since then spread to various parts of the world. It has become a major pulse crop outside Asia and many tropical African countries including Kenya where it is grown in the eastern part of the country. Green gram is used in very many ways such as whole grain mixed with maize to form a main meal, soups, porridge, split to form dhal, sprouted and eaten either raw or cooked; its immature pods and young leaves eaten as vegetables. The remnants (plant, pod shells) can be fed to livestock. Green gram is also grown for fodder, green manure as well as cover crop.

Kenya's economy depends on agriculture and with only 20% of the land area lying in high and medium potential that is not enough to produce adequate food for the growing population. This therefore calls for production of food crops in the Arid and Semi-Arid Lands (ASALs), areas characterized by high temperatures, low and erratic rainfall. Hence the need to grow crops which are suitable in such areas e.g green grams. Green gram (*Vigna radiata* (L.) is the hardiest of all pulses (Chhidda *et al.*, 2011) and is well adapted to ASALs. However, the high light intensities, high temperatures and erratic rainfall experienced in these areas lead to high evapo-transpiration rates leaving less water available to plant, which may negatively affect the growth and yield parameters. The amount of light intensity in these areas is high and causes high evapo-transpiration and there is need to manage it.

Light is one of the ecological factors exerting the greatest effect on germination, seedling emergence and development (Benvenuti *et al.*, 2001; Guenni *et al.*, 2008). Shading reduces air and soil temperature (Makus, 2001; Makus and Lester, 2002) thus reducing water loss through evaporation and transpiration from plants and this may lead to better agronomic performance of crops in ASALs. According to Hashem *et al.*, (2006), shade, irrespective of its source, reduces irradiance especially so in the Photosynthetically Active Radiation (PAR) at (400-700nm). Guenni *et al.*, (2008) indicated that 3 major physiological responses to shade have been observed that is a reduction in the respiration rate, an increase in the shoot to root partitioning and an increase in the specific leaf area with a relatively low leaf mass ratio. Further, Guenni *et al.*, (2008) indicated that in areas where water and nutrients are limited, there is increasing evidence that substantial improvements in herbage yield and forage nutrient quality can be obtained when C4 grasses are grown under tree shade in tropical and subtropical grasslands. According to Wilson (1996) the most consistent benefit from shade is better soil moisture, leading to a higher soil organic matter breakdown and, therefore, more Nitrogen (N) is available in the soil. Therefore, it is important to introduce shade to a crop in order to achieve good agronomic performance.

According to Makus, (2001) reducing the light intensity by 30% did not affect the yield of snap bean and that light reduction tended to decrease pod size, plant biomass, and leaf greenness, while leaf area and chlorophyll contents were increased with increased shading. Also incidences of powdery mildew occurred late in the season and were linearly increased by reduced light. The objective of this study was to evaluate the agronomic performance of green gram accessions under reduced light intensity in the Arid and Semi-Arid areas in Machakos and Makueni Counties.

4.3 Materials and Methods

4.3.1 Site description

The sites are as described in section 3.3.1 and detailed on Figures 3.1 and 3.2

4.3.2 Sources of green gram genotypes

Four green gram genotypes were used in this study. The genotypes were identified from the study on seed yield during 2011 short rains and long rains of 2012 carried out in two different sites, whereby the best overall across sites, the best in each of the sites and the best commercial genotype were selected. The selected accessions were; GBK-022494A as the best across sites, GBK-022502A as the best in Kiboko, GBK-022501A best in Machakos ATC, while the commercial accession was Nylon-1 as indicated on Table 4.1.

Table 4. 1: Green Gram accessions and their source

Accession	Seed Yield (gm plant^{-1})	Seed yield (ton ha^{-1})	Remarks
GBK-022494A	55.6	7.4	Best overall
GBK-022502A	45.2	6.0	Best in Kiboko
GBK-022501A	35.4	5.8	Best in MKS ATC
Nylon-1	43.8	4.7	Commercial variety

4.3.3 Preliminary trial on the appropriate shade net for the study

Before embarking on this experiment, a preliminary trial was conducted to establish the appropriate shade net that reduced the amount of light striking the plant canopy without interfering with the Photosynthetically Active Radiation (PAR). Shade nets that reduced the amount of light intensity striking the plant canopy by 35%, 45% and 50% were evaluated. The shade net reducing the amount of light by 35% was found not to interfere with PAR, and hence was used in this study.

4.3.4 Experimental layout and treatments

The experiment was laid out in a split-plot design with three replications. The main plot was shade while the accessions were the sub-plots (Plate 4.1). The 4 accessions were then planted under the shade net which reduced the amount light intensity by 35% and also under direct light intensity. This acted as the control. The plot sizes were as indicated on 3.3.3. During the 2012 short rains, the crop was planted on 2nd November 2012 at

Machakos ATC. At Kiboko the crop was planted on 4th December, 2012. During the 2013 long rains, planting took place on 22nd March, 2013 at Machakos ATC and 28th March, 2013 at Kiboko. The onset of rains determined the planting date. However, the plots at Machakos ATC were replanted on 6th April 2013 due to poor germination, which might have been occasioned by heavy rainfall (Figure 4.1).

Plate 4. 1: Green gram genotypes grown under shade net during the 2012 short rain season at Kiboko

4.3.5 Agronomic practices

The agronomic practices were carried out as described in section 3.3.4

4.3.6 Data collection

Data collection was carried out as decribed on section 3.3.5

4.4 Data analysis.

Data analysis was undertaken as indicated on 3.4.

4.5 Results from Machakos ATC, Machakos County

4.5.1 Weather data

During the 2013 long rain season Machakos ATC received higher (497.9mm) amount of rainfall as compared 245.3mm received in 2012 rain season, Relative humidity (RH %) ranged between 49 and 71.2 % (Figure 4.1). The recorded mean temperature ranged from 17.1 to 21.8 ^{o}C (Figure 4.2).

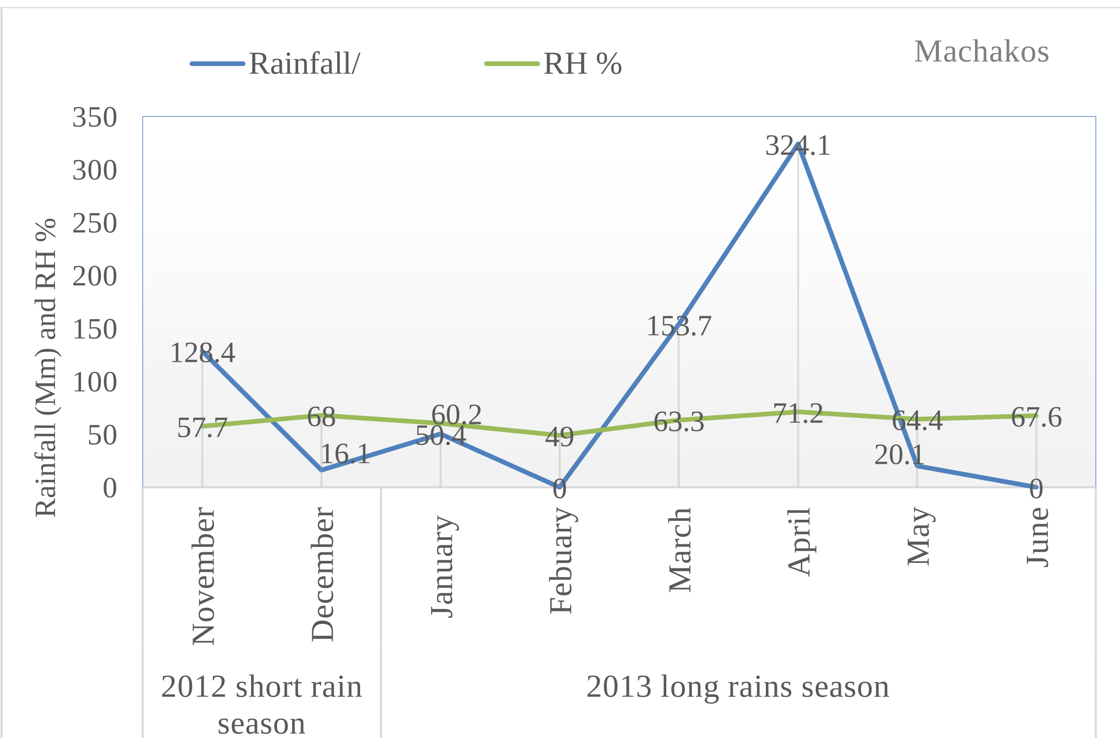

Figure 4.1: Rainfall (mm) and RH % data recorded during the 2012 short and 2013 long rain seasons for Machakos ATC

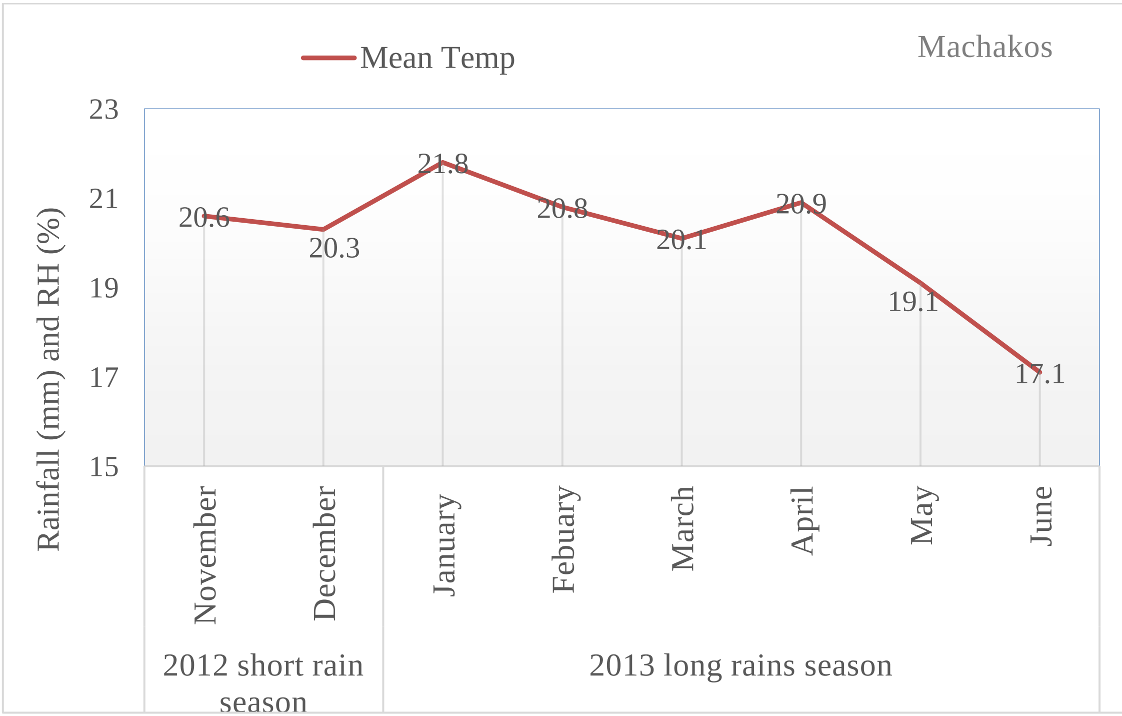

Figure 4.2: Mean Temperature data recorded during the 2012 short and 2013 long rain seasons for Machakos ATC

4.5.2 Plant Height

The study results indicated that shade had no significant ($P \leq 0.05$) effect on accessions' plant height during the 2012 short rain season (Table 4.2). Significant ($P \leq 0.05$) differences among the accessions' plant height under the shade treatment were observed while accessions had no effect on plant height during the 2013 long rains season (Table 4.3). The plants had an average plant height of 37.4 cm under the control compared to the shade net (23.2 cm).

4.5.3 Number of days to flowering

The study indicated accessions had significant ($P \leq 0.05$) effect on the number of days to flowering while shade had no effect on number of days to flowering during the 2012 short rains (Table 4.2). Accession GBK- 022501A took the least (44) number of days to flower though it was not significantly different from GBK-022494A which took 46 days to flower. Nylon-1 (the check) took the most (50) number of days to flower, though it was not significantly different from GBK-022502A which took 48 days to flower.

4.5.4 Pod length

The results of the study indicated that shade treatments had significant ($P \leq 0.05$) differences on the pod length of the green gram accessions during the 2013 long rain season (Table 4.2). Pod length was the longest (8.1cm) under the control as compared to pod length of 6.1cm under the shade net. Accessions had significant ($P \leq 0.05$) effect on the pod length during the 2012 short rain season (Table 4.3). Accession GBK-022502A had the longest (8.2 cm) pod length although it was not significantly different from Nylon-1 (7.8 cm) while GBK=022494A had the shortest (7.5 cm) pod length although it was not significantly different from GBK-022501A (7.7 cm) during the 2012 short rains (Table 4.3).

4.5.5 Number of pods per plant

The study results indicated that shade had significant ($P \leq 0.05$) effect on the accessions' number of pods per plant during the 2013 long rain season (Table 4.2). Under the shade net, plants had a lower (8) number of pods per plant while under the direct solar radiation (control), the plants had a higher (22) number of pods per plant.

4.5.6 Number of seeds per pod

The study results indicated that shade had significant ($P \leq 0.05$) effect on the number of seeds per pod during the 2012 short rain season (Table 4.2). The pods had a higher (10) number of seeds under the shade net while a lower (9) number of seeds per pod was realized under the control.

Table 4. 2: Values for net and control treatments of all the traits at MKS ATC during 2012 short and 2013 long rain seasons

Shade	Plant height (cm)		No. of days to flowering		No. of days to maturity		Pod length (cm)		No. of pods per plant		No. of seeds per pod		100 seeds weight (g)		Seed yield (g)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Net	74.6	23.2	48.5	47.5	86.2	73.7	7.9	6.1	32.5	8.0	10.2	8.0	5.7	3.7	18.9	3.9
Control	66.2	37.4	46.6	51.9	81.5	95.0	7.7	8.1	24.6	22.1	9.7	10.0	5.8	5.3	13.9	12.1
Mean	70.4	30.3	47.5	49.7	83.8	84.3	7.8	7.1	28.5	15.0	9.9	9.0	5.8	4.5	16.4	8.0
LSD($P \leq 0.05$)	12.45	7.1	5.046	30.51	4.218	31.65	0.46	1.687	17.84	11.43	0.56	3.075	0.626	1.732	11.2	5.58
Shade (P-Value)	0.101	0.013	0.252	0.599	0.04	0.101	0.255	0.036	0.196	0.034	0.049	0.112	0.346	0.056	0.191	0.19
Shade.Accen (P-Value)	0.686	0.895	0.188	0.366	0.259	0.669	0.608	0.75	0.657	0.588	0.356	0.74	0.448	0.889	0.793	0.79
CV%	5	6.7	3	17.5	1.4	10.7	1.7	6.8	17.8	21.7	1.6	9.8	3.1	10.9	19.3	19.8

Table 4. 3: Values for accessions of all the traits at MKS ATC during 2012 short and 2013 long rain seasons

Accessions	Plant height (cm)		No. of days to flowering		No. of days to maturity		Pod length (cm)		No. of pods per plant		seeds per pod		100 seeds weight (g)		Seed yield (g)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
GBK-022494A	70.1	31.6	46.2	52.7	82.8	88.5	7.5	7.2	27.1	16.3	9.7	9.1	5.8	4.6	15.3	8.3
GBK-022501A	69.4	27.3	44.8	48.7	83.1	78.5	7.7	6.6	31.2	15.4	9.5	8.3	5.7	4.4	17.2	8.6
GBK-022502A	73.6	32.1	48.4	46.4	84.2	81.3	8.2	7.0	29.0	14.9	10.2	8.8	5.3	4.1	15.7	7.5
Nylon-1	68.5	30.2	50.7	51.1	85.2	89.1	7.9	7.6	26.9	13.5	10.3	9.7	6.2	5.0	17.5	7.7
Mean	70.37	30.3	47.53	49.7	83.83	84.3	7.811	7.1	28.5	15	9.93	8.97	5.75	4.52	16.4	8
LSD($P \leq 0.05$)	4.298	11.6	3.145	7.92	1.954	22.18	0.481	1.808	10.69	9.06	0.712	2.38	0.725	1.252	7.26	5.8
Accession (*P-Value*)	0.106	0.8	0.008	0.373	0.077	0.665	0.024	0.737	0.804	0.92	0.08	0.61	0.089	0.572	0.88	0.88
Shade.Accession (*P-Value*)	0.686	0.9	0.188	0.366	0.259	0.669	0.608	0.75	0.657	0.588	0.356	0.74	0.448	0.889	0.79	0.79
CV%	5	6.7	3	17.5	1.4	10.7	1.7	6.8	17.8	21.7	1.6	9.8	3.1	10.9	19.3	19.8

4.6 Results from Kiboko, Makueni County

4.6.1 Weather data

During the 2012 short rain season, Kiboko received less (140 mm) amount of rainfall as compared to 320 mm received during the 2013 long rain season with RH % ranging from 80.9 to 92.6 (Figure 4.3). The mean Temperature ranged from 20.1 to 26.1 ºC (Figure 4.5).

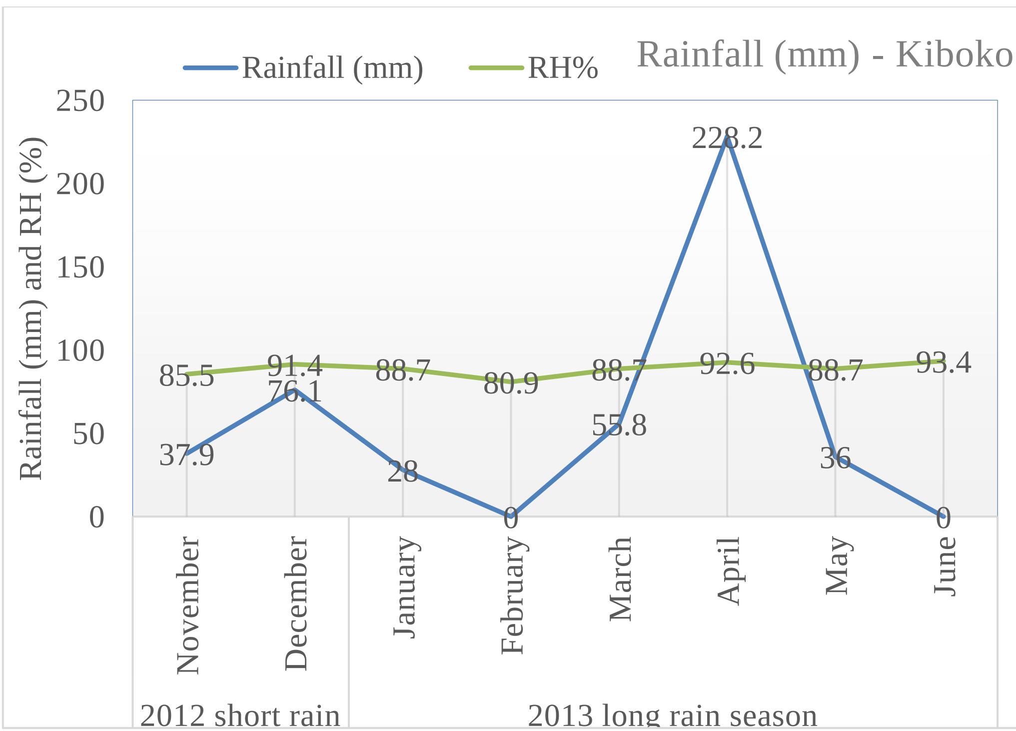

Figure 4.3: Rainfall (mm) and RH (%) data recorded during the 2012 short and 2013 long rains for Kiboko

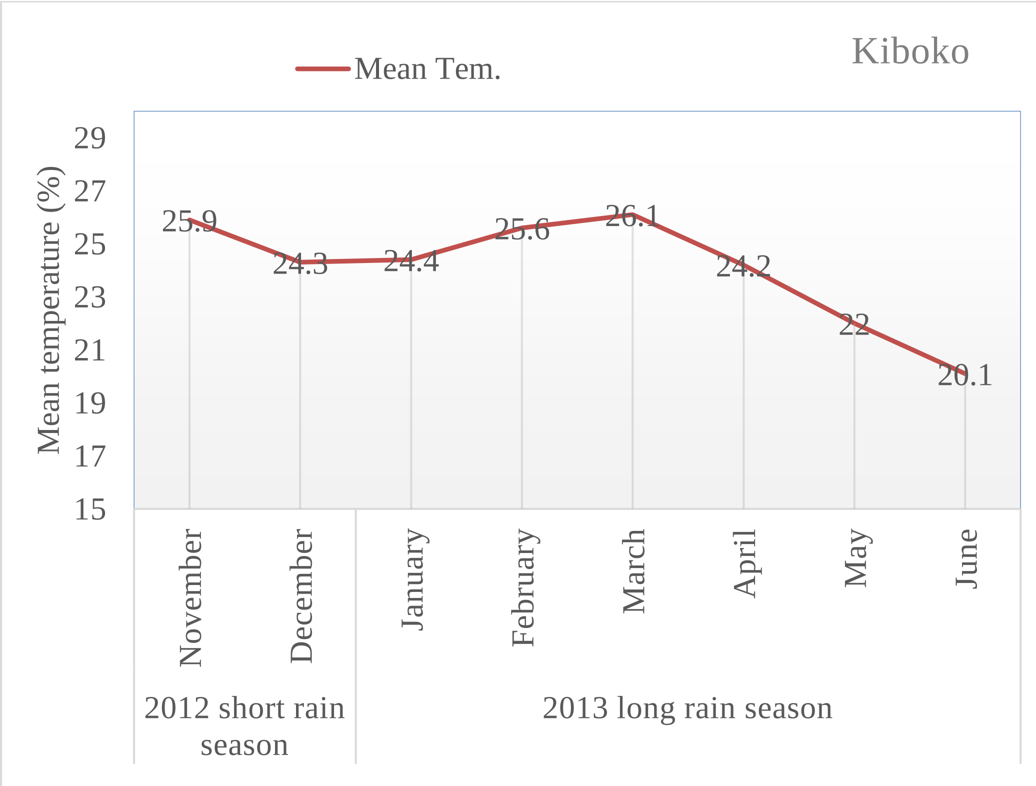

Figure 4.4: Mean Temperature data recorded during the 2012 short and 2013 Long rains for Kiboko

4.6.2 Plant height

The results indicated that accessions had significant ($P \leq 0.05$) effect on plant height during the 2012 short rains (Table 4.4). The accessions' plant height ranged between 44.4 cm and 55.1 cm. Accession GBK-022501A had the highest (55.1 cm) plant height although it was not significantly taller than GBK-022502A (52.5 cm) and GBK-022494A (49.0 cm) while Nylon-1 (check) had the shortest (44.4 cm) plant height during the 2012 short rains. Accession had no significant (($P \leq 0.05$) effect on plant height during the 2013 long rain season. Shade had significant ($P \leq 0.05$) effect on plant height during 2013 long rains (Table 4.7). Plants had higher (54.7 cm) plant height under shade net and a plant height of 50.0 cm under direct light intensity (control) during the 2013 long rain season.

Table 4. 4: Values for accessions of all the traits at Kiboko during 2012 short and 2013 long rain seasons

Accessions	Plant height (cm)		No. of days to flowering		No. of days to maturity		Pod length (cm)		No. of pods per plant		No. of seeds per pod		100 seeds weight (g)		Seed yield (g)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
GBK-022494A	49.0	48.8	39.7	38.3	68.5	64.6	7.6	7.5	34.0	24.9	8.7	9.9	5.0	5.4	14.5	13.9
GBK-022501A	55.1	53.8	39.5	37.5	68.6	66.0	7.6	7.5	40.3	31.4	8.7	9.6	4.9	5.6	17.2	17.3
GBK-022502A	52.5	56.5	40.0	37.0	69.8	64.3	7.6	7.8	29.4	25.4	8.8	9.2	5.1	5.3	12.7	12.5
Nylon-1	44.4	50.3	38.6	38.9	69.3	63.1	7.4	7.6	25.8	24.0	8.6	10.2	6.0	5.7	12.4	14.6
Mean	50.3	52.3	39.4	37.9	69.1	64.5	7.6	7.6	32.4	26.4	8.7	9.7	5.2	5.5	14.2	14.6
LSD($P \leq 0.05$)	6.6	12.3	2.61	1.908	1.17	2.758	0.214	0.401	7.37	9.2	0.67	1.225	1.1	0.938	2.724	5.939
Accession (*P-Value*)	0.022	0.53	0.694	0.187	0.091	0.188	0.144	0.28	0.006	0.327	0.93	0.37	0.17	0.806	0.009	0.385
Shade.Accession	0.881	0.92	0.821	0.81	0.504	0.474	0.29	0.224	0.12	0.448	0.26	0.992	0.87	0.769	0.113	0.529
CV%	1.5	1.6	2.9	2.6	1.5	2.6	0.3	0.8	27.3	3	6.2	5.1	2.7	4.2	31.7	9.8

Table 4. 5: Values of all the traits under shade treatment at Kiboko during 2012 short and 2013 long rain seasons

Shade	Plant height (cm)		No. of days to flowering		No. of days to maturity		Pod length (cm)		No. of pods per plant		No. of seeds per pod		100 seeds weight (g)		Seed yield (g)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Net	49.9	54.7	39.8	38.6	69.1	66.8	7.6	7.7	31.1	25.4	9.0	10.1	5.2	5.4	14.0	14.2
Control	50.7	50.0	39.1	37.3	69.0	62.2	7.6	7.4	33.7	27.5	8.4	9.4	5.3	5.7	14.4	15.0
Mean	50.3	52.3	39.5	37.9	69.1	64.5	7.6	7.6	32.4	26.4	8.7	9.7	5.2	5.5	14.2	14.6
LSD($P \leq 0.05$)	2.69	3.03	4.02	3.5	3.54	5.95	0.083	0.22	31	2.77	0.47	1.73	0.5	0.824	15.8	5
Shade (P-Value)	0.316	0.021	0.523	0.27	0.872	0.081	0.349	0.03	0.75	0.084	0.016	0.198	0.387	0.267	0.914	0.534
Shade.Accession (P-Value)	0.881	0.917	0.821	0.81	0.504	0.474	0.29	0.22	0.12	0.448	0.258	0.992	0.866	0.769	0.113	0.529
CV%	1.5	1.6	2.9	2.6	1.5	2.6	0.3	0.8	27.3	3	6.2	5.1	2.7	4.2	31.7	9.8

4.6.3 Pod length

The study results indicated that shade had significant ($P \leq 0.05$) effect on the accessions' pod length during the 2013 long rain season (Table 4.5). The average pod length under the shade net was longer (7.7cm) than that under the direct solar radiation (7.4cm).

4.6.4 Number of pods per plant

The study results indicated that accessions had significant ($P \leq 0.05$) effect on number of pods per plant during the 2012 short rains (Table 4.4). The number of pods per plant ranged between 25 pods and 40 pods per plant. Accession GBK-022501A had the highest (40) number of pods per plant although it was not significantly different from GBK-022494A with 34 pods per plant while Nylon-1 had the least (25) number of pods per plant although it was not significantly differently from GBK-022502A which had 29 pods per plant. The number of pods per plant was not significantly ($P \leq 0.05$) influenced by neither the accessions nor by shading during 2013 long rain season.

4.6.5 Number of seeds per pod

The results indicated that shade had significant ($P \leq 0.05$) effect on the number of seeds per pod while accessions had no effect on the number of seeds per pod during the 2012 short rains (Table 4.5). Number of seeds per pod was higher (9 seeds) under the shade net while under control, the number of seeds per pod was 8 during the 2012 short rain season.

4.6.6 Seed yield

The results indicated that accessions had significant ($P \leq 0.05$) effect on seed yield during the 2012 short rains (Table 4.4). Accession GBK-022501A had the heavier (17.2 g) seed yield while Nylon-1 had the least (12.4 g) seed yield although it was not significantly different from GBK-022502A (12.7 g) and GBK-022494A which had a seed yield of 14.5 g.

4.7 Discussion

The mean values of the parameters measured were found to be higher under the reduced light intensity (shade net) as compared to those under solar radiation (control) during the 2012 rain season in both sites. However, during the 2013 long rains all the measured parameters had lower mean values recorded under shade net as compared to those measured under the solar radiation. This could be due to the fact that with in-adequate rainfall, the soils retain little amounts of water which is lost through evapo-transpiration. This leaves very little water for the plants' use especially so under direct solar radiation, leading to reduced agronomic performance of plants. However, under reduced light intensity (under shade-net) evapo-transpirations are low due to reduced amount of light striking the canopy of the plants as well as the soil surface. This leads to more water available to the plants. This in turn leads to better agronomic performance (Adugna and Paul, 2010; Makus, 2001; Hashem *et al.*, 2006).

The accessions attained an average plant height of between 71.9 cm and 78.0 cm under net and 63.8 – 69.1 cm under control at Machakos. The accessions had an average plant height of 44.8 – 53.9 cm under net and 44.1 – 56.3 cm under control at Kiboko. Higher plant height under the shade could be due to reduction in the rate of evapo-evaporation of the water from the soil providing cooler root zone leading to enhanced root development which might have led to higher plant height and also due to photosynthesis rate which may be proportional to chlorophyll content only at low light intensity. The higher plant height in Machakos ATC compared to that in Kiboko, could be due to the higher amount of rainfall received at Machakos ATC. These results corroborate with the findings of Kumar *et al.*, (2015), Sunilkumar and Geethakumari (2002) Akhter *et al.*, (2009) and Moniruzzamam *et al.*, (2009), Araki *et al.*, (2014), Na Chiangmai *et al.*, (2012); Abd *et al.*, (2015) and Abdul *et al.*, (2003); Polthanee *et al.*, (2011), which showed that plants grown under reduced light intensity had a higher plant height as compared to those under direct solar radiation.

The accessions took an average of between 44 and 50 days to flower under net and between 43 and 50 days to flower under the control at Machakos ATC. The accessions took an average of between 38-40 days to flower under net and between 38 and 39 days to flower under the control at Kiboko. Light is an indispensable resource for plant growth because the light energy supplied from the sun is the basic factor that regulates growth rate, organ development or structure, function and behavior. Therefore, the increase in the days to flowering under the shade net could probably be due to the fact that shading reduces air and soil temperature (Makus, 2001; Makus and Lester, 2002) thus reducing water loss through evaporation and transpiration from plants and this leads to plant being more vegetative, hence delaying the flowering process.

The accessions took an average of between 84 and 87 days to mature under the net and between 79 and 83 days under the control at Machakos ATC). At Kiboko, the accessions took an average of between 68 and 69 days to mature under net and under the control respectively. The days to maturity under the net treatment were more because the reduced irradiance intensity led to low photosynthetic apparatus of carbon assimilation and photochemical systems in the leaf thereby slowing growth. The results were comparable to those reported by Makus, (2001), who indicated that reducing light intensity delayed maturity of snap beans.

The accessions had an average pod length of between 7.4cm -8.2cm both under the net and under the control at Machakos ATC. The accessions had a pod length of 7.4 - 7.7 cm under net and 7.5 cm under control at Kiboko. The resistance to low light intensity or shading might have been an important factor for the green gram accession in terms of pod length where they were the longest as compared to the control. Shaded plant had a higher specific leaf area, because the leaves were characterized by having larger layer (and more densely packed) of palisade cells. This may have caused the increase in the number of chlorophylls, by which the photosynthetic rate per unit leaf area increased at low light intensity. The results were in line with those by Makus, (2001) who indicated that reduced light intensity reduced pod size.

The accession had an average of between 27 and 38 pods per plant under net and between 22 and 26 pods per plant under the control at Machakos ATC. At Kiboko the accessions had an average of between 28 and 37 pods per plant under net and between 22 and 43 pods per plant under the control. The difference in the number of pods per plant within the same shade could be due to genetic variation of the different accessions while the variation in the average number of pods per plant due to shades (shade net and control) could be brought about by the observed darker green color of the leaves a sign of high chlorophyll content which is responsible for better production in plants thus leading to the variations. These results were contrary to those reported by Verghis *et al.,* (1999); Abdul *et al.*, (2003); Ahmed *at el.*, (2003), Odeleye *et al.*, (2004); Akhter *et al.*, 2009, and Polthanee *et al.*, (2011), who reported that low light reduced number of pods per plant. This is because light regulates plant growth and development in addition to influencing Photosynthesis (Adelusi and Aileme, 2006), therefore without enough light plants cannot photosynthesise very quickly eventually resulting in reduced production.

The accessions had an average of between 9 and 10 seeds per pod both under net and the control at Machakos ATC. At Kiboko, accessions had an average of between 8 and 9 seeds per pod both under net and the control. The less solar energy supply by shading might have had no impact on the formation of seeds in the accessions thereby resulting in almost the same productivity compared to the control. These results were in line with Bing *et al.*, (2010); who reported that light reduction had no effect on the number of seeds per pod. The results were however contrary to those reported by Verghis *et al.*, (1999); Abdul *et al.,* (2003); Ahmed *at el.*, (2003), and Akhter *et al.*, (2009) and, Polthanee *et al.*, (2011), who reported that reducing light intensity results in fewer number of seeds per pod.

The accessions had an average of 100 seed weight of between 5.0g and 6.1g under net and between 5.6g to 6.3g under the control at Machakos ATC. At Kiboko, the accessions had an average of 100 seed weight of between 5.0g and 5.7g under net and between 4.7g and 6.3g under the control. These results are in line with Verghis *et al.*, (1999); Akhter *et al.*, (2009); Ahmed *at el.*, (2003); Araki *et al.*, (2014; Na Chiangmai *et al.*, (2012). The results were contrary to those by Polthanee *et al*, (2011). The no effect on 100 seed weight could have been brought about by the genetic make-up of the accessions (Roman *et al.*, 2013).

The accessions had an average seed yield of between 3.9 g and 18.9 g under net and between 12.1 g and 13.9 g under the direct solar radiation at Machakos ATC. At Kiboko, the accessions had an average seed yield of between 14.0 g and 14.2 g under net and between 14.4g and 15.0 g under the control. The leaves of the accessions under net were found to have a darker green color probably a sign of high chlorophyll content. Chlorophyll plays a key role in determining the light absorption efficiency within a leaf (Jaqueline *et al.*, 2007). The chlorophyll degree is influenced by differences in the accession genetic makeup and thus the differences in yield. The reduced light intensity probably allowed increased absorption of photosynthetic active radiation and thus enhancing the assimilation efficiency. The results are in line with Sunilkumar and Geethakumar (2002) who reported that maximum grain yield of rice was realized under open situation (open direct sunshine); Akhter *et al.*, (2009), Makus, (2001), Kumar *et al.*, (2015), Verghis *et al.*, (1999); Abdul *et al.*, (2003); Bing *et al* (2010); and Polthanee *et al.*, (2011), who reported that shading/ low light reduced seed yield.

Higher amount of rains was received during the 2013 long rains as compared to 2012 short rains at both sites; most of the traits had higher values under reduced light intensity than under the direct solar radiation during the 2012 short rains while during the 2013 long rains, the values were higher under direct solar radiation than under the reduced light intensity at Machakos ATC. The results at Kiboko were comparable during the two seasons both under direct solar radiation and under the reduced light intensity. Therefore, it can be concluded that green gram accessions perform well under reduced (35%) light intensity as long as rainfall amount is just enough and distributed fairly during the growing period of the plants. This study recommends that farmers seek advice from Meterological Department on the nature of the expected rainfall and only install shade net if the rainfall would be below normal and that there should be provision for rolling back the net in case the rainfall is intense.

CHAPTER FIVE

EFFECTS OF MICRO-CATCHMENTS ON THE AGRONOMIC PERFORMANCE OF FOUR GREEN GRAM ACCESSIONS IN MACHAKOS AND MAKUENI COUNTIES, KENYA

5.1 Abstract

In order to evaluate the effect of two micro-catchments on the agronomic performance of green grams in Arid and Semi-Arid areas of Kenya, a field experiment was carried out in two sites, Machakos ATC in Machakos County and Kiboko in Makueni County. The trials were laid out in Randomized Complete Block Design with split-plot arrangement. The main plot was the open and tied ridge micro-catchments with flatbeds as the control while the four accessions were the sub-plots. Data collected on various traits including plant height, number of days to maturity, pod length, number of pods per plant, number of seeds per pod, 100 seeds weight and seed yield was subjected to analysis of variance. The results at Kiboko indicated that micro-catchments had significant (P=0.043) effect on plant height, micro-catchment and accession had significant (P=0.003) interactive effect on the number of days to flowering, Nylon-1 took 35 days to flower under open ridges while GBK-022494A took 39 days with GBK-022502A and GBK-022502A taking 40 days each during the 2012 short rains. Tied ridges had higher improvement on number of days to flowering, number of days to maturity, pod length, number of pods per plant, number of seeds per pod, and seed yield as compared to those planted in the open ridges. Accessions had significant effect on the genotypes' traits including number of pods per plant in Machakos ATC while number of days to flowering and number of seeds per pod had significant effect in Kiboko during the 2013 long rain season.

5.2 Introduction

Limited and erratic rainfall in the dry semi-arid region of Kenya often results in low crop yields and sometimes in total crop failure. The Arid and Semi-Arid Areas receive about 650mm of rainfall per annum. This amount could be enough to achieve good green gram agronomic performance if it is distributed evenly through the plant growing period. However, sometimes, the rain is quite erratic, such that, the total amount is received within a very short time (Rosegrant *et al.*, 2002). This quite often results in runoff and causes soil erosion (Moges, 2004). In such cases, irrigation would be the best option for crop production. However, it is expensive and is not available in most parts of ASALs of Kenya (Hatibu and Mohan, 1999; Moges, 2004). Therefore, any intervention to increase the quantity of water available to crops could lead to an improvement of the reliability of crops' level of production. The quantity of water available for crop production could be improved through various soil and water management practices which direct rainwater to the root area of the crops (Xiao-Yan *et al.*, 2000). Such practices are often water-harvesting technologies or micro-catchments and include semi – circular bunds, contour ridges, ridge and furrows (Mati *et al.*, 2006 and MOA-CPPMU, 2008).

Semi-circular bunds are a network of earthen bunds shaped as half – circles with tips facing upslope and on the contour. These bunds are normally used in areas where the rainfall ranges between 200 -700 mm, with deep soil and low slope. The bunds are made in such a manner that those on one row, are not directly above the ones on the row below it. Also the tips of adjacent bunds do not touch each other as the tips are meant to discharge excess water which is trapped by a series of bunds below it (Mati *et al.*, 2006, and MOA-CPPMU, 2008). The semi- circular bunds act as a micro- catchment that harvests rainwater and retains it in the planting pit. This ensures water availability to the root zone even after the rains. The stored moisture can be adequate to support the plant through the dry spell, if the semi- circular bunds are well designed (MOA-CPPMU, 2008).

Ridges are a network of continuous earth bumps parallel to each other with furrows in between them. Just like in the case of semi-circular bunds, ridges and furrows are normally constructed where rainfall range between 200 mm and 700 mm per annum and where the land is relatively flat. They are graded in such a manner that when full it feeds to the furrows below, however in most cases, the ends points of the furrows are normally blocked (to form tied ridges) in order to concentrate the water within the root areas of the plant (MOA-CPPMU, 2008). The crop is normally planted along the furrows; therefore, the distance from one ridge to the other depends on the spacing of the crop. When constructing ridges and furrows, the height at which the crop starts bearing should be taken into account so that the pods/fruits/leaves do not come into contact with water or soil.

Green gram is an important crop that is widely grown in the Machakos and Makueni Counties of Kenya. Low yields are realized by farmers in these areas as a result of low rainfall. In order to enhance green gram performance in these Counties, there is need to enhance the quantity of water available for the crop, which could be achieved by constructing micro-catchments. However, no study has been conducted to evaluate the performance of green gram planted in micro-catchments and hence the need for this study. The objective of this study was to evaluate the effect of two micro-catchments on the agronomic performance of green gram accessions in Machakos and Makueni Counties which are located in Arid and Semi-Arid areas of Kenya.

5.3 Materials & Methods

5.3.1 Site desription

The sites are as s described on section 3.3.1 and detailed in Figures 3.1 and 3.2

5.3.2 Green gram genotypes

The source of the genotypes was as indicated in 4.3.2 (Table 4.1)

5.3.3 Experiment layout & treatment

The trial was laid out in a split-plot design with three replications. The main plots were the two micro-catchments (open ridges and tied ridges) and flatbeds as the control with the four accessions as the sub-plots (Plate 5.1). The rest of the practices were as indicated in section 4.3.4.

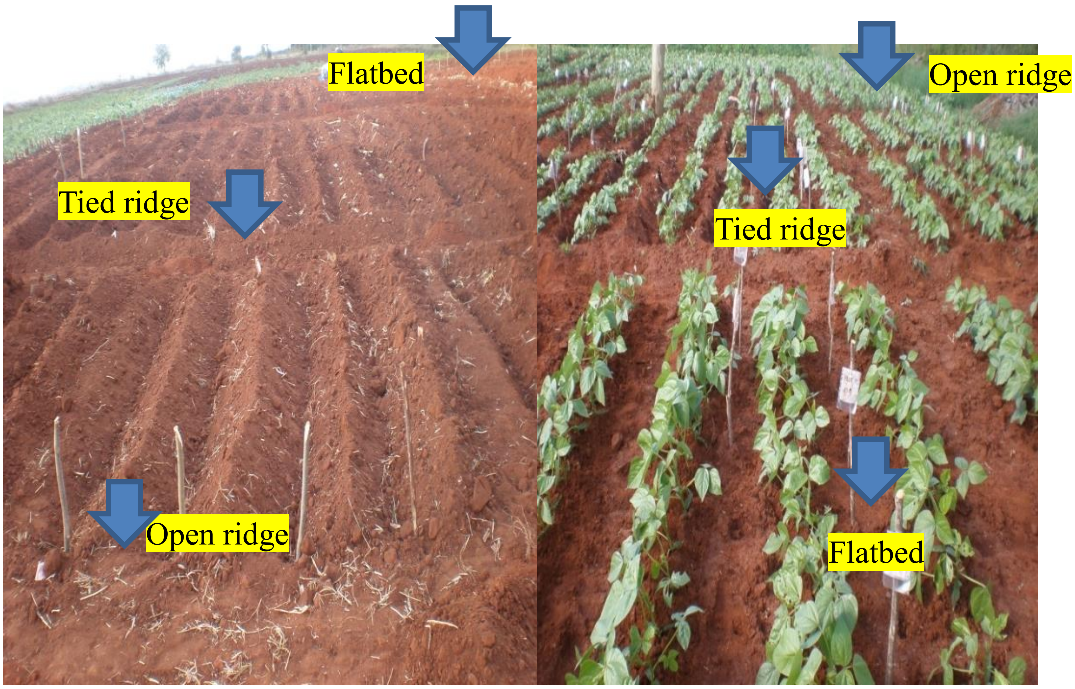

Plate 5. 1: Micro-catchments at Machakos ATC during the 2012 long rain season

5.3.4 Agronomic Practices

This was undertaken as described in section 3.3.4

5.3.5 Data collection

The data collection was as described in section 4.3.6. Additionally, for soil moisture content data collection, three soil samples were collected randomly within each micro-catchment from week 2 after germination at an interval of 2 weeks up to 8th or 10th week depending on the growth stage of the plants. The soil samples were collected at a depth of

15 cm (depth of the Genotypes' root system) under the shade net. The three samples were then mixed thoroughly. From the mixture, one sample weighing 150 gm was obtained. The same was repeated for the plots under direct solar radiation. This gave 72 soil samples (one sample per plot). The samples were then dried in an oven at 100^{o}C for 48hours until the soil was dry.

5.3.6 Data analysis

The data was analysed as described in section 3.4. Additionally, Regression analysis was used to determine the effect of soil moisture content on the various green gram traits under tied ridges, open ridges and flatbeds.

5.4 Results from Machakos ATC, Machakos County

5.4.1 Weather data

Weather data as indicated in Figures 4.3 and 4.4

5.4.2 Plant height

Results indicated that plant height had significant ($P \leq 0.05$) differences among the accessions during the 2012 short rain season (Table 5.1). The plant height ranged between 59.4 cm and 67.2 cm. Accession GBK-022494A had the highest (67.2 cm) plant height although it was not significantly different from Nylon-1 (66 cm) and GBK-022502A which had a height of 64.7 cm accession GBK-022501A had the shortest plants (59.4 cm) during the 2012 short rain season. During the 2012 short rain season the micro-catchments had significantly ($P \leq 0.05$) affected the plant height of green gram accessions (Table 5.2). Plant height under the flatbeds was the highest (66.2 cm), followed by open ridges (64.4 cm) and tied ridges (62.4 cm) during both the 2012 short rain season.

5.4.3 Days to flowering

The study results indicated that number of day to flowering had significant ($P \leq 0.05$) differences among the accessions during the 2012 short rain season (Table 5.1). Accession GBK-022494A and GBK-022501A were the earliest (45 days) to flower though they were not significantly different from GBK-022502A that took 47days to flower. Nylon-1 (the check) took the highest (50) number of days to flower. Micro-catchment had significant ($P \leq 0.05$) effect on the number of days to flowering during the 2012 short rain season. Plant height was the highest (47.5 cm) under tied ridges though it was not significantly different from open ridges (47.0 cm). Flatbeds had the least (46.6 cm) plant height.

5.4.4 Number of pods per plant

Results indicated that accessions had significant ($P \leq 0.05$) effect on the number of pods per plant during the 2013 long rains (Table 5.1). Accession GBK-022494A had the highest (30) number of pods per plant although it was not significantly different from GBK-022502A which had 25 pods per plant. Nylon-1 had the least (17) number of pods per plant although it was not significantly different from GBK-022501A which had 21pods per plant (Table 5.1).

5.4.5 Number of seeds per pod

Results indicated that accessions had significant ($P \leq 0.05$) effect on the accession's number of seeds per pod during the 2012 short rains (Table 5.1). The highest (10) number of seeds per pod were observed in accession Nylon-1 although it was not significantly different from GBK-022494A which had 9 seeds per pod. Accession GBK-022501A had the least (8) number of seeds per pod although it was not significantly different from GBK-022502A which had 9 seeds per pod.

Table 5. 1: Values of all the traits recorded on the accessions at MKS ATC during 2012 short and 2013 long rain seasons

Accessions	Plant height (cm)		No. of days to flowering		No. of days to maturity		Pod length (cm)		No. of pods per plant		No. of seeds per pod		100 seeds weight (g)		Seed yield (g)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
GBK-022494A	67.2	43.2	45.0	50.0	81.2	93.3	7.6	8.1	29.4	30.1	9.8	10.2	5.6	5.2	15.9	15.6
GBK-022501A	59.4	36.6	45.4	50.6	79.8	93.8	7.3	8.4	21.6	21.6	8.9	10.0	5.6	5.6	11.4	12.4
GBK-022502A	64.7	39.2	47.2	50.8	81.5	93.9	7.9	8.3	23.5	25.2	9.3	10.2	5.7	4.8	12.5	12.4
Nylon-1	66.0	35.9	50.6	52.3	83.0	95.5	7.8	8.1	22.9	17.8	10.5	10.4	6.1	5.2	14.8	9.8
Mean	64.3	38.8	47.0	50.9	81.4	94.1	7.6	8.2	24.4	23.7	9.6	10.2	5.7	5.2	13.6	12.5
LSD($P \leq 0.05$)	5.031	5.828	2.803	2.048	3.13	2.611	0.57	0.456	6.11	8.51	0.774	0.656	0.59	0.72	3.711	4.708
Accession (*P-Value*)	0.022	0.067	0.002	0.159	0.25	0.339	0.22	0.447	0.069	0.042	0.002	0.717	0.24	0.18	0.076	0.121
Micro_catchment.Accession (*P-Value*)	0.195	0.598	0.658	0.955	0.4	0.762	0.75	0.702	0.655	0.444	0.187	0.421	0.63	0.79	0.602	0.315
CV%	5.08	8.9	3.5	2.5	1.9	1.9	2.8	2.5	10.3	15.8	4.1	2	4.4	4.6	8.2	12.9

5.4.6 Effect of micro-catchment on seed yield at Machakos ATC

Results on regression analysis on the effect of soil moisture content on the various green gram traits under ridges, open ridges and flatbeds indicated that; there was positive significant (r=-0.432, p=0.035) relation between moisture content and number of days to maturity [Figure 5.1 (a)], under tied ridges and negative significant (r=-0.481, p=0.017) relation between moisture content and plant height [Figure 5.1 (b)], under open ridges at Machakos ATC during the 2012 short and 2013 long rain seasons.

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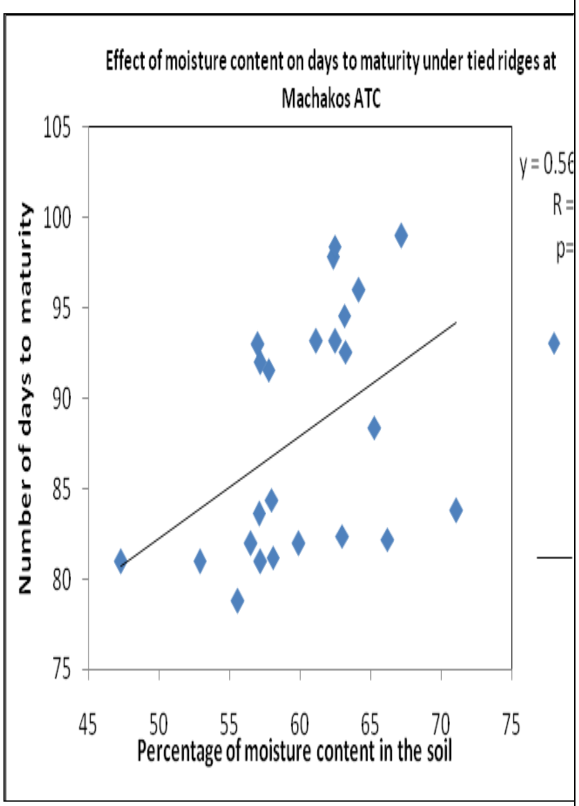
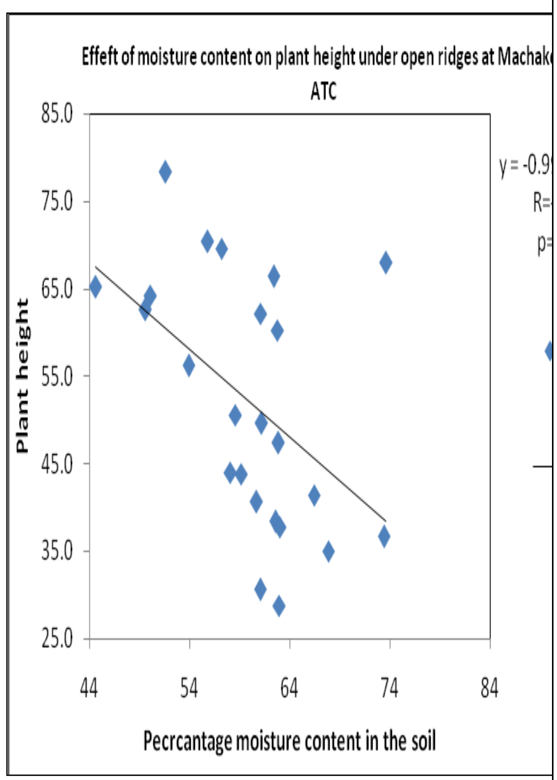


(a)



(b)

Figure 5.1: Effect of moisture content on days to (a) maturity and (b) plant height under tied ridges at Machakos ATC

5.5 Results from Kiboko, Makueni County

5.5.1 Weather

Weather data was as shown on Figures 4.3 and 4.4.

5.5.2 Plant height

The results indicated that accessions had significant ($P \leq 0.05$) effect on plant height during the 2012 short rain season (Table 5.2). The plant height ranged between 44.5cm and 53.0 cm. Accession GBK-022502A had the highest (53.0 cm) plant height (Table 5.2) although it was not significantly different from GBK-022501A (50.5 cm) while Nylon-1 had the least (44.5 cm) plant height, although it was not significantly different from GBK-022494A which had a plant height of 46.7 cm. Results indicated that micro-catchments had significant ($P \leq 0.05$) effect on plant height during the 2012 short rains (Figure 5.2). Plant height was highest (50.7 cm) in flatbeds (Figure 5.2) although it was not significantly different from the plant height (50.1 cm) in tied ridges while plant height was least (45.2 cm) under open ridges.

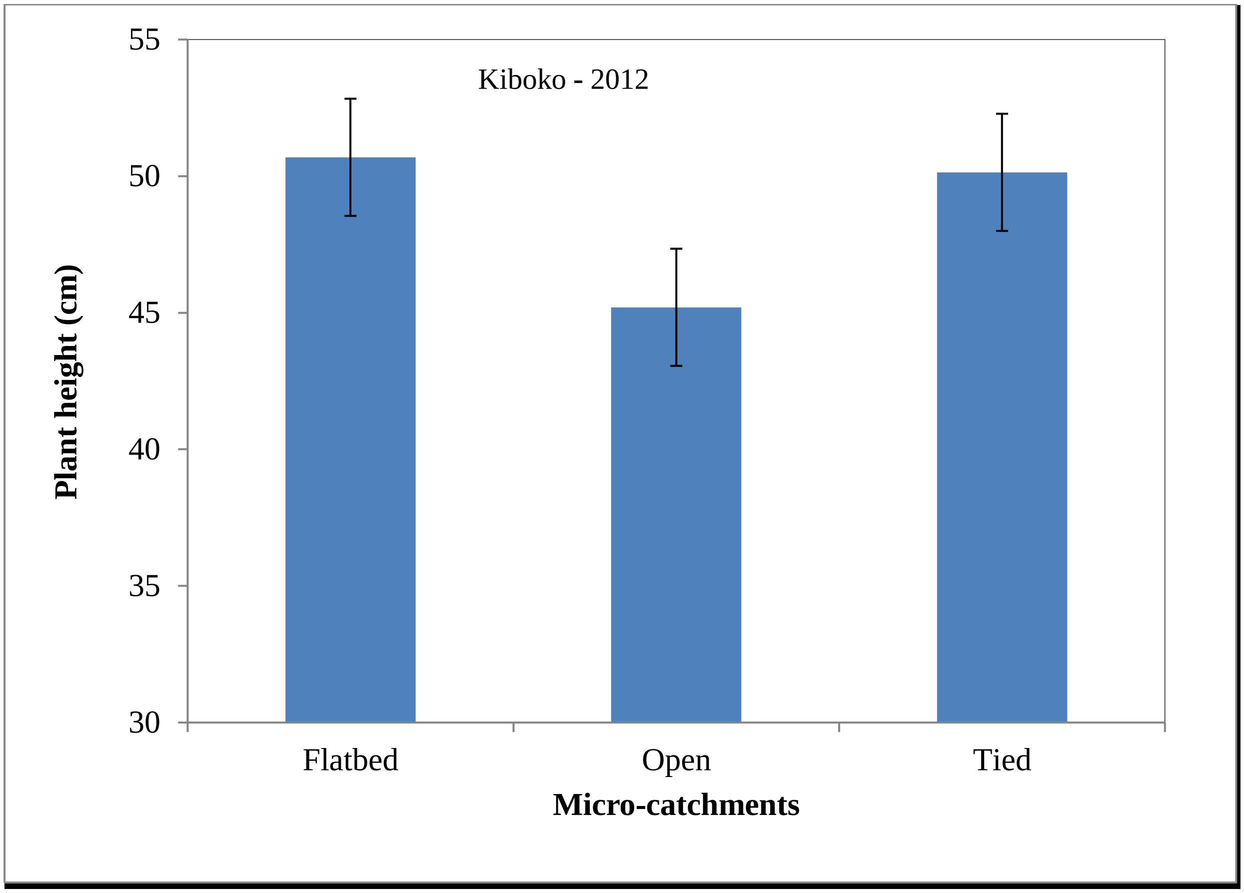


Figure 5.2: Effect of Micro-catchments on plant height in Kiboko during the 2012 short rain season

5.5.3 Days to flowering

The results indicated significant (P≤0.05) interactive effect between micro-catchment and accessions were revealed on number of days to flowering during the 2012 short rain season (Table 5.3 andFigure 5.3). Under open ridges, accession Nylon-1 was the earliest (35 days) to flower (Figure 5.3) although it was not significantly different from GBK-022494A (39 days), GBK-022502A and GBK-022501A, which took 40 days each to flower. Under tied ridges, Nylon-1 was earliest (37 days) to flower although it was not significantly different from GBK-022494A which took 38 days to flower while accessions GBK-022501A and GBK-022502A were the latest (39 days) to flower. Under flatbed, GBK-022494A and Nylon-1 were the earliest (38 days) to flower although they were not significantly different from GBK-022501A and GBK-022501A that took 39 days each to flower. Accessions had significant (P≤0.05) effect on days to flowering during the 2013 long rains (Table 5.2). Accession GBK-022501A was the earliest (36 days) to flower although it was not significantly (P≤0.05) different from GBK-022494A and GBK-022502A which took 37 days each to flower. Nylon-1 (the check) took the longest (39 days) to flower during the 2013 long rain season.

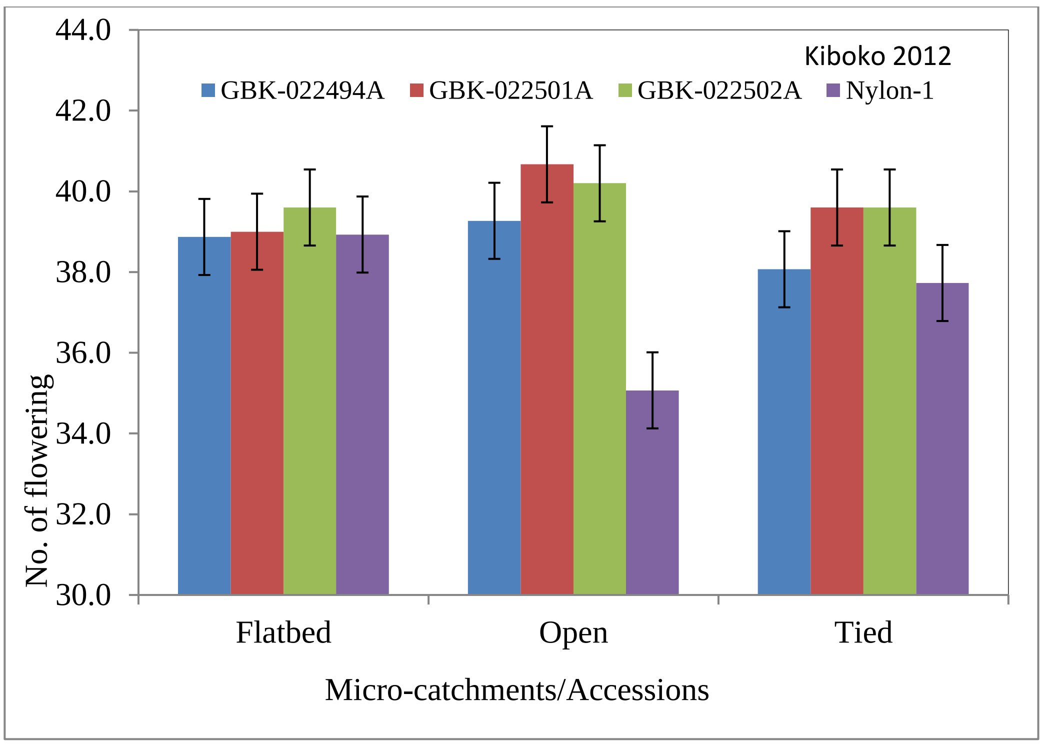


Figure 5.3: Interactive effect between micro-catchments and accessions on the number of days to flowering at Kiboko during the 2012 short rains

Table 5. 2: Values of all the traits of the accessions treatment at Kiboko during 2012 short and 2013 long rain seasons

Accessions	Plant height (cm)		No. of days to flowering		No. of days to maturity		Pod length (cm)		No. of pods/ plant		No. of seeds per pod		100 seeds weight (g)		Seed yield (g)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	**2013**
GBK-022494A	46.7	50.3	38.7	37.2	67.6	64.0	7.6	7.3	36.7	32.2	8.8	9.8	5.2	5.6	16.6	**18.2**
GBK-022501A	50.5	53.5	39.8	36.6	69.3	64.4	7.6	7.1	39.4	33.0	8.6	9.2	4.9	5.7	16.7	**18.1**
GBK-022502A	53.0	52.3	39.8	37.4	69.4	59.6	7.7	7.0	33.3	26.0	8.4	8.4	5.1	5.4	14.1	**13.3**
Nylon-1	44.5	49.9	37.2	39.2	68.6	64.9	7.6	7.6	31.3	28.2	8.4	10.4	6.4	5.9	16.2	**17.8**
Mean	48.7	51.5	38.9	37.6	68.7	63.2	7.6	7.3	35.1	29.9	8.6	9.5	5.4	5.6	15.9	**16.8**
LSD(P-1502A	5.34	6.86	0.979	1.504	1.263	7.01	0.1603	0.93	8.94	7.74	0.3383	1.336	0.672	0.943	4.442	**4.705**
Accessions (*P-Value*)	0.02	0.67	<.001	0.011	0.03	0.395	0.677	0.61	0.269	0.225	0.105	0.035	0.001	0.666	0.587	**0.117**
CV%	3.9	5.9	1.885	1.5	1.5	7.5	1.6	3.7	18.9	16.7	3.3	4.3	4.5	5.1	20.8	**15.9**

Table 5. 3: Values of all the traits under Micro-catchment treatment at Kiboko during 2012 short and 2013 long rain seasons

Micro-catchments	**Plant height (cm)**		**No. of days to flowering**		**No. of days to maturity**		**Pod length (cm)**		**No. of pods/ plant**		**No. of seeds per pod**		**100 seeds weight (g)**		**Seed yield (g)**	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	**2013**
Flatbed	50.7	49.9	39.1	37.3	69.0	62.2	7.6	7.5	33.7	27.5	8.4	9.4	5.3	5.7	14.4	**15.0**
Open ridges	45.2	51.1	38.8	37.9	68.3	62.4	7.7	7.1	32.5	31.0	8.5	9.4	5.6	5.5	14.8	**17.7**
Tied ridges	50.1	53.4	38.8	37.5	68.9	65.0	7.6	7.3	39.3	31.1	8.8	9.6	5.4	5.7	18.4	**17.8**
Mean	48.7	51.5	38.9	37.6	68.7	63.2	7.6	7.3	35.1	29.9	8.6	9.5	5.4	5.6	15.9	**16.8**
LSD(P≤0.05)	4.288	6.88	1.547	1.275	2.407	10.71	0.269	0.607	15.04	11.28	0.6473	0.931	0.551	0.652	7.474	**6.071**
Micro_catchment (*P-Value*)	0.043	0.44	0.804	0.468	0.739	0.751	0.41	0.301	0.477	0.631	0.362	0.69	0.475	0.76	0.366	**0.434**
Micro_catchment.Accessions (*P-Value*)	0.586	0.726	0.003	0.631	0.933	0.374	0.333	0.457	0.399	0.345	0.398	0.83	0.062	0.689	0.376	**0.363**
CV%	3.9	5.9	1.89	1.5	1.5	7.5	1.6	3.7	18.9	16.7	3.3	4.3	4.5	5.1	20.8	**15.9**

5.5.4 Days to Maturity

The results indicated that accessions had significant ($P \leq 0.05$) effect on number of days to maturity during the 2012 short rains (Table 5.2). The number of days to maturity ranged between 67 and 69 days. Accession GBK-022494A took the least (67) number of days to mature although it was not significantly different from Nylon-1 (the check) which took 68 days to mature. Accessions GBK-022502A and GBK-022501A took the longest (69 days each) to mature although they were not significantly different from Nylon-1.

5.5.5 Number of seeds per pod

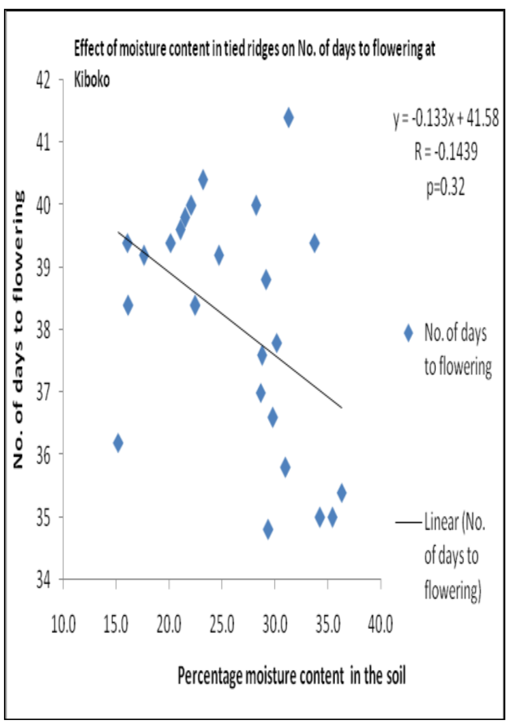
The results indicated that accession had significant ($P \leq 0.05$) effect on the number of seeds per pod during the 2013 long rains (Table 5.2). Nylon-1 (check) had the highest (10) number of seeds per pod although it was not significantly different from GBK-022494A and GBK-022501A which had 9 seeds per pod each, while GBK-022502A had the least (8) number of seeds per pod. Accession had significant ($P \leq 0.05$) effect on the number of seeds per pod during the 2012 short rain season (Table 5.2).

5.5.6 100 seed weight

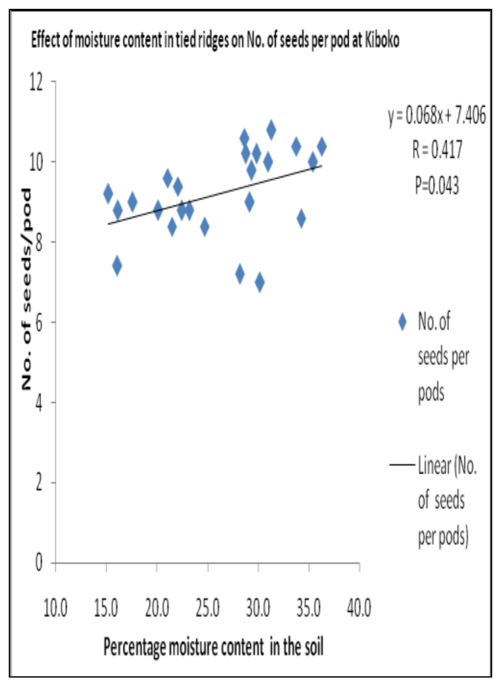
The results indicated that accessions revealed significant ($P \leq 0.05$) effect on the 100 seed weight during the 2012 short rain season (Table 5.2). Accession Nylon-1 (check) had the highest (6.4 g) 100 seed weight while GBK-022501A had the least (4.9 g) 100 seed weight although it was not significantly different from GBK-022502A (5.1 g) and GBK-022494A (5.2 g) during the 2012 short rain season.

5.5.7 The effect of soil moisture content on green gram traits under tied ridges, open ridges and flatbeds at Kiboko

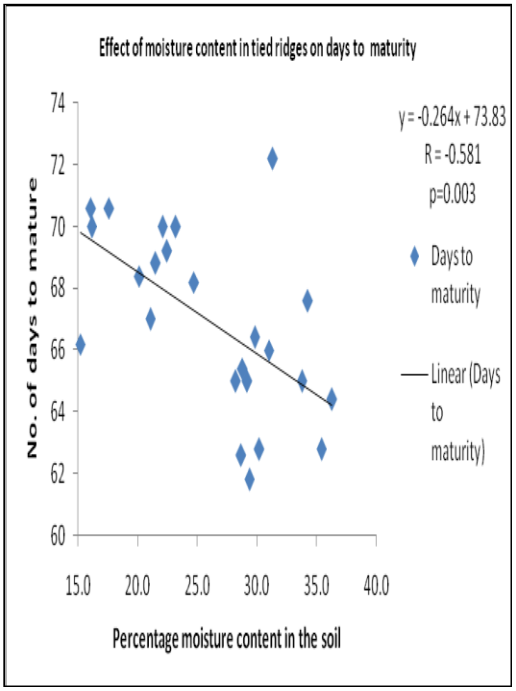
The results of regression analysis on the effect of soil moisture content on the various green gram traits under ridges, open ridges and flatbeds indicated that; there was negative significant ($r=-0.1439$, $p=0.032$) relation between soil moisture content and number of days to flowering under tied ridges [Fig. 5.4 (a)], there was positive significant (r=0.417, p=0.043) between soil moisture content and the number of seeds per pod as indicated in Fig. 5.4 (b), there was negative (r=-0.581, p=0.003) relation between soil moisture content and number of days to maturity [Fig.5.4 (c)] under tied ridges; there was positive significant (r=0.435, p=0.034) relation between soil soil moisture content and plant height [Fig.5.4 (d)] under open ridges; there was positive significant (r=0.527, p=0.008) relation between soil moisture content and number of seeds per pod under flatbeds [Fig.5.4 (e)] and negative significant (r=-0.436, p=0.033) relation between soil moisture content and number of days to maturity [Fig.5.4 (f)] under flatbeds[Figure 5.1 (a)] at Kiboko during the 2012 short and 2013 long rain seasons.



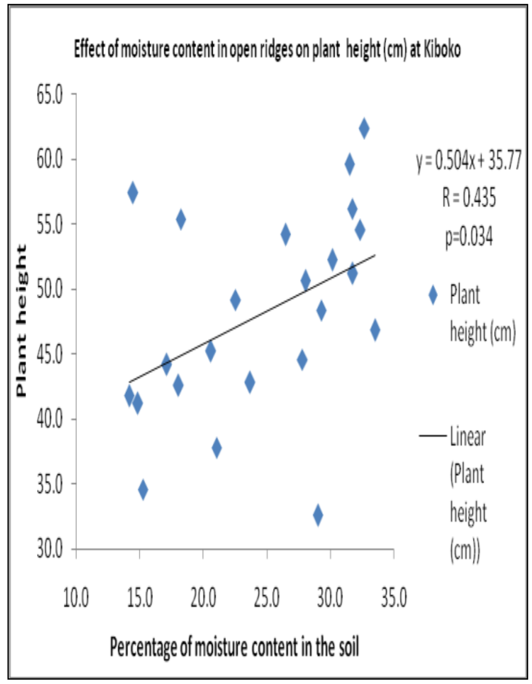
(a) Effect of soill moisture content in tied ridges on number of days to flowering



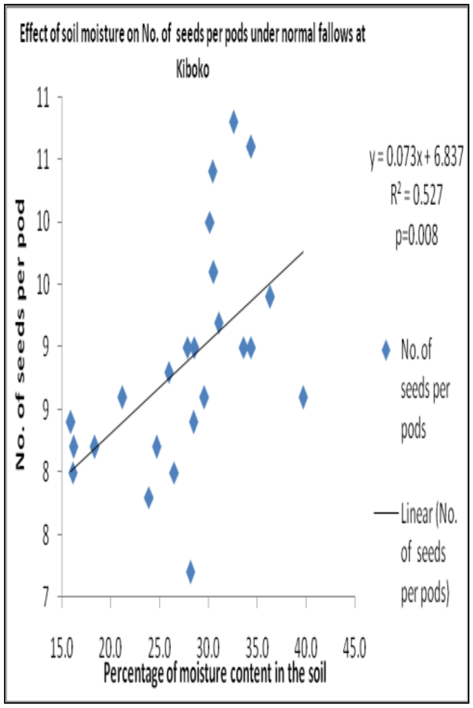
b) Effect of soil moisture content in tied ridges on number of seeds per pod



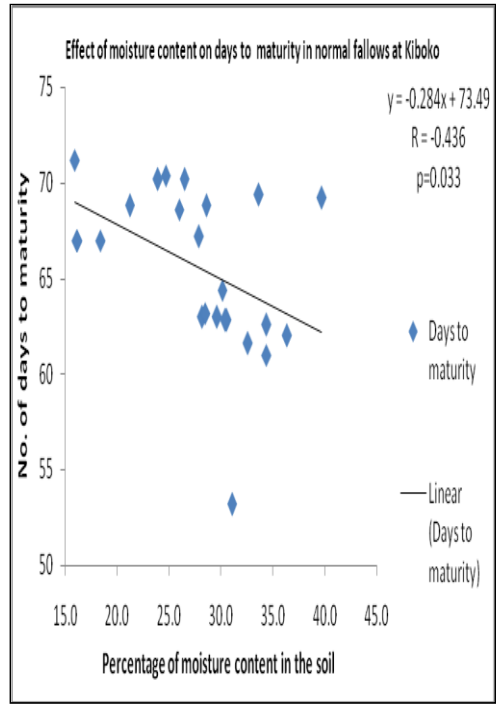
c) Effect of soil moisture content in tied ridges on number of days to maturity



(d) Effect of soil moisture content in open ridges on plant height



(e)Effect of soil moisture content in flatbeds on number of seeds per pod



(f) Effect of soil moisture content in flatbeds on number of days to maturity

Figure 5.4: Effect of moisture content in tied ridges on No. of days of flowering, Noz of seeds/pod, and No. of days to maturity; effect of soil moisture content in open ridges on plant height; effect of moisture content in flatbeds on No. of seeds per pod and No. of days to maturity at Kiboko

5.6 Discussion

The accessions attained an average plant height of between 49.0 cm and 58.9 cm under open ridges, 46 and 54.6 cm tied ridges and 49.1and 55.4 cm under flatbed at Machakos. The accessions attained an average plant height of between 45.6 and 50.2cm under open ridges, 50.8 and 53.4 cm under tied ridges and 45.3 and 54.8 cm under flatbed at Kiboko. The accessions were most vigorous under the open ridges probably because the contours create small storage volumes of water that accumulate and allowing more time for infiltration while the flatbed tillage the capacity to retain water was less effective and volumes of water rapidly diminished reducing uptake by the plant thus lower growth.

The accessions took an average of between 46 and 51 days to flower under open ridges, 48-50 days to flower under tied ridges and 47 and 51 days to flower under flatbed at Machakos ATC. The accessions took an average of between 37 and 39 days to flower under open ridges, while under tied ridges and flatbed the accessions took between 37 and 38 days to flower at Kiboko. The differences among the accessions on the days to flowering indicate the genetic diversity among them on phenological development whose vigor could have been enhanced by water held within the tied ridges. This was in accordance with Mati (2005) who stated that tied ridges have been found to be very efficient in storing water which could result in substantial plant growth in some dryland crops including green grams.

The accessions took an average number of days to maturity of between 84 and 88 days under the open ridges, 86 and 89 days under the tied ridges and between 87 and 89 days under the flatbeds at Machakos ATC**.** The accessions took an average number of days to maturity of between 60 and 67 days under the open ridges, 65 and 68 days under the tied ridges and between 64 and 66 days under the flatbeds at Kiboko. The technologies reviewed here allow rainwater retention for a prolonged duration on the soil surface for increased infiltration and retention and better rainwater use efficiency, thus the differences in the number of days taken to mature.

The accessions had an average pod length of between 7.7 and 7.9 cm under open ridges, 8.0 and 8.2 cm under tied ridges and between 7.8 and 8.3 cm under flatbeds at Machakos ATC. The accessions had an average pod length of between 6.9 and 7.9 cm under open ridges, 7.2 and 7.6 cm under tied ridges and between 7.4 and 7.8 cm under flatbeds at Kiboko. The water utilization efficiency was higher in the micro-catchment treatments where there was reduced water lost through runoff by holding it on the soil surface thus encouraging infiltration thereby increasing the water available for crop growth and yield.

This process increased water use efficiency as more rainwater that could have been lost is available for crop growth. However, with less rainfall there were minimal and insignificant differences between the treatments.

The accessions had an average number of pods per plant of between 19 and 30 pods per plant under open ridges, 20 and 34 pods per plant under tied ridges and between 19 and 25 pods per plant under the flatbeds at Machakos ATC. The accessions had an average number of pods per plant of between 29 and 34 pods per plant under open ridges, 31 and 38 pods per plant under tied ridges and between 24 and 39 pods per plant under the flatbeds at Kiboko. The tied ridges showed higher number of pods compared to the open ridges probably because water accumulated and retained was higher thus the plants grown on the tied ridges were well supplied with water leading to higher reproduction rates. These results are higher than those reported by Singh *et al.*, (2006) who reported that plant under ridge planting and irrigation produced 15 pods per plant, while those under flatbed and irrigation produced 17 pods per plant.

The accessions attained an average of between 9 and 10 seeds per pod under all the micro-catchment at Machakos - while at Kiboko, all the accessions had an average of between 8 and 9 seeds per pod under all the micro-catchments. These results are higher than those reported by Singh *et al.*, (2006) who reported that plant under ridge and irrigation had 7 seeds per pod, while those planted under flatbeds and irrigation had 8 seeds per pod.

The accessions had an average 100 seeds weight of between 5.2 and 5.6 g under the open ridges, 4.9 and 5.7 g under tied ridges and between 5.2 and 6.1 g under flatbeds at Machakos ATC. The accessions had an average 100 seed weight of between 4.7 and 6.8 g under the open ridges, 5.3 and 5.7 g under tied ridges and between 5.2 and 6.0 g under flatbeds at Kiboko. Tied-ridging allowed rain water to be conserved *in-situ* as it infiltrates the soil. The prolonged time it is retained on flatbeds also allowed increased infiltration and hence increased soil water which is used by crops. This could have resulted into increased number of seeds per pod, leading to smaller grain size which may have contributed to lower 100 seed weight as compared to those obtained from flatbeds.

The accessions had an average seed yield (g per plant) of between 11.5 and 15.1 g under the open ridges, 10.9 and 18.7 g under tied ridges and between 12.2 and 13.3 g under flatbeds at Machakos ATC. The accessions had an average seed yield of between 13.0 and 20.0 g under the open ridges, 15.3 and 18.7 g under tied ridges and between 12.8 and 18.1 g under flatbeds at Kiboko. This was in accordance with Mati (2005) who stated that tied ridges have been found to be very efficient in storing rainwater which results in substantial grain yield in some dryland crops including green grams, Kayombo *et al.*, (2004) who reported that micro-catchment (rain water harvesting) significantly increased the grain yield of maize in a semi-arid area. The findings are in line those with reported by Shuhuai *et al.*, (2012) who found that crop yield increases in micro-catchments as compared to conventional farming. This is contrary to Kalathunga *et al.*, (2008) who stated that yield of mung bean were higher in flatbeds than in ridges and furrow system of land preparation. However, this depends on soil type and the amount of rainfall. This corroborates Onyango *et al.*, (2013); Sijali and Kamoni (2005) who indicated that when rainfall is higher (224 mm), tied ridges can yield more maize crop dry matter than flatbed tillage and that when the amount of rainfall is less (144 mm), flatbed tillage yields more dry matter than the tied ridges. These results are higher than those reported by Singh *et al.*, (2006) who reported that planting under ridge irrigation attained a seed yield of 6.5 g, while those under flatbed planting and irrigation attained a seed yield of 5.0 g. Therefore, it can be concluded that micro-catchment improve plant height and shortened the number of days to flowering (accession Nylon-1) of green grams in Machakos and Makueni Counties, Kenya. This study recommends that micro-catchments can be used where plant height needs to be improved and also in cases where plants are required to flower earlier than their normal period.

CHAPTER SIX

EFFECTS OF INTEGRATED PACKAGES INCORPORATING REDUCED LIGHT INTENSITY AND MICRO-CATCHMENTS ON AGRONOMIC PERFORMANCE OF FOUR GREEN GRAM GENOTYPES

6.1 Abstract

To evaluate the effects of integrated packages incorporating reduced light intensity and micro-catchments on agronomic performance of four green gram genotypes in Arid and Semi-Arid areas of Kenya. The trial was carried out in Machakos ATC and Kiboko and was laid out in Split-split plot design with three replications. The main plot was shade, the micro-catchments were the sub-plots and the 4 accessions were the sub-sub plots. The accessions were evaluated for several agronomic traits including; plant height, number of pods per plant, 100 seed weight and seed yield. The collected data was subjected to analysis of variance. At Machakos ATC, results indicated interaction between shade and accessions, interaction between micro-catchment and accessions had significant ($P \leq 0.05$) effect on plant height. Number of pods per plant, number of seeds per pod and seed yield had higher values under shade net and tied ridges followed by the values under shade net and flatbeds. At Kiboko, the results indicated that number of pods per plant was high under shade net and tied ridges. Under direct solar radiation, the accessions had similar average seed yield both in tied ridges and flatbeds at Machakos ATC. Under shade net, the accessions had higher seed yield in tied ridges followed by open ridges, while under flatbed, the accessions had higher seed yield followed by open ridges at Kiboko. This study concludes that traits perform better under shade and in tied ridges, under shade net, the accessions attained higher seed yield in tied ridges followed by accessions in flatbeds.

6.2 Introduction

The introduction was as described in sections 4.2 and 5.2 earlier in this document. Additionally, for each individual factor; reduced solar radiation and micro-catchment there is data in the literature review. However, there is literature available on integrated packages on reduced light intensity and micro-catchments. The objective of this study was therefore, to evaluate the effects of integrated packages incorporating reduced light intensity and micro-catchments on productivity of green gram accessions in Arid and Semi-Arid areas of Kenya.

6.3 Materials and Methods

6.3.1 Site description

The site is as decribed in section 3.3.1 and as shown on figures 3.1 and 3.2.

6.3.2 Green gram genotypes

The source of the genotypes was as indicated 4.3.2 (Table 4.1).

6.3.3 Experiment layout & treatment

The experiment was laid out in a split-split-plot design with three replications. The main plot was the shade; Split-plots were the two micro-catchments (open ridges and tied ridges) and flatbeds as the control while the sub-plots were the four accessions (Plate 6.1). The 4 accessions were planted under the micro-catchments – tied and open ridges with a shade net which reduced the amount light intensity by 35% constructed approximately 2m high. The rest is described in section 4.3.4.

Plate 6. 1: Green gram accessions plant under shade net and micero-catchments at Machakos ATC during the 2012 long rain season

6.3.4 Agronomic Practices

The agronomic practices were carried out as described in section 3.3.4

6.3.5 Data collection

The data was collected as described in section 4.3.6.

6.3.6 Data analysis

Data analysis was carried out as described on section 3.4.

6.4 Results from Machakos ATC, Machakos County

Rainfall and RH % data was as shown on Figure 4.1 and mean Temperature as shown on figure 4.2.

Table 6. 1: ANOVA (P value) Summary for Machakos ATC during 2012 short rain seasons

Variate	**Plant height**	**Days to flowering**	**Days to maturity**	**Pod length**	**Pods per plant**	**Seeds per pod**	**100 seeds weight**	**Seed yield**
Source of variation: Machakos ATC 2012 short rain season	F pr.	F pr.	F pr.	F pr.	F pr.	F pr.	F pr.	F pr.
Rep.Shade stratum	-	-	-	-	-	-	-	-
Shade	0.1	0.055	0.008	0.012	0.07	0.078	0.24	0.057
Rep.Shade.Micro_catchment stratum								
Micro_catchment	0.136	0.646	0.888		0.129	0.294	0.444	0.1
Shade.Micro_catchment	0.81	0.818	0.435	0.339	0.812	0.83	0.792	0.719
Rep.Shade.Micro_catchment.Accession stratum								
Accession	0.024	<.001	0.009	0.081	0.175	<.001	0.006	0.239
Shade.Accession	0.043	0.912	0.766	0.084	0.085	0.074	0.067	0.051
Micro_catchment.Accession	0.02	0.516	0.618	0.165	0.413	0.102	0.646	0.661
Shade.Micro_catchment.Accession	0.401	0.186	0.18	0.951	0.387	0.403	0.579	0.584

Table 6. 2: ANOVA (P value) Summary for Machakos ATC during 2013 long rain season

Variate	Plant height	Days to flowering	Days to maturity	Pod length	Pods per plant	Seeds per pod	100 seeds weight	Seed ield
Source of variation: Machakos ATC 2013long rain season	F pr.	F pr.	F pr.	F pr.	F pr.	F pr.	F pr.	F pr.
Rep.Shade stratum	-	-	-	-	-	-	-	-
Shade	0.04	0.438	0.197	0.129	0.009	0.167	0.161	0.007
Rep.Shade.Micro_catchment stratum								
Micro_catchment	0.677	0.529	0.67	0.504	0.607	0.678	0.707	0.648
Shade.Micro_catchment	0.692	0.616	0.767	0.773	0.36	0.481	0.713	0.46
Rep.Shade.Micro_catchment.Accession stratum								
Accession	0.26	0.74	0.691	0.445	0.065	0.675	0.178	0.158
Shade.Accession	0.431	0.417	0.566	0.625	0.04	0.499	0.901	0.105
Micro_catchment.Accession	0.571	0.6	0.437	0.343	0.645	0.327	0.271	0.355
Shade.Micro_catchment.Accession	0.594	0.706	0.475	0.465	0.244	0.604	0.843	0.229

6.4.1 Plant height

The results indicated significant ($P \leq 0.05$) interactive effect between shade and accession and significant ($P \leq 0.05$) interactive effect between micro-catchments and accession on plant height during the 2012 short rain season (Table 6.1). All the accessions attained a higher plant height under reduced light intensity (shade net) as compared to direct light intensity. Accession GBK-022502A had a plant height of 74.7 cm under reduced light intensity [Plate 6.2 (a)] as compared to 10 cm less (64.7 cm) under direct solar radiation [Plate 6.2 (b)]. GBK-022501A had a plant height of 71.5 cm under reduced light intensity as compared to 59.4cm attained under direct light intensity. Accession GBK-022494A had a plant height of 71.4cm under reduced light intensity as compared to 67.2cm attained under direct light intensity (Table 6.3). The accessions attained higher plant height under flatbed and open ridges as compared to the height attained under tied ridges. Accession GBK-022494A had a plant height of 70.1 and 70.7 under flatbed and open ridges respectively while it attained 67.3 cm under tied ridges (Table 6.5), GBK-022501A had a plant height of 69.4 cm and 66.3 cm under flatbed and open ridges respectively as compared to 60.7 cm under tied ridges. Shade had significant ($P \leq 0.05$) effect on plant height during the 2013 long rain season (Table 6.2). A higher (38.8 cm) average plant height [Plate 6.2 (c)] was recorded under direct solar radiation as compared to 23.7 cm plant height attained under reduced light intensity (Table 6.7) during 2012 short rain season .

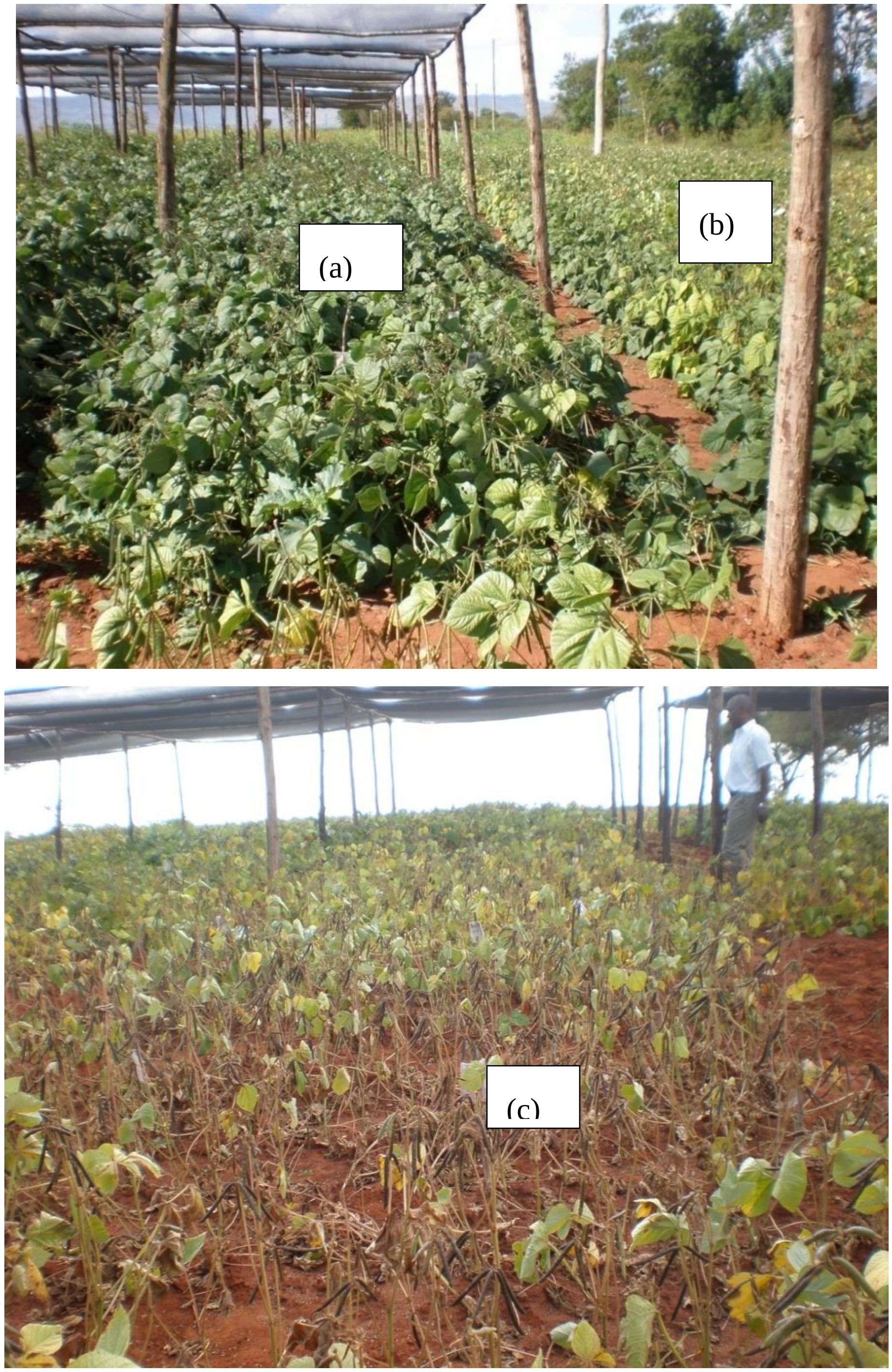


Plate 6. 2: Green gram accessions during the 2012 short rains (a) & (b) and 2013 long rain seasons (c)

Table 6.3: Interaction between shade and accessions during the 2012 short rain season at Machakos ATC for variables

Variables	Genotyes	Shading Net	Control	Mean	LSD (P≤0.05)	CV%
Plant height	GBK-022494A	71.4	67.2	68.4	9.153	6.5
	GBK-022501A	71.5	59.4			
	GBK-022502A	74.7	64.7			
	Nylon-1	72.0	66.0			
Days to flowering	GBK-022494A	47.3	45.0	47.9	2.36	5.4
	GBK-022501A	46.7	45.4			
	GBK-022502A	49.5	47.2			
	Nylon-1	52.1	50.6			
Days to maturity	GBK-022494A	85.4	81.2	83.9	2.234	2.9
	GBK-022501A	86.0	80.0			
	GBK-022502A	87.0	82.0			
	Nylon-1	88.2	83.0			
Pod length	GBK-022494A	7.6	7.6	7.8	0.4418	5.3
	GBK-022501A	8.0	7.3			
	GBK-022502A	7.9	7.9			
	Nylon-1	8.2	7.8			
Pods per plant	GBK-022494A	33.4	29.4	28.9	8.426	23.3
	GBK-022501A	37.0	22.0			
	GBK-022502A	32.7	23.5			
	Nylon-1	30.1	22.9			
Seeds per pod	GBK-022494A	9.8	9.8	9.9	0.7886	7.4
	GBK-022501A	10.0	8.9			
	GBK-022502A	10.2	9.3			
	Nylon-1	11.0	10.5			
100 seeds weight	GBK-022494A	5.6	5.6	5.749	0.5513	9.9
	GBK-022501A	5.7	5.6			
	GBK-022502A	4.9	5.7			
	Nylon-1	5.9	6.1			
Seed yield	GBK-022494A	18.0	16.0	16.36	4.881	26.9
	GBK-022501A	21.9	11.4			
	GBK-022502A	16.5	12.5			
	Nylon-1	19.5	14.8			

6.4.2 Number of days to flowering

The results indicated that accessions had significant ($P \leq 0.05$) effect on the number of days to flowering during the 2012 short rain season at Machakos ATC (Table 6.1). Accession Nylon-1 took the longest (51 days) time to flower while GBK-022494A and GBK-022501A and GBK-022502A took the shortest (46 days) time to flower each (Table 6.9).

6.4.3 Number of days to maturity

The results indicated that shade had significant ($P \leq 0.05$) effect on the number of days to maturity of the 4 green gram accessions under the integration of reduced light intensity and micro-catchment treatments during the 2012 short rain season (Table 6.1). The highest (86) number of days to maturity was observed under shade net as compared to 81 days recorded under direct light intensity (Table 6.7). Accessions indicated significant ($P \leq 0.05$) effect on the number of days to maturity of the 4 green gram accessions under the integration of reduced light intensity and micro-catchment treatments during the 2012 short rain season (Table 6.1). Accession GBK-022502A showed the shortest period to maturity (82 days) while Nylon-1 took the longest (85days) to mature (Table 6.9).

6.4.4 Pod length

The results indicated that shade had significant ($P \leq 0.05$) effects on pod length during the 2012 short rains season (Table 6.1). Higher (7.9 cm) pod length was recorded under reduced light intensity as compared to the pod length of 7.6 cm attained under direct light intensity (table 6.7).

Table 6. 4: Interaction between Shade and accessions during the 2013 long rain season at Machakos ATC

Variables	Genotypes	Shading Net	Control	Mean	LSD (P≤0.05)	CV%
Plant height	GBK-022494A	25.0	43.0	31.2	10.377	26.2
	GBK-022501A	27.0	37.0			
	GBK-022502A	22.0	39.0			
	Nylon-1	21.0	36.0			
Days to flowering	GBK-022494A	46.3	50.0	47.5	24.36	19.6
	GBK-022501A	47.9	50.6			
	GBK-022502A	41.8	50.8			
	Nylon-1	41.0	52.0			
Days to maturity	GBK-022494A	76.8	93.3	83.0	38.06	24.8
	GBK-022501A	80.0	94.0			
	GBK-022502A	65.5	93.9			
	Nylon-1	66.0	96.0			
Pod length	GBK-022494A	6.2	8.1	7.1	2.951	23.2
	GBK-022501A	6.8	8.4			
	GBK-022502A	5.4	8.3			
	Nylon-1	5.5	8.1			
Pods per plant	GBK-022494A	8.5	30.0	16.1	6.489	42.7
	GBK-022501A	10.0	22.0			
	GBK-022502A	6.9	25.0			
	Nylon-1	8.0	18.0			
Seeds per pod	GBK-022494A	7.8	10.2	8.9	4	23.6
	GBK-022501A	8.6	10.0			
	GBK-022502A	6.8	10.0			
	Nylon-1	7.2	10.0			
100 seed weight	GBK-022494A	3.9	5.2	4.5	2.097	26.5
	GBK-022501A	4.3	5.6			
	GBK-022502A	3.5	4.8			
	Nylon-1	3.4	5.2			
Seed yield	GBK-022494A	4.0	15.6	8.4	3.443	44.4
	GBK-022501A	5.4	12.4			
	GBK-022502A	3.5	12.4			
	Nylon-1	4.2	9.8			

6.4.5 Number of pods per plant

The results indicated that shade and accessions had significant ($P \leq 0.05$) interactive effect on number of pods per plant across all the micro-catchments during the 2013 long rain season (Table 6.2). All the accessions had higher number of pods under direct light intensity as compared those under reduced light intensity. Accession GBK-022494A exhibited the highest (30) number of pods per plant under direct light intensity as compared to 8 pods per plant under shade net. Nylon-1 had the least (18) number of pods per plant under direct light intensity as compared to 8 pods per plant under shade net (Table 6.4).

6.4.6 Number of seeds per pod

The results indicated that accessions had significant ($P \leq 0.05$) effect on the number of seeds per pod during the 2012 short rain season (Table 6.1). Accessions had a higher number of seeds per pod under reduced light intensity across the micro-catchments as compared to those accessions under direct light intensity (control). Accession Nylon-1 had the highest (10) number of seeds per pod as compared to accessions; GBK-022494A, GBK-022501A and GBK-022502A which recorded an average of 9 seeds per pod (Table 6.9).

Table 6. 5: Interaction between Micro-catchments and accessions during the 2012 short rain season at Machakos ATC for variables

Variables	Genotype	Micro_catchment			Mean	LSD (P≤0.05)	CV%
		Flatbed	Open	Tied			
Plant height	GBK-022494A	70.1	70.7	67.3	68.4	5.535	6.5
	GBK-022501A	69.0	66.4	61.0			
	GBK-022502A	73.6	68.3	67.4			
	Nylon-1	68.5	66.3	72.0			
Days to flowering	GBK-022494A	46.2	46.3	45.8	47.9	3.044	5.4
	GBK-022501A	44.8	45.4	47.9			
	GBK-022502A	48.4	48.6	48.0			
	Nylon-1	50.7	52.3	51.0			
Days to maturity	GBK-022494A	83.0	84.0	83.0	83.9	2.862	2.9
	GBK-022501A	83.1	81.3	84.0			
	GBK-022502A	84.0	84.0	84.0			
	Nylon-1	85.2	86.1	85.4			
Pod length	GBK-022494A	7.5	7.7	7.7	7.8	0.7202	5.3
	GBK-022501A	8.0	8.0	8.0			
	GBK-022502A	8.2	7.6	7.7			
	Nylon-1	7.9	8.2	7.8			
Pods per plant	GBK-022494A	27.1	29.9	37.2	28.9	7.519	23.3
	GBK-022501A	31.2	27.9	29.3			
	GBK-022502A	29.0	27.1	28.2			
	Nylon-1	26.9	23.7	28.8			
Seeds per pod	GBK-022494A	9.7	9.6	10.1	9.9	0.8626	7.4
	GBK-022501A	9.5	9.1	10.0			
	GBK-022502A	10.2	9.3	9.9			
	Nylon-1	10.3	11.2	10.7			
100 seeds weight	GBK-022494A	5.8	5.4	5.6	5.749	0.638	9.9
	GBK-022501A	5.7	5.4	5.8			
	GBK-022502A	5.3	5.5	5.2			
	Nylon-1	6.2	5.9	5.9			
Seed yield	GBK-022494A	15.3	15.6	20.6	16.4	4.88	26.9
	GBK-022501A	17.2	15.1	17.7			
	GBK-022502A	15.7	13.7	14.2			
	Nylon-1	17.5	15.8	18.0			

Table 6. 6: Interaction between Micro-catchments and accessions during the 2013 long rain season at Machakos ATC

	Genotypes	Micro-catchments			Mean	LSD (P≤0.05)	CV%
		Flatbed	Open	Tied			
Plant height	GBK-022494A	31.6	33.3	37.2	31.2	10.108	26.2
	GBK-022501A	27.0	35.0	33.0			
	GBK-022502A	32.1	29.6	30.1			
	Nylon-1	30.2	25.1	30.4			
Days to flowering	GBK-022494A	52.7	40.2	51.6	47.5	24.36	19.6
	GBK-022501A	48.7	48.3	50.6			
	GBK-022502A	46.4	42.3	50.3			
	Nylon-1	51.1	43.0	45.1			
Days to maturity	GBK-022494A	89.0	73.0	94.0	83	25.08	24.8
	GBK-022501A	78.5	94.2	87.5			
	GBK-022502A	81.0	78.0	80.0			
	Nylon-1	89.1	72.8	80.1			
Pod length	GBK-022494A	7.2	6.4	7.9	7.1	2.022	23.2
	GBK-022501A	6.6	8.2	7.9			
	GBK-022502A	7.0	6.4	7.1			
	Nylon-1	7.6	6.0	6.8			
Pods per plant	GBK-022494A	16.0	19.0	22.0	16.1	7.76	42.7
	GBK-022501A	15.4	17.6	14.9			
	GBK-022502A	14.9	18.3	14.9			
	Nylon-1	14.0	10.0	15.0			
Seeds per pod	GBK-022494A	9.1	8.0	9.9	8.9	2.553	23.6
	GBK-022501A	8.3	10.3	9.4			
	GBK-022502A	8.8	8.0	8.7			
	Nylon-1	9.7	7.9	8.7			
100 seeds weight	GBK-022494A	4.6	4.0	5.0	4.48	1.453	26.5
	GBK-022501A	4.4	5.5	5.0			
	GBK-022502A	4.1	4.2	4.1			
	Nylon-1	5.0	3.5	4.3			
Seed yield	GBK-022494A	8.3	9.2	11.8	8.4	4.114	44.4
	GBK-022501A	8.6	10.0	8.1			
	GBK-022502A	7.5	9.4	7.1			
	Nylon-1	7.7	5.1	8.2			

Table 6. 7: Shading treatments on several parameters of the 4 green gram accessions during the 2012 short rain season at Machakos ATC

Shade	Plant height (cm)	Days to flowering	Days to maturity	Pod length (cm)	Pods per plant	Seeds per pod	100 seeds weight (g)	Seed yield (g)
Control	64.3	47	81.4	7.6	24.4	9.6	5.7	13.6
Net	72.4	48.9	86.5	7.9	28.9	10.3	5.5	19.1
Mean	68.4	47.9	83.9	7.8	28.9	9.9	5.749	16.36
LSD ($P \leq 0.05$)	11.911	1.986	1.972	0.2224	10.811	0.9155	0.5804	5.879
CV%	5.0	1.2	0.7	1.3	10.7	2.6	2.9	10.2

6.4.7 100 Seed weight

The results indicated that accessions had significant ($P \leq 0.05$) effect on 100 seed weight due to the integration of reduced light intensity and micro-catchment treatments during the 2012 short rain season (Table 6.1). Accession Nylon-1 had the highest (6.0 g) 100-seed weight (Table 6.9). The lowest (5.3 g) 100-seed weight was recorded on accession GBK-022502A.

Table 6. 8: Shading treatments on several parameters of the 4 green gram accessions during the 2013 long rain season at Machakos ATC

Shade	Plant height (cm)	Days to flowering	Days to maturity	Pod length (cm)	pods per plant	Seeds per pod	100 seeds weight (g)	Seed yield (g)
Control	38.8	50.9	94.1	8.2	23.7	10.2	5.2	12.5
Net	23.7	44.1	71.9	6.0	8.4	7.6	3.8	4.3
Mean	31.2	47.5	83.0	7.1	16.1	8.9	4.48	8.4
LSD (P≤0.05)	13.363	30.52	50.15	3.898	6.252	5.256	2.773	3.091
CV%	12.2	18.2	17.2	15.7	11.1	16.8	17.6	10.5

Table 6. 9: Different parameters of the 4 green gram accessions as influenced by micro-catchment and shading treatments during the 2012 short rain season at Machakos ATC

Accession	Plant height (cm)	Days to flowering	Days to maturity	Pod length (cm)	Pods per plant	Seeds per pod	100 seeds weight (g)	Seed yield (g)
GBK-022494A	69.3	46.1	83.3	7.6	31.4	9.8	5.6	17.2
GBK-022501A	65.5	46.0	82.8	7.7	29.4	9.5	5.6	16.6
GBK-022502A	69.7	48.3	84.1	7.9	28.1	9.8	5.3	14.5
Nylon-1	69.0	51.3	85.6	8.0	26.5	10.7	6.0	17.1
Mean	68.4	47.9	83.9	7.8	29.9	9.9	5.6	16.4
LSD (P≤0.05)	2.996	1.757	1.642	0.442	4.536	0.501	0.377	2.97
CV%	4.3	1.2	0.9	1.2	7.5	0.2	2.9	4.8

6.4.8 Seed yield

There results indicated that shade recorded significant (P≤0.05) effect on seed yield of the 4 green gram accessions during the 2013 long rain season (Table 6.2). The highest (12.5 g) seed yield was observed under shade control (direct light intensity) as compared to the seed yield of 4.3 g achieved under shade net (Table 6.8).

6.5 Results from Kiboko site, Makueni

The rainfall and RH% data was shown on Figure 4.3 and mean temperature as shown on Figure 4.4

Table 6. 10: ANOVA (P value) Summary for Kiboko during the 2012 short season

Variate	**Plant height**	**Days to flowering**	**Days to maturity**	**Pod length**	**Pods pe plant**	**Seeds per pod**	**100 seeds weight**	**Seed yield**
Source of variation: Machakos ATC 2012 short rain season	F pr.	F pr.	F pr.	F pr.	F pr.	F pr.	F pr.	F pr.
Rep.Shade stratum								
Shade	0.1	0.055	0.008	0.012	0.07	0.078	0.24	0.057
Rep.Shade.Micro_catchment stratum								
Micro_catchment	0.136	0.646	0.888		0.129	0.294	0.444	0.1
Shade.Micro_catchment	0.81	0.818	0.435	0.339	0.812	0.83	0.792	0.719
Rep.Shade.Micro_catchment.Accession stratum								
Accession	0.024	<.001	0.009	0.081	0.175	<.001	0.006	0.239
Shade.Accession	0.043	0.912	0.766	0.084	0.085	0.074	0.067	0.051
Micro_catchment.Accession	0.02	0.516	0.618	0.165	0.413	0.102	0.646	0.661
Shade.Micro_catchment.Accession	0.401	0.186	0.18	0.951	0.387	0.403	0.579	0.584

Table 6. 11: ANOVA (P value) Summary for Kiboko during the 2013 long rain seasons

Variate	**Plant height**	**Days to flowering**	**Days to maturity**	**Pod length**	**Pods per plant**	**Seeds per pod**	**100 seeds weight**	**Seed yield**
Source of variation: Machakos ATC 2013long rain season	F pr.	F pr.	F pr.	F pr.	F pr.	F pr.	F pr.	F pr.
Rep.Shade stratum								
Shade	0.04	0.438	0.197	0.129	0.009	0.167	0.161	0.007
Rep.Shade.Micro_catchment stratum								
Micro_catchment	0.677	0.529	0.67	0.504	0.607	0.678	0.707	0.648
Shade.Micro_catchment	0.692	0.616	0.767	0.773	0.36	0.481	0.713	0.46
Rep.Shade.Micro_catchment.Accession stratum								
Accession	0.26	0.74	0.691	0.445	0.065	0.675	0.178	0.158
Shade.Accession	0.431	0.417	0.566	0.625	0.04	0.499	0.901	0.105
Micro_catchment.Accession	0.571	0.6	0.437	0.343	0.645	0.327	0.271	0.355
Shade.Micro_catchment.Accession	0.594	0.706	0.475	0.465	0.244	0.604	0.843	0.229

6.5.1 Plant height

There results indicated that accession had significant (P<.001) differences effects on plant height under the integration between shade and micro-catchment (Table 6.10). Plant height ranged between 44.8 cm and 53.4 cm during the 2012 short rain season (Table 6.12). Accessions GBK-022501A and GBK-022502A attained the highest (53.4 cm each) plant height while Nylon-1 had the shortest (44.8 cm) plant height.

Table 6. 12: Different parameters of the 4 green gram accessions as influenced by micro-catchment and shading treatments during the 2012 short rain season at Kiboko for variables

	Plant height (cm)	Days to flowering	Days to maturity	Pod length	Pods per plant	Seeds per pod	100 seeds weight (g)	Seed yield(g)
GBK-022494A	50.1	38.9	68.2	7.6	39.4	8.7	5.1	17.4
GBK-022501A	53.4	40.0	69.2	7.6	38.6	8.8	4.9	16.6
GBK-022502A	53.4	39.7	69.5	7.6	31.4	8.7	5.2	14
Nylon-1	44.8	37.4	68.5	7.5	30.2	8.6	6.2	15.4
Mean	50.4	38.9	68.9	7.6	34.9	8.7	5.345	15.8
LSD (P≤0.05)	3.651	1.263	0.79	0.106	5.559	0.2902	0.4784	2.77
CV%	7.2	1.9	1	1.1	12.8	4.4	8.8	10.6

Table 6. 13: Different parameters of the 4 green gram accessions as influenced by micro-catchment and shading treatments during the 2013 long rain season at Kiboko for variables

	Plant Height (cm)	Days to flowering	Days to maturity	Pod Length	Pods per plant	Seeds per pod	100 seeds weight (g)	Seed Yield (g)
GBK-022494A	48.6	37.2	63.9	7.3	29.2	9.8	5.4	16.4
GBK-022501A	48.9	35.6	62.1	6.9	27.6	9.2	5.4	15.6
GBK-022502A	54.4	38.1	63.1	7.3	25.7	9.1	5.2	13.1
Nylon-1	50.4	39.2	65.6	7.6	25.4	10.3	5.7	15.7
Mean	50.6	37.5	63.7	7.3	27	9.6	5.43	15.2
LSD (P≤0.05)	7.28	3.467	6.9	0.821	6.05	1.154	0.712	3.78
CV%	7.6	2.1	2.9	1.4	9.7	4.9	1.6	9.9

6.5.2 Number of day to flowering

Results indicated that accession had significant (P≤0.05) effect on days to flowering under the integration of reduced light intensity and micro-catchment during the 2012 short rain season (Table 6.10). The period taken by the accessions to flower ranged from 37 to 40 (Table 6.12). Accession Nylon-1) took the shortest (37 days) period to flower while GBK-022501A took the longest (40 days) to flower.

6.5.3 Number of days to maturity

Results indicated that accession had significant (P≤0.05) effect on number of days to maturity during the 2012 short rain season (Table 6.10). The accessions took a range of from 68 days to 69 days to mature (Table 6.12). Accessions GBK-022494A and Nylon-1 were the earliest (68 days) to mature where GBK-022501A and GBK-022502A mature at 69 days each. Shade, micro-catchments and accessions had significant (P≤0.05) effects on the days to maturity during the 2013 long rain season (Tables 6.11).

6.5.4 Number of pods per plant

Results indicated that accession had significant (P≤0.05) effect on number of pods per plant under the integration of reduced light intensity (shade net) and micro-catchment treatments during the 2012 short rain season (Table 6.10). Accession GBK-022494A had the highest (39) number of pods per plant while Nylon-1 had the least (30) number of pods per plant (Table 6.12).

6.5.5 100 Seed weight

Accession had significant (P≤0.05) effect on 100 seed weight under the integration of reduced light intensity (shade net) and micro-catchment treatments (Table 6.10) during the 2012 short rain season. The accessions had 100 seed weight ranging from 4.9 g to 6.2 g (Table 6.12). Accession Nylon-1 had the highest (6.2 g g) 100 seed weight while accession GBK-022501A had the lowest (4.9 g) 100 seed weight. Shade had significant (P≤0.05) effect on the 100 seed weight during the 2013 long rain season (Table 6.11). Accessions had 100 seed weight ranging between 5.2 g and 5.6 g (Table 6.14). The highest (5.6 g) 100 seed weight was observed under shade control (direct solar radiation) as compared to the 100 seed weight of 5.2 g achieved under shade net.

Table 6. 14: Shading treatments on several parameters of the 4 green gram accessions during the 2013 short long rain season at Kiboko

Shade	Plant height (cm)	Days to flowering	Days to maturity	Pod length (cm)	Pods per plant	Seeds per pod	100 seeds weight (g)	Seed yield (g)
Control	51.5	37.6	63.2	7.3	29.9	9.5	5.6	16.8
Net	49.6	37.5	64.2	7.3	24.1	9.8	5.2	13.6
Mean	50.6	37.5	63.4	7.3	27	9.6	5.4	15.2
LSD (P≤0.05)	5.36	3.42	1.81	0.52	12	1.803	0.138	10.206
CV%	3	2.6	0.8	2	12.7	5.3	1.6	19.1

6.6 Discussion

The values for the measured parameters were higher during the 2012 short rain seasons when the rainfall amount was lower as compared to those values recorded during the 2013 long rains when rainfall amount was high. In connection with this, the discussions will be based on the values recorded during the 2012 short rains.

The accessions attained an average plant height of 71.3 cm both under the net and open ridges, and under net and tied ridges; 74.6 cm under net and flatbed; 64.4 cm under the control and open ridges, 62.4 cm under the control and tied ridges, 66.2 cm under the control and flatbeds at Machakos ATC. At Kiboko, the accessions attained an average plant height of 52.2 cm under net and open ridges, 54.5 cm under shade net and tied ridges, and 49.9 cm under shade net and flatbeds; 45.2 cm under net and open ridges, 50.1 cm under the control and tied ridges and 50.7 cm under control and flatbeds. The plant's average height was higher under shade net and flatbeds as well as under direct solar radiation and flatbeds.The accessions had higher plant height under shade nets as compared to direct light intensity. The heat generated by sunshine causes loss of water from the plant and soil surfaces through evapo-transpiration. Shading reduces the amount of light striking the surfaces of both plant and soil, hence reducing water loss through evapotranspiration. This saves more water for use by the plant. This leads to higher growth rate for the plants under the shade as compared to those under direct light intensity (Adugna and Paul, 2010). Since flatbeds hold more water than normal flatbeds, tending towards water logging which may have led to less plant growth (plant height). This is in line with Rono *et al*, (2013) who found that when micro-catchments hold a lot of water, it could lead to waterlogging which slows down the plant's development while working on effects of micro-catchment rain water harvesting on survival and growth of multipurpose trees and shrubs in Nyando, Western Kenya.

The accessions took a range of between 46 to 51 days to flower at Machakos ATC and between 37 to 39 days to flower at Kiboko under the integration of shade and micro-catchments. According to Romana *et al*, (2013), the varied number of days taken by different accessions to flower can be attributed to the inherent genes. The accessions had an average of 49 days to flower under the shade net and open ridges, 48 days under the net and tied ridges, 48 days under net and furrow; 46 days under direct solar radiation (control) and open ridges, 47 days under the control and tied ridges, 46 days under the control and flatbed at Machakos ATC. The accessions took an average of between 38 days to flower under the net and open ridges, 38 days under the net and tied ridges, 39 days under net and flatbeds; 38 days under direct solar radiation (control) and open ridges, 38 days under the control and tied ridges, 39 days under the control and flatbeds at Kiboko. The accessions took shorter time to flower under the shade net and open ridges. The accessions took fewer days to flower under the integration of normal flatbed and under direct sunshine and as compared to those under shade nets in the long rains season probably due to the weather conditions predisposed to the crops. As a primary source of energy, light is one of the most important environmental factors for plant growth (Fukuda *et al*., 2008). The intensity of light is essential for the growth, morphogenesis and other physiological responses of plants and therefore the crop responded as to the exact amount required. In tied ridges, were blocked with earth ties spaced at a fixed distance apart to form a series of micro-catchment basins in the field. According the Rono *et al.*, (2013) and Kimani *et al.*, (2015), such created basins catch and hold rainwater, minimize surface runoff, improve downward infiltration of water and thus enhancing the crops' growth and development.

The accessions took an average of 86 days to mature under shade net and 81 days under direct light intensity. The shading provided by the shade net reduced water loss through evapotranspiration leading to more water being available to the plants which in turn prolonged the vegetative period making the plants under shade net take longer to mature compared to those under direct light intensity. This agrees with Makus, (2001); Makus and Lester, 2002 who reported that shading reduces air and soil temperature. The accessions took a range of between 82 to 85 days to mature at Machakos ATC and between 68 to 69 days to mature at Kiboko under the integration of shade and micro-catchments. According to Romana *et al.*, (2013), the varied number of days taken by different accessions to flower can be attributed to the inherent genes. The accessions took an average of 87 days to mature under the net and open ridges, 86 days under net and tied ridges, 86 days under net and flatbeds; 80 days under the control and open ridges, 81days under control and tied ridges, 81 days under the control and flatbeds at Machakos ATC. The accessions took an average of 68 days to mature under the net and open ridges, 68 days under net and tied ridges, 68 days under net and flatbeds; 68 days under the control and open ridges, 69 days under control and tied ridges, 69 days under the control and flatbeds at Kiboko. The accessions matured earliest under the direct light intensity as compared to those under shade net. This could be due to higher moisture content under the shade which could have prolonged the vegetative period.

The pod length attained under the shade net was 7.9 cm as compared to 7.6 cm attained under the direct solar radiation (7.6 cm). According to Jaqueline *et al.*, (2007), shading increases chlorophyll content and this could have resulted in increased pod length under shade net as compared to those under direct solar radiation. Shading reduces air and soil temperature (Makus, 2001; Makus and Lester, 2002) thus reducing water loss through evaporation and transpiration from plants and this leads to better agronomic performance of crops in Machakos and Makueni Counties. The accessions had an average pod length of between 8.0 cm under net and open ridges, 7.9 cm under net and tied ridges, 7.9 cm under net and flatbeds; 7.5 cm under the control and open ridges, 7.7 cm under the control and tied ridges, 7.7 cm under the control and flatbed at Machakos ATC. The accessions had an average pod length of 7.5 cm under net and open ridges, 7.5 cm under net and tied ridges, 7.6 cm under net and flatbeds; 7.6 cm under the control and open ridges, 7.6 cm under the control and tied ridges, 7.6 cm under the control and flatbed at Kiboko. Under shade net, the pods had a higher pod length in open ridges.

The accession had a range of number of pods per plant between 30 and 39 pods. According to Romana *et al.*, (2013), the varied number of pods per plant can be attributed to the inherent genes. The accessions an average of 31 pods per plant under net and open ridges, 35 under net and tied ridges, 32 under net and flatbeds, 22 under the control and open ridges, 25 under the control and tied ridges, 24 under net and flatbeds at Machakos ATC. The number of pods per plant was higher in tied ridges under both shade net and direct sunshine. The accessions had higher number of pods per plant under direct sunshine as compared to under shade net. The accession had an average of between 32 pods per plant under net and open ridges, 40 under net and tied ridges, 31 under net and flatbeds, 32 under the control and open ridges, 39 under the control and tied ridges, 33 under net and flatbeds at Kiboko.

The accession had an average of 10 seeds per pod under net and all micro-catchments while under direct light intensity and under all micro-catchments, the accessions had an average of 9 seeds per pod; at Machakos ATC. Under shade net, the accessions had higher number of seeds per pod in all the micro-catchments than under the direct light intensity. The accession had an average of 8 pods per plant under net and open ridges, and under net and tied ridges, 9 under net and flatbed. The accessions had an average of 8 seeds per pod under direct light intensity and all the micro-catchments at Kiboko.

The accessions had a range of 100 seed weight between 5 and 6 g both at Machakos ATC and Kiboko. According to Romana *et al.*, (2013), the varied number of number of pods per plant can be attributed to the inherent genes. The accessions had an average of 100 seed weight of 5.7 g under net and open ridges, 5.4 g under net and tied ridges, 5.7 g under net and flatbeds; 5.6 g under control and open ridges, 5.8 g under control and tied ridges, 5.8 g under control and flatbeds at Machakos ATC. The accessions had an average of 100 seed weight of 5.3 g under net and open ridges, 5.4 g under net and tied ridges, 5.2 g under net andflatbed; 5.6 g under control and open ridges, 5.4 g under control and tied ridges, 5.3 g under control and flatbedss at Kiboko.

The accessions had an average seed yield of 17.5 g under net and open ridges, 20.0 g under net and tied ridges, 18.9 g under net and flatbeds; 12.6 g under control and open ridges, 14.4 g under control and tied ridges, 13.9 g under control and flatbeds at Machakos ATC. Under shade net, the accessions had higher seed yield under tied ridges. Under direct sunshine, the accessions had higher seed yield in tied ridges. The accessions had an average seed yield of between 14.8 g under net and open ridges, 18.6 g under net and tied ridges, 14.0 g under net and flatbed; 14.8 g under control and open ridges, 18.4 g under control and tied ridges, 14.4 g under control and flatbeds at Kiboko. Closed-end tied ridges gave more time for the rain water to penetrate and infiltrate than the other micro-catchment treatments and therefore allowed the crop plants to use water that could have been lost as runoff. Additional advantage due to planting in tied ridges is that rainwater falling on the ridges can be re-collected in the planting belts (flatbeds) and thus can increase the availability of soil moisture to plant roots. It presents the advantage of the water harvesting techniques. This result is in agreement with Belachew *et al.*, (2010), Rono *et al.*, (2013) and Kimani *et al.*, (2015). In the semi-arid region of northern Ethiopia, tied-ridges improved the barley yield by 44% compared to the traditional tillage (Araya and Stroosnijder, 2010). Applications of tied-ridges in Zimbabwe doubled yield in comparison to the conventional tillage without ridges (Motsi *et al.*, 2004). The accessions had higher seed yield under direct sunshine as compared to those under shade net. Under shade net, the accession had higher seed yield under tied ridges while under direct sunshine, the accessions had higher seed yield in open ridges. The accessions had higher seed yield under direct sunshine as compared to those under shade net. It was earlier reported that the grain yield of soybean reduced under the low light because of reduction in dry matter production, total pod number per plant and thousand grains weight (Hayder *et al*., 2003).

Conclusion

From the results, there were significant interaction between shade and accession and between micro-catchment and accession. Therefore, this study concludes that, Green gram genotypes perform better under shade net except in cases of above normal rain and that under the shade net, construction of micro-catchments may not be necessary.

Recommendation

This study recommends in pursuit of improving agronomic performance of green grams genotypes be planted under reduced light intensities (when rainfall are anot dequate) or be planted under micro –catchment (tied ridges).

CHAPTER SEVEN

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

7.1 Discussion

Different accessions were found to take varied number of days to flowering ranging from 38-47 days which was in agreement with Romana *et al.,* (2013), Raturi *et al.,* (2012), Khajudparn and Tantasawat (2011). The accessions were found to take more days to flower under reduced light intensity (shade nets) as compared to those under direct light intensity (control). This was supported by findings for the accessions grown under shade which took longer to flower as compared to those grown under direct sunshine. The results showed that the accessions took a longer period to flower under open ridges as compared to those planted on tied ridges. This could be occasioned by the fact that by tying the ridges, the amount of water available (during times of less rainfall) was confined and directed to the roots of the plant. This implies that the plants got adequate water under the tied ridges as compared to the open ridges. The green gram accessions were found to take fewer days to flower under direct sunshine as compared to those grown under the shade net. This could be attributed to the fact the plants take more time in the vegetative stage as it had more water available occasioned by reduced evapotranspiration due to reduced light intensity as indicated by Makus, (2001); and Makus and Lester (2002).

Green gram genotypes attained a plant height ranging from 37-63 cm which was in line with other researchers who reported a plant height range of 29-58 cm (Narasimhulu *et al.,* (2013), 42-67cm (Machikowa and Laosuwan, 2009) and 38-60cm (Mondal *et al.,* 2009). Romana *et al*, (2013), attributed this variation to inherent genes. Plant height was found to be significantly and positively correlated to growth and yield parameters including number of days to flowering, number of pods per plant and seed yield, a finding which was echoed by Thippani *et al.,* (2013), and Huang *et al.,* (2013). This implies that improving plant height would lead to increased number of leaves per plant resulting in a larger surface area for photosynthesis to take place. This leads to production of many pods per plant resulting to increased seed yield. Therefore, improving plant height would lead to increased seed yield. The average plant height was found to be taller under reduced light intensity as compared those under direct solar radiation. These results were in line with those those by Araki *et al.*, (2014) at Kyushu University, Japan, Na Chiangmai *et al.*, (2012) at Phetchaburi, Thailand; Abd *et al* (2015) at Egypt and Abdul *et al.*, (2003) at Japan who found that plants attained a higher plant height under shade as compared to those under direct solar radiation. This is because; plants under reduced light would grow faster as they look for more light and had more water available due to reduced light intensity, which in effect reduced evapotranspiration. The plants under open ridges were found to be taller as compared to those under tied ridges at one of the experimental site while the results were the opposite in the other experimental site with a higher plant height under tied ridges as compared to those under open ridges. This could be explained by the amount of rainfall received. If the amount of rainfall is higher, more water is retained in the tied ridges, which could bring about water logging, thus reducing growth rate, leading to shorter plants as opposed to when rainfall is low and some water is retained in the tied ridges, this could lead to increased plant height. The plant's average height was higher under shade net and flatbeds while under direct sunshine, average plant height was higher under open flatbeds. The accessions had higher plant height under shade nets as compared to under direct light intensity.

In this study, the genotypes attained a range of 23-72 pods per plant. This was in line with the studies by other researchers such as Khajudparn and Tantasawat (2011) who reported that number of pods per plant ranged from 19-49; Machikowa and Laosuwan, (2009) 36 – 46; Rozina *et al.*, (2007) 33-59. Number of pods per plant was found to be significantly and positively correlated to number of leaves per plant, plant height and seed yield. This finding was in agreement with those of; Huang *et al.*, (2013), Thippani *et al.*, (2013), Khajudparn and Tantasawat, (2011); Rozina *et al.*, (2008) and Malik *et al.*, (2007). A higher plant height enables the plant to produce and carry many leaves. This implies that a plant which has many leaves, commands a larger surface area on which manufacturing of plant food through photosynthesis take place leading to a higher number of pods resulting in higher seed yield. The accessions grown under reduced sunshine were found to produce higher number of pods per plant as compared to those under direct sunshine. This could be due to the fact that those under shade have more water available and enough chlorophyll for production of plant food leading to high number of pods per plant. Accessions planted on tied ridges had more pods per plant as compared to those planted in open ridges implying that adequate water could have been concentrated around the plants' roots making it possible for the roots to translocate nutrients required for photosynthesis. The accessions planted on micro-catchments under shade net had a higher number of pods per plant as compared to those planted on micro-catchments under direct light intensity and that in both cases, those on tied ridges had higher number of pods per plant than those on open ridges.

The selected green gram accessions produced number of seeds per pod ranging from 8-13 seeds, which agreed with results from other researchers such as Raturi *et al.,* (2012), Asghar *et al.,* (2000), (Gadakh *et al.*, 2013) with a range of 8-14 seeds per pod. The variation was attributed to the inherent genes (Romana *et al.*, 2013). The accessions planted under both reduced light intensity and under direct sunshine produced the same number of seeds per pod. These results were in line with findings by other researchers such as Bing *et al.,* (2010); who reported that light reduction had no effect on the number of seeds per pod. However, other researchers reported that reducing light intensity reduces the number of seeds per pod due to reduced amount of chlorophyll resulting in reduced plant food production. The accessions were found to have the same number of seeds per pod in the two micro-catchments. The accessions planted in micro-catchments under the shade net were found to have a higher number of seeds per pod as compared to those grown on micro-catchments under direct light intensity.

The results in this study indicated that pod length ranged from 8.0 to 13.8 cm. This was in line with those of other researchers such as (Gadakh *et al.*, 2013) who reported a pod length range of 7.1 cm – 10.3 cm and Khajudparn and Tantasawat (2011) 6.9 cm – 9.9 cm. According to Romana *et al.*, 2013, the variation was due to the inherent genes. Correlation analysis indicated that pod length was significantly and positively correlated to 100 seed weight which was in agreement with those of Thippani *et al.*, (2013); Khajudparn and Tantasawat (2011). Reducing the light intensity was found to increase pod length, a finding which was contrary to those of other researchers as such Makus, (2001). The accessions planted on open ridges were found to have longer pod length as compared to those planted in tied ridges at one experimental site and a longer pod length in open ridges than in tied ridges in the other site.

The study reported that the accessions matured within a range of 69-87 days. Other researchers reported a range of 82-89 days to maturity (Machikowa and Laosuwan, 2009), while Khajudparn and Tantasawat (2011) reported 53-62 days to maturity. This variation in number of days to maturity is attributed to the inherent genes (Romama *et al.*, 2013). Correlation analysis indicated that number of days to maturity was significantly and positively correlated to number of days to flowering. The results were in line with those of Khajudparn and Tantasawat (2011); Machikowa and Laosuwan, (2009); Malik *et al.*, (2007). This implies that improving (increasing) the number of days to flowering leads to more days to maturity and in most cases results in higher seed yield. The accessions were found to take slightly fewer days to mature under direct sunshine as compared to those grown under shade net. This was in line to the expected results as under the direct sunshine to have more chlorophyll, thus quickening the process of maturing. The accessions were found to mature faster under open ridge as compared to tied ridges.The accessions planted in micro-catchment and under net took more days to mature as compared to those under in micro-catchment under direct sunshine.

The study reported a 100 seed weight range of 4.1- 9.3 g. This was in line with the finding of other researchers such as Machikowa and Laosuwan, (2009) who reported a 100 seed weight range of 5.0 g–9.1 g. According to Romana *et al.*, 2013 the variation was as a result of inherent genes. Correlation analysis indicated that 100 seeds weight was significantly and positively correlated to pod length. This implies that improving pod length leads to reduced seed size and weight leading to reduced 100 seed weight. The study reported a higher 100 seeds weight range from the accessions planted under direct sunshine as compared to those planted under reduced light intensity. These results were in line with those reported by other researchers such as; Akhter *et al.*, (2009); Ahmed *et al.*, (2003). The accessions planted in the open ridges had higher 100 seed weight range than those planted on tied ridges. The accessions planted in micro-catchments under direct sunshine had a higher 100 seed weight as compared to those under reduced light intensity.

The study reported seed yield range of between 15.8 - 55.6 g which was quite high as compared to results of other studies such as; Narasimhulu *et al.,* (2013) 4.1 g – 9.0 g per plant; and Rozina *et al.,* (2007) 10.9 - 19.7 g per plant. Correlation analysis results indicated that seed yield was significantly and positively correlated to number of leaves per plant, plant height, and number of pods per plant. The results were comparable to those of Khajupparn and Tantasawat (2011), Rozina *et al.*, (2008) and Thippani *et al*, (2013). Seed yield was found to be higher for the accessions planted under direct sunshine as compared to those under reduced light intensity. This was in line with other researchers such as; Ephrath *et al.,* (1993), and Verghis *et al.,* (1999), who indicated that shading reduces seed yield - Seed yield range was found to be higher for the accessions planted on tied ridges. In general, the accessions planted in micro-catchment under direct sunshine had a higher seed yield as compared to those under reduced light intensity in one experimental site as compared to the other.

Results on regression analysis on the effect of moisture content on the various green gram traits under ridges, open ridges and normal flatbeds indicated that; there was positive relation between moisture content and plant height and number of seeds per pod while there was negative relation with number of days to flowering and number of days to maturity on all micro-catchments.

7.2 Conclusion

- The cluster analysis revealed that GBK-022494A stood out in both sites and also had the highest number of pods per plant in both sites, hence this should be emphasized.
- Agronomic performance of the 40 green gram genotypes varied within the same environment and across the two varying environments with accessions GBK-022494A and Nylon-1 performing well at Kiboko in Makueni County and GBK-022501A while GBK-022494A performed well at Machakos ATC in Machakos County
- Green gram accessions performed well under reduced (35%) light intensity as long as rainfall amount was normal and distributed fairly well during the growing period of the plants
- Micro-catchment improved plant height and shortened the number of days to flowering (Accession Nylon-1) of green grams in Machakos and Makueni Counties, Kenya.
- Integrated packages incorporating reduced light intensity and micro-catchments had no effect on the productivity of four green gram genotypes
- Green gram genotypes perform better under shade net except in cases of rainfall above the normal
- Under the shade net, construction of micro-catchments may not be necessary

7.3 Recommendations

- For better agronomic performance, green gram genotypes should be grown in the enviroments, where they are best suited. For instance, GBK-022494A and Nylon-1 should be grown in Kiboko and its environs. In Machakos, GBK-022501A and GBK-022494A are the most suited.

- Farmers seek advice from Meteorological Department on the nature of the expected rainfall and only install shade net if the rainfall would be below normal and that there should be provision for rolling back the net in case the rainfall is intensifies
- This study recommends that micro-catchments can be used where plant height needs to be improved and also in cases where plants are required to flower earlier than their normal period.
- This study recommends in pursuit of improving agronomic performance of green grams genotypes be planted under reduced light intensities (when rainfall are not adequate) or be planted under micro –catchment (tied ridges)

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APPENDICES

Appendix 1: Green gram accessions and their source

S/No	Accessions	Source
1	GBK-017437A	National Gene Bank of Kenya
2	GBK-017438A	National Gene Bank of Kenya
3	GBK-017456A	National Gene Bank of Kenya
4	GBK-018629A	National Gene Bank of Kenya
5	GBK-018633A	National Gene Bank of Kenya
6	GBK-018635A	National Gene Bank of Kenya
7	GBK-022491A	National Gene Bank of Kenya
8	GBK-022492A	National Gene Bank of Kenya
9	GBK-022493A	National Gene Bank of Kenya
10	GBK-022494A	National Gene Bank of Kenya
11	GBK-022495A	National Gene Bank of Kenya
12	GBK-022497A	National Gene Bank of Kenya
13	GBK-022498A	National Gene Bank of Kenya
14	GBK-022499A	National Gene Bank of Kenya
15	GBK-022500A	National Gene Bank of Kenya
16	GBK-022501A	National Gene Bank of Kenya
17	GBK-022502A	National Gene Bank of Kenya
18	GBK-022504A	National Gene Bank of Kenya
19	GBK-022505A	National Gene Bank of Kenya
20	GBK-022506A	National Gene Bank of Kenya
21	GBK-022507A	National Gene Bank of Kenya
22	GBK-022508A	National Gene Bank of Kenya
23	GBK-022509A	National Gene Bank of Kenya
24	GBK-022531A	National Gene Bank of Kenya
25	GBK-022532A	National Gene Bank of Kenya
26	GBK-022534A	National Gene Bank of Kenya
27	GBK-022536A	National Gene Bank of Kenya
28	GBK-022537A	National Gene Bank of Kenya
29	GBK-022539A	National Gene Bank of Kenya
30	Nylon-1	Kalama in Machakos county
31	Uncle-1	Kalama in Machakos county
32	N26	Central Div. Machakos county
33	Olayo	Homabay Sub- county
34	Cotton	Makueni County
35	Uncle-2	Machakos county
36	Nylon-2	Machakos county
37	Ndengu-1	Wote in Makueni county
38	Ndengu-2	Loitokitok
39	Ndengu-3	Makueni county
40	Ndengu-4	Loitokitok

Appendix 2: Analysis of Variance values during 2011 short 2012 long rain seasons – for both Machakos ATC and Kiboko

MACHAKOS ATC - 2011 Short rain season

Number of leaves per plant at Week 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	57.848	28.924	8.77	
Replication.*Units* stratum					
Accession	34	151.848	4.466	1.35	0.143
Residual	68	224.152	3.296		
Total	104	433.848			

Plant height

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		2062.21	1031.10	33.41	
Replication.*Units* stratum						
Accession	34		2735.92	80.47	2.61	<.001
Residual	67	(1)	2067.75	30.86		
Total	103	(1)	6755.80			

Number of days to flowering

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		10.842	5.421	1.01	
Replication.*Units* stratum						
Accession	34		199.069	5.855	1.09	0.373
Residual	67	(1)	359.788	5.370		
Total	103	(1)	568.154			

Number of days to maturity

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		239.836	119.918	40.34	
Replication.*Units* stratum						
Accession	34		135.059	3.972	1.34	0.157
Residual	65	(3)	193.212	2.972		
Total	101	(3)	565.509			

Pod length

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.2658	0.1329	0.44	
Replication.*Units* stratum						
Accession	34		29.7598	0.8753	2.92	<.001
Residual	65	(3)	19.5153	0.3002		
Total	101	(3)	48.1702			

Pod girth

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.74742	0.37371	14.48	
Replication.*Units* stratum						
Accession	34		1.82429	0.05366	2.08	0.006
Residual	65	(3)	1.67789	0.02581		
Total	101	(3)	4.22873			

Number of pods per plant

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		2378.5	1189.3	5.70	
Replication.*Units* stratum						
Accession	34		21676.7	637.5	3.05	<.001
Residual	65	(3)	13568.2	208.7		
Total	101	(3)	33909.4			

Number of seeds per pod

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		0.4238	0.2119	0.34	
Replication.*Units* stratum						
Accession	34		75.2242	2.2125	3.58	<.001
Residual	65	(3)	40.1156	0.6172		
Total	101	(3)	113.9691			

Weight of 100 seeds

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		2.041	1.021	0.68	
Replication.*Units* stratum						
Accession	34		106.647	3.137	2.08	0.006
Residual	65	(3)	98.079	1.509		
Total	101	(3)	201.601			

Seed yield

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		586.3	293.1	2.90	
Replication.*Units* stratum						

Accession	34		7576.4	222.8	2.21	0.003
Residual	65	(3)	6559.3	100.9		
Total	101	(3)	14047.0			

MACHAKOS – 2012 Long rain season
Number of leaves per plant at Week 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	104.629	52.314	13.08	
Replication.*Units* stratum					
Accession	34	214.133	6.298	1.57	0.056
Residual	68	272.038	4.001		
Total	104	590.800			

Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	605.01	302.50	4.67	
Replication.*Units* stratum					
Accession	34	5910.11	173.83	2.69	<.001
Residual	68	4401.33	64.73		
Total	104	10916.45			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	23.881	11.941	6.12	
Replication.*Units* stratum					
Accession	34	113.231	3.330	1.71	0.031
Residual	68	132.600	1.950		
Total	104	269.712			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	434.095	217.048	24.69	
Replication.*Units* stratum					
Accession	34	424.554	12.487	1.42	0.110
Residual	68	597.865	8.792		
Total	104	1456.514			

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	1.5012	0.7506	2.96	
Replication.*Units* stratum					
Accession	34	42.5210	1.2506	4.93	<.001
Residual	68	17.2343	0.2534		
Total	104	61.2566			

Pod girth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.093743	0.046872	5.56	
Replication.*Units* stratum					
Accession	34	2.574294	0.075715	8.98	<.001
Residual	68	0.573497	0.008434		
Total	104	3.241535			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	1153.2	576.6	3.87	
Replication.*Units* stratum					
Accession	34	8473.0	249.2	1.67	0.036
Residual	68	10138.1	149.1		
Total	104	19764.4			

Number of seeds per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	8.5883	4.2942	9.21	
Replication.*Units* stratum					
Accession	34	80.4347	2.3657	5.08	<.001
Residual	68	31.6944	0.4661		
Total	104	120.7175			

Weight of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	13.6944	6.8472	24.52	
Replication.*Units* stratum					
Accession	34	129.9868	3.8231	13.69	<.001
Residual	68	18.9924	0.2793		
Total	104	162.6736			

Seed yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	914.96	457.48	6.84	
Replication.*Units* stratum					
Accession	34	2300.81	67.67	1.01	0.471
Residual	68	4548.45	66.89		
Total	104	7764.22			

KIBOKO – 2011 Short rain season
Variate: No. of leaves per plant at Week 6

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Replication stratum	2		5.0184	2.5092	6.01	
Replication.*Units* stratum						
Accession	35		14.8565	0.4245	1.02	0.466
Residual	68	(2)	28.4077	0.4178		
Total	105	(2)	48.1509			

Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	559.29	279.64	9.39	
Replication.*Units* stratum					
Accession	35	2405.53	68.73	2.31	0.001
Residual	70	2085.33	29.79		
Total	107	5050.16			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	5.196	2.598	0.35	
Replication.*Units* stratum					
Accession	35	412.923	11.798	1.58	0.052
Residual	70	521.679	7.453		

Total	107	939.798			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	305.32	152.66	11.77	
Replication.*Units* stratum					
Accession	35	749.63	21.42	1.65	0.038
Residual	70	907.93	12.97		
Total	107	1962.89			

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	18.478	9.239	0.98	
Replication.*Units* stratum					
Accession	35	293.136	8.375	0.88	0.649
Residual	70	663.221	9.475		
Total	107	974.835			

Pod girth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.20156	0.10078	9.56	
Replication.*Units* stratum					
Accession	35	0.53609	0.01532	1.45	0.092
Residual	70	0.73765	0.01054		
Total	107	1.47530			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	3340.6	1670.3	10.03	
Replication.*Units* stratum					
Accession	35	31305.7	894.4	5.37	<.001
Residual	70	11660.4	166.6		
Total	107	46306.7			

Number of seeds per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	11.4232	5.7116	5.76	
Replication.*Units* stratum					
Accession	35	46.8876	1.3396	1.35	0.142
Residual	70	69.3828	0.9912		
Total	107	127.6935			

Weight of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	6.022	3.011	1.42	
Replication.*Units* stratum					
Accession	35	132.053	3.773	1.78	0.021
Residual	70	148.413	2.120		
Total	107	286.488			

Seed weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	395.0	197.5	0.91	
Replication.*Units* stratum					
Accession	35	20259.2	578.8	2.66	<.001
Residual	70	15207.0	217.2		
Total	107	35861.3			

Kiboko – 2012 short rain season
Variate: No. of leaves per plant at Week 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	39.574	19.787	10.62	
Replication.*Units* stratum					
Accession	35	86.324	2.466	1.32	0.159
Residual	70	130.426	1.863		
Total	107	256.324			

Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	2043.42	1021.71	26.06	
Replication.*Units* stratum					
Accession	35	2176.29	62.18	1.59	0.051
Residual	70	2744.24	39.20		
Total	107	6963.95			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	409.870	204.935	24.43	
Replication.*Units* stratum					
Accession	35	398.046	11.373	1.36	0.139

Residual	70	587.211	8.389		
Total	107	1395.127			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	54.909	27.454	6.94	
Replication.*Units* stratum					
Accession	35	137.306	3.923	0.99	0.499
Residual	70	277.035	3.958		
Total 107 469.249					

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	18.4916	9.2458	48.77	
Replication.*Units* stratum					
Accession	35	16.8972	0.4828	2.55	<.001
Residual	70	13.2709	0.1896		
Total	107	48.6597			

Pod girth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.10084	0.05042	4.10	
Replication.*Units* stratum					
Accession	35	0.78056	0.02230	1.81	0.018
Residual	70	0.86132	0.01230		
Total	107	1.74273			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	1310.18	655.09	16.31	
Replication.*Units* stratum					
Accession	35	2142.04	61.20	1.52	0.068
Residual	70	2810.70	40.15		
Total	107	6262.92			

Number of seeds per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	29.2659	14.6329	28.06	
Replication.*Units* stratum					
Accession	35	32.5564	0.9302	1.78	0.020

Residual	70	36.4991	0.5214		
Total	107	98.3214			

Weight of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	7.0807	3.5403	6.48	
Replication.*Units* stratum					
Accession	35	48.3345	1.3810	2.53	<.001
Residual	70	38.2321	0.5462		
Total	107	93.6473			

Seed weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	736.08	368.04	22.19	
Replication.*Units* stratum					
Accession	35	1272.84	36.37	2.19	0.003
Residual	70	1161.18	16.59		
Total	107	3170.10			

Appendix 3: Analysis of Variance values during 2012 short 2013 long rain seasons – for both Machakos ATC and Kiboko

Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	251.58	125.79	2.50	
Rep.Shade stratum					
Shade	1	425.38	425.38	8.47	0.101
Residual	2	100.47	50.24	4.30	
Rep.Shade.Accession stratum					
Accession	3	88.63	29.54	2.53	0.106
Shade.Accession	3	17.70	5.90	0.51	0.686
Residual	12	140.11	11.68		
Total	23	1023.85			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	9.903	4.952	0.60	
Rep.Shade stratum					
Shade	1	20.907	20.907	2.53	0.252
Residual	2	16.503	8.252	1.32	
Rep.Shade.Accession stratum					
Accession	3	118.733	39.578	6.33	0.008
Shade.Accession	3	35.160	11.720	1.88	0.188
Residual	12	75.007	6.251		
Total	23	276.213			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2.410	1.205	0.21	
Rep.Shade stratum					
Shade	1	135.375	135.375	23.48	0.040
Residual	2	11.530	5.765	2.39	
Rep.Shade.Accession stratum					
Accession	3	21.218	7.073	2.93	0.077
Shade.Accession	3	11.032	3.677	1.52	0.259
Residual	12	28.940	2.412		
Total	23	210.505			

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0984	0.0492	0.72	
Rep.Shade stratum					
Shade	1	0.1700	0.1700	2.49	0.255
Residual	2	0.1364	0.0682	0.47	
Rep.Shade.Accession stratum					
Accession	3	1.9953	0.6651	4.54	0.024
Shade.Accession	3	0.2782	0.0927	0.63	0.608
Residual	12	1.7577	0.1465		
Total	23	4.4360			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	51.24	25.62	0.25	
Rep.Shade stratum					
Shade	1	376.04	376.04	3.64	0.196
Residual	2	206.33	103.17	1.43	
Rep.Shade.Accession stratum					
Accession	3	71.65	23.88	0.33	0.804
Shade.Accession	3	119.58	39.86	0.55	0.657
Residual	12	867.23	72.27		
Total	23	1692.06			

Number of seeds pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.9633	0.4817	4.74	
Rep.Shade stratum					
Shade	1	1.9267	1.9267	18.95	0.049
Residual	2	0.2033	0.1017	0.32	
Rep.Shade.Accession stratum					
Accession	3	2.7733	0.9244	2.88	0.080
Shade.Accession	3	1.1400	0.3800	1.19	0.356
Residual	12	3.8467	0.3206		
Total	23	10.8533			

Weight of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.5972	0.7986	6.29	
Rep.Shade stratum					
Shade	1	0.1894	0.1894	1.49	0.346
Residual	2	0.2539	0.1270	0.38	
Rep.Shade.Accession stratum					
Accession	3	2.7465	0.9155	2.75	0.089
Shade.Accession	3	0.9466	0.3155	0.95	0.448
Residual	12	3.9888	0.3324		
Total	23	9.7223			

Seed yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.36	2.68	0.07	
Rep.Shade stratum					
Shade	1	152.76	152.76	3.78	0.191
Residual	2	80.72	40.36	1.21	
Rep.Shade.Accession stratum					
Accession	3	22.51	7.50	0.23	0.877
Shade.Accession	3	34.44	11.48	0.34	0.793
Residual	12	399.45	33.29		
Total 23 695.24					

MACHAKOS – 2013 Long rain season

Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	596.21	298.11	18.26	
Rep.Shade stratum					
Shade	1	1204.17	1204.17	73.75	0.013
Residual	2	32.65	16.33	0.19	
Rep.Shade.Accession stratum					
Accession	3	86.06	28.69	0.33	0.800
Shade.Accession	3	51.07	17.02	0.20	0.895
Residual	12	1027.59	85.63		
Total	23	2997.75			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	263.20	131.60	0.44	
Rep.Shade stratum					
Shade	1	115.28	115.28	0.38	0.599
Residual	2	603.34	301.67	7.61	
Rep.Shade.Accession stratum					
Accession	3	135.35	45.12	1.14	0.373
Shade.Accession	3	137.58	45.86	1.16	0.366
Residual	12	475.40	39.62		
Total	23	1730.16			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	489.8	244.9	0.75	
Rep.Shade stratum					
Shade	1	2726.4	2726.4	8.40	0.101
Residual	2	649.1	324.6	1.04	
Rep.Shade.Accession stratum					
Accession	3	502.0	167.3	0.54	0.665
Shade.Accession	3	495.8	165.3	0.53	0.669
Residual	12	3729.5	310.8		
Total	23	8592.7			

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.030	2.515	2.73	
Rep.Shade stratum					
Shade	1	24.523	24.523	26.59	0.036
Residual	2	1.845	0.922	0.45	
Rep.Shade.Accession stratum					
Accession	3	2.649	0.883	0.43	0.737
Shade.Accession	3	2.527	0.842	0.41	0.750
Residual	12	24.785	2.065		
Total	23	61.358			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	179.89	89.94	2.12	
Rep.Shade stratum					
Shade	1	1184.41	1184.41	27.98	0.034
Residual	2	84.67	42.34	0.82	
Rep.Shade.Accession stratum					
Accession	3	25.22	8.41	0.16	0.920
Shade.Accession	3	103.81	34.60	0.67	0.588
Residual	12	622.19	51.85		
Total	23	2200.18			

Number of seeds pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	12.090	6.045	1.97	
Rep.Shade stratum					
Shade	1	22.815	22.815	7.44	0.112
Residual	2	6.130	3.065	0.86	
Rep.Shade.Accession stratum					
Accession	3	6.738	2.246	0.63	0.609
Shade.Accession	3	4.525	1.508	0.42	0.740
Residual	12	42.767	3.564		
Total	23	95.065			

Weight t of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.1573	0.0786	0.08	
Rep.Shade stratum					
Shade	1	16.0688	16.0688	16.53	0.056
Residual	2	1.9441	0.9720	0.98	
Rep.Shade.Accession stratum					
Accession	3	2.0669	0.6890	0.70	0.572
Shade.Accession	3	0.6191	0.2064	0.21	0.889
Residual	12	11.8902	0.9909		
Total	23	32.7464			

Seed yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.36	2.68	0.07	
Rep.Shade stratum					
Shade	1	152.76	152.76	3.78	0.191
Residual	2	80.72	40.36	1.21	
Rep.Shade.Accession stratum					
Accession	3	22.51	7.50	0.23	0.877
Shade.Accession	3	34.44	11.48	0.34	0.793
Residual	12	399.45	33.29		
Total	23	695.24			

KIBOKO- 2012 Short rain season

Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	107.17	53.59	22.93	
Rep.Shade stratum					
Shade	1	4.12	4.12	1.76	0.316
Residual	2	4.67	2.34	0.08	
Rep.Shade.Accession stratum					
Accession	3	385.84	128.61	4.67	0.022
Shade.Accession	3	18.09	6.03	0.22	0.881
Residual	12	330.30	27.52		
Total	23	850.19			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	17.773	8.887	1.70	
Rep.Shade stratum					
Shade	1	3.082	3.082	0.59	0.523
Residual	2	10.453	5.227	1.22	
Rep.Shade.Accession stratum					
Accession	3	6.338	2.113	0.49	0.694
Shade.Accession	3	3.925	1.308	0.30	0.821
Residual	12	51.507	4.292		
Total	23	93.078			

Number ofdays to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	15.8433	7.9217	1.95	
Rep.Shade stratum					
Shade	1	0.1350	0.1350	0.03	0.872
Residual	2	8.1300	4.0650	4.69	
Rep.Shade.Accession stratum					
Accession	3	7.0583	2.3528	2.71	0.091
Shade.Accession	3	2.1517	0.7172	0.83	0.504
Residual	12	10.4000	0.8667		
Total	23	43.7183			

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.01163	0.00582	2.62	
Rep.Shade stratum					
Shade	1	0.00327	0.00327	1.47	0.349
Residual	2	0.00443	0.00222	0.08	
Rep.Shade.Accession stratum					
Accession	3	0.18753	0.06251	2.17	0.144
Shade.Accession	3	0.12113	0.04038	1.40	0.290
Residual	12	0.34553	0.02879		
Total	23	0.67353			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	180.22	90.11	0.29	Rep.Shade
stratum					
Shade	1	40.56	40.56	0.13	0.753
Residual	2	623.29	311.65	9.09	
Rep.Shade.Accession stratum					
Accession	3	710.19	236.73	6.90	0.006
Shade.Accession	3	246.17	82.06	2.39	0.120
Residual	12	411.63	34.30		
Total	23	2212.07			

Number of seeds per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.2100	0.6050	2.08	
Rep.*Units* stratum					
Accession	3	0.1333	0.0444	0.15	0.926
Shade	1	2.1600	2.1600	7.43	0.016
Accession.Shade	3	1.3067	0.4356	1.50	0.258
Residual	14	4.0700	0.2907		
Total	23	8.8800			

Weight of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4.8232	2.4116	30.21	
Rep.Shade stratum					
Shade	1	0.0963	0.0963	1.21	0.387
Residual	2	0.1596	0.0798	0.11	
Rep.Shade.Accession stratum					
Accession	3	4.5367	1.5122	2.00	0.168
Shade.Accession	3	0.5475	0.1825	0.24	0.866
Residual	12	9.0934	0.7578		
Total	23	19.2567			

Seed yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.893	1.947	0.02	
Rep.Shade stratum					
Shade	1	1.222	1.222	0.02	0.914
Residual	2	162.363	81.182	17.31	
Rep.Shade.Accession stratum					
Accession	3	87.368	29.123	6.21	0.009
Shade.Accession	3	34.612	11.537	2.46	0.113
Residual	12	56.265	4.689		
Total	23	345.724			

KIBOKO – 2013 Long rain season Objective 2- Chapter four

Plant height

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		144.61	72.31	24.28	
Rep.Shade stratum						
Shade	1		136.64	136.64	45.89	0.021
Residual	2		5.96	2.98	0.03	
Rep.Shade.Accession stratum						
Accession	3		219.22	73.07	0.78	0.528
Shade.Accession	3		46.68	15.56	0.17	0.917
Residual	11	(1)	1027.30	93.39		
Total	22	(1)	1564.29			

Number of days to flowering

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		7.676	3.838	0.97	
Rep.Shade stratum						
Shade	1		9.209	9.209	2.32	0.267
Residual	2		7.925	3.963	1.76	
Rep.Shade.Accession stratum						
Accession	3		12.912	4.304	1.91	0.187
Shade.Accession	3		2.174	0.725	0.32	0.810
Residual	11	(1)	24.811	2.256		
Total	22	(1)	64.689			

Number of days to maturity

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		12.135	6.068	0.53	
Rep.Shade stratum						
Shade	1		124.517	124.517	10.87	0.081
Residual	2		22.908	11.454	2.43	
Rep.Shade.Accession stratum						
Accession	3		26.861	8.954	1.90	0.188
Shade.Accession	3		12.667	4.222	0.90	0.474
Residual	11	(1)	51.804	4.709		
Total	22	(1)	240.504			

Number Pod length

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		0.07185	0.03592	2.22	
Rep.Shade stratum						
Shade	1		0.53600	0.53600	33.11	0.029
Residual	2		0.03238	0.01619	0.16	
Rep.Shade.Accession stratum						
Accession	3		0.43391	0.14464	1.46	0.280
Shade.Accession	3		0.50665	0.16888	1.70	0.224
Residual	11	(1)	1.09278	0.09934		
Total	22	(1)	2.66470			

Number of pods per plant

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		9.15	4.58	1.84	
Rep.Shade stratum						
Shade	1		25.83	25.83	10.40	0.084
Residual	2		4.97	2.48	0.05	
Rep.Shade.Accession stratum						
Accession	3		202.64	67.55	1.29	0.327
Shade.Accession	3		149.94	49.98	0.95	0.448
Residual	11	(1)	576.41	52.40		
Total	22	(1)	959.11			

Number of seeds per pod

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		1.6278	0.8139	0.84	
Rep.Shade stratum						
Shade	1		3.5007	3.5007	3.61	0.198
Residual	2		1.9402	0.9701	1.04	
Rep.Shade.Accession stratum						
Accession	3		3.2225	1.0742	1.16	0.370
Shade.Accession	3		0.0857	0.0286	0.03	0.992
Residual	11	(1)	10.2194	0.9290		
Total	22	(1)	20.5391			

Weight of 100 seeds

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		0.9029	0.4514	2.05	
Rep.Shade stratum						
Shade	1		0.5098	0.5098	2.32	0.267
Residual	2		0.4397	0.2199	0.40	
Rep.Shade.Accession stratum						
Accession	3		0.5338	0.1779	0.33	0.806
Shade.Accession	3		0.6217	0.2072	0.38	0.769
Residual	11	(1)	5.9938	0.5449		
Total	22	(1)	8.8334			

Seed yield

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		2.60	1.30	0.16	
Rep.Shade stratum						
Shade	1		4.50	4.50	0.56	0.534
Residual	2		16.20	8.10	0.37	
Rep.Shade.Accession stratum						
Accession	3		73.04	24.35	1.11	0.385
Shade.Accession	3		51.21	17.07	0.78	0.529
Residual	11	(1)	240.28	21.84		
Total	22	(1)	378.45			

Appendix 4: Analysis of Variance values during 2012 short 2013 long rain seasons – for both Machakos ATC and Kiboko

Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	561.41	280.71	6.66	
Rep.Micro-catchment stratum					
Micro-catchment	2	85.93	42.97	1.02	0.439
Residual	4	168.49	42.12	1.63	
Rep.Micro-catchment.Accession stratum					
Accession	3	319.07	106.36	4.12	0.022
Micro-catchment.Accession	6	252.90	42.15	1.63	0.195
Residual	18	464.49	25.81		
Total	35	1852.30			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.949	0.474	0.04	
Rep.Micro-catchment stratum					
Micro-catchment	2	4.542	2.271	0.21	0.821
Residual	4	43.884	10.971	1.37	
Rep.Micro-catchment.Accession stratum					
Accession	3	175.133	58.378	7.29	0.002
Micro-catchment.Accession	6	33.360	5.560	0.69	0.658
Residual	18	144.207	8.011		
Total	35	402.076			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	33.629	16.814	1.69	
Rep.Micro-catchment stratum					
Micro-catchment	2	8.976	4.488	0.45	0.666
Residual	4	39.858	9.964	1.00	
Rep.Micro-catchment.Accession stratum					
Accession	3	45.396	15.132	1.51	0.245
Micro-catchment.Accession	6	66.251	11.042	1.10	0.397
Residual	18	179.873	9.993		
Total	35	373.982			

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.2438	0.1219	0.65	
Rep.Micro-catchment stratum					
Micro-catchment	2	0.3200	0.1600	0.86	0.490
Residual	4	0.7470	0.1867	0.57	
Rep.Micro-catchment.Accession stratum					
Accession	3	1.6023	0.5341	1.63	0.217
Micro-catchment.Accession	6	1.1258	0.1876	0.57	0.746
Residual	18	5.8802	0.3267		
Total	35	9.9191			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	442.36	221.18	8.73	
Rep.Micro-catchment stratum					
Micro-catchment	2	63.53	31.76	1.25	0.378
Residual	4	101.36	25.34	0.67	
Rep.Micro-catchment.Accession stratum					
Accession	3	321.29	107.10	2.81	0.069
Micro-catchment.Accession	6	159.51	26.59	0.70	0.655
Residual	18	685.32	38.07		
Total	35	1773.37			

Number of seeds per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.9489	0.4744	0.75	
Rep.Micro-catchment stratum					
Micro-catchment	2	0.7022	0.3511	0.55	0.614
Residual	4	2.5378	0.6344	1.04	
Rep.Micro-catchment.Accession stratum					
Accession	3	12.9189	4.3063	7.05	0.002
Micro-catchment.Accession	6	6.0978	1.0163	1.66	0.187
Residual	18	10.9933	0.6107		
Total	35	34.1989			

Weight of 100 seedsz

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum 2 1.8908 0.9454 3.76					
Rep.Micro-catchment stratum					

Micro-catchment	2	0.2651	0.1326	0.53	0.626
Residual	4	1.0046	0.2511	0.71	
Rep.Micro-catchment.Accession stratum					
Accession	3	1.6500	0.5500	1.54	0.237
Micro-catchment.Accession	6	1.5678	0.2613	0.73	0.629
Residual	18	6.4103	0.3561		
Total	35	12.7886			

Seed Yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	92.36	46.18	9.14	
Rep.Micro-catchment stratum					
Micro-catchment	2	20.46	10.23	2.03	0.247
Residual	4	20.20	5.05	0.36	
Rep.Micro-catchment.Accession stratum					
Accession	3	113.94	37.98	2.70	0.076
Micro-catchment.Accession	6	65.05	10.84	0.77	0.602
Residual	18	252.73	14.04		
Total 35 564.74					

Appendix 5: Machakos ATC – 2013-long rain season

Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	327.01	163.50	3.43	
Rep.Micro-catchment stratum					
Micro-catchment	2	33.41	16.70	0.35	0.724
Residual	4	190.63	47.66	1.38	
Rep.Micro-catchment.Accession stratum					
Accession	3	295.77	98.59	2.85	0.067
Micro-catchment.Accession	6	161.54	26.92	0.78	0.598
Residual	18	623.35	34.63		
Total	35	1631.71			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	58.380	29.190	4.59	
Rep.Micro-catchment stratum					
Micro-catchment	2	17.147	8.573	1.35	0.357
Residual	4	25.413	6.353	1.49	
Rep.Micro-catchment.Accession stratum					
Accession	3	24.898	8.299	1.94	0.159
Micro-catchment.Accession	6	6.302	1.050	0.25	0.955
Residual	18	76.980	4.277		
Total	35	209.120			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	25.029	12.514	1.02	
Rep.Micro-catchment stratum					
Micro-catchment	2	18.029	9.014	0.73	0.535
Residual	4	49.078	12.269	1.77	
Rep.Micro-catchment.Accession stratum					
Accession	3	24.981	8.327	1.20	0.339
Micro-catchment.Accession	6	23.056	3.843	0.55	0.762
Residual	18	125.093	6.950		
Total	35	265.266			

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.4591	0.2295	1.31	
Rep.Micro-catchment stratum					
Micro-catchment	2	0.9068	0.4534	2.59	0.190
Residual	4	0.7015	0.1754	0.83	
Rep.Micro-catchment.Accession stratum					
Accession	3	0.5907	0.1969	0.93	0.447
Micro-catchment.Accession	6	0.8061	0.1343	0.63	0.702
Residual	18	3.8135	0.2119		
Total	35	7.2777			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	295.15	147.57	2.62	
Rep.Micro-catchment stratum					
Micro-catchment	2	75.33	37.66	0.67	0.561
Residual	4	225.05	56.26	0.76	
Rep.Micro-catchment.Accession stratum					
Accession	3	745.71	248.57	3.37	0.042
Micro-catchment.Accession	6	451.47	75.25	1.02	0.444
Residual	18	1328.45	73.80		
Total	35	3121.15			

Number of seeds per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.4022	0.7011	4.35	
Rep.Micro-catchment stratum					
Micro-catchment	2	1.1022	0.5511	3.42	0.136
Residual	4	0.6444	0.1611	0.37	
Rep.Micro-catchment.Accession stratum					
Accession	3	0.5989	0.1996	0.45	0.717
Micro-catchment.Accession	6	2.7911	0.4652	1.06	0.421
Residual	18	7.9000	0.4389		
Total	35	14.4389			

Weight of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.2570	0.1285	0.57	
Rep.Micro-catchment stratum					
Micro-catchment	2	0.4771	0.2385	1.06	0.426
Residual	4	0.8979	0.2245	0.43	
Rep.Micro-catchment.Accession stratum					
Accession	3	2.8362	0.9454	1.80	0.183
Micro-catchment.Accession	6	1.6140	0.2690	0.51	0.791
Residual	18	9.4420	0.5246		
Total	35	15.5241			

Seed Yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	92.71	46.35	4.46	
Rep.Micro-catchment stratum					
Micro-catchment	2	6.52	3.26	0.31	0.748
Residual	4	41.62	10.40	0.46	
Rep.Micro-catchment.Accession stratum					
Accession	3	150.57	50.19	2.22	0.121
Micro-catchment.Accession	6	173.56	28.93	1.28	0.315
Residual	18	406.71	22.60		
Total	35	871.68			

Kiboko – 2012-short rains season

Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	269.46	134.73	9.41	
Rep.Micro-catchment stratum					
Micro-catchment	2	219.66	109.83	7.67	0.043
Residual	4	57.25	14.31	0.49	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	390.94	130.31	4.48	0.016
Micro-catchment.Accessions	6	138.79	23.13	0.79	0.586
Residual	18	523.98	29.11		
Total	35	1600.09			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	6.5867	3.2933	1.77	
Rep.Micro-catchment stratum					
Micro-catchment	2	0.8600	0.4300	0.23	0.804
Residual	4	7.4533	1.8633	1.91	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	38.7856	12.9285	13.23	<.001
Micro-catchment.Accessions	6	29.8778	4.9796	5.10	0.003
Residual	18	17.5867	0.9770		
Total	35	101.1500			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2.960	1.480	0.33	
Rep.Micro-catchment stratum					
Micro-catchment	2	2.940	1.470	0.33	0.739
Residual	4	18.040	4.510	2.77	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	18.320	6.107	3.75	0.030
Micro-catchment.Accessions	6	2.847	0.474	0.29	0.933
Residual	18	29.293	1.627		
Total	35	74.400			

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.11576	0.05788	1.02	
Rep.Micro-catchment stratum					
Micro-catchment	2	0.12709	0.06354	1.12	0.410
Residual	4	0.22604	0.05651	2.16	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	0.04048	0.01349	0.52	0.677
Micro-catchment.Accessions	6	0.19469	0.03245	1.24	0.333
Residual	18	0.47153	0.02620		
Total	35	1.17559			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	366.91	183.45	1.04	
Rep.Micro-catchment stratum					
Micro-catchment	2	315.58	157.79	0.90	0.477
Residual	4	704.71	176.18	2.16	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	347.52	115.84	1.42	0.269
Micro-catchment.Accessions	6	538.86	89.81	1.10	0.399
Residual	18	1466.65	81.48		
Total	35	3740.23			

Number of seeds per pods

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.1822	0.5911	1.81	
Rep.Micro-catchment stratum					
Micro-catchment	2	0.8622	0.4311	1.32	0.362
Residual	4	1.3044	0.3261	2.80	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	0.8267	0.2756	2.36	0.105
Micro-catchment.Accessions	6	0.7733	0.1289	1.10	0.398
Residual	18	2.1000	0.1167		
Total	35	7.0489			

Weight of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.4883	1.7441	7.39	
Rep.Micro-catchment stratum					
Micro-catchment	2	0.4253	0.2126	0.90	0.475
Residual	4	0.9437	0.2359	0.51	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	11.0101	3.6700	7.98	0.001
Micro-catchment.Accessions	6	6.8855	1.1476	2.49	0.062
Residual	18	8.2827	0.4602		
Total	35	31.0355			

Seed yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	65.91	32.95	0.76	
Rep.Micro-catchment stratum					
Micro-catchment	2	113.48	56.74	1.30	0.366
Residual	4	173.95	43.49	2.16	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	39.89	13.30	0.66	0.587
Micro-catchment.Accessions	6	138.45	23.08	1.15	0.376
Residual	18	362.04	20.11		
Total	35	893.72			

Kiboko- 2013 long rain season

Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	492.47	246.23	6.69	
Rep.Micro-catchment stratum					
Micro-catchment	2	74.68	37.34	1.01	0.440
Residual	4	147.30	36.83	0.77	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	76.81	25.60	0.53	0.665
Micro-catchment.Accessions	6	172.95	28.83	0.60	0.726
Residual	18	863.59	47.98		
Total	35	1827.80			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	25.620	12.810	10.13	
Rep.Micro-catchment stratum					
Micro-catchment	2	2.340	1.170	0.92	0.468
Residual	4	5.060	1.265	0.55	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	34.084	11.361	4.92	0.011
Micro-catchment.Accessions	6	10.122	1.687	0.73	0.631
Residual	18	41.533	2.307		
Total	35	118.760			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	78.60	39.30	0.44	
Rep.Micro-catchment stratum					
Micro-catchment	2	55.02	27.51	0.31	0.751
Residual	4	357.19	89.30	1.78	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	157.67	52.56	1.05	0.395
Micro-catchment.Accessions	6	346.29	57.72	1.15	0.374
Residual	18	901.59	50.09		
Total	35	1896.36			

Pod length cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.9657	0.4828	1.68	
Rep.Micro-catchment stratum					
Micro-catchment	2	0.9464	0.4732	1.65	0.301
Residual	4	1.1484	0.2871	0.32	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	1.6754	0.5585	0.63	0.607
Micro-catchment.Accessions	6	5.3239	0.8873	1.00	0.457
Residual	18	16.0174	0.8899		
Total	35	26.0772			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	611.12	305.56	3.09	
Rep.Micro-catchment stratum					
Micro-catchment	2	102.45	51.22	0.52	0.631
Residual	4	395.91	98.98	1.62	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	293.11	97.70	1.60	0.225
Micro-catchment.Accessions	6	445.17	74.20	1.21	0.345
Residual	18	1100.75	61.15		
Total	35	2948.51			

Number of seeds per pods

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	16.649	8.324	12.34	
Rep.Micro-catchment stratum					
Micro-catchment	2	0.549	0.274	0.41	0.690
Residual	4	2.698	0.674	0.37	Rep.Micro-
catchment.Accessions stratum					
Accessions	3	19.532	6.511	3.58	0.035
Micro-catchment.Accessions	6	4.998	0.833	0.46	0.830
Residual	18	32.760	1.820		
Total	35	77.186			

Weight of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.1421	0.0711	0.21	
Rep.Micro-catchment stratum					
Micro-catchment	2	0.1942	0.0971	0.29	0.760
Residual	4	1.3224	0.3306	0.36	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	1.4462	0.4821	0.53	0.666
Micro-catchment.Accessions	6	3.5413	0.5902	0.65	0.689
Residual	18	16.3123	0.9062		
Total	35	22.9585			

Weight of seeds per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	301.25	150.62	5.25	
Rep.Micro-catchment stratum					
Micro-catchment	2	59.40	29.70	1.04	0.434
Residual	4	114.76	28.69	1.27	
Rep.Micro-catchment.Accessions stratum					
Accessions	3	152.35	50.78	2.25	0.117
Micro-catchment.Accessions	6	158.87	26.48	1.17	0.363
Residual	18	406.27	22.57		
Total	35	1192.90			

Appendix 6: Analysis of Variance values during 2012 short 2013 long rain seasons – for both Machakos ATC and Kiboko

Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	409.92	204.96	1.49	
Rep.Shade stratum					
Shade	1	1171.76	1171.76	8.49	0.100
Residual	2	275.90	137.95	4.49	
Rep.Shade. Micro-catchment stratum					
Micro-catchment	2	158.89	79.44	2.59	0.136
Shade.Micro-catchment	2	13.29	6.65	0.22	0.810
Residual	8	245.76	30.72	1.56	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	209.28	69.76	3.55	0.024
Shade.Accession	3	176.63	58.88	3.00	0.043
Micro-catchment.Accession	6	345.17	57.53	2.93	0.020
Shade.Micro-catchment.Accession	6	125.56	20.93	1.07	0.401
Residual	36	706.97	19.64		
Total	71	3839.14			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.990	1.995	0.52	
Rep.Shade stratum					
Shade	1	64.601	64.601	16.85	0.055
Residual	2	7.668	3.834	0.54	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	6.503	3.252	0.46	0.646
Shade.Micro-catchment	2	2.908	1.454	0.21	0.818
Residual	8	56.376	7.047	1.04	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	334.215	111.405	16.49	<.001
Shade.Accession	3	3.562	1.187	0.18	0.912
Micro-catchment.Accession	6	35.897	5.983	0.89	0.516
Shade.Micro-catchment.Accession	6	63.457	10.576	1.57	0.186
Residual	36	243.220	6.756		
Total	71	822.395			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	29.861	14.931	3.95	
Rep.Shade stratum					
Shade	1	477.405	477.405	126.24	0.008
Residual	2	7.563	3.782	0.59	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	1.551	0.776	0.12	0.888
Shade.Micro-catchment	2	11.893	5.947	0.92	0.435
Residual	8	51.436	6.429	1.09	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	78.602	26.201	4.44	0.009
Shade.Accession	3	6.788	2.263	0.38	0.766
Micro-catchment.Accession	6	26.333	4.389	0.74	0.618
Shade.Micro-catchment.Accession	6	56.107	9.351	1.58	0.180
Residual	36	212.420	5.901		
Total	71	959.959			

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.3961	0.1981	2.57	
Rep.Micro-catchment stratum					
Micro-catchment	2	0.0676	0.0338	0.44	0.672
Residual	4	0.3081	0.0770	0.30	
Rep.Micro-catchment.Accession stratum					
Accession	3	1.6238	0.5413	2.09	0.137
Micro-catchment.Accession	6	2.1908	0.3651	1.41	0.263
Residual	18	4.6510	0.2584	1.52	
Rep.Micro-catchment.Accession.*Units* stratum					
Shade	1	1.5429	1.5429	9.09	0.006
Micro-catchment.Shade	2	0.3027	0.1514	0.89	0.423
Accession.Shade	3	1.6058	0.5353	3.15	0.043
Micro-catchment.Accession.Shade	6	0.3513	0.0585	0.34	0.906
Residual	24	4.0747	0.1698		
Total	71	17.1148			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	225.84	112.92	0.99	
Rep.Shade stratum					
Shade	1	1459.80	1459.80	12.84	0.070
Residual	2	227.30	113.65	3.56	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	171.25	85.63	2.68	0.129
Shade.Micro-catchment	2	13.67	6.84	0.21	0.812
Residual	8	255.60	31.95	0.71	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	235.84	78.61	1.75	0.175
Shade.Accession	3	322.69	107.56	2.39	0.085
Micro-catchment.Accession	6	282.17	47.03	1.04	0.413
Shade.Micro-catchment.Accession	6	294.24	49.04	1.09	0.387
Residual	36	1620.83	45.02		
Total	71	5109.23			

Number of seeds per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0211	0.0106	0.01	
Rep.Shade stratum					
Shade	1	9.2450	9.2450	11.34	0.078
Residual	2	1.6300	0.8150	1.48	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	1.5744	0.7872	1.43	0.294
Shade.Micro-catchment	2	0.2100	0.1050	0.19	0.830
Residual	8	4.3956	0.5494	1.00	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	15.3083	5.1028	9.31	<.001
Shade.Accession	3	4.1394	1.3798	2.52	0.074
Micro-catchment.Accession	6	6.3500	1.0583	1.93	0.102
Shade.Micro-catchment.Accession	6	3.4922	0.5820	1.06	0.403
Residual	36	19.7400	0.5483		
Total	71	66.1061			

Weight of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.3223	0.6611	2.02	
Rep.Shade stratum					
Shade	1	0.8956	0.8956	2.73	0.240
Residual	2	0.6550	0.3275	1.22	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	0.4833	0.2417	0.90	0.444
Shade.Micro-catchment	2	0.1289	0.0645	0.24	0.792
Residual	8	2.1504	0.2688	0.86	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	4.4779	1.4926	4.80	0.006
Shade.Accession	3	2.4297	0.8099	2.60	0.067
Micro-catchment.Accession	6	1.3181	0.2197	0.71	0.646
Shade.Micro-catchment.Accession	6	1.4849	0.2475	0.80	0.579
Residual	36	11.1945	0.3110		
Total	71	26.5406			

Seed yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	29.26	14.63	0.44	
Rep.Shade stratum					
Shade	1	540.06	540.06	16.07	0.057
Residual	2	67.20	33.60	2.68	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	77.84	38.92	3.11	0.100
Shade.Micro-catchment	2	8.62	4.31	0.34	0.719
Residual	8	100.24	12.53	0.65	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	85.10	28.37	1.47	0.239
Shade.Accession	3	165.40	55.13	2.86	0.051
Micro-catchment.Accession	6	79.54	13.26	0.69	0.661
Shade.Micro-catchment.Accession	6	91.45	15.24	0.79	0.584
Residual	36	694.89	19.30		
Total	71	1939.60			

Machakos 2013-long rains
Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1768.34	884.17	5.09	
Rep.Shade stratum					
Shade	1	4085.78	4085.78	23.53	0.040
Residual	2	347.25	173.62	1.75	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	81.22	40.61	0.41	0.677
Shade.Micro-catchment	2	76.35	38.18	0.39	0.692
Residual	8	791.97	99.00	1.48	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	279.44	93.15	1.39	0.260
Shade.Accession	3	188.71	62.90	0.94	0.431
Micro-catchment.Accession	6	323.51	53.92	0.81	0.571
Shade.Micro-catchment.Accession	6	311.22	51.87	0.78	0.594
Residual	36	2404.27	66.79		
Total	71	10658.04			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1019.07	509.53	0.56	
Rep.Shade stratum					
Shade	1	835.04	835.04	0.92	0.438
Residual	2	1811.29	905.64	2.10	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	594.81	297.41	0.69	0.529
Shade.Micro-catchment	2	444.07	222.03	0.52	0.616
Residual	8	3447.34	430.92	4.99	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	108.79	36.26	0.42	0.740
Shade.Accession	3	251.83	83.94	0.97	0.417
Micro-catchment.Accession	6	397.74	66.29	0.77	0.600
Shade.Micro-catchment.Accession	6	325.90	54.32	0.63	0.706
Residual	36	3108.62	86.35		
Total	71	12344.50			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4052.5	2026.3	0.83	
Rep.Shade stratum					
Shade	1	8868.9	8868.9	3.63	0.197
Residual	2	4891.5	2445.8	4.24	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	486.4	243.2	0.42	0.670
Shade.Micro-catchment	2	315.5	157.8	0.27	0.767
Residual	8	4612.1	576.5	1.36	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	623.1	207.7	0.49	0.691
Shade.Accession	3	873.2	291.1	0.69	0.566
Micro-catchment.Accession	6	2552.6	425.4	1.00	0.437
Shade.Micro-catchment.Accession	6	2404.0	400.7	0.95	0.475
Residual	36	15242.6	423.4		
Total	71	44922.5			

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	40.741	20.370	1.38	
Rep.Shade stratum					
Shade	1	92.571	92.571	6.27	0.129
Residual	2	29.545	14.773	3.83	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	5.760	2.880	0.75	0.504
Shade.Micro-catchment	2	2.050	1.025	0.27	0.773
Residual	8	30.836	3.855	1.42	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	7.418	2.473	0.91	0.445
Shade.Accession	3	4.806	1.602	0.59	0.625
Micro-catchment.Accession	6	19.040	3.173	1.17	0.343
Shade.Micro-catchment.Accession	6	15.625	2.604	0.96	0.465
Residual	36	97.591	2.711		
Total	71	345.983			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	333.66	166.83	4.39	
Rep.Shade stratum					
Shade	1	4192.23	4192.23	110.32	0.009
Residual	2	76.00	38.00	1.02	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	39.36	19.68	0.53	0.607
Shade.Micro-catchment	2	86.21	43.11	1.16	0.360
Residual	8	296.60	37.08	0.79	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	370.16	123.39	2.63	0.065
Shade.Accession	3	431.84	143.95	3.07	0.040
Micro-catchment.Accession	6	199.54	33.26	0.71	0.645
Shade.Micro-catchment.Accession	6	392.36	65.39	1.39	0.244
Residual	36	1689.23	46.92		
Total	71	8107.20			

Number of seeds per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	66.523	33.262	1.24	
Rep.Shade stratum					
Shade	1	122.201	122.201	4.55	0.167
Residual	2	53.721	26.861	4.56	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	4.813	2.407	0.41	0.678
Shade.Micro-catchment	2	9.471	4.736	0.80	0.481
Residual	8	47.156	5.894	1.33	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	6.824	2.275	0.52	0.675
Shade.Accession	3	10.668	3.556	0.81	0.499
Micro-catchment.Accession	6	31.884	5.314	1.20	0.327
Shade.Micro-catchment.Accession	6	20.213	3.369	0.76	0.604
Residual	36	159.000	4.417		
Total	71	532.475			

Weight of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	9.997	4.999	0.67	
Rep.Shade stratum					
Shade	1	35.587	35.587	4.76	0.161
Residual	2	14.949	7.474	3.76	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	1.438	0.719	0.36	0.707
Shade.Micro-catchment	2	1.405	0.703	0.35	0.713
Residual	8	15.895	1.987	1.42	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	7.271	2.424	1.73	0.178
Shade.Accession	3	0.810	0.270	0.19	0.901
Micro-catchment.Accession	6	11.151	1.859	1.33	0.271
Shade.Micro-catchment.Accession	6	3.750	0.625	0.45	0.843
Residual	36	50.447	1.401		
Total	71	152.699			

Seed yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	113.41	56.71	6.11	
Rep.Shade stratum					
Shade	1	1229.21	1229.21	132.35	0.007
Residual	2	18.58	9.29	1.11	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	7.67	3.84	0.46	0.648
Shade.Micro-catchment	2	14.35	7.18	0.86	0.460
Residual	8	66.90	8.36	0.60	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	76.44	25.48	1.84	0.158
Shade.Accession	3	91.46	30.49	2.20	0.105
Micro-catchment.Accession	6	95.65	15.94	1.15	0.355
Shade.Micro-catchment.Accession	6	119.48	19.91	1.43	0.229
Residual	36	499.66	13.88		
Total	71	2332.81			

Kiboko 2012
Plant height cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	640.19	320.10	20.08	
Rep.Shade stratum					
Shade	1	218.37	218.37	13.70	0.066
Residual	2	31.88	15.94	0.61	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	157.79	78.90	3.02	0.106
Shade.Micro-catchment	2	188.37	94.19	3.60	0.077
Residual	8	209.19	26.15	0.90	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	880.33	293.44	10.06	<.001
Shade.Accession	3	144.78	48.26	1.65	0.194
Micro-catchment.Accession	6	53.57	8.93	0.31	0.930
Shade.Micro-catchment.Accession	6	156.54	26.09	0.89	0.509
Residual	36	1049.85	29.16		
Total	71	3730.86			

Number No of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	25.866	12.933	0.87	
Rep.Shade stratum					
Shade	1	0.750	0.750	0.05	0.843
Residual	2	29.623	14.812	8.22	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	8.541	4.271	2.37	0.156
Shade.Micro-catchment	2	3.126	1.563	0.87	0.456
Residual	8	14.417	1.802	0.52	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	69.049	23.016	6.60	0.001
Shade.Accession	3	1.161	0.387	0.11	0.953
Micro-catchment.Accession	6	22.684	3.781	1.08	0.391
Shade.Micro-catchment.Accession	6	14.059	2.343	0.67	0.673
Residual	36	125.588	3.489		
Total	71	314.867			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	22.234	11.117	2.81	
Rep.Shade stratum					
Shade	1	0.934	0.934	0.24	0.675
Residual	2	7.901	3.951	1.33	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	3.524	1.762	0.59	0.575
Shade.Micro-catchment	2	0.324	0.162	0.05	0.947
Residual	8	23.791	2.974	2.18	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	20.295	6.765	4.95	0.006
Shade.Accession	3	5.024	1.675	1.22	0.315
Micro-catchment.Accession	6	9.107	1.518	1.11	0.376
Shade.Micro-catchment.Accession	6	4.884	0.814	0.60	0.732
Residual	36	49.220	1.367		
Total	71	147.239			

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.32017	0.16008	3.26	
Rep.Shade stratum					
Shade	1	0.14178	0.14178	2.88	0.232
Residual	2	0.09834	0.04917	0.91	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	0.03597	0.01798	0.33	0.725
Shade.Micro-catchment	2	0.12479	0.06239	1.16	0.361
Residual	8	0.43021	0.05378	2.18	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	0.09377	0.03126	1.27	0.300
Shade.Accession	3	0.09965	0.03322	1.35	0.274
Micro-catchment.Accession	6	0.15638	0.02606	1.06	0.406
Shade.Micro-catchment.Accession	6	0.23256	0.03876	1.57	0.184
Residual	36	0.88736	0.02465		
Total	71	2.62097			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	960.78	480.39	6.14	
Rep.Shade stratum					
Shade	1	5.42	5.42	0.07	0.817
Residual	2	156.60	78.30	0.40	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	850.58	425.29	2.17	0.177
Shade.Micro-catchment	2	40.19	20.10	0.10	0.904
Residual	8	1568.70	196.09	2.90	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	1234.14	411.38	6.08	0.002
Shade.Accession	3	225.62	75.21	1.11	0.357
Micro-catchment.Accession	6	402.10	67.02	0.99	0.446
Shade.Micro-catchment.Accession	6	914.88	152.48	2.26	0.060
Residual	36	2433.98	67.61		
Total	71	8792.98			

Number of seeds per pods

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	7.1633	3.5817	2.10	
Rep.Shade stratum					
Shade	1	1.8689	1.8689	1.10	0.405
Residual	2	3.4078	1.7039	6.48	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	0.2800	0.1400	0.53	0.606
Shade.Micro-catchment	2	0.8578	0.4289	1.63	0.254
Residual	8	2.1022	0.2628	1.43	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	0.2733	0.0911	0.49	0.688
Shade.Accession	3	1.3222	0.4407	2.39	0.085
Micro-catchment.Accession	6	1.4533	0.2422	1.31	0.276
Shade.Micro-catchment.Accession	6	2.2978	0.3830	2.08	0.080
Residual	36	6.6333	0.1843		
Total	71	27.6600			

Weight of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	10.7313	5.3657	15.12	
Rep.Shade stratum					
Shade	1	0.2893	0.2893	0.82	0.462
Residual	2	0.7097	0.3549	2.12	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	0.4895	0.2448	1.46	0.288
Shade.Micro-catchment	2	0.3564	0.1782	1.06	0.389
Residual	8	1.3396	0.1674	0.33	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	17.5758	5.8586	11.70	<.001
Shade.Accession	3	0.6203	0.2068	0.41	0.745
Micro-catchment.Accession	6	2.4058	0.4010	0.80	0.576
Shade.Micro-catchment.Accession	6	5.5205	0.9201	1.84	0.119
Residual	36	18.0261	0.5007		
Total	71	58.0644			

Seed yield

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	130.53	65.26	4.97	
Rep.Shade stratum					
Shade	1	0.09	0.09	0.01	0.940
Residual	2	26.25	13.12	0.25	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	260.89	130.44	2.48	0.145
Shade.Micro-catchment	2	1.55	0.78	0.01	0.985
Residual	8	421.13	52.64	3.15	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	122.87	40.96	2.45	0.079
Shade.Accession	3	24.75	8.25	0.49	0.689
Micro-catchment.Accession	6	116.46	19.41	1.16	0.349
Shade.Micro-catchment.Accession	6	154.04	25.67	1.53	0.195
Residual	36	602.35	16.73		
Total	71	1860.90			

Kiboko-2013 long rain
Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	712.6	356.3	12.75	
Rep.Shade stratum					
Shade	1	63.5	63.5	2.27	0.271
Residual	2	55.9	27.9	0.68	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	21.0	10.5	0.26	0.780
Shade.Micro-catchment	2	156.9	78.4	1.91	0.209
Residual	8	328.0	41.0	0.35	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	382.5	127.5	1.10	0.362
Shade.Accession	3	447.2	149.1	1.28	0.294
Micro-catchment.Accession	6	386.1	64.4	0.55	0.763
Shade.Micro-catchment.Accession	6	655.4	109.2	0.94	0.478
Residual	36	4178.4	116.1		
Total	71	7387.5			

Number of days to flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	29.89	14.95	1.31	
Rep.Shade stratum					
Shade	1	0.18	0.18	0.02	0.911
Residual	2	22.75	11.38	0.30	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	56.68	28.34	0.75	0.502
Shade.Micro-catchment	2	31.72	15.86	0.42	0.670
Residual	8	301.68	37.71	1.43	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	121.80	40.60	1.54	0.220
Shade.Accession	3	26.24	8.75	0.33	0.802
Micro-catchment.Accession	6	176.01	29.33	1.12	0.373
Shade.Micro-catchment.Accession	6	145.86	24.31	0.92	0.489
Residual	36	947.01	26.31		
Total	71	1859.82			

Number of days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	168.9	84.4	26.57	
Rep.Shade stratum					
Shade	1	16.1	16.1	5.05	0.154
Residual	2	6.4	3.2	0.02	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	142.0	71.0	0.50	0.627
Shade.Micro-catchment	2	109.5	54.8	0.38	0.694
Residual	8	1147.5	143.4	1.38	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	122.6	40.9	0.39	0.759
Shade.Accession	3	310.4	103.5	0.99	0.407
Micro-catchment.Accession	6	611.2	101.9	0.98	0.454
Shade.Micro-catchment.Accession	6	622.9	103.8	1.00	0.442
Residual	36	3748.6	104.1		
Total	71	7006.0			

Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	331.75	165.88	1.18	
Rep.Shade stratum					
Shade	1	596.28	596.28	4.23	0.176
Residual	2	282.10	141.05	2.02	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	113.19	56.59	0.81	0.477
Shade.Micro-catchment	2	13.53	6.76	0.10	0.909
Residual	8	557.38	69.67	0.87	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	169.18	56.39	0.70	0.555
Shade.Accession	3	234.46	78.15	0.98	0.414
Micro-catchment.Accession	6	150.69	25.12	0.31	0.925
Shade.Micro-catchment.Accession	6	459.31	76.55	0.96	0.468
Residual	36	2879.83	80.00		
Total	71	5787.70			

Number of seeds per pods

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	10.671	5.336	1.69	
Rep.Shade stratum					
Shade	1	1.681	1.681	0.53	0.542
Residual	2	6.324	3.162	0.97	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	4.088	2.044	0.63	0.559
Shade.Micro-catchment	2	4.348	2.174	0.67	0.540
Residual	8	26.084	3.261	1.12	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	18.624	6.208	2.13	0.114
Shade.Accession	3	7.499	2.500	0.86	0.472
Micro-catchment.Accession	6	14.001	2.334	0.80	0.576
Shade.Micro-catchment.Accession	6	19.972	3.329	1.14	0.359
Residual	36	104.973	2.916		
Total	71	218.266			

Pod length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.532	0.266	1.01	
Rep.Shade stratum					
Shade	1	0.036	0.036	0.14	0.748
Residual	2	0.525	0.263	0.14	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	0.168	0.084	0.04	0.957
Shade.Micro-catchment	2	2.819	1.409	0.74	0.506
Residual	8	15.195	1.899	1.29	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	4.416	1.472	1.00	0.404
Shade.Accession	3	1.954	0.651	0.44	0.724
Micro-catchment.Accession	6	8.649	1.441	0.98	0.454
Shade.Micro-catchment.Accession	6	10.597	1.766	1.20	0.329
Residual	36	53.055	1.474		
Total	71	97.946			

Weight of 100 seeds

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.376	0.188	10.23	
Rep.Shade stratum					
Shade	1	3.159	3.159	171.68	0.006
Residual	2	0.037	0.018	0.03	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	1.218	0.609	0.88	0.450
Shade.Micro-catchment	2	2.636	1.318	1.91	0.210
Residual	8	5.519	0.690	0.62	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	2.588	0.863	0.78	0.514
Shade.Accession	3	0.288	0.096	0.09	0.967
Micro-catchment.Accession	6	6.244	1.041	0.94	0.480
Shade.Micro-catchment.Accession	6	5.915	0.986	0.89	0.513
Residual	36	39.910	1.109		
Total	71	67.891			

Seed yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	108.97	54.49	0.54	
Rep.Shade stratum					
Shade	1	191.28	191.28	1.89	0.303
Residual	2	202.55	101.28	4.70	
Rep.Shade.Micro-catchment stratum					
Micro-catchment	2	70.54	35.27	1.64	0.254
Shade.Micro-catchment	2	13.62	6.81	0.32	0.738
Residual	8	172.47	21.56	0.69	
Rep.Shade.Micro-catchment.Accession stratum					
Accession	3	112.65	37.55	1.20	0.323
Shade.Accession	3	54.11	18.04	0.58	0.633
Micro-catchment.Accession	6	59.38	9.90	0.32	0.924
Shade.Micro-catchment.Accession	6	171.07	28.51	0.91	0.496
Residual	36	1123.69	31.21		
Total	71	2280.35			