EFFECT OF SPATIAL ARRANGEMENT AND VARIETY ON PERFORMANCE OF COMMON BEAN (*Phaseolus vulgaris L*) IN WESTERN KENYA

BY

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DECLARATION

Declaration by the Candidate

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DEDICATION

I dedicate this work to my parents (Jacob S Wafula Mafuta and Joyce Enny Wafula) and my siblings Juliet, Jimmy, Stellar and John who made great effort in my education.

ABSTRACT

Common bean (*Phaseolus vulgaris*) is one of the most important food security pulse crops grown in Kenya. Its production is limited by a number of agronomic practices including spatial crop arrangement and crop cultivar. A study was conducted between March to June 2016 at Mabanga ATC in Bungoma and University of Eldoret in Uasin Gishu Counties to determine the suitable field spatial arrangement and variety for optimum bean yield. Three bean varieties (*Canadian Wonder, KAT B1 and Rose Coco*) were studied under the following spatial arrangement: 60 cm x 15 cm, 45 cm x 20 cm, 36 cm x 25 cm and 30 cm x 30 cm. In both sites, RCBDesign was used to conduct the experiment. This was replicated 3 times. Data was collected on plant height, number of flowers per plant, pods per plant, seeds per pod, 1000 - seed weight and seed yield. Data was subjected to ANOVA in GENSTAT version software and means separated by Tukey's HSD at $p \leq 0.05$. The results indicated significant differences due to spatial arrangement on plant height in Mabanga site only. There were significant differences on number of pods per, number of seeds per pod, 1000 seed yield and seed weight (kg/ha) in both sites. On the other hand, variety showed significant difference on 1000 seed weight in both sites. Number of pods per plant, seed weight (kg/ha) were significantly affected by variety at Mabanga site only. It is concluded that the spatial arrangement of 30 cm x 30 or 36 cm x 25 cm showed good performance in terms of seed yield/hectare in Mabanga, while a spatial arrangement of 36 cm x 25 cm or 45 cm x 20 cm performed better in terms of seed yield/hectare at University of Eldoret. Varieties *Rose Coco* and *KAT B1* proved superior in terms of seed yield/hectare in both sites. In this study spatial arrangement of 30 cm x 30 cm or 36 cm x 25 cm is therefore recommended for farmers within Bungoma County, while 36 cm x 25 cm and 45 cm x 20 cm recommended for farmers within Uasin Gishu with *KAT B1* and *Rose coco* being the suitable varieties at both sites.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS

ANOVA	Analysis of Variance
ATC	Agricultural training centre
CIAT	International Centre for Tropical Agriculture
CSA	Central Statistical Agency
CV	Coefficient of variation
FAO	Food and Agricultural organization of the United Nation
FAOSTAT	Food and Agriculture Organization statistics
GDD	Growing degree days
GIZ-PSDA	Private Sector Development Agriculture
GOK	Government of Kenya
KALRO	Kenya Agriculture and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
KAT	Katumani
LAI	Leaf area index
RCBD	Randomized Complete Block Design
UOE	University of Eldoret

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CHAPTER ONE

INTRODUCTION

1.1 Background information

In Kenya, common bean is the most important pulse crop after maize as a major food crop (GOK, 2014). The national annual demand for beans is estimated to be 500,000 metric tonnes (potential yield) according to (GOK, 2014) against the actual production of about 125,000 metric tonnes. This translates to a yield gap of 375,000 tonnes. The total area under bean cultivation in Kenya is estimated to be 500000 ha (GOK, 2014) giving actual bean yields of 250 kg/ha, and this is also partly under mixed cropping. In pure stands, yields of 700 kg/ha have been realized (Songa *et al*., 2013). According to FAOSTAT estimate for the year 2006, world beans production was 1235 kg /ha while that of Africa was 799 kg/ ha.

Spatial arrangement is defined as the pattern of plants over the ground, which determines the shape of the area available to the individual plant (Reddy, 2000). For crops regularly arranged in rows, spatial arrangement can be concisely defined by the rectangularity, which is the ratio of the inter row spacing to the intra row spacing (Willey and Osiru, 2012). Spatial arrangement of plants determines: resource utilization such as light, nutrients and water; the extent of vegetative growth and development of crops particularly that of plant height; yield and yield components; development of important diseases and pests and the seed cost (Jettner *et al.,* 2012; Matthews *et al*., 2013). Spatial arrangement of crops affects early ground cover, competitive ability of crops with weed, soil surface evaporation, light interception, lodging and development of an optimum number of fruiting sites in a crop canopy. It also affects canopy development, plant architecture and distribution of pods (Matthews *et al*., 2012). Suitable plant arrangement in an area allows crops to exploit resource optimally thus high yield production (Squire, 2014). However, crop spatial arrangement varies depending on varietal differences in vigour, height and branching, time of sowing, and the nature of the season (Anderson *et al*., 2011). Response of crops to spatial arrangement tends to be less in the low potential as compared to the high yielding environments (Matthews *et al.*, 2013).

There are two types of common bean: determinate, in which the main axis is terminated in an inflorescence and produces no vegetative nodes after flowering and the other is indeterminate which produce vegetative node after flowering. The determinate type is short, self-supporting or bushy and of short growth duration while indeterminate genotypes show a wide range of node number on the main stem, climbing tendency and growth (Danial, 2013). Since there are different growth habits for common bean, suitable spatial arrangement remains a key research component for optimum bean yield production particularly in Western Kenya.

1.2 Statement of the problem

According to GOK (2014), there exist 75% yield gap between the potential and the actual bean yield production. This has been attributed to a number of factors such as low yielding varieties, poor soil fertility, pests, diseases, high cost of fertilizer, poor market prices, poor cropping system and poor plant arrangement management. Poor spatial arrangement may also contribute to low production of beans especially in Western Kenya and its effect is not well understood. Beans have been treated as a minor crop in the conventional cropping system where it is grown as an intercrop with maize as the major crop.

There are different growth habits for common bean cultivar but a common spacing recommendation has been given without paying attention to the specific bean growth patterns. This may give room to either overcrowding or under population leading to low bean yield. The study focus was on suitable field spatial arrangement and bean cultivar for optimum bean yield production in Western Kenya.

1.3 Justification

The bean value chain in Kenya employs over 2.5 million people (GOK, 2014) with approximately 800,000 bean farmers growing the crop on about 158,000 hectares annually as subsistence. The average yield is less than 500,000 metric tonnes per hectare (GOK, 2014). This requires some intervention to promote high yields. This can be achieved by determining the best spatial arrangement and bean cultivar in the field that will give high crop yield. The study will enhance production of common bean. Hence, improving livelihood and increase food security of a small scale farmer in western Kenya since the correct spatial arrangement enhances high yield of beans and farmers will also select high yielding bean varieties. Hence need to determine spatial arrangement and variety for variation in performance of beans.

1.4 Objectives

1.4.1 General objectives

To improve bean yield production among small holder farmers in Western Kenya.

1.4.2 Specific objectives

1) To determine effect of spatial arrangement on the growth and development of bean in Western Kenya
2) To evaluate the performance of varieties of bean in Western Kenya

1.5 Research hypotheses

H_{a1}: Spatial arrangement influences the yield of bean

$H_{a2:}$ variety choice influences the performance of bean

CHAPTER TWO

LITERATURE REVIEW

2.1 Nutritional and economic importance of beans

Dry bean is one of the few pulse crops, besides common dry pea and lentils that can be grown successfully (Kakar et al.,2013)

Common bean is important in the human diet, being a good source of protein (18%–22%), dietary fibre, minerals (such as potassium, zinc and iron) and vitamins (such as folic acid and B12) (Kakar *et al*., 2013) . The properties of the carbohydrates found in common beans, along with their fibre content, make them ideal foods for the management of abnormalities associated with insulin resistance and diabetes (Raatz, 2013). Common beans are rich in both soluble and insoluble fibres that provide nutritional benefit. The soluble fibre in beans dissolves in water, trapping bile which helps to lower blood levels of cholesterol, especially if cholesterol levels were high to begin with, without compromising the level of protective cholesterol. Insoluble fibres in common beans attract water to the stool and enhance transit time of waste through the colon. This may help to combat constipation, colon cancer and other conditions that afflict the digestive tract (Raatz, 2013).

Although dry beans vary considerably in flavour, size, colour, and shape, their nutritional composition is similar Table 1 provides an example of the nutrient content of cooked dry beans.

Table 1: Nutritional value of cooked dry beans (Adapted from Raatz, 2013)

Nutrient available	**Quantity in 100g**
Calorie	**1.2g**
Saturated fat	**1.2g**
Cholesterol	**0g**
Carbohydrates	**23g**
Proteins	**9.3g**
Dietary fibre	**9.3mg**
Sodium	**1.2mg**
Thiamine	**1.2mg**
Folic acid	**14mg**
Copper	**1.2mg**
Iron	**2.4mg**
Magnesium	**70mg**
Manganese	**1.2mg**
Phosphorus	**140mg**
Potassium	**356mg**

Having short maturity period of about three months beans are available for family consumption during the period when other crops are immature (Amare, 2000). However, there is small-scale production of dry beans in every region of Kenya, where the crop has been grown as an intercrop with maize on a small scale for over 100 years (Ismail and Hall, 2000).

2.2 Agronomic requirements

Common bean can grow well in temperatures between 15 ^{0} c and 30 ^{0} c, with higher temperatures resulting in poor pod set (Norman, 1992). Common bean requires a minimum frost free period of 105-120 days, as it is killed by frost. In general, very high temperature during flowering causes the dropping of buds and flowers, which reduces yield (Amare, 2000).

Common bean *(P. vulgaris* L.) is widely grown in low land and mid altitude areas. It has a wide range of adaptations and grows well between 1400 to 2000 meters above sea level. The crop also does well in some areas in altitudes as low as 500 m that receive well distributed average rainfall of 500 to 1500 mm throughout the growing season (Amare, 2000). Common beans are adapted to a wide range of soils. They produce successfully when grown on well drained soils of medium texture (loams).

Depending on growth habit type and location, full maturity for dry bean seed type can be attained from 45 to 150 days after emergence (Singh, 2011). The late maturing beans were more often indeterminate while the early ones were determinate (Kelly *et al.*, 2012).Days to maturity of beans increased with rise in altitude.Low temperature prolonged the maturity period of beans which was more pronounced in indeterminate than determinate types. Rose coco matured in 90 days at 1200 m, 96 days at 1600 m and 115 days at 2200 m above sea level (Amare, 2011).

2.3 Botanical description of common bean (Phaseolus vulgaris)

Common bean belongs to the order Rosales, family Fabaceae, subfamily Papilionoideae, tribe Phaseoleae (CIAT, 1986). Cultivated forms are herbaceous annuals, which are determinate or indeterminate in growth habit. On germination, the plant is initially tap-rooted, but adventitious roots emerge soon thereafter, and dominate the tap root which remains 10-15 cm in length (Duke, 2009).

Papilionaceous flowers are borne in auxiliary and terminal racemes. Racemes may be one or many flowered. Flowers are zygomorphic with a bi-petalled keel, two lateral wing petals and a large outwardly displayed standard petal. Flower colour is genetically independent of seed colour, but association between particular flower and seed colours is common. Flowers may be white, pink or purple. The flower contains ten stamens and a single multi ovule ovary, is predominantly self fertilized, and develops into a straight or slightly curved fruit or pod (Graham and Ranalli 2014).

Seeds may be round, elliptical, somewhat flattened or rounded elongate in shape, and a rich assortment of coat colours and patterns exists. Seed size ranges from 50 mg/ seed in wild accessions collected in Mexico, to more than 2000 mg/ seed in some large seeded Colombian varieties (Graham and Ranalli, 2014)

In developmental terms, there are two types of common bean: determinate, in which the main axis terminates in an inflorescence and produce no vegetative nodes after flowering and the other one, indeterminate. Singh (2011) classified the world bean collections into four main types on the bases of determinacy, node production after flowering and growth habit (height and climbing). The determinate type is self-supporting or bushy and is of short growth duration. Indeterminate genotypes show a wide range of node number on the main stem, climbing tendency and growth duration.

Most beans cultivated in East Africa are determinate, with bushy growth habit but indeterminate non-climbing, semi-bush types, and indeterminate climbing types also are adopted Acland (1971).

Laing *et al.* (2011) pointed out that an indeterminate genotype might change growth habit category with change in temperature/day length combinations. The different three types of indeterminate were distinguished by Van Schoonhoven and Pastor-Corrales (2012): growth habit I, upright habit, with an erect stem and few branches, and often without a guide; growth habit II, bush habit with weak and prostrate stem and numerous branches; having a short or long guide and with variable ability to climb; and growth habit III, climbing if supported on a suitable tutor, with a weak, long and twisted stem and reduced branching.

Determinate plants of common bean may have 3 to 7 trifoliate leaves on the main stem before the terminal double raceme (as found in bush or dwarf cultivars selected for earliness in Europe and the USA), or may be many nodded with 7-15 (Middle American) or 15-25 (Andean) trifoliate leaves on the main stem (Debouck, 2013).

Flowering in cultivars of determinate growth habit is concentrated over a very short period of time (usually 5-6 days), with drought or other stresses imposed at this time having a marked effect on yield. Seed filling periods may extend for as few as 23 days in the case of the determinate cultivars.

Germination in common bean is epigeal, and requires 5-7 days at a soil temperature of 36-47 ^{0}C; time to flowering varies with cultivar, temperature and photoperiod. Flowering is usually initiated 28-42 days after planting, but amongst climbing varieties grown at high elevation, can be significantly later. Indeterminate cultivars produce additional nodes after initial flowering, with flower formation thereby extended to 15-30 days. As many as two thirds of all the flowers produced may abort, and under temperature or water stress young fruits and/or developing seeds may also abort. Abscission is greatest among flowers formed on the upper nodes and branches, and within a raceme is greatest among the later flowers to form (CIAT, 2011).

Physiological maturity, the stage beyond which no further increase in seed dry matter takes place, may occur only 60-65 days after planting amongst those early varieties used in areas where the growing season is very short, or extend to 200 days after planting amongst climbing varieties used in cooler upland elevations (CIAT, 2011).

2.4. Common bean production in Kenya

Common bean is the most important food legume in Kenya. Beans offer a low cost alternative to beef and milk because it serves as a main source of dietary protein, iron, fibres, and complex carbohydrates however, considered as poor man’s meat. (Hacisalihoglu *et al*., 2011; Mwale *et al*., 2012).

Common bean is solely an important legume in the Kenya as a rotation crop, mainly for consumption particularly in the western and maybe also for export (Amare, 2011). Common beans also yield fairly well in areas where other pulses perform poorly due to incidence of diseases and pests (CIAT, 2011).

Common bean is a principal food crop (Broughton *et al.,* 2003; Vance, 2013) and supplements other staple foods in production areas (Vance, 2013). Besides, it has a short maturity period of only three months and, hence, it fills gaps for household food needs during the hunger period and serves as a substitute for income provision (Amare, 2011; Ayele, 2009)

2.5 Effect of spatial arrangement on production of beans

Spatial arrangement is defined as the pattern of plants over the ground, which determines the shape of the area available to the individual plant (Reddy, 2000). For crops regularly arranged in rows, spatial arrangement can be concisely defined by the rectangularity, which is the ratio of the inter row spacing to the intra raw spacing (Willey and Osiru, 2012). Plant arrangement in the field is important and plays a significant role in determining plant growth and development. Crop spatial pattern is an agronomic factor which affects grain yield and crop competitiveness against weeds (Olsen and Weiner, 2012). It has been suggested that uniform planting pattern increases the spatial uniformity in leaf area index (LAI), reduces mutual shading, and hastens canopy closure, all of which result in increased radiation interception by the canopy (Olsen and Weiner, 2007) and increased crop growth and yield (Mashingaidze,2009). Solomon (2010) reported that thousand seed weight decreased with decrease in plant inter row space on bean haricot. Moreover, Al-Abduselam and Abdai, (1995), Turk and Tawaha, (2002) and Matthews *et al*. (2008) reported that hundred seed weight of faba bean was negatively related with inter row space of spatial arrangement. In contrast to this, Lemlem and Giorgis (2011) obtained insignificant effect of spatial arrangement on thousand seed weight of soybean.

Plants show extreme plasticity, responding remarkably in size and form to environmental conditions. One of the most potent of these external forces is the presence of competing neighbours, which may reduce a plant to diminutive size. The factors for which competition may occur among plants are water, nutrient, light, and carbon dioxide and in the reproductive phase, agents of pollination and dispersal. Water, nutrients and light are the factors most commonly deficient. When the immediate supply of a single necessary factor falls below the combined demand of the plants, competition begins (Norman,2013). Abo El-Zahab *et al.*, (1981), Ayaz *et al.*, (2001), and (Abdel 2008) reported that number of seeds per pod increased with increased intra row space of faba bean. Moreover, Oad *et al*., (2002) while working on safflower reported that higher number of seeds per pod was associated with wider inter and intra-row spacing. Ball *et al*., (2000) reported that decreasing intra row space reduced yield of individual plants but increased yield per unit area of common bean. Similarly, Egli *et al.,* (1988) reported that closely spaced plants ensures early canopy coverage thus minimizing light interception for lesser growth rate and crop biomass which gave poor yield in soybean. Grafton *et al*. (1988) found there was greater seed yield increase with increased intra row space of dry bean.

In pure stands, increase in the intensity of competition manifests itself by the reduction of the performance of the individual plant, for example biomass of single plant and/or reduction of grain weight per plant (Sobkowicz and Podgorska, 2011). (Reddy, 2011) described that too narrow spacing do affect grain yields through competition and due to the effect of shading. (Singh and Singh, 2010) reported that establishment of narrow spacing per unit area is essential to get maximum yield.

Under conditions of sufficient soil moisture and nutrients, higher density is necessary to utilize all the growth factors efficiently. Each growth factor for which the plant competes has limitation to support a crop beyond the given plant spacing used per unit area. The greater light interception increases photosynthesis and reduces evaporation of water from the soil (Robinson *et al*., 2013). Plant arrangement must be adjusted to available soil moisture levels, either within rows or between rows (Gobeze, 2010). Planting arrangement alters both the spatial and temporal pattern of interception or retrieval of the limiting resource, especially in dry land cropping where soil water is rarely adequate throughout the growing season. In such cases, inter and intra row spacing are normally a matter of compromise (Bora *et al*., 2011). Holmes and Sprague (2013) reported that narrow row square planting pattern suppressed weed growth more effectively than wide row planting pattern in beans. Dusabumuremyi (2014) reported that bean yield was influenced significantly by planting pattern, they found that bean yield was increased significantly by 22% in wide row planting pattern compared to Narrow Square planting pattern. The results established by Ngo van Man and Nguyen Van Hao (2015) was that *Acacia mangium* planted with a Spatial arrangement of 50*100 gave the highest yield of fresh matter after one year . (Yayeh, 2014) found out that planting field pea using intra row space of 5cm gave the highest plant height as compared to intra row space of 15cm showed the lowest plant height. Dusabumuremyi (2014) noted that wide intra row increase the evenness of LAI distribution, reduce mutual shading, and shorten the time taken by the canopy to achieve full ground cover. (Dusabumuremyi,2014) reported that reduced intra-specific competition (for water, mineral, nutrients, and radiation) in the square planting increased growth and yield.

The average bean yield per annum in many African countries is always lower than that of the world. (Dusabumuremyi, 2014) reported that number of pods per plant was higher in the wide row planting pattern than in narrow row planting pattern. (Yayeh, 2014) concluded that increase in number of pods per plant in wider row may be due to vigorous plants He further reported that in closer inter row the plant growth rate was low thus resulting in less number of pods per plant. Qamar and Malik (2013) observed significant effect of row in crop spatial arrangement in bean and reported that 90 cm apart double row strip produced higher seed weight. Ismail and Hall (2000) found a decrease in seed weight of cowpea with increased spatial arrangement. (Muchow, 2014) examined the competitive response of range of legumes to soil moisture regimes and reported that grain legumes varied significantly from each other in terms of phenology and yield.

The non-significant effect of row spatial arrangement on the plant height has been reported by Sharar *et al.*, (2012).Nadeem *et al* ., (2004) reported that the 60 cm apart double row produced more number of pods per plant than 40 cm apart single row strips in all legume crops. He further concluded that higher number of pods might have been due to efficient interception of light and utilization of available resources. A significant effect of planting geometry on number of pods per plant has been reported by Ali *et al*.,(2010). Nadeem *et a*l., (2004) reported that crops sown in 60 cm apart double row strip produced significantly higher seed yield than 40 cm apart single rows.

2.5.1 Effect of spatial arrangement on growth and development of pulse crops

Plant spatial arrangement highly influences common bean growth and development. The degree of the influence generally depends up on the availability and/or scarcity of environmental resources for which plants compete with each other and the growth pattern and morphological characteristics of the competing plants (Matthews *et al*., 2012).

Narrow arrangement brings out certain modifications in the growth of plants, for example, increase in plant height, reduction in leaf thickness, alteration in leaf orientation, and leaves become erect, narrow and are arranged at longer vertical intervals to intercept more sun light (Singh and Singh, 2010). This is because in narrow arrangement, plants compete more and reduction in number of branches per plant and nodes per branch were observed. Loss *et al.,* (2010) observed that narrow arrangement resulted in significantly earlier canopy closure, larger leaf area index, more radiation absorption and dry matter accumulation particularly during the early vegetative stages than in treatments where wider spacing was established in common bean. They also showed that early canopy closure and greater dry matter production under narrow spacing caused greater suppression of weeds and aphids. In soybean, Parvez *et al.*, (2011) indicated that with narrow spatial arrangement, there was an increase in plant height, while branching and node development decreased. Taj *et al*., (2002) found that competition for light in narrow spacing in mung bean resulted in taller plants while at wider spacing light distribution was normal. Similarly, (Shamsi and Kobraee, 2009) worked on spatial arrangement experiment on soybean, observed that decreasing intra row spacing led to significant increases in plant height. This was primarily because of lower amount of light intercepted by plants planted in a close intra row space resulting into increased inter node length. However, Shahein *et al*., (1995) reported that plant height was not affected by decrease in intra row space on faba bean. In contrast to the result of this study, Turk *et al*., (2003) worked on lentil and reported negative correlation of plant height with spatial arrangement of plants in relation to inter row space.

2.5.2 Effects of spatial arrangement on yield and yield components of pulse crops

The seed yield of bean is the result of many plant growth processes which ultimately influence the yield components such as number of pods per plant, seeds per pod, and unit weight of seed. The highest seed yield is obtained when all these components get maximized.

The spatial distribution of plants in a crop community is an important determinant of yield (Egli, 2014) and many experiments have been conducted to determine the spacing between rows and between plants within the row that maximize yield. Two general concepts are frequently used to explain the relationship between row spacing and yield. First, maximum yield could be obtained only if the plant community produced enough leaf area to provide maximum light interception during reproductive growth (Shibles and Weber, 2007). Secondly, equidistant spacing between plants affected interplant competition (Pendleton and Hartwing, 2013). Pilbeam *et al.,* (1991) noted decrease in number of pods per plant in faba bean due to a reduction in the number of stems per plant at narrow intra row space in a spatial arrangement. Similarly, (Al-Abdselam and Abdai., 1995), (Hodgson and Blackman, 2005) and (Abdel, 2008) worked on faba bean and reported that the development of more and vigorous leaves under wide intra and inter row space in spatial arrangement helped to improve the photosynthetic efficiency of the crop and supported large number of pods.

2.5.3 Growth and plant spatial arrangement interaction

In crops, inter and intra row depends on factors such as moisture, type of crop, the climate and the crop variety. Competition in crops is commonly between plants of same genotype when all sown at the same time and in similar environmental conditions. A major factor influencing plant arrangement for any particular crop is the genotype (Mekonnen, 2010). Genotype by plant spatial arrangement interaction was found to be evident in faba bean (Amare and Adamu, 2000) and field pea (Rezene, 2014).

2.6 Effect of variety on production of beans

Common bean (*Phaseolus vulgaris* L.) is an important herbaceous annual grain legume in the world chiefly grown as a cheap source of protein among majority of Sub-Saharan African people (Sharar *et al.*, 2012). Growers experience suggests that local dry bean varieties are well adapted however; available varieties have not been studied on. (Sharar *et al.*, 2012).

In contrast, there are 1800–2800 growing degree days (GDD) in the major dry bean growing regions in Western Kenya (Kakar *et al.,* 2013) . Maugoud (2005) show that snap bean varieties in both seasons significantly differed in their vegetative growth parameters.(Maugold *et al*.,2005) reported that *Coby* cultivar recorded the highest pod yield and the lowest yield was recorded with *Royalnel.*

Amare *et al*.,(2014) regarding variety effect, the highest value for plant height was recorded with *Nasir* variety (58.72 cm) while the lowest value of plant height was recorded with I*bado* variety (41.7 cm) .

Turk *et al.,* (1980) reported that seed weight of cowpea cultivar was affected by genetic factors except in case of severe water stress and hot desiccating winds causing forced maturity.(Amare *et al*., 2014) reported that *Dume* variety produced the highest significant number of seeds per pod (5.367) followed by *Nasir* (5.16) whereas *ibbado* produced the least seed number per pod (4.022). (Amare *et al*., 2014) recorded that maximum significant seed yield (23.76g) was recorded from variety *Dume* followed by *Nasir* (22.46kg/ha. *Ibbado* which gave the lowest seed yield (19.2 g). (Amare *et al*., 2014) observed that *Ibbado* produced the highest harvest index (0.56) followed by *Dume* (0.53) while the least value was recorded from *Nasir* (0.50). In the present study the focus was on Rose coco, Canadian wonder and KAT B1.

The study was carried out in Mabanga and University of Eldoret to determine the best performing variety and suitable spatial arrangement for beans so as to improve food security and the livelihood of +small holder’s farmers.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental sites

The experiment was conducted at the University of Eldoret and Mabanga ATC in Uasin-Gishu and Bungoma Counties respectively.

3.1.1 University of Eldoret

UOE farm is situated 10 km North of Eldoret town. The farm is within the Uasin Gishu plateau which is in the lower highlands (LH3) agro-ecological zone (Jaetzold and Schmidt, 2008). The site is located at latitude $0^{0}30'$ N and longitude $35^{0}15'$ E; at an elevation of 2180 m above sea level (Jaetzold and Schmidt, 1982). The site is characterized by a mean maximum temperature of 23^{0}C and a relative humidity of 45 %(Jaetzold and Schmidt, 2008). An annual rainfall of 900-1100mm p.a. has been recorded for this site. The soils are shallow, well drained ferralsol.

3.1.2 Mabanga ATC

The site is within Bungoma County. The area lies between latitude $0^{o}26^{'}$ to $0^{0}18^{'}$north, longitude $33^{0}58^{'}$east and $34^{0}33^{'}$ west and an altitude of 1400 meters above sea level. Mean annual temperature of 22.5^{0}c and mean annual precipitation of 1800-2000mm (Jaetzold and Schmidt, 2008). The soil type is acrisol. The rains are bimodal (Jaetzold and Schmidt, 1982)

3.2 Treatments

3.2.1 Varieties

a) Canadian wonder (GLP 24).

Figure 1: Canadian Wonder (GLP 24) (Source: Author, 2017)

Grows well at an altitude of 1200 M-1800M and matures within three months with the grain yield of 1.3-1.8 t/ha. Seeds are shiny, dark reddish purple, recommended for medium rainfall areas; they are of climbing variety (indeterminate variety). Grows up to height of 40-60 cm.

b) KAT B1 (determinate)

Figure 2: KAT BI (Source: Author, 2017)

Grows well at an altitude of 1000-1800 M and matures within 2 ½ months with the grain yield of 1.4 to 1.9t/ha. Seeds creamish-green, grows well under tree/banana shades. It is a determinate variety. Grows up to a height of 35-40 cm.

C) Rose coco (GLP 2) (determinate)

Figure 3: Rose coco (Source: Author, 2017)

Grows well at an altitude of 1500-2000 M and matures within 3 months with the grain yield of 1.8-2.0 t/ha its wide adaptability, recommended for medium and high rainfall areas, seeds red with cream flecks. They are bush beans (determinate variety). It grows up to a height of 20-60.

3.2.2 Spatial arrangement

The same bean population of approximately 11 plants/m^2 was achieved by spacing at 60 cm X 15 cm, 45 cm X 20 cm, 36 cm X 25 cm and 30 cm X 30 cm hence four different spatial arrangements.

3.3 Treatment combinations

Table 2: Treatment Combinations

S/V	**V_1**	**V_2**	**V_3**
S_1	**S_1V_1**	**S_1V_2**	**S_1V_3**
S_2	**S_2V_1**	**S_2V_2**	**S_2V_3**
S_3	**S_3V_1**	**S_3V_2**	**S_3V_3**
S_4	**S_4V_1**	**S_4V_2**	**S_4V_3**

Where

S_1 =Spatial arrangement of 60 cm x 15 cm

S_2 =Spatial arrangement of 45 cm x 20 cm

S_3 =Spatial arrangement of 36 cm x25 cm

S_4 =Spatial arrangement of 30 cm x30 cm

V_1=Canadian wonder variety

V_2=Katumani B1 variety

V_3=Rose coco variety

3.4 Data collected

a) Plant height (cm)

Random samples of three plants were taken from each plot to determine plant height at maturity. The plant height was measured from the ground level to the highest tip of the stem for the three randomly sampled plants. This was done with the use of a meter rule. The average plant height was calculated for each treatment.

b) Number of flowers

Flowers of the three random plants were counted and average taken for each treatment

c) Number of pods/plant

For pod number, three randomly sampled plants were taken from each plot when the crop had reached the harvest maturity stage. These were then counted manually and the average pod number was calculated.

d) Number of seeds/pod

The number of seeds per pod was also determined by taking the three randomly sampled pods of the three randomly sampled plants from each plot at harvest maturity stage. Seeds were counted in each pod, and then average calculated.

e) 1000 - seeds weight(g)

The 1000 - seed weight was determined by counting 1000 seeds taken at random from the threshed and oven dried to a moisture content of 13% seeds from each plot when the crop had reached the harvest maturity stage. These were weighed to represent the mean seed weight.

f) Seed weight/ hectare (kg/ha)

Seed yield per hectare was determined by threshing the harvested plants from the central one square meter in each plot. These were put in labelled envelopes and oven dried to a constant moisture content of 13 % at 60 ^{0}C for 48 hours, and then weighed using electric balance. The resulting average weights, in grams (g) per meter square were then scaled up to kg per hectare.

3.5 Experimental design

Randomized complete block design with three replications was used in this work.

3.5.1 Plot lay-out

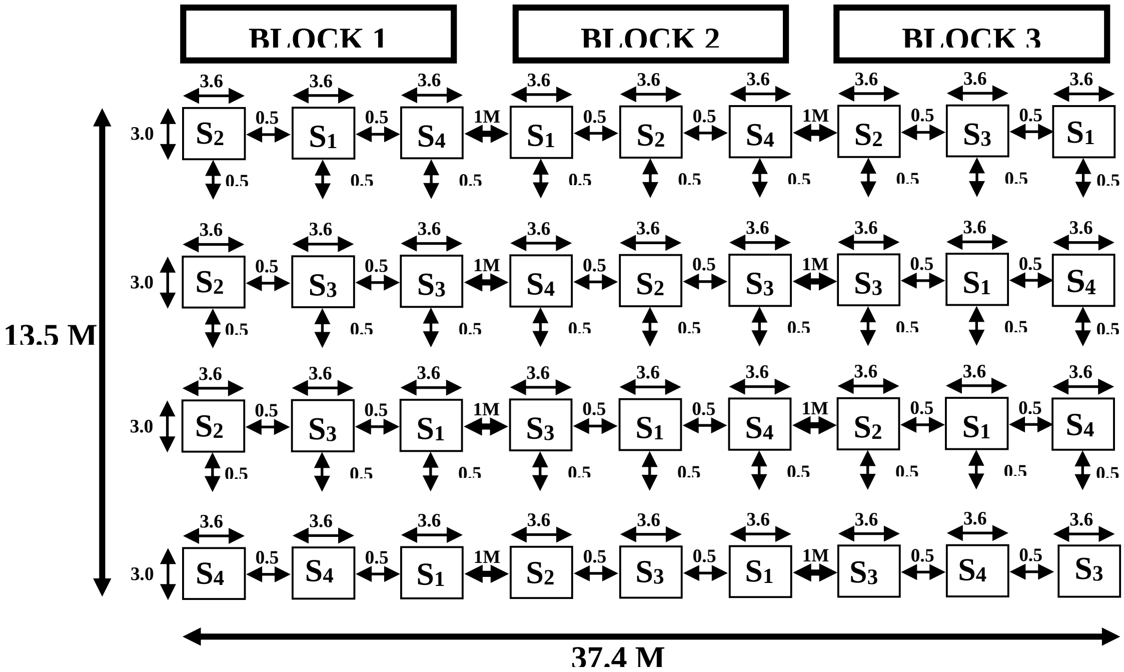

Figure 4: Plot layout (Source: Author, 2017)

3.5.2 Statistical analysis

All recorded data were subjected to analysis of variance (ANOVA) using Genstat statistical programme version 13. Tukey's HSD at 5% level of significance was used to separate means.

3.5.3 Statistical model

Data was analyzed according to this model

$Y_{ijkl} = \mu + \beta_i + S_j + V_k + S*V_{jk} + \varepsilon_{ijkl}$ where

Y_{ijkl} = Yield

μ = Overall mean

β_i = Block effect

S_j = Effect due to spatial arrangement

V_k = Effect due to variety

$V*S_{jk}$ = Effect due to interaction between spatial arrangement and variety

ε_{ijkl} = Residual error

CHAPTER FOUR

RESULTS

4.1 Effect of spatial arrangement on the performance of bean in Western Kenya.

4.1.1 Plant height

For the beans planted in Eldoret, the difference in plant height was not significant (*$p \leq 0.05$*) as shown in (Table 4). There was also no significant difference seen on the interaction between variety and spatial arrangement on plant height (appendix 7).

On the other hand, for the beans planted in Mabanga site, the effect of spatial arrangement on plant height was significant ($p \leq 0.05$) as shown in table 4. The plant height of 35.9cm was the highest recorded at 36 cm x 25 cm while the least plant height of 17.6 cm recorded at 30 cm x 30 cm. There was however no significance ($p \leq 0.05$) seen on the interaction between variety and spatial arrangement (appendix 1).

4.1.2 Number of flowers / plant

There was no significant difference between the number of flowers per plant ($p \leq 0.05$) in the different spatial arrangements for the beans planted at both sites, University of Eldoret and at Mabanga ATC as shown in tables 4 and 5. Likewise, there was no significant interaction between variety and spatial arrangement in Mabanga (appendix 2) and University of Eldoret (appendix 8) at ($p \leq 0.05$) on number of flowers per plant.

4.1.3 Number of pods / plant

There was significant difference ($p \leq 0.05$) on number of pods per plant of common bean in University of Eldoret with the highest number of pods per plant of 18.3 recorded at 30 cm x 30 cm while the least number of pods per plant of 12.2 recorded at 60 cm x 15 cm (Table 4). However, the effect of interaction between variety and spatial arrangement was not significant ($p \leq 0.05$) in Eldoret (appendix 9).

On the other hand, the arrangement significantly affected number of pods per plant in Mabanga the highest number of pods per plant of 20.6 was recorded at 30 cm x 30 cm .While the least number of pods per plant of 16.3 recorded at 60 cm x 15 cm which was at par with 16.3 recorded at 45 cm x 20 cm (Table 5). The interaction between variety and spatial arrangement was also significant *($p \leq 0.05$)* (Table 3).

Table 3: Interaction effect between spatial arrangement and varieties on number of pods/plant in Mabanga

Spatial arrangement	Varieties		
	Canadian wonder	KAT B1	Rose Coco
60 cm X 15 cm	15.67 de	20.00 abc	13.33 e
45 cm X 20 cm	15.00 de	16.67 cde	17.33 bcde
36 cm X 25 cm	15.67 de	18.67 bcd	24.00 a
30 cm X 30 cm	20.67 abc	20.00 abc	21.00 ab
CV (%)	8.0		
Tukey's HSD($p \leq 0.05$)	5.12		

Means followed by same letter are not significantly different at p≤0.05

Table 4: Effect of spatial arrangement on growth and yield of beans at University of Eldoret site

Spatial arrangement	Plant height (cm)	No.of flowers / plant	Pods/plant	Seeds/pod	Weight of seeds/plant	1000 seed weight (g)	Seed yield kg/ha
30cm x 30cm	24.9a	26.7a	18.3a	5.2ab	56.8b	278.0b	332.6b
36 cmx 25cm	27.4a	23.8a	13.7b	5.1b	99.2a	279.3b	484.8a
45 cmx 20cm	27.0a	25.1a	14.6b	6.4a	78.3a	276.5b	479.4a
60cm x 15cm	25.3a	24.1a	12.2b	5.0b	65.1b	299.2a	363.7b
Grand mean	26.2	24.9	14.7	5.4	72.4	282.8	415.1
CV %	8.4	20.1	15.8	13.2	19.6	3	7.5
Tukey`s HSD (0.05)	2.8	9.9	3	0.9	28.2	10.91	39.8

Means within column followed by same letter are not significantly different at $p \leq 0.05$

Table 5: Effect of spatial arrangement on growth and yield of beans at Mabanga site

Spatial arrangement	plant height(cm)	Flowers/ plant	pods/plant	Seeds/pod	1000 - seed weight	Seed yield (kg/ha)
30cmx30cm	17.6c	12.6a	20.6a	6.2b	273.7b	549.1a
36cmx25cm	35.9a	13.8a	19.4a	6.1b	277.7ab	454.0ab
45cmx20cm	24.0b	13.0a	16.3b	7.4a	275.0ab	317.5bc
60cmx15cm	20.2bc	13.0a	16.3b	6.0b	279.2a	426.2b
CV(%)	7.1	10.7	8	15.6	1.4	17.1
Tukey's HSD (0.05)	5.5	1.9	2.09	1.1	5.1	100.8

Means within column followed by same letter are not significantly different at $p \leq 0.05$

4.1.4 Number of seeds /per pod

Analysis of variance revealed that there was significant effect *($p \leq 0.05$)* on number of seeds per pod of common bean both at University of Eldoret and Mabanga ATC (Table 4 and 5). At University of Eldoret the highest number of seeds per pod of 6.4 recorded at 45 cm x 20 cm and the least number of seeds per pod of 5 recorded at 60 cm x 15 cm. There was no significant difference in the interaction between spatial arrangement and variety ($p \leq 0.05$) (appendix 10).

At Mabanga, the highest number of seeds per pod of 7.4 was recorded at 45 cm x 20 cm while the least number of seeds per pod of 6.1 was recorded at 36 cm x 25 cm. However, there was no significant difference *($p \leq 0.05$)* between the varieties interacting with spatial arrangement (Appendix 4).

4.1.5 1000- seed weight

There was significant ($p \leq 0.05$) effect of spatial arrangement on 1000-seed weight for common bean planted in Mabanga and University of Eldoret. The highest thousand seed weight of 297.4 g was recorded at 60 cm x 15 cm while the least thousand seed weight of 276.5 g was recorded at 45 cm x 20 cm at University of Eldoret (Table 4). There was also significant difference ($p \leq 0.05$) in the interaction between variety and spatial arrangement at University of Eldoret as shown on table 6 below and also on (Appendix 11).

Table 6: Interaction effect between spatial arrangement and varieties on 1000-Seed weight (g) at University of Eldoret

Spatial arrangement	Bean Varieties		
	Canadian wonder	KAT B1	Rose Coco
60 cm X 15 cm	317.1 a	293.2 ab	281.9 bc
45 cm X 20 cm	289.6 bc	267.1 c	273.0 bc
36 cm X 25 cm	277.6 bc	276.9 bc	283.2 bc
30 cm X 30 cm	280.9 bc	271.9 bc	281.2 bc
CV (%)	3.0		
Tukey's(HSD $p \leq 0.05$)	24.2		

Means followed by same letter are not significantly different at p≤0.05

There was significant difference ($p \leq 0.05$) on thousand seed weight of common beans in Mabanga with the highest thousand seed weight of 279.2g recorded at 60 cm x 15 cm. The least thousand seed weight of 273.7g recorded at 30 cm x 30cm (Table 5). Likewise, there was significant difference ($p \leq 0.05$) in interaction between variety and spatial arrangement in Mabanga as shown on table 6 below and also on Appendix 5

Table 7: Interaction effect between spatial arrangements and varieties on 1000- Seed weight in Mabanga

Spatial arrangement	Varieties		
	Canadian wonder	KAT B1	Rose Coco
60 cm X 15 cm	289.3 a	282.9 ab	265.4 cd
45 cm X 20 cm	290.6 a	273.0 bcd	261.5 d
36 cm X 25 cm	283.5 ab	282.6 ab	267.1 cd
30 cm X 30 cm	277.0 bc	275.1 bc	269.0 cd
CV (%)	1.4		
Tukey's HSD ($p \leq 0.05$)	11.5		

Means followed by same letter are not significantly different at $p \leq 0.05$

4.1.6 Seed weight

Spatial arrangements resulted to significant seed yield ($p \leq 0.05$) for the beans planted in University of Eldoret. High seed yield of 484.8kg/ha was recorded at 36 cm x 25 cm while the least seed yield 332.6kg/ha was recorded at 30 cm x 30 cm (Table 4). Likewise, there was significant difference ($p \leq 0.05$) in the interaction as shown on table 8 below and also on appendix 12.

Table 8: Interaction effect between spatial arrangement and variety on Seed weight/ hectare in University of Eldoret

Spatial arrangement	Bean Varieties		
	Canadian wonder	KAT B1	Rose Coco
60 cm X 15 cm	284.8 e	505.1 ab	301.3 de
45 cm X 20 cm	388.9 cd	491.8 ab	557.6 a
36 cm X 25 cm	456.6 bc	446.5 bc	551.4 a
30 cm X 30 cm	488.2 ab	254.3 e	255.1 e
CV (%)	7.5		
Tukey's HSD($p \leq 0.05$)	89.5		

Means followed by same letter are not significantly different at p≤0.05

At Mabanga ATC there was significant difference ($p \leq 0.05$) on seed yield of common beans. Where the highest seed yield of 549.1 kg/ha was recorded at 30 cm x 30 cm. Whereas, the least seed yield 317.5 kg/ha recorded at 45 cm x 20 cm (Table 5). However, it was noted that the interaction between variety and spatial arrangement was not significant (appendix 6).

Table 9: Interaction between spatial arrangement and variety on Seed weight in Mabanga site

Spatial arrangement	Bean Varieties		
	Canadian wonder	KAT B1	Rose Coco
60 cm X 15 cm	252.2e	555.6ab	471.0c
45 cm X 20 cm	398.0be	440.1bc	414.4c
36 cm X 25 cm	401.2b	362.3c	598.5ab
30 cm X 30 cm	619.5a	473.3b	554.5ab
CV (%)	17.1		
Tukey's HSD (*$p \leq 0.05$*)	79.5		

Means followed by same letter are not significantly different at $p \leq 0.05$

4.2 Effect of varieties on performance of bean in Western Kenya

4.2.1 Plant height

There was no significant difference in height ($p \leq 0.05$) at Mabanga and University of Eldoret (Table 11 and 10). There was no significant difference in the interaction between variety and spatial arrangement (appendix 7 and 1) in University of Eldoret and Mabanga respectively.

4.2.2 Number of flowers / plant

There were no significant differences ($p \leq 0.05$) at both sites, University of Eldoret and Mabanga on number of flowers per plant of common beans planted (Table 10 and 11).

There was also no significant difference in terms of interaction between variety and spatial arrangement in both sites, University of Eldoret and Mabanga (appendix 8 and 2).

Table 10: Performance of bean varieties at University of Eldoret site

Variety	Plant height, (cm)	Flowers / plant	Pods/plant	Seeds / pod	1000 - seed weight	Seed yield, (kg/ha)
Canadian	25.5a	26.4a	14.8a	5.1a	291.3a	404.6a
KAT B1	22.5a	21.9a	15.0a	5.8a	277.3b	424.4a
Rose coco	26.5a	26.4a	14.3a	5.4a	279.8b	416.4a
CV (%)	8.4	20.1	15.8	13.2	3	7.5
Tukey's HSD (0.05)	2.2	7.7	2.3	0.7	8.6	31.2

Means within column followed by same letter are not significantly different at p≤0.05

Table 11: Performance of bean varieties at Mabanga site

Variety	Plant height, (cm)	Flowers/ Plant	Pods/plant	Seeds /pod	1000 - seed weight	Seed yield (kg/ha)
Canadian	34.1a	13.8a	16.8b	6.2a	285.1a	417.7b
KAT B1	34.0a	12.8a	18.8a	6.3a	278.4b	457.8ab
Rose coco	35.7a	12.8a	18.9a	6.9a	265.8c	509.6a
CV%	7.1	10.7	8	15.6	1.4	17.1
Tukey's HSD (0.05)	4.3	1.5	1.6	0.9	4	79

Means within column followed by same letter are not significantly different at p≤0.05

4.2.3 Number of pods / plant

There was significant difference ($p \leq 0.05$) on number of pods per plant of beans in Mabanga ATC. The highest number of 18.9 recorded with *Rose coco* while the least number of 16.8 recorded with *Canadian Wonder* (Table 11). There was also significant interaction ($p \leq 0.05$) between variety and spatial arrangement as shown in table (3) above and also in (appendix 3). However, there was no significance ($p \leq 0.05$) on number of pods per plant of beans in University of Eldoret (Table 10). Furthermore, there was no significance ($p \leq 0.05$) in the interaction between variety and spatial arrangement (appendix 9).

4.2.4 Number of seeds / pod

Analysis of variance revealed no significant effect of treatments on seeds/ pod of common bean at University of Eldoret and Mabanga ATC (Table 10 and 11) Likewise, there was no significance ($p \leq 0.05$) in the interaction between variety and spatial arrangement in both sites (appendix 10 and 4).

4.2.5 1000 -Seed weight

The differences between varieties on 1000- seed weight were significant ($p \leq 0.05$) at both the University of Eldoret and Mabanga ATC (Table 10 and 11). The highest 1000 seed weight of 291.3g recorded with *Canadian wonder* and 285.1g recorded with *Canadian wonder* in University of Eldoret and Mabanga respectively. The least 1000 - seed weight of 277.3g was recorded with *KAT B1* and 265.8g recorded with *Rose coco* at University of Eldoret and Mabanga respectively.

There was significant ($p \leq 0.05$) interaction between variety and spatial arrangement on 1000 – seed weight at University of Eldoret and Mabanga ATC (Table 6 and 7 and also appendices 11 and 5).

4.2.6 Seed weight / hectare

There were significant differences between varieties *($p \leq 0.05$)* on seed yield of common bean in Mabanga ATC. The highest seed yield of 509.6kg/ha recorded on *Rose Coco* while the least seed yield of 417.7kg/ha recorded with *Canadian Wonder* (Table 11).

At University of Eldoret, there was no significant difference ($p \leq 0.05$) between varieties on seed yield of beans (Table 10). However, there were significant interaction ($p \leq 0.05$) between variety and spatial arrangement at Mabanga ATC and University of Eldoret as shown on table 8 and appendix 12 and 6 respectively.

CHAPTER FIVE

DISCUSSION

5.1 Effect of treatments on plant height at maturity

The significant effect on plant height at Mabanga site only in plant height could be justified on the basis of its agro climatic factors and soil factors which favoured the growth of beans in this site and not at University of Eldoret, and also increase in plant height could be justified on the basis of how plants are arranged in space. Increase in plant height could be due to plants planted closely to each other within the row due to increase in plant competition for solar radiation and nutrients within the row. This is because of lower amount of light intercepted by a plant through crop canopy resulting into increased inter node length probably due to the intra plant competition for light which causes such variation in plant height. This result is in line with Taj *et al*., (2002) who found that competition for light in narrow spacing in mung bean resulted in taller plants while at wider spacing light distribution was normal. Similarly, (Shamsi and Kobraee,2009) working on spatial arrangement experiment on soybean, observed that decreasing intra row spacing led to significant increases in plant height. This was primarily because of lower amount of light intercepted by plants planted in a close intra row space resulting into increased inter node length. However, Shahein *et al*., (1995) reported that plant height was not affected by decrease in intra row space on faba bean. In contrast to the result of this study, Turk *et al*., (2003) worked on lentil and reported negative relationship of plant height with spatial arrangement of plants in relation to inter row space.

5.2 Effect of treatments on pods / plant

Number of pods per plant is a key factor for determining the yield performance in leguminous plants (Abdel, 2008). There was significant effect on number of pods per plant in both sites because of plant arrangement in time and space at both sites which enhanced the significant effect. The decrease in the number of pods per plant with a decrease in intra row spacing could be due to increased intra specific competition which eventually might have caused reduction in the number of pods per plant.

Furthermore, the increase in the number of pods per plant with increased intra and inter row spacing might be due to higher net assimilation rate due to reduction in competition in wider intra row space in crop spatial arrangement. On the other hand, decreased intra and inter row space induced competition between the early and late emerged flowers that could lead to flower abortion. In wider inter and intra-row spacing, the growth factors (nutrient, moisture and light) for individual plants might be easily accessible hence retaining more flowers for pod formation and support the development of lateral branches for more pod development. The result of this study support Pilbeam *et al.,* (1991) who noted a decrease in number of pods per plant in faba bean due to a reduction in the number of stems per plant at narrow intra row space in a spatial arrangement. Similarly, (Al-Abdselam and Abdai ,1995; Hodgson and Blackman ,2005 and Abdel ,2008) who worked on faba bean reported that the development of more and vigorous leaves under wide intra and inter row space in spatial arrangement helped to improve the photosynthetic efficiency of the crop which supported large number of pods.

At Mabanga site, there was significance on number of pods per plant due to effect of variety and this could be justified on the basis of genetic factors of beans, environmental factors of Mabanga site and growth habit of bean variety ,the highest mean number of pods per plant was obtained for variety *Rose coco* having determinate prostrate growth habits while the lowest was recorded with *Canadian Wonder* having indeterminate erect growth habit and this might have been due to the highest plant height of *Rose coco* with 35.7 cm that contain more number of pods per plant. According to Maugold *et al*., (2005) *coby* cultivar recorded the highest pod yield which had the highest height and the lowest pod yield was recorded with *Royalnel* which had the lowest height. The interaction effect was significant at Mabanga because of genetic factor, environmental factor and how plants were arranged in space that might have favoured the formation of pods. This is in line with (Mekonnen, 2010) who reported that a major factor influencing plant arrangement for any particular crop is the genotype. Therefore, Genotype by plant spatial arrangement interaction was found to be evident in faba bean (Amare and Adamu, 2000) and field pea (Rezene, 2014.

5.3 Effect of treatments on number of seeds / pod

Number of seeds per pod is considered an important factor that directly imparts in exploiting potential yield recovery in leguminous crops Ayaz et al.,(2001). The significant effect in both sites could be due to the environmental factors, soil factors of the site, genetic factors of bean cultivar that enhanced the formation of seeds in the pods and how the plant architecture is done in space and time. This variation might be due to the fact that wide intra row spaced plants encountered less interplant competition than in closely spaced plants and thus exhibited better growth that contributed to more number of seeds per pod. This result support Abo El-Zahab *et al.,* (1981), Ayaz *et al.,* (2001), and (Abdel, 2008) who reported that number of seeds per pod increased with increase in intra row space of faba bean. Moreover, Oad *et al*., (2002) while working on safflower reported that higher number of seeds per pod was associated with wider inter and intra-row spacing.

5.4 Effect of treatments on 1000- seed weight

Among the various parameters contributing towards final yield of a crop, 1000-seed Weight is of prime importance, (Al-Abduselam and Abdai, 1995). The significant effect at both sites could be justified on the basis of genetic differences of bean variety. The result of present investigation is in agreement with earlier investigation on cowpea by Turk *et al*., (*1980*) who reported that individual seed weight was highly affected by genetic factors except in case of severe water stress and hot desiccating winds causing forced maturity. The significant effect due to spatial arrangement in both sites could be due to how plants are arranged in intra and inter space. Therefore, this decrease could be due to assimilates division between seeds in connection with the increased inter plant competition in utilizing the environmental inputs such as solar radiation and nutrients in building great amount of metabolites to be used in developing new tissues ,hence, decrease in weight. However, in wider inter row spaced plants, there could be improved supply of assimilates stored in the seed, hence, increase in a thousand seed weight. The result of this study agrees with Solomon (2010) in which a thousand seed weight of haricot beans decreased with reduction in plant inter row space. Moreover, (Al-Abduselam and Abdai ,1995;Turk and Tawaha (2002) and Matthews *et al*., 2008) reported that hundred seed weight of faba bean was negatively correlated with inter row space. In comparison to this, (Lemlem and Giorgis, 2011) obtained non-significant effect of spatial arrangement on thousand seed weight of soybean.

5.5 Effects of treatments on seed weight / hectare

Seed yield of a variety is the result of interplay of its genetic makeup and environmental factors in which plant grows (Abbas, 2000). There were significant differences due to effect of spatial arrangement in both sites because of environmental and soil differences which might have favoured the bean production and also how the plants were arranged in space to each other. Hence, the yield was low at the reduced intra row space and this might be due to intense interplant competition for resources such as nutrients, water and solar radiation as manifested by high plant mortality and low number of pods per plant at the narrow intra space plant. The latter might be attributed to high level of flower abortion due to competition for the available resource. The result of this study was in line with Ball *et al*., (2000) who reported that decreasing intra row space reduced yield of individual plants but increased yield per unit area of common bean. Similarly, (Egli,1988) reported that closely spaced plants ensures early canopy coverage which minimizes light intercepted by a plant thus low crop growth rate and crop biomass resulting into decreased yield in soybean. This result is also in line with Grafton *et al*., (1988) who found there was greater seed yield increase with increased intra row space of dry bean. There was significance due to effect of variety at Mabanga only because of environmental factors in this site which favoured the performance of bean varieties in this site and also the genotypic characteristic of varieties might have accounted for the significant differences. These findings are quite in line with the findings of (Abbas, 2000) who reported significant differences in the yield of various legume cultivars.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The conclusions from the results of this study are:

- The varieties Rose Coco and KAT B1 performed better at both sites Mabanga and University of Eldoret based on yield.
- The spatial arrangements of 30 cm x 30 cm and 36 cm x 25 cm were the best at Mabanga ATC
- The spatial arrangements of 36 cm x 25 cm and 45 cm x 20 cm were the best at the University of Eldoret.

6.2 Recommendations

It is therefore recommended that:

- Beans under the agro-climatic conditions of Uasin Gishu be planted using a spatial arrangement of 36 cm x 25 cm or 45 cm x 20 cm while those at Mabanga should be grown using a spatial arrangement of 30 cm x 30 cm or 36 cm x 25 cm in order to achieve maximum yield.
- Further research should be carried out on different bean varieties in same environments and spatial arrangements
- Further studies on SA and bean varieties trial should be done at farm level to verify the findings above.
- Further research should be carried out to compare yield of common bean in both sites

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APPENDICES

Appendix 1: ANOVA Table for effect of spatial arrangement and variety on Plant height at Mabanga

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	1160.056	580.028	100.26	
Spatial arrangement	3	17.889	5.963	1.03	<.001
Varieties	2	29.556	14.778	2.55	0.101
Spatial arrange. Varieties	6	27.111	4.519	0.78	0.594
Residual	22	127.278	5.785		
Total	35	1361.889			

Appendix 2: ANOVA Table for effect of spatial arrangement and variety on number of Flowers / plant at Mabanga.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	12.500	6.250	3.16	
Spatial arrangement	3	6.972	2.324	1.18	0.342
Varieties	2	8.000	4.000	2.02	0.156
Spatial arrange. Varieties	6	25.778	4.296	2.17	0.085
Residual	22	43.500	1.977		
Total	35	96.750			

Appendix 3: ANOVA Table for effects of spatial arrangement and variety on number of Pods / plant at Mabanga.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	26.000	13.000	6.13	
Spatial arrangement	3	126.556	42.185	19.89	<.001
Varieties	2	36.167	18.083	8.53	0.002
Spatial arrange. Varieties	6	149.611	24.935	11.76	<.001
Residual	22	46.667	2.121		
Total	35	385.000			

Appendix 4: ANOVA Table for effects of spatial arrangement and variety on number of Seeds / pod at Mabanga.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	0.0556	0.0278	0.04	
Spatial arrangement	3	12.2222	4.0741	5.62	0.005
Varieties	2	4.0556	2.0278	2.80	0.083
Spatial arrange. Varieties	6	4.6111	0.7685	1.06	0.415
Residual	22	15.9444	0.7247		
Total	35	36.8889			

Appendix 5: ANOVA Table for effect of spatial arrangement and variety on 1000-seed weight at Mabanga

Source of variation	d.f.	s.s	m.s.	v.r.	F pr.
Blocks	2	12.23	6.12	0.40	
Spatial arrangement	3	169.15	56.38	3.69	0.028
Varieties	2	2311.42	1155.71	75.55	<.001
Spatial arrange. Varieties	6	505.96	84.33	5.51	0.001
Residual	22	321.24	15.30		
Total	35	3275.22			

Appendix 6: ANOVA Table for effect of spatial arrangement and variety on Seed yield/ ha at Mabanga

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	265520	132760	0.21	
Spatial arrangement	3	9817633	3272544	5.27	0.007
Varieties	2	5093339	2546669	4.10	0.031
Spatial arrange. Varieties	6	22732087	3788681	6.11	<.001
Residual	22	13651396	620518		
Total	35	51559975			

Appendix 7: ANOVA Table for effect of spatial arrangement and variety on Plant height at University of Eldoret.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	16.167	8.083	1.69	
Spatial arrangement	3	41.889	13.963	2.92	0.057
Varieties	2	8.000	4.000	0.84	0.446
Spatial arrange. Varieties	6	27.778	4.630	0.97	0.469
Residual	22	105.167	4.780		
Total	35	199.000			

Appendix 8: ANOVA Table for effect of spatial arrangement and variety on Number of flowers / plant at University of Eldoret.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	1936.50	968.25	38.62	
Spatial arrangement	3	45.42	15.14	0.60	0.619
Varieties	2	162.00	81.00	3.23	0.059
Spatial arrange. Varieties	6	91.33	15.22	0.61	0.722
Residual	22	551.50	25.07		
Total	35	2786.75			

Appendix 9: ANOVA Table for effect of spatial arrangement and variety on number of Pods / plant at University of Eldoret.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	9.389	4.694	0.87	
Spatial arrangement	3	183.861	61.287	11.37	<.001
Varieties	2	3.722	1.861	0.35	0.712
Spatial arrange. Varieties	6	20.056	3.343	0.62	0.712
Residual	22	118.611	5.391		
Total	35	335.639			

Appendix 10: ANOVA Table for effect of spatial arrangement and variety on number of Seeds / pod at University of Eldoret

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	0.7222	0.3611	0.70	
Spatial arrangement	3	6.0000	2.0000	3.90	0.022
Varieties	2	3.3889	1.6944	3.31	0.056
Spatial arrange. Varieties	6	1.5000	0.2500	0.49	0.810
Residual	22	11.2778	0.5126		
Total	35	22.8889			

Appendix 11: ANOVA Table for effect of spatial arrangement and variety on 1000- seed weight at University of Eldoret

Source of Variation	d	Df	s.s.	m.s.	v.r.	F pr.
Block		2	17.81	8.91	2.16	
Spatial arrangement		3	2592.22	864.07	7.4	<.001
Varieties		2	1336.06	668.03	0.06	0.001
Spatial arrang. Varieties		6	1651.65	275.27	1.65	0.01
Resdual		22	1597.13	72.6		
Total		35	7194.87			

Appendix 12: ANOVA Table for effect of spatial arrangement and variety on Seed yield at University of Eldoret

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks	2	97734	48867	0.51	
Spatial arrangement	3	16604194	5534731	57.40	<.0011
Varieties	2	238385	119193	1.24	0.310
Spatial arrange. Varieties	6	26056071	4342678	45.04	<.001
Residual	22	2121248	96420		
Total	35	45117632			