EFFECTS OF FOLIAR FERTILIZER APPLICATION RATES ON PRODUCTIVITY OF SELECTED BEAN *(PHASEOLUS VULGARIS L.)* VARIETIES

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Declaration

I understand that plagiarism is an offence and I therefore declare that this report is my original work and has not been presented to any other institution for any other award.

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Dedication

To my beloved wife (Elizabeth Mutheu), Son (Vincent Sila), Daughter (Millicent Mutanu) for your prayers, encouragement, tolerance and comprehensive support through out my study. May the lord bless you all!

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Abbreviations and acronyms

ASALS……………………………..Arid and semi-arid lands

KALRO…………………………….Kenya Agricultural and Livestock Research Organization

SEKU………………………………South Eastern Kenya University

CIAT………………………………. International Centre for TropicalAgriculture

CEC…………………………………Cation Exchange Capacity

SAS…………………………….......Statistical Analysis System

SIDA………………………………..Swedish International Development Cooperation Agency

SDGs………………………………..Sustainable development goals

ANOVA…………………………….Analysis of variance

LAI………………………………….Leaf Area Index

LSD…………………………………Least Significance Difference

FAO………………………………...Food and Agriculture Organization

g…………………………………. ....gramme

Gok…………………………………Government of Kenya

CGIAR……………………………..Consortium of international agricultural research centers

MoA………………………………...Ministry of Agriculture

ha…..Hectare

HI……………………………….......Harvest Index

SSA………………………………....Sub Saharan Africa

MRI………………………………...Magnetic Resonance Imaging

N…………………………………....Nitrogen

P………………………………….....Phosphorus

K……………………………………Pottasium

cm…………………………………..Centimeters

C.V………………………………….Covariance

Kg…………………………………...Kilogramme

MUE…………………………………Macro nutrient use efficiency

Zn……………………………………Zinc

pH……………………………………potential hydrogens

Fe……………………………………...Iron

Mg…………………………………...Magnisium

$Mgkg^{-1}$……………………………….Milligram per kilogramme

Mgm^{-2}…………………………….. …Milligram per meter square

DAP…………………………………..Diammoniun phosphate

ppm…………………………………....parts per million

NPK……………………………………Ratio of nitrogen phosphorus and potassium

Mls……………………………………..Millilitres

Abstract

Food security is a global problem despite the many efforts put to produce enough food to feed the ever rising global population. Common bean (Phaseolus vulgaris L) is an important crop for food security and provision of proteins for poor households in sub Saharan Africa. In arid and semi-arid lands, beans are very important for they play a major role in food security and nutrition. However, its production in ASALs is constrained by erratic rainfall, moisture deficit, low nutrients uptake, nutrients fixation, poor bean germination and crop establishment. The main objective of this study was to determine the effect of water on bean seed germination in a laboratory study and performace of the beans with foliar fertilizer application under green house and field conditions. In the laboratory study, nine bean varieties (Wairimu,Wairimu dwarf, Piriton, KAT B9, KAT X56, KATRAM, GLP 1004, KATB 1 and GLP 2) were left to absorb distilled water for 3, 6, 9, 12, 15,18, 21 and 24 hours arranged in a completely randomized design with three replications and allowed to germinate under aerobic conditions. This was followed by a green house pot experiment which examined the productivity of the nine bean varieties in a completely randomized design replicated three times. The four best performing varieties were tested under field conditions in a randomized complete block design with three replications. In the green house and field experiments, the effect of three concentrations (0, 2.5mls/L and 5mls/L) of foliar fertilizer on bean productivity was tested for each variety. Data was collected on the effect of water imbibition on germination at different times in the laboratory study while data collected in the green house and field study included above ground biomass, grain yield, harvest index, pod length, weight of empty pod, weight of grain per pod, number of pods, chlorophyll content, stem girth, leaf area index, weight of 100 seeds and correlation of yield components. All the data from the experiments were analysed using Analysis of variance (ANOVA). Results from the laboratory experiment showed that the bean varieties which absorbed maximum water amounts in the first 9-12 hours were the first to germinate. In the green house, above ground biomass and grain yield increased with increasing foliar fertilizer application. Overall, there was a significant ($p<0.05$) increase in biomass production in piriton above all other varieties. Wairimu produced significantly higher biomass compared to other varieties except Piriton. It was followed by KAT B9, KAT B1, Wairimu dwarf, GLP 2, GLP 1004, KATRAM, and KAT X56 in that order.Wairimu had the highest harvest index while KAT B9 produced the lowest harvest index. In the field experiment above ground and grain yield also increased with the increasing foliar fertilizer application. Overall, KAT B9 showed a significant ($p<0.05$) increase in biomass production followed by Wairimu dwarf, Wairimu and Piriton in that order.Wairimu produced significantly ($p<0.05$) higher grain yield compared to other varieties. It was followed by Wairimu dwarf, Piriton and KAT B9 in that order. Wairimu had the highest harvest index while KAT B9 produced the lowest harvest index. The study confirmed that under laboratory conditions imbibed seeds germinates earlier compared to unimbibed seeds while foliar fertilizer application significantly increases yields and yields components under green house and field conditions.The study recommends that beans which germinated early and performed well in the greenhouse be considered for areas which are humid whilst those that germinated early and perfomed well in the field can be used for production in the semi-arid areas.

Key words: Bean varieties, water imbibition, foliar fertilizer, yields

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Food security has been an integral part of global efforts concerning development and reduction of poverty (Vink, 2012). Despite the fact that there is sufficient food produced to feed the population, one billion people are still food hungry (CGIAR, 2011). Due to the expected increase in global population from 7 to 9 billion, the amount of food insecure people is also projected to grow (Rayfuse & Weisfelt, 2012). Increase in population worldwide pressures the governments to come up with strategies to increase food production to meet increasing food demand (Patel *et al*., 2012). Kenya is food insecure even though it is the leading economy in East Africa as well as regional business center (Glopolis, 2013; GoK, 2011). In Kenya, many types of cereals and legumes are grown to alleviate food insecurity. Common bean (*Phaseolus vulgaris* L.) is an important legume in the pulses category and is second to maize as a food crop in Kenya (Anon 2010; Gethi *et al*., 1997). Compared to cowpeas (*Vigna unguiculata* L.) and green grams (*Vigna radiata* L.), beans occupy the largest acreage in areas where it is grown. Kenya is ranked the seventh largest world producer of dry beans which is the second most important staple food nationally, accounting for 9% of staple food calories and 5% of total food calories in the national diet (Kirimi *et al*., 2010) hence having a critical relevance to national food security. It has become increasingly usual for Kenya to import beans as domestic demand outweighs production. Kenya has been experiencing deficits in dry beans production in all the years since 2004, except in 2006 (MoA, 2006). The country imports the deficit mainly from Uganda (Waluse, 2012), Tanzania and Central Africa. Beans play a key role in reducing food insecurity, hunger and malnutrition (Korir *et al.*, 2003), since can be utilized as leaves, pods, green and dry seeds, and can be prepared in a wide range of recipes. Dry beans can be boiled and consumed, mashed with bananas or potatoes or mixed with other cereal grains like maize and consumed as "Githeri" (Wortman *et al.*, 2008).

Despite its importance, dry bean yields in developing countries are among the lowest in the world, producing an average of 0.5 tons ha^{-1} (FAO, 2007) compared to 1–2 tons ha^{-1} commonly reported in experimental fields. In ASALs) where conditions for crop growing are unfavourable, lack of uniformity in bean seed germination has been evident due to hard seed coat (Shaoa *et al* ., 2007). Poor crop establishment can also be attributed to variable moisture in the soil and excessive ambient soil temperatures (Wuebker *et al*., 2001). The low yields of beans in the ASALs are due to interaction of moisture stress, soil fertility, pests and diseases (Katungi *et al.,* 2010). For instance, in the semi-arid areas of south eastern Kenya, where rainfall is bimodal, drought is the most important common bean production constraint (Itabari *et al*., 2004) and it is a problem that occurs within the season and among seasons with a 60% probability of occurrence (Katungi *et al*., 2010, Mungai *et al*., 2000). In addition, rainfall is low and variable within and among seasons (Kaggwa *et al*., 2011). Because of the poorly structured soils in ASALs, water infiltration is considerably low leading to excessive run-off, low moisture retention and soil degradation (Kilewe, 1987). Evapotranspiration rates are 4-6 mm per day (Anon 2009; Stewart and Faught 1984). Intermittent or mid-season rainfall gaps aggravate the moisture deficit which affect bean development and yield during the growing period. Soil moisture deficit (Beebe *et al.,* 2013; Miller *et al*., 2003) coupled with deficiency in intrinsic Phosphorus (P) available for plants (Wortman *et al*., 2004) constitute major limitations of common bean production in these areas. Owing to climatic change, the problem deepens (Beebe *et al.*, 2013; Boko *et al*., 2007), warranting interest to investigate synergistic effects of the two factors. Micronutrient deficiencies do occur in soil during the growing season which negatively affect crops yield. Foliar application at the vegetative phase has been shown to correct some of the deficiencies (Mallarino *et al.,* 2005) that constrain bean production. According to studies by (Harris *et al.*, 2001) imbibing bean seeds with water increase emergence and lead to better plant stands, more vigorous plants, better drought tolerance, earlier flowering, earlier harvest and higher grain yield.

Even when there is enough moisture to aid in seed germination, hard seed coat limits the beans ability to germinate; besides, lack of sufficient moisture in ASALs limits the uptake of nutrients even after applying the nutrients to soil. Further, other nutrients may be leached, while others may be chemically bound by soil components (Sanchez and Uehara, 1980; Slaton *et al.,* 2002). It is apparent that studies to examine moisture uptake of different varieties followed by assessment of foliar applied nutrients and field evaluation of the different bean varieties seems a plausible approach to provide integrated data on their performance. Therefore the objectives of this study were to determine:- the effect of water imbibed by selected bean varieties on seed germination under laboratory conditions, the effect of foliar fertilizer application on yield components and grain production of selected bean varieties under green house and field condions, and establish the relationships between bean grain yield and yield components of selected bean varieties under green house and field conditions.

1.2 Statement of the Problem

In ASALs of South Eastern Kenya, bean yields have continued to decline over the years. Seed coat permeability, which influences variability in germination within a seed population, is one of the main causes of low bean yields (Shaoa *et al.*, 2007). Drought significantly reduces bean yields due to low nutrients absorption (Itabari *et al*., 2004). In addition, soil moisture deficit and poor timing of nutrient application leads to low nutrients absorption which is aggravated by leaching and volitilisation. Other factors that lead to low bean production are nutrients fixation by soil factors, soil infertility, pests and diseases (Katungi *et al*., 2010). According to (Beebe *et a*l., 2013; Miller *et al*., 2003) soil moisture deficit coupled with deficiency in (P) nutrient absorption available for plants (Wortman *et al*., 2004) constitute major limitations of common bean production in arid and semi arid areas

Due to insufficient, unpredictable and unreliable rainfall as well as poor distribution within the seasons, use of conventional solid fertilizers to satisfy plants' nutrient requirements is often ineffective, because of inadequate moisture for nutrients uptake (Keller, 2005). Foliar fertilizer therefore provides solution to plants' nutrients inadequacy by allowing highly localized and specific nutrient applications that are not easily provided using solid products (Schonherr, 2005).

1.3 Objectives

1.3.1 General objective

The main objective of this study was to investigate the effects of water imbibition on bean seed germination, and foliar fertilizer application on productivity of selected bean varieties under laboratory, green house and field conditions.

1.3.2 Specific Objectives

1. To determine the effect of water imbibed by selected bean varieties on seed germination under laboratory conditions
2. To establish the effect of foliar fertilizer application on yield components and grain production of selected bean varieties under green house and field condions.
3. To establish the relationships between bean grain yield and yield components of selected bean varieties under green house and field conditions.

1.4 Hypothesis (Ho)

1. Imbibed water has no effect on germination of selected bean varieties

2. Foliar fertilizer application has no effect on yield components and grain production of selected bean varieties under green house and field conditions.

3. There is no relationship between bean grain yield and yield components of selected bean varieties under greenhouse and field conditions

1.5 Justification

The response of newly developed dry bean varieties to foliar fertilizer application in ASALs of South Eastern Kenya has not been extensively studied. However, similar studies have been reported in other parts of the country with varying results. Results of the study conducted by Starling *et al.*, (2000) showed that plant growth and grain yield of dry beans were higher after foliar fertilizer application. Similar studies need to be conducted in the dry areas using the available bean varieties to identify those suited to the prevailing environmental conditions. Knowledge of effect of foliar fertilizer application to dry beans in ASALs provides valuable information to policy makers and farmers about the potential opportunities for maximizing its production in the Kitui County. The results obtained are expected to lead to improved dry bean production, increase in bean net farm incomes due to large production and by extension also contribute to the Sustainable Development Goals (SDGs) by eradicating extreme poverty and hunger. This study plays a vital role in food production especially for bean farmers. This helps to reduce food insecurity which continues to prevail in Kitui County which is one of the ASAL counties.

1.6 Scope of the study

The study covered the effects of water imbibition on selected bean varieties and the effects of foliar fertilizer application rates of the same varieties in ASALs of South Eastern Kenya region under greenhouse and field conditions. The study was limited to SEKU and KALRO sub-station in Kitui County.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Importance of beans (*Phaseolus Vulgaris L.*)

Common bean is a food-secure and nutritious crop, especially in Sub Saharan Africa (SSA) (Wortman *et al.,* 2004). It plays a big dietary role; supplying proteins, carbohydrates, essential elements and vitamins to both rural and urban households. It is estimated that beans meets more than 50% of dietary protein requirements of households in SSA (Wortman *et al.,* 2004; Broughton *et al*., 2003). The annual per capita consumption of common bean is higher among low income people who cannot afford to buy nutritious food stuff, such as meat and fish (Beebe *et al.,* 2013; Broughton *et al*., 2003). Additionally, its consumption also varies by region. For instance, in eastern Africa, the per capita consumption of 50 to 60 kg $year^{-1}$ in Rwanda, Kenya and Uganda is considerably higher than in Latin America where per capita consumption is 4 and 17 kg $year^{-1}$ in Colombia and Brazil, respectively (Beebe *et al*., 2013; Broughton *et al*., 2003). In addition to its subsistence value, common bean is an important commercial crop contributing significant incomes to the majority of the rural peasants in SSA (Wortman *et al.,* 2004).

2.2 Constraints to bean production

In resource-poor farming of SSA, poor absorption of macro and micronutrients are among the constraints for cultivation of common bean (Beebe *et al*., 2011). Nutrients fixation by soil factors, soil infertility, pests and diseases also reduce total bean production per unit area (Katungi *et al*., 2010). Drought which is common in ASALs significantly reduces bean yields due to low nutrients absorption (Itabari *et al*., 2004). Moreover, soil moisture deficit and poor timing of nutrient application leads to low nutrients absorption which is aggravated by leaching and volitilisation. According to (Beebe *et al.,* 2013; Miller *et al*., 2003) soil moisture deficit coupled with deficiency in (P) nutrient absorption available for plants (Wortman *et al*., 2004) constitute major limitations of common bean production in arid and semi arid areasIn ASALs where crop growing conditions are unconducive, lack of uniformity in bean seed germination has been evident due to impermeable seed coat (Shaoa *et al* ., 2007). Poor crop establishment can also be attributed to variable moisture in the soil and excessive ambient soil temperatures (Wuebker *et al*., 2001). Further, poorly structured soils in ASALs, water infiltration is considerably low leading to excessive run-off, low moisture retention and soil degradation which negatively affects bean production trends (Kilewe, 1987)

2.3 Water imbibition

Imbibition involves the absorption of water by cell wall and protoplasmic macromolecules such as proteins and polysaccharides, wherein water molecule dipoles are held by electrostatic forces, such as hydrogen bonds, in hydration shells (Noggle and Fritz, 1976). During imbibition the seed rapidly swells and changes in size and shape (Robert *et al*., 2008; Preston *et al*., 2009). The water imbibed by the seed activates enzymes and facilitates metabolism of the stored starch and protein in seed (Kikuchi *et al*., 2006) and thus, water absorption is the most important event for ensuring nutrient supply to the germinating embryo and to generate energy for the commencement of active germination and seedling growth (Abebe and Modi, 2009). During the process of water uptake the cell wall enlarges and seed coat becomes softened allowing oxygen diffusion for seed respiration. The amount of water to be imbibed for seed germination depends on variety and species. The water needed for soybean and maize may be about 50% and around 34%, respectively (McDonald *et al*., 2006). The rate of imbibition increases with increase in temperature in many crop seeds such as sorghum (Kader and Jutzi, 2002), amaranth grain (Resio *et al*., 2006). Seeds germinate after absorbing sufficient amount of water from its surrounding soil under field conditions. If drought prevails, seed germination becomes uncertain. In drought-prone areas of India, Nepal, Pakistan and Zimbabwe, farmers usually use pre-soaked seeds of different crops to ensure seedling emergence and good crop stand (Harris *et al.*, 2001).

seed imbibition involves soaking seeds in water to imbibe water and complete the early phases of germination under limiting water content conditions for less than 24 hours (Guedes and Cantliffe, (1980) Seed priming prior to planting enhances germination and seedling growth by controlling the imbibition conditions and reducing vagaries of adverse weather and soil conditions (McDonald, 1999). Seed priming is a process of hydrating and dehydrating the seeds following various protocols which results in improvement in seed vigour, increased germination rate and more uniform emergence under a wider range of field environments (Modi, 2005). Hydropriming (hydration of seed with water only) is the simplest approach to increase the percent and rate of seed germination and increase the uniformity of stand establishment under stress conditions especially in dry areas (Mavi *et al*., 2006;Berchie *et al*., 2010). During hydropriming the seeds are hydrated to a moisture level sufficient to initiate the early events of germination but not sufficient to permit radicle protrusion (Ashraf and Foolad, 2005). Priming has been practiced in many parts of the world. For instance, a huge area in the North-West part of Bangladesh remains fallow after winter season due to lack of rainfall and irrigation facilities. Farmers of this region usually try to grow some crops such as chickpea (*Cicer arietinum*) and maize (*Zea mays*) after "amon" harvest using residual soil moisture by sowing pre soaked seeds in well prepared soil (Musa *et al.*, 2001). The time window between harvesting of "amon" rice and planting of rabi crop is very narrow and therefore, farmers get very minimum time for crop establishment. Imbibition is the simple technique that could enhance quick and uniform stand establishment under this situation (Sharifzadeh *et al.*, 2006; Ghassemi-Golezani *et al.*, 2008). Many farmers fail to get uniform plant establishment after planting different bean varieties in ASALS of South Eastern Kenya even after sowing certified seeds, probably because of differences in hardness of the seed coat (Shaoa *et al.*, 2007), excessive ambient temperature (Wuebker *et al.*, 2001), the coexistence of pathogens (Kato *et al.*, 2013), lack of proper selection of cultivars in terms of germination potential (Van Toai *et al*., 2010). Imbibition is done by soaking of seed in water for a certain period (Harris *et al.,* 2001) to allow water to get into the seed. However, the factors affecting lengths of soaking time or pre-germination period for different bean varieties in relation to the size of seed components have not yet been established. Therefore, it is necessary to determine imbibition of different bean genotypes so as to determine the varieties which imbibes water fast in the ASALs as they are likely to germinate earlier than others.

2.4 Importance of imbibing seeds

The practice of seed priming entails soaking the seeds from overnight to 24 h (Harris *et al.,* 1999). Following soaking, the seeds are surface dried and sown in the imbibed state. This practice has been promoted to improve establishment especially in the semi arid tropics where crop failure if frequent (Harris *et al.,* 1999. Under these conditions priming increase emergence and results to better crop stands, more vigorous crops, better drought tolerance, earlier flowering, earlier harvest and higher grain yield (Harris *et al.,* 2001). However, the reasons for these improvements are not well understood, nor are the reason for the variable response to priming that can be experienced (Murungu *et al., 2004*). The considerable benefits that can be achieved from priming have resulted to speculation that imbibition may result in a major physiological change that persists throughout growth to influence yield, and recent results have shown that imbibition can result in resistance to or avoidance of diseases (Rashid *et al., 2004*).

2.5 Measurement of imbibed water

Water uptake by dry seeds has been traced by measuring the increase in weight against initial dry weight, by the changes in morphology under an electron microscope (McDonald *et al*., 1988). The most common method of taking measurement of water imbibed is by measuring the increase in weight of imbibed seed against the initial weight of dry seed (McDonald *et a*l., 1988). Water imbibition by dry seeds has been studied by use of MRI in legumes (Pietrzak *et al*., 2002). MRI has also been used which is useful for tracing the dynamic movement of water in plant tissues (Callaghan, 1991). It is also used for studying the biological implications of imbibed water in relation to its distribution (Ishida *et al*., 2000), including seed germination (Pietrzak *et al*., 2002) and evaluation of seed quality (McEntyre *et al*., 1998).

2.6 Factors affecting imbibition

Imbibition is hindered by high rates of water uptake and lack of or high ambient temperature (Wuebker *et al*., 2001). Differences in seed coat permeability may influence variability in germination within a seed population (Shaoa *et al*., 2007). Likewise, in beans, the seed coat has a role of protecting the seed especially in the case of black-seeded cultivars which have tougher seed coats and which imbibe water more slowly (Tully *et al.*, 1981). According to the study conducted by Duke and Kakefuda, (1981), when large-seeded legumes such as soybean, navy bean, pea and peanut were imbibied in water, leakage of mitochondrial marker enzymes (fumarase, cytochrome oxidase, and adenylate kinase) occurred only when the testa was absent. High temperatures may allow seed imbibition; however, they do not ensure embryo expansion and seedling establishment (Bradbeer, 1988). Seeds of most ASALs cannot germinate promptly when subjected to condition favourable for germination due to water impermeable seed coat (Finch and Leubner, 2006).

2.7 Effects of temperature on germination of seeds in arid areas

Successful growth and establishment of plants considerably depends on optimum germination (Gorai and Neffati, 2007). Germination is a crucial stage in the life cycle of plants and tends to be highly unpredictable over space and time. Several environmental factors such as temperature, salinity, light, and soil moisture simultaneously influence germination (Gorai and Neffati, 2007; Huang *et al.*, 2003; Ungar, 1995). Temperature is a major limiting factor affecting germination in the arid and semi arid areas (Tlig *et al.*, 2008). Initial establishment of a plant species in high temperature area is related to germination response of seeds to temperature and early establishment usually determines if a population will survive to maturity (Song *et al.,* 2005; Huang *et al.,* 2003; Tobe *et al.,* 2000). Cardinal temperatures (minimum, optimum and maximum) determine the range of temperatures at which a particular plant seeds can germinate. Species dispersion area, suitable time and place for growing can be evaluated by knowing cardinal temperatures (Song *et al.,* 2005).

2.8 Seed germination

Seed germination is defined as emergence of radical and plumule (Mohanty and Sahoo, 2000). Seed germination incorporates activities that commence with water uptake by the dry seed and terminates with the elongation of the embryonic axis (Bewley and Black, 1994)**.** As the first important step of the plant life cycle, seed germination is an integral part of crop growth. Depending on water uptake rate, the time course of germination and subsequent growth is divided into three levels. In level I, which is also called imbibition, water uptake is rapid; in level 2, water uptake is much slower and reaches a plateau; in phase 3 (post-germination), there is an increase in water uptake (Bewley, 1997, Weitbrecht *et al*., 2011)

2.8.1 Factors affecting germination

Bean seed germination is negatively affected by injury which may occur when the beans are exposed to long duration of flooding (Scott *et al*., 1989), inadequate ambient soil temperature (Wuebker *et al*., 2001), High soil temperatures reduce plant emergence (Al-Khatib and Paulsen 1999), the coexistence of pathogens destroys the seeds germination potential (Kato *et al.,* 2013), lack of proper selection of cultivars may lead to low germination potential of seeds (Van Toai *et al.,* 2010). Bean seeds with a cracked seed coat are more prone to non-germination under excess soil moisture; therefore, germination could be improved by removing cracked seeds before seeding (McDonald *et al.,* 1988),

2.9 Foliar fertilizer application

Foliar feeding is the practice of applying liquid fertilizers to plant leaves (Kovačević, 2003). Silberbush (2002) reported that foliar fertilization is a widely used practice to correct nutritional deficiencies in plants caused by improper supply of nutrients to roots. Ranđelović (2009) reported that the uptake of mineral nutrients from the soil and the extent of their utilization by the soybean plant depend on weather conditions during the growing season. In this case, preference should be given to the application of foliar fertilizers. Nutrients are best applied when the plant is cool and filled with water (turgid) (Girma *et al.,* 2007). The efficiency of foliar fertilizer application is affected by a number of factors, including the nutritional status of plants, the developmental stage and age of leaves, properties of leaf surface, weather conditions and application time (Fageria 2009; Fernández and Eichert 2009). Therefore, foliar urea application provides an alternative fertilization strategy minimizing the potential risk of nutrient leaching loss compared with conventional soil fertilization (Gooding and Davies 1992; Dong *et al.,* 2005).The flow of cations through the cuticular membrane is much easier than that of anions. It is estimated that cation ability to penetrate the cuticular membrane is ca. 1000 times higher than for anions (Mengel, 2002). However, it has also been shown that ions are also absorbed by leaves stomata (Eichert *et al*., 1998; Eichert and Burkhardt, 2001). Stomata control the uptake of CO_2 and the loss of water (Outlaw, 2003). Therefore, stomatal function is critical, and guard cells will respond quickly to physiological and environmental signals. Stress conditions altering stomatal functioning and plant physiological processes will affect the rate of absorption of leaf-applied chemicals. In this regard, a recent investigation carried out with water and K stressed olive trees, showed an associated decrease in the rate of foliar uptake of leaf-applied K under plant stress conditions (Restrepo-Díaz *et al.,* 2008).

The characteristics of the leaf surface and in particular the presence of epicuticular waxes, will determine the rate of retention and wettability of a leaf-applied solution (Koch and Ensikat, 2008). Surface roughness and hydrophobicity will lead to reduced adhesion of water, contaminants and microorganisms and to the occurrence of large contact angles of water on leaves (Neinhuis *et al.,* 2001; Koch and Ensikat, 2008). Surface wetness is furthermore influenced by atmospheric variables (e.g., irradiation, relative humidity or temperature), physical properties of plants (leaf topography, shape or position in the plant) and initial water distribution (drop volume and film thickness) (Magarey *et al*., 2005)

2.10 Effects of temperature on foliar fertilizer absorption

Temperature affects chemical reactions and physical properties of beans at the cellular, organ and entire plant level (Gruda, 2005). Gruda, (2005) mentioned the beneficial effects of moderately warm temperature in stimulating foliar penetration through increasing the rate of physiological processes such as photosynthesis and translocation within the plant. However, high temperature in combination with low relative humidity as observed over the summer season in most arid and semi-arid areas of the world is likely to limit the rate of spray absorption due to the fast drying of the solution and the lower level of cuticle hydration

2.11 Uptake of mineral nutrients from foliar fertilization

The physico-chemistry of the solution is described by Fick's law of 1855 and further emphasized in studies carried by (Paradisi *et al.*, 2001). The law stipulates that the concentration gradient is the driving force for diffusion. The penetration rates of diffusion of any externally-applied solute through the leaf surface thus depend on both its concentration on the leaf surface and its concentration inside the leaf. The concentration of a given solute inside the leaf, i.e., in the epidermal apoplast, depends on the nature of the compound under consideration and on physiological plant factors such as mobility and uptake rate into the epidermal and mesophyll cells (Grignon *et a*l., 1999; Ewert *et al.*, 2000). It can be concluded that foliar uptake rates are chiefly governed by the external concentration of the solutes. The relationship between concentration of the applied solution and foliar penetration rates is not completely clear. While a positive relationship between increasing concentrations and penetration rates has been measured in several studies for certain elements and plant species (Schönherr, 2001) a different behaviour has also been reported. Working with Fe-compounds and intact leaves or cuticles, Schlegel *et al.*, (2006) and Schönherr *et al*., (2005) measured a negative correlation between increasing concentrations and the penetration rate expressed as a percentage of the applied amount, which, however, represents a high concentration of Fe penetrating the leaf or the cuticle.

2.12 Types of foliar fertilizers

2.12.1 Potassium foliar fertilizer

Previous studies have shown that supplementing soil K supply with foliar K applications during the pod development period can improve pod quality and that differences may exist among K compounds for foliar feeding (Lester *et al*., 2005, 2006). Uptake of K from the soil solution depends on plant factors, including genetics (Rengel *et al*., 2008). In many species, uptake occurs mainly during the vegetative stages when root growth is not inhibited by carbohydrate availability.

2.12.2 Phosphorus foliar fertilizer

Phosphorus is applied much less in foliar sprays compared to N. This may be because field crops require phosphorus early in the season when there is only a small leaf-area to retain spray, and because many phosphorus compounds have low water solubility (Girma *et al*., 2007)

2.12.3 Nitrogen foliar fertilizer

Studies by (Babar *et al.,* 2011; Iftikhar *et al.,* 2010) reveal that applications of N near flowering increased post flowering N uptake, grain protein content, and overall grain yield. Studies conducted by (Woolfolk *et al.,* 2002) shows that foliar N applications are often associated with leaf burn when applications are made early in the morning when the dew is still on the crop. Foliar fertilization, does not totally replace soil fertilization on crops with large leaf area, but may improve the uptake and the efficiency of the nutrients applied to the soil (Kannan, 2010; Tejada and Gonzales, 2004). Nitrogen foliar fertilization is increasingly adopted in order to alleviate nitrogen deficiency as a macro nutrient in the plant. However, data is scanty in literature on effects of applied elements and on the concentration of other micro- and macro-elements within the plant (Kaya and Higgs, 2002).

2.12.4 Foliar applied micronutrients

Micronutrients are just as essential for optimum growth and yield although they are required in much smaller quantities. Micronutrient requirements are dependent on plant uptake, soil availability and growing seasonal conditions. Most importantly, micronutrients are involved in the key physiological processes of photosynthesis and respiration (Mengel *et al*., 2001) and their deficiency can impede these vital physiological processes and thus limiting yield gain.

Dry beans are sensitive to Zn deficiency (Bert, 2005). Early deficiency symptoms include mild interveinal yellowing and leaf deformation appearing first on new leaves. As the symptoms progress, necrotic (dead) spots develop, and margins appear lighter in color than the interior of the leaf (Bert, 2005). Soil conditions such as high pH, low organic matter, coarse texture, high available P, compaction, restricted root zones, and leveled or eroded soils as found in ASALs lead to development of Zn deficiencies, which can reduce yields and delay crop maturity (Bert, 2005). The main functions of zinc is tendency to make up tetragonal complexes with nitrogen, oxygen and sulfur, thus zinc have a catalytic, building and activating role in the enzymes (Mousavi *et al*., 2013). It can be critical in case of deficiency (Kacar and Katkat, 2007). Zinc has important functions in protein and carbohydrate metabolism and visible Zn deficiency symptoms in crops usually occur only in cases of relatively severe deficiency. In marginal deficiency, crop quality and yield may be reduced because of hidden Zn deficiency without obvious symptoms (Alloway, 2004). This hidden Zn deficiency may go undetected for several seasons at a high cost to farmers. Most soils with low plant-available Zn can be treated with Zn fertilizers to correct crop Zn deficiency. Several different Zn sources, including $ZnSO_4$, $ZnCO_3$, ZnO, $Zn(NO_3)_2$ and $ZnCl_2$ are currently being used as fertilizers.

2.12.5 Foliar applied boron

Boron (B) is necessary in dry beans for translocation of sugars, increased reproduction and germination of pollen grains. It tends to keep calcium in soluble form within the plant and also act as regulator of potassium ratios. Boron has significant role in cell wall formation (O'Neill *et al.,* 2004) and cellular membrane functions (Goldbach *et al*., 2001).

2.12.6 Foliar applied iron

Beans are susceptible to iron (Fe) deficiency chlorosis, which is commonly associated with high soil pH, high free calcium carbonate (lime) in the soil, and low soil organic matter such as those found in the ASALS (Bert, 2005). Cool, wet conditions also promote iron deficiency chlorosis, but symptoms that develop under these circumstances will often disappear as soils warm. Similar to Zn, Fe deficiency is characterized by interveinal yellowing of the new leaves. However, there are some distinct differences in visual symptoms that will help distinguish Fe from Zn deficiency (Bert, 2005). Often iron is found in oxidized (Fe^{3+}) in aerobic soils, which has low solubility, and in most cases there is not enough iron to meet the needs of plants (Schulte, 2004). Deficiency has a powerful effect on chloroplast protein, so that chloroplast protein is reduced significantly by iron deficiency. In conditions of severe iron deficiency, cell division stops and therefore leaf growth decreases. Iron is needed to produce chlorophyll; hence its deficiency causes chlorosis (Eskarandi *et al.,* 2011).

2.12.7 Foliar applied Molybdenum foliar and its effects on beans

Molybdenum is a component of two enzymes, both of which are important for nitrogen metabolism: nitrogenase, which is essential for nitrogen fixing in the root system, and nitrate reductase, which is indispensable for the use of nitrates adsorbed by the common bean plant Molybdenum deficiency in beans can be a problem because it can cause alterations in developing flowers and reduce pollen grain development (Possenti *et al.,* 2010). It is important for plants in seed production systems to have sufficient molybdenum because the poor pollination that is associated with molybdenum deficiency may result in lower yield due to lower fertilization rates (Sharma *et al.,* 1991; ASK (2012). Some studies have shown that the yield obtained from plants that have had foliar applications of molybdenum is higher than plants that have not (Ide *et al*., 2011).

2.13 Effects of different rates of foliar fertilizer to bean yields and yield components

Many researchers have reported that foliar fertilization treatments significantly increase plant height (Popović *et al*., 2013 ; Ranđelović, 2009; Yildirim *et al.*, 2008; Prijić *et al*., 2003), pod length (Ranđelović, 2009), number of nodes per plant (Odeleye *et al.*, 2007; Ranđelović, 2009), number of pods per plant (Schon and Blevins, 1990; Yildirim *et al.*, 2008; Ranđelović, 2009), number of grain per plant (Odeleye *et al*., 2007; Ranđelović, 2009), grain yield per plant (Schon and Blevins, 1990; Ranđelović, 2009) and 1000-grain weight (Ranđelović, 2009; Popović *et al*., 2013). Contrary, Yildirim *et al*., (2008) reported that foliar fertilization did not have any statistical effect on 1000-grain weight. The study conducted by Achakzai and Bangulzai (2006) showed significant effect of nitrogen fertilizer application in pod length of pea plant. According to the study conducted by El-Habbasha (2007), increasing nitrogen fertilizer increases pod weight per plant. This is consistent with the results of Odeleye *et al*., (2007) who found that foliar nitrogen fertilizer on bean plant led to an increase in the weight of pod. Ayed (2012) conducted a study on broad bean and found that seed weight increased with the increase in nitrogen fertilizer application. Similar results have been reported by El-Habbasha *et al.,* (2007). Study conducted by Urzúa (2005) revealed increased H.I as a result of increment in nutrient absorption and transport toward the pod. The study on effect of foliar fertilizer on vegetative biomass production by Mitova and Stancheva, (2013) reveals an increase in biomass production. Similarly, study by Kushwaha (2001), Kimithi *et al*., (2009) reports an increase in biomass production. The study conducted by Pilbram *et al.,* (2009) reports an increase in chlorophyll content as a result of nitrogen fertilizer application. Werner and Newton (2005) found a positive relationship between LAI and Nitrogen fertilizer application.

In a study by Oko *et al*., (2003) foliar fertilization of urea at early reproductive stage increased soybean grain yield between 6 and 68% compared to control. In another study by Ranđelović *et al.*, (2009) foliar feeding has been shown to be an effective tool for increasing grain yield in two soybean cultivars with reduced content of Kunitz trypsin inhibitor. In other studies, Sultan *et al.,* (2003) showed that spraying with foliar fertilizers at 45 days after sowing increased grain yield of soybean.

2.14 Foliar application time

Application of nutrients should be timed to coincide with proper environmental conditions: that is to provide adequate nutrients when nature does not supply them during the critical stages of the seasonal growth cycle (Keller, 2005). Nutrients are best applied when the plant is cool and filled with water (turgid) (Girma *et al.*, 2007). Applications that are misapplied or too late in the season may not be effective. The most critical times to apply are when the crop is under a given nutrient stress. Stress periods occur during periods of active growth. This is likely when the plant is changing from a vegetative to a reproductive stage (Cantisano, 2000). Foliar application, like soil application is also less effective when soil moisture is limited.

2.15 Nutrients mobilization and partitioning

The regulation of sink-source relations is a complex process (Fester *et al*., 2013). It is well-known that mineral nutrient deficiencies may substantially influence dry matter partitioning between plant organs (Marschner *et al*., 1996), as nutrient-deprived plants generally tend to invest in their root system (Lemoine *et al*., 2013). Moreover, the shoot to root communication may act as an important feedback control signal for nutrient uptake and partitioning. For instance, sufficient Fe content in the leaves can modulate the synthesis of the ferric chelate reduction system and the capacity of the phloem to carry Fe from the roots, regulating the 'EF reaction,' acting as a negative feedback control (Maas *et al*., 1988). Source leaves export photoassimilates to sink tissues when the demand exceeds the production via photosynthesis (Ludewig and Flügge, 2013) and nutrient movement to sink tissues could be controlled by the dynamics of source-sink carbohydrate partitioning (Grusak, 2002). Besides, the sink–sink competition also influences these regulatory processes, usually with one plant organ having a negative effect upon another by consuming or controlling access to a resource that is limited in its availability (Sadras and Denison, 2009). Hence, nutrient deficiency may not only affect the provision of photosynthates by decreasing source capacity, but also by altering partitioning between the source organs and various sinks (Marschner *et al*., 1996).

2.16 Conceptual framework

Intervening variable

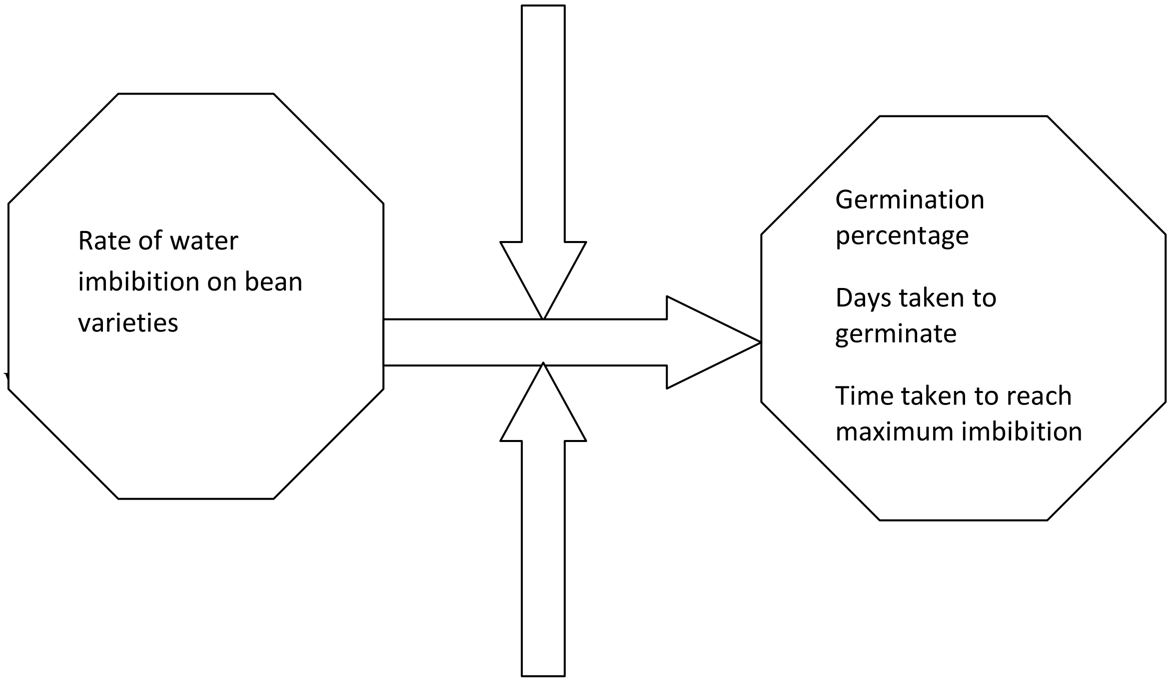
Ambient temperature of the environment

Internal and external conditions of the seeds

Edaphic factor

Independent variables

Dependent variables



Biotic factors

Abiotic factors

Figure 1.1 Conceptual model for laboratory experiment

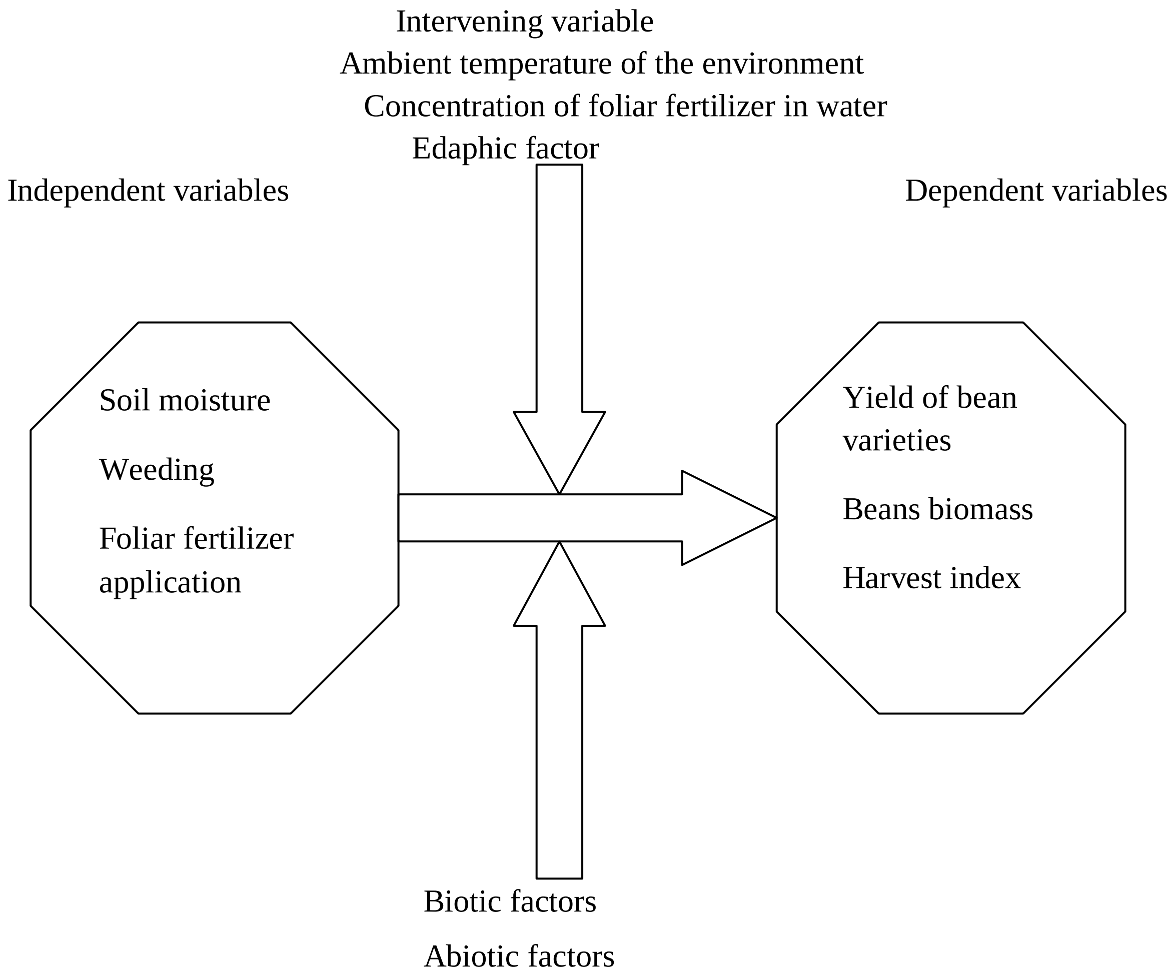


Figure 1.2 Conceptual model for green house and field experiments

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Introduction

The study involved laboratory, greenhouse, and field experiments. Nine bean varieties (Wairimu, Wairimu dwarf, Piriton, KAT B1, KAT B9, KATRAM, KAT X56, GLP 2, GLP 104) were first tested on the effect of water imbibition on germination in laboratory at SEKU followed by a green house experiment where the nine varieties were screened for yield components, biomass and yield. The field experiment was conducted at KALRO Katumani substation, Kitui. The four best varieties from the green house experiment namely Wairimu dwarf, Wairimu, KAT B9, and Piriton were screened for their adaptability to ASALs of South Eastern Kenya region.

3.2. Laboratory experiment

3.2.1 Description of study site

The first experiment was conducted in a laboratory at SEKU located at latitude 1° 18’58.19” S, longitude 37° 43’47.86” E, altitude 1105m above sea level, temperature of 20°c and a relative humidity of 60% (Oremo, 2013).

3.2.2 Experimental design

The experiment was laid out in a complete randomized design with nine bean varieties

3.2.3 Treatments

The treatments were nine varieties (Wairimu, Wairimu dwarf, Piriton, KAT B1, KAT B9, KATRAM, KAT X56, GLP 2, GLP 104) and eight imbibition times each taking three hours and three replications.

3.2.4 Procedure of imbibition

Five seeds for each variety were randomly sampled and placed on double folded 125mm filter paper soaked with 15 mls of distilled water in a petri dish measuring 8 cm in diameter and 1 cm in height and kept under aerobic condition for 24 hours according to procedure outlined by Harris *et al*., (1999). The seeds were blotted dry between paper towels to remove any surface water and amount of water imbibed by the seeds in each variety determined after 3, 6, 9, 12, 15, 18, 21 and 24 hours by the difference in weight before and after soaking following the procedure described by Baskin *et al.*, (2006). After 24 hours, water was removed from the petri-dishes but filter paper was kept moist to aid in seed germination. A similarly sampled set of seeds were germinated without being subjected to imbibition to act as control for each variety.

3.2.5 Data collection

Weights were taken following imbibition after 3, 6, 9, 12, 15, 18, 21 and 24 hours and the amount of water imbibed by different varieties in different times calculated by difference between weight before imbibition and weight after imbibition as explained by Baskin *et al.*, (2006). Time (in hours) taken to reach maximum water imbibition were recorded for each variety. Time (in days) taken to germinate for each variety was also determined for imbibed and unimbibed seeds by recording the date of emergence of radical and plumule which marked the start of germination process. The data on germination (days) was later transformed before running it in SAS soft ware to obtain the LSD.

3.2.6 Data analysis

The collected data was subjected to ANOVA using SAS; version 8.0 (SAS Institute, 2001) to detect differences between treatments. Treatment means were separated using Least Significant Difference (LSD) at $p \leq 0.05$.

The model for the design used in the analysis is as stated below

$Y_{ij} = \mu + \alpha_i + \epsilon_{ij}$

Where,

μ = A constant, the mean for all experiments of this type

α_i = A constant for the *i*th treatment group, the effect of the *i*th treatment.

ϵ_{ij} = A random effect due to the *ij*th observation. It contains all uncontrolled variability.

3.3 Green house experiment

3.3.1 Description of study site

A pot experiment was conducted in a green house at SEKU main campus; located at, latitude 1 ° 8’58.19” S, longitude 37 ° 43’47.86” E and altitude 1105m above sea level. As a semi-arid region, Kitui County is among the most drought-vulnerable regions in Kenya with annual rainfall of 500 – 1050 mm and 40% reliability (Oremo, 2003). The annual mean minimum temperatures range from 22 – 28ºC, while the annual mean maximum temperatures range from 28 – 32º C (Oremo, 2013).

The ‘long rains’ fall in April-May; the ‘short rains’ last from October to December, and are more reliable. Annual precipitation ranges from 500 to 1050 mm/yr, but is highly erratic and unreliable, both spatially and temporally. Overall, approximately 90% of the annual precipitation falls during the rain seasons (Hoogmoed, 2007). Elevation and topographical features of the landscape strongly influence the amount of rainfall at a regional scale: the higher areas and hill masses in the West of the district receive most rainfall (700-1050 mm/yr), these amounts decline to the South and East where the annual rainfall is less than 500 mm (NAAIAP, 2014).

3.3.2 Experimental design and treatments

The experiment was laid out in randomized complete block design with four varieties (Wairimu dwarf, Wairimu, KAT B9 and Piriton) ,three replications and 3 foliar fertilizer concentrations namely 0mls/Litre of water, 2.5 mls/Litre of water, 5mls/Litres of water. The composition of the foliar fertilizer was NPK 12:0:0+12.8 CaO+2.6Mgo+ Micronutrients 12.8% Nitrogen,12.8% Calcium (CaO), 2.6 Magnesium (MgO), 750ppm Copper, 1500ppm Iron,750ppm zinc, 750ppm manganese, 105ppm molybdenum , 1500 ppm Boron

3.3.3 Soil physiochemical properties

Soil samples were collected before establishing the experiment at depth of 0-15 cm using an augar for analysis.Plant litter on the soil surface was removed before collecting the samples. The samples were air dried ,visible planr roots removed and samples gently crushed to pass through a 2-mm sieve.The fractions sample <2mm were used for subsequent chemical and physical analysis.Total N,Available P,exchangeable K, Ca^{2+} Mg, and K were estimated following standard methods as described by (Okalebo et al., 2002). Cation ca^{2+},Mg^{2+}, and K^{+}

were determined by atomic absoption spectrometry and soil P was measured by (Murphy and Riley, 1962)

3.3.4 Procedure

The soil used for filling pots was dug from the top 10cm of soil and mixed thoroughly using a shovel. Fertilizer in the form of DAP was added at a rate of 2kg/ha to the soil and mixed thoroughly. Eighty one pots were each filled with 3kg of soil where each pot measured 16 cm and 10cm height. Before sowing seeds into the pots, field capacity was determined according to the procedure described by Zhen-tao Cong *et al*., (2014). Field capacity was used as a reference value to guide on quantity of water required for watering (Rodríguez-Iturbe and Porporato, 2004). It was found that the soil had a field capacity of 30.26 %. Watering was done every day to maintain the moisture at field capacity.

3.3.5 Sowing and harvesting the seeds

Five bean seeds were planted in each of the pots at a depth of 2.5 cm and later thinned to three seedlings per pot after germination. Three treatments of foliar fertilizer were made which comprised, 0 mls/L, 2.5mls/L and 5mls/L. The first foliar fertilizer application was done two weeks after germination (DAG), second application was done after one week after the first application, third application was done a week after the second application. The fourth and the final foliar fertilizer application was carried out at early podding stage. Other Management practices included removing weeds by hand and close monitoring of pest and diseases throughout the growing period and harvesting. Harvesting of beans was done according to varieties and treatments by cutting plants at soil level with all dry leaves attached and later threshing was done by hand to release the seeds from the pods.

3.3.6 Data collection

3.3.6.1 Leaf Area

Data for the leaf area was collected at 50% flowering for each variety and the fully expanded leaf still attached to the mother plant was sampled in each treatment. The leaf area was calculated as follows: Leaf area (cm^2) = leaf length (cm) × leaf width (cm) × 0.83 according to the formular derived by Xiong *et al*., 2006.

3.3.6.2 Leaf Area Index (LAI)

The leaf area of the fully expanded leaf was divided by the area occupied by the canopy (ground cover) to obtain LAI.

3.3.6.3 Stem girth (cm)

The stem girth (diameter) of each bean plant was measured at 50% flowering using veneer calipers in centimeters.

3.3.6.4 Chlorophyll (mg m^{-2})

Third leaf from the top of each plant was sampled for chlorophyll content in each treatment using the Spad . Three leaves were sampled per treatment according to procedure outlined by (Li *et al.,* 2010).

3.3.6.5 Number of Pods

Number of pods for all plants in every treatment was physically counted before harvesting and determined using the procedure described by Egho (2009).

$$Number\ of\ pods\ per\ plant = \frac{No.of\ pods}{No\ .of\ plants}$$

3.3.6.6 Length of pods (cm)

Length of all pods in each treatment was measured at reproductive phase just before harvesting using 30cm ruler and recorded.

3.3.6.7 Weight of empty pods (g)

Weights of all dry empty pods were taken in each plant per treatment after harvesting using digital weighing balance.

3.3.6.8 Weight of 100 seeds (g)

A sample of 100 grains was collected randomly from each and then the weight taken using a digital weighing balance and recorded.

3.3.6.9 Grain yield of beans (g)

Grain yield of beans from all dry pods in all treatment was taken using a digital weighing balance.

3.3.6.10 Plant biomass (g)

Dry weight of above ground dry plant biomass for plants in every treatment was taken using a digital weighing balance.

3.3.6.11 Harvest index

Harvest Index was calculated by dividing the grain yield per plant with above ground biomass of the same plant as outlined by (Donald, 1976)

$$\text{Harvest index} = \frac{\text{Economic yield (grain)}}{\text{Biological yield (grain + stover)}} \times 100$$

3.3.8 Data analysis

The data was subjected to analysis of variance (ANOVA) using SAS; version 8.0 (SAS Institute 2001) and Least Significant Difference (LSD) at $p \leq 0.05$ used to separate treatment means of signicant treatments.

The model for the design used in the analysis is as stated below

$Y_{ij} = \mu + \alpha_i + \epsilon_{ij}$

where

μ = A constant, the mean for all experiments of this type

α_i = A constant for the *i*th treatment group, the effect of the *i*th treatment.

ϵ_{ij} = A random effect due to the *ij*th observation. It contains all uncontrolled variability.

3.4 Field experiment

3.4.1 Description of the study site

The experiment was carried out in Kenya Agricultural and Livestock Research Organization (KALRO) sub-station at Kitui located at 38 ° 02'E, 1 ° 37'S and altitude 1150 m above sea level.The mean rainfall is 1010 mm in bimodal pattern with long rains occurring from March to May and the short rains from October to December with peaks in April and November. Mean temperatures are 22.5^0 C. The dorminant soil is chromic Luvisols, which is low in organic carbon and highly deficient in N and P and generally has poor structure (NAAIAP, 2014).

3.4.2 Experimental design and treatments

The experiment was laid out in randomized complete block design with four varieties (Wairimu dwarf, Wairimu, KAT B9 and Piriton) ,three replications and 3 foliar fertilizer concentrations namely 0mls/Litre of water, 2.5 mls/Litre of water, 5mls/Litres of water. The composition of the foliar fertilizer was NPK 12:0:0+12.8 CaO+2.6Mgo+ Micronutrients 12.8% Nitrogen,12.8% Calcium (CaO), 2.6 Magnesium (MgO), 750ppm Copper, 1500ppm Iron,750ppm zinc, 750ppm manganese, 105ppm molybdenum , 1500 ppm Boron

3.4.3 Soil physiochemical properties

Soil samples were collected before establishing the experiment at depth of 0-15 cm using an augar for analysis.Plant litter on the soil surface was removed before collecting the samples. The samples were air dried ,visible planr roots removed and samples gently crushed to pass through a 2-mm sieve.The fractions sample <2mm were used for subsequent chemical and physical analysis.Total N,Available P,exchangeable K, Ca^{2+} Mg, and K were estimated following standard methods as described by (Okalebo et al., 2002). Cation ca^{2+}, Mg^{2+}, and K^+ were determined by atomic absoption spectrometry and soil P was measured by (Murphy and Riley, 1962)

3.4.4 Procedure

Experimental plot was laid out in RCBD with three levels of treatments with plots measuring 1.5.by 1.5 meters. There were four rows per plot each with 16 seedlings.The treatments were 0mls/L, 25mls/L and 50 mls/L of foliar fertilizer application.The control (0 mls) was pure water without any foliar fertilizer. Soil field capacity was determined according to the procedure by Zhen-tao Cong *et al*., (2014) in the laboratory at SEKU before the experiment to guide on the amount of water required for watering (Rodríguez-Iturbe and Porporato, 2004). Watering was done every day to maintain the moisture at field capacity. Two bean seeds were sown per hole with spacing of 20cm between seeds and 50 cm between the rows and thinned to one plant after two weeks after germination. The main plot was separated by one meter foot path for easy access during management.Weeding was done by hand two weeks after seed germination and one week before flowering.

3.4.5 Harvesting the beans

Harvesting was done by hand in the two middle rows leaving one plant from each end to avoid border effects and was done by uprooting the plants with roots and dry leaves attached and later threshing was done according to treatments.

3.4.6 Data collection in the field

3.4.6.1 Leaf Area

Data was collected at 50% flowering for each variety and the fully expanded leaf was sampled for each plant in every treatment by measuring the length and width. The leaf area was calculated as follows: Leaf area (cm^2) = leaf length (cm) × leaf width (cm) × 0.83 (Xiong, *et al*., 2006)

3.4.6.2 Leaf Area Index

The area of fully expanded leaf of every plant in all treatments in the two inner most rows were each divided by the area occupied by their canopy (ground cover).

3.4.6.3 Stem girth (cm)

The stem girth (diameter) of each of the plant per treatment in the two middle rows was measured using veneer calipers at 50 % flowering.

3.4.6.4 Number of Pods

Number of pods for every plant per treatment in two inner rows was physically counted before harvesting using the procedure described by (Egho, 2009)

$$Number\ of\ pods\ per\ plant = \frac{No.of\ pods}{No\ .of\ plants}$$

3.4.6.5 Length of pods (cm)

Length of all pods per treatment in the two middle rows was measured using 30cm ruler and recorded before harvesting.

3.4.6.6 Weight of empty pods (g)

Weight of all dry empty pods per treatment in the two middle rows were taken and recorded using digital weighing balance.

3.4.6.7 Grain yield of beans (g)

Grain yield was determined after threshing in each treatment for plants in the two middle rows using a digital weighing balance after drying to constant weight.

3.4.6.8 Above ground plant biomass (g)

Weight of above ground dry plant biomass for all plants per treatment in the two middle rows was taken using a digital weighing balance after drying to constant weight.

3.4.6.9 Harvest index

Harvest Index was calculated by dividing the dry weight of grain per treatment with dry weight of above ground biomass of the same rows as outlined by (Donald,1976)

$$\text{Harvest index} = \frac{\text{Economic yield (grain)}}{\text{Biological yield (grain + stover)}} \times 100$$

3.4.7 Data analysis

All the data was subjected to analysis of variance (ANOVA) using SAS; version 8.0 (SAS Institute 2001) and Least Significant Difference (LSD) at $p \leq 0.05$ used to separate treatment means of signicant treatments.

The model for the design used in the analysis is as stated below

$Yij = \mu + \alpha i + \beta ij + \epsilon\ ijk$

Where,

μ = A constant, the mean for all experiments of this type

αi = A constant for for the ith treatment group, the effect of the ith treatment.

B_{ij}=A random effect due to the *ij*th treatment unit;

ϵ_{ijk}= A random effect due to the *ijk*th observation. It contains all uncontrolled variability

CHAPTER FOUR

4.0 RESULTS

4.1 Soil physiochemical characteristics

The results for physiochemical analysis of soil samples collected from the experimental sites at 0-15 cm indicated that the soils were sandy loam in both Kalro substation-ithookwe and SEKU Table 4.1 Soil pH was 5.43 and 5.48 for Kalro and SEKU respectively.Organic carbon waslow in both sites; 0.41% in SEKU and 0.52% im Kalro. Other nutrients were low for legume production in both sites.

Table 4.1 Physiochemical properties of soils at the experimental sites (0-15cm depth)

Soil properties	SEKU	Kalro substation-Ithookwe
Ph	5.48	5.43
Organic carbon%	0.41	0.52
Total N%	0.08	0.83
Available P ($mgkg^{-1}$)	12.85	13
Calcium (ppm)	1.7	1.9
Mg (ppm)	0.06	3.62
K (ppm)	0.23	0.25
CEC	13.2	14.8

4.2 Laboratory experiment

4.2.1 Comparison of the amount of water (g) imbibed by different bean varieties in different times.

Bean varieties showed significant ($p<0.05$) difference in response to water imbibition with increasing time of water imbibition in different bean varieties (Table 4.2.1). Within the first 9 hours, Wairimu dwarf, Wairimu and Piriton imbibed maximum water, followed by KAT B9 after 12 hrs. Wairimu dwarf and KAT X56 had maximum imbibition at 18 hrs. All other varieties reached maximum imbibition after 21 hrs of water imbibition

Table 4.2.1 Comparison of the amount of water (g) imbibed by different bean varieties in relation to time

Bean Variety	T1 g/3hrs	T2 g/6hrs	T3 g/9hr	T4 g/12hrs	T5 g/15hrs	T6 g/18hs	T7 g/21hrs	T8 g/24hrs
KAT B9	0.37a	0.46a	0.56a	0.66a	0.66b	0.66b	0.66b	0.66b
WAIRIMU DWARF	0.23b	0.33b	0.43b	0.43b	0.43b	0.43b	0.43b	0.43b
KAT X56	0.23b	0.33b	0.43b	0.53b	0.63b	0.66b	0.66b	0.66b
GLP 2	0.00d	0.06b	0.16d	0.26e	0.37e	0.47d	0.66b	0.66b
WAIRIMU	0.27b	0.37b	0.43b	0.43c	0.43c	0.43e	0.43e	0.43e
PIRITON	0.13c	0.23c	0.33c	0.33d	0.33d	0.33f	0.33f	0.33f
KAT B1	0.00d	0.03d	0.16d	0.26e	0.37e	0.46d	0.53d	0.53d
KATRAM	0.00d	0.03b	0.13d	0.23f	0.33d	0.50c	0.60c	0.60c
GLP 1004	0.00d	0.00d	0.03e	0.13g	0.20f	0.26g	0.53d	0.53d
MEANS	0.13G	0.20F	0.29E	0.37D	0.44C	0.51B	0.58A	0.58A
LSD	0.02	0.03	0.03	0.02	0.02	0.02	0.03	0.01
C.V	8.55	9.93	11.03	8.25	7.34	6.23	6.23	5.82

Means in the same column followed by the different lower case letters (a, b, c, d, e….i) are significantly different at ($P < 0.05$) using Fisher's LSD

Where T1, T2, T3………………and T8 denotes 3hrs, 6hrs, 9hrs…………..and 24hrs respectively

4.2.2 Effect of maximum water imbibition time (hrs) on germination of different bean varieties

The varieties that reached maximum water imbibition in the first 9-12 hours (Wairimu dwarf, Piriton, Wairimu and KAT B9) germinated significantly earlier than the others (Table 4.2.2). The varieties that reached their maximum water imbibition after 18- 21 hours (KAT X56, GLP 1004, GLP2, KATRAM and KAT B1) germinated later.

Table 4.2.2 Effect of maximum water imbibition time (hrs) on days to germination of different bean varieties

Bean variety	Maximum water imbibition time (hrs)	Days to germination
WAIRIMU DWARF	9d	4.66b
PIRITON	9d	4.66b
WAIRIMU	9d	5.00b
KAT B9	12c	5.00b
KAT X56	18b	6.33a
GLP 1004	21a	6.33a
GLP 2	21a	6.33a
KATRAM	21a	6.66a
KAT B1	21a	6.66a

C.V= 8.24 LSD column 0.70

Means in the same column followed by the different lower case letters (a, b ,c ,d) are significantly different at ($P < 0.05$) using Fisher's LSD

4.2.3 Comparison of germination time (days) between imbibed and unimbibed seeds in different bean varieties

Imbibed seeds germinated earlier than unimbibed seeds (Table 4.2.3). Imbibed Piriton Wairimu Dwarf, KAT X56 and Wairimu seeds germinated significantly ($p<0.05$) earlier than imbibed seeds of all other varieties. They were followed by Katram, KAT B9, GLP 2, GLP 1004 and KAT B9 but were not significantly different from each other. Wairimu dwarf germinated earlier than all other unimbibed seeds whose germination period was not significantly different from each other. KAT B1, GLP 1004, GLP 2 and Katram had the smallest difference of time between germination of imbibed seeds and unimbibed seeds followed by Wairimu, KAT X56, Piriton and Wairimu dwarf in that order.

Table 4.2.3 Comparison of germination (days) between imbibed and unimbibed seeds in different bean varieties

Bean variety	imbibed seeds	unmbibed Seeds	Difference (days)
PIRITON	5.65Bb	8.65Ab	3.00b
WAIRIMU DWARF	5.65Bb	9.65.Aa	4.00a
KAT X56	6.00Bb	8.65Ab	2.65b
KATRAM	7.65Ba	8.65Ab	1.00c
WAIRIMU	6.00Bb	8.66Ab	2.66b
KAT B9	7.32Ba	8.32Ab	1.00c
GLP 2	7.35Ba	8.35Ab	1.00c
GLP 1004	7.33Ba	8.33Ab	1.00c
KAT B1	7.66Ba	8.66Ab	1.00c
Means	6.73	8.66	1.92

C.V=9.25 LSD in columns=0.70; across the rows 0.30

Means in the same row followed by different upper upper case letters (A, B) and in the same column followed by the different lower case letters (a, b ,c) are significantly different at ($P < 0.05$) using Fisher's LSD

4.3 .0 Green house experiment

4.3.1 Effect of foliar fertilizer application rates on Leaf Area Index of different bean varieties

Leaf area index increased with the increase in foliar fertilizer application (Table 4:3.1). Overall, foliar fertilizer application increased the leaf area index of all bean varieties. Application of foliar fertilizer significantly (P=0.0001 increased the LAI of Wairimu dwarf above other bean varieties. It was followed by Wairimu, Piriton, GLP 1004= KAT B9, KAT X56= Katram, KAT B1= GLP 2 in that order. At zero treatment KAT B1 and GLP 2 had the lowest LAI.

Table 4:3.1 Effect of foliar fertilizer application rate on leaf area index of different bean varieties

Bean genotype	0 mls/L	2.5ml/L	5.0mls/L	Means
Wairimu dwarf	0.09Ba	0.10Aa	0.10Aa	0.096a
Wairimu	0.08Bb	0.09Ab	0.09Ab	0.086b
Piriton	0.08Bb	0.09Ab	0.08Bc	0.083c
GLP 1004	0.06Bc	0.07Ac	0.07Ad	0.066d
KAT B9	0.06Bc	0.07Ac	0.07Ad	0.066d
KAT X56	0.06Bc	0.06Bd	0.07Ad	0.063e
Katram	0.06Ac	0.06Ad	0.06Ae	0.060e
KAT B1	0.05Bd	0.06Ad	0.06Ae	0.057f
GLP 2	0.05Bd	0.06Ad	0.06Ae	0.057f
Means	0.07A	0.07A	0.07A	

C.V=10.02 LSD in columns=0.003; across the rows 0.002

Means in the same row followed by different upper upper case letters (A and B) or in the same column followed by the different lower case letters (a, b ,c d e,f) are significantly different at (P < 0.05) using Fisher's LSD

4.3.2 Effect of foliar fertilizer application rate on stem girth (cm) of different bean varieties

Stem girth increased (P<0.0001) with the increasing level of foliar fertilizer application (Table 4.3.2). Overall, Wairimu dwarf had the highest stem girth compared to all other varieties. It was followed by Katram, KAT B9=GLP 1004, KAT X56, GLP 2,

Table 4.3.2 Effect of foliar fertilizer application rate on stem girth (cm) of different bean varities

Bean genotype	**0 mls/L**	**2.5mls/L**	**5mls/L**	**Means**
Wairimu dwarf	1.50Ca	1.76Ba	1.90Aa	1.72a
Katram	1.60Ca	1.67Bb	1.80Ab	1.69b
KAT B9	1.43Ca	1.77Ba	1.80Ab	1.67c
GLP 1004	1.47Ca	1.53Bd	1.90Aa	1.63c
KAT X56	1.37Cb	1.60Bc	1.80Ab	1.59d
GLP 2	1.20Cb	1.60Bc	1.70Ac	1.50e
Piriton	1.10Cb	1.17Be	1.30Ad	1.19f
Wairimu	1.10Cb	1.17Be	1.23Ae	1.17f
KAT B1	0.37Cb	1.10Bf	1.27Ad	0.91g
Means	1.23C	1.48B	1.63A	
C.V=2.75	**LSD in columns=0.03 ;in rows 0.02**			

Means in the same row followed by different upper upper case letters (A,B,C) or in the same column followed by the different lower case letters (a, b ,c ,d , e….g) are significantly different at (P < 0.05) using Fisher's LSD.

4.3.3 Effect of foliar fertilizer application rate on chlorophyll content of bean varieties

Chlorophyll content increased with the increasing rate of foliar fertilizer application (Table 4.3.3). Overall, Piriton had significantly (P<0.0001) the highest chlorophyll content compared to other varieties. This was followed by KAT B9, Wairimu dwarf, KAT B1=KAT X56, Katram, Wairimu, GLP 1004= GLP 2 in that order. Piriton had significantly the highest chlorophyll content at treatment zero and 2.5 mls/L while Wairimu dwarf had the highest content of chlorophyll at treatment 5mls/L. GLP 2 had the lowest chlorophyll content at both treatment zero and 2.5mls/L. Katram, Wairimu and GLP 1004 had significantly the lowest chlorophyll content at treatment 5mls/L compared to other varieties.

Table 4.3.3 Effect of foliar fertilizer application rate on chlorophyll content of different bean varieties (mg m^{-2})

Bean genotype	0 mls/L	2.5mls/L	5mls/L	Means
Piriton	42.53Ca	44.50Ba	46.37Ac	44.46a
KAT B9	41.30Cb	42.57Bb	46.77Ab	43.53b
Wairimu dwarf	39.60Cc	41.40Bc	48.33Aa	43.11c
KAT B1	32.07Ch	44.30Ba	46.27Ac	40.88d
KAT X56	35.33Ce	42.40Bb	44.33Ad	40.69d
Katram	37.40Bd	40.47Ae	40.63Af	39.50e
Wairimu	33.33Cf	40.17Be	40.50Af	38.00f
GLP 1004	32.53Cf	38.50Bf	40.33Af	37.13g
GLP 2	31.77Ci	37.43Bg	41.23Ae	36.81g
Means	36.20C	41.32B	43.84A	
C.V= 0.50	**LSD in the columns=0.32; in the rows=0.18**			

Means in the same row followed by different upper upper case letters (A, B, C) or in the same column followed by the different lower case letters (a, b ,c,d,..g) are significantly different at (P < 0.05) using Fisher's LSD.

4.3.4 Effect of foliar fertilizer application rate on number of pods per plant (g) of different bean varieties

The number of pods per plant increased with the increasing rate of foliar fertilizer application (Table 4.3.4). Overall, there was a significant ($P<0.0001$) increase in number of pods in Wairimu dwarf compared to other varieties. It was followed by Wairimu, Piriton, KAT B9= GLP, KAT X56 = Katram, KAT B1= GLP 2 in that order. The lowest number of pods per plant was produced without foliar fertilizer application followed by treatment of foliar fertilizer at 2.5mls/L and the highest number of pods was produced at 5mls/L.

Table 4.3.4 Effect of foliar fertilizer application rate on number of pods per plant (g) of different bean varieties

Bean variety	0 mls/L	2.5mls/L	5mls/L	Means
Wairimu dwarf	11.00Ca	12.67Ba	14.00Aa	12.55a
Wairimu	10.00Cb	10.33Bb	11.33Ab	10.55b
Piriton	8.67Cc	10.33Bb	11.00Ab	10.02c
KAT B9	8.33Cd	9.00Bc	11.00Ab	9.44d
GLP 1004	8.67Cc	9.00Bc	10.00Ac	9.22d
KAT X56	7.33Ce	8.33Bd	10.00Ac	8.55e
Katram	6.00Cf	9.33Bc	11.00Ab	8.77e
KAT B1	4.00Cg	6.33Be	11.00Ab	7.11f
GLP 2	4.00Cg	6.33Be	10.00Ac	6.78f
Means	7.55C	9.07B	11.03A	

C.V= 4.99 LSD in the columns=0.38; across the rows 0.22

Means in the same row followed by different upper upper case letters (A, B,C) or in the same column followed by the different lower case letters (a, b ,c d …g) are significantly different at (P < 0.05) using Fisher's LSD.

4.3.5 Effect of foliar fertilizer application rate on pod length of bean varieties

Application of foliar fertilizer increased significantly (P<0.0001) pod length of each variety (table 4.3.5). Overall, GLP 1004 had significantly longer pod length than all other varieties. It was followed by GLP 2, KAT X56, Katram, Piriton in that order but KAT B1= KAT B9= Wairimu= Wairimu dwarf were not significantly different from each other.Wairimu dwarf produced the smallest pod length at treatment 2.5mls/L. KAT B9 produced the smallest pod length at treatment 5mls/L.

Table 4.3.5 Effect of foliar fertilizer application rate on pod length of bean varieties

Bean variety	0 mls/L	2.5mls/L	5mls/L	Mean
GLP 1004	11.53Ba	11.63Ba	12.40Aa	11.85a
GLP 2	10.60Cb	11.47Bb	12.50Aa	11.52b
KAT X56	10.47Bb	10.60Bc	11.50Ab	10.85c
Katram	8.67Ce	9.90Bd	10.03Ac	9.53d
Piriton	8.80Cd	9.40Be	9.57Ae	9.26e
KAT B1	7.87Cg	8.77Bg	9.96Ad	8.87f
KAT B9	8.53Be	8.80Bg	9.00Ag	8.78f
Wairimu	8.33Bf	9.17Af	9.20Af	8.90f
Wairimu dwarf	8.40Bf	8.43Bh	9.70Ae	8.84f
Means	9.24C	9.79B	10.42A	
C.V=1.28, LSD in columns=0.14; across the rows=0.08				

Means in the same row followed by different upper upper case letters (A, B, C) or in the same column followed by the different lower case letters (a, b ,c d e….h) are significantly different at (P < 0.05) using Fisher's LSD.

4.3.6 Effect of foliar fertilizer application rates on empty pod weight (g) of bean varieties

Empty pod weight increased with increasing foliar fertilizer application (Table 4.3.6). Overall, there was significant (p< 0.0001) increase in pod weight in GLP 2 compared to all other varieties. It was followed by KAT B1, KATX56=Katram, GLP 1004= Piriton, KAT B9, Wairimu, Wairimu dwarf in that order. GLP 2 had the highest empty pod weight across all treatments followed by KAT B1 while Wairimu dwarf had the lowest empty pod weight in all treatment.

4.3.7 Effects of different rates of foliar fertilizer application on weight of 100 seeds (g) of different bean varieties

Overall, GLP had significantly (P<0.0001) the highest increase in weight of 100 seeds (Table 4.3.7). This was followed by Katram, KAT B1, KAT B9 = KAT X56 = GLP 1004, Wairimu dwarf, Wairimu and Piriton in that order. Without foliar fertilizer application Katram had the highest weight of 100 seeds while Wairimu and Piriton had the lowest weight. GLP 2 had the highest weight at treatment 2.5 mls/L and 5 mls/L but Piriton had the lowest weight at both treatment 2.5mls/L and 5 mls/L. The increase in foliar fertilizer concentration from zero to

2.5mls/L to 5 mls/L resulted to significant decrease in weight in varieties such as GLP 2, Katram, KAT B9, KAT X56, GLP 1004, Wairimu dwarf, Wairimu and Piriton.

Table 4.3.6 Effect of foliar fertilizer application rates on empty pod weight (g) of selected bean varieties

Bean variety	0 ml/L	2.5ml/L	5 ml/L	Means
GLP 2	1.43Ca	1.60Ba	1.80Aa	1.61a
KAT B1	1.37Ab	1.43Bb	1.50Cb	1.43b
KAT X56	1.13Cc	1.20Bc	1.27Ac	1.20c
Katram	1.13Cc	1.20Bc	1.23Ad	1.19c
GLP 1004	1.10Cd	1.13Bd	1.23Ad	1.16d
Piriton	1.10Cd	1.13Bd	1.17Ae	1.13d
KAT B9	0.77Ae	0.90Be	0.96Cf	0.88e
Wairimu	0.60Cf	0.70Bf	0.90Af	0.73f
Wairimu dwarf	0.50Cg	0.60Bg	0.80Ag	0.63g
Means	1.01C	1.10B	1.20A	
C.V=4.19 LSD in columns=0.02; within the rows=0.03				

Means in the same row followed by different upper upper case letters (A, B, C) or in the same column followed by the different lower case letters (a, b ,c d e….g) are significantly different at (P < 0.05) using Fisher's LSD

Table 4.3.7 Effect of foliar fertilizer application rate on weight of 100 seeds (g) of different bean varieties

Bean genotype	0 mls/L	2.5mls/L	5mls/L	Means
GLP 2	14.13Ab	14.13Aa	13.07Ba	13.80a
Katram	14.30Aa	12.23Bb	10.33Cc	12.28b
KAT B1	10.80Bc	11.30Ac	10.93Bb	11.01c
KAT B9	10.40Ad	10.30Ae	10.03Bd	10.24d
KAT X56	10.50Ad	10.36Be	10.33Bc	10.39d
GLP 1004	10.50Ad	10.43Ae	10.40Ac	10.44d
Wairimu dwarf	11.00Ac	11.03Ad	6.23Be	9.42e
Wairimu	7.33Ae	6.37Bf	6.33Be	7.01f
Piriton	7.33Ae	6.33Bf	5.66Cf	6.44g
Means	10.69A	10.62A	9.25B	
C.V= 0.001 LSD in the columns=0.23; on rows=0.13				

Means in the same row followed by different upper upper case letters (A, B, C) or in the same column followed by the different lower case letters (a, b ,c d e….g) are significantly different at (P < 0.05)

4.3.8 Effect of foliar fertilizer application rates on grain yield of bean varieties (g)

Grain yield per pot increased with increasing concentrations of foliar fertilizer (Table 4.3.8). Overall, Wairimu dwarf produced significantly (P<0.0001) higher grain yield per pot compared to all other varieties followed by Wairimu, Piriton, KAT B9 and GLP 1004, KATRAM = KAT 56 and KAT B1, in that order. GLP 2 produced the lowest grain yield per pot. Without foliar fertilizer application, KAT B9 produced the highest grain yield while KAT B1 and GLP2 produced the lowest yields. At treatment 2.5/L, Wairimu had significantly higher grain yield compared to other varieties while Wairimu dwarf had the highest grain yield at treatment 5ml/L.

Table 4.3.8 Effect of different foliar fertilizer concentrations on grain yield of bean varieties

Bean genotype	0 mls/L	2.5mls/L	5mls/L	Means
Wairimu dwarf	6.30Cb	10.36Ab	12.50Aa	9.72a
Wairimu	5.60Cd	10.47Ba	10.70Ab	8.92b
Piriton	6.30Cb	9.77Bc	10.13Ac	8.73c
KAT B9	7.63Ca	8.47Be	8.77Ag	8.29d
GLP 1004	5.60Cd	8.77Bd	9.87Ad	8.08e
Katram	5.40Ce	7.30Bg	9.43Ae	7.38f
KAT X56	5.70Cc	7.57Bf	8.77Ag	7.34f
KAT B1	2.50Cf	7.60Bf	9.33Af	6.48g
GLP 2	2.50Cf	7.30Bg	8.83Ag	6.21h
Means	5.28C	8.62B	9.81A	

C.V= 1.111 LSD in the columns=0.09; on rows 0.05

Means in the same row followed by different upper case letters (A, B, C) or in the same column followed by the different lower case letters (a, b ,c d e….h) are significantly different at (P < 0.05) using Fisher's LSD.

4.3.9 Effect of different application rates of foliar fertilizer on above ground biomass production in bean varieties

Increasing foliar fertilizer application rates significantly (P<0.0001) increased above ground biomass production in all bean varieties (Table 4.3.9). Overall, there was significant (P<0.0001) increase in biomass production in piriton above all other varieties. Wairimu also significantly produced higher biomass compared to other varieties but lower than Piriton. It was followed by KAT B9, KAT B1, Wairimu dwarf, GLP 2, GLP 1004, Katram and KAT X56 in that order.Wairimu dwarf had the highest dry biomass without foliar fertilizer application and KAT X56 had the lowest biomass. KAT B1 had the highest biomass at 2.5mls/L while Katram and KAT X56 had the lowest biomass. At treatment 5mls/L KAT B9 had the highest biomass and while Wairimu dwarf had the lowest biomass.

Table 4.3.9 Effect of different application rates of foliar fertilizer on above ground biomass production in bean varieties in g/pot

Bean genotype	0 mls /L	2.5mls/L	5mls/L	Means
Piriton	17.03Cb	19.33Bd	24.77Ac	20.38a
Wairimu	15.33Cd	19.40Bc	25.10Ab	19.94b
KAT B9	13.67Ch	18.43Be	26.66Aa	19.58c
KAT B1	15.17Ce	19.57Ba	23.63Ad	19.45d
Wairimu dwarf	17.37Ca	19.50Bb	20.80Ah	19.22e
GLP 2	16.47Bc	16.73Bf	21.80Af	18.33f
GLP 1004	14.37Cg	16.60Bg	22.27Ae	17.74g
Katram	14.57Cf	16.53Bh	21.57Ag	17.55h
KAT X56	12.20Ci	16.57Bh	21.53Ag	16.77i
Means	15.13C	18.07B	23.12A	

C.V= 18.77 LSD in the rows 0.02 ;on the columns 0.03

Means in the same row followed by different upper upper case letters (A, B, C) or in the same column followed by the different lower case letters (a, b ,c d e….i) are significantly different at (P < 0.05) using Fisher's LSD.

4.3.10 Effect of foliar fertilizer application rate on harvest index of bean varieties

Harvest index increased with increasing foliar application (Table 4.3.10). Overall, Wairimu dwarf had significantly (P<0.0001) the highest harvest index compared to all other varieties. It was followed by KAT B9= GLP 1004, KAT X56 = Wairimu, Piriton = Katram, GLP 2 and KAT B1 in that order. KAT B9 had significantly higher harvest index at treatment zero while KAT B1 had the lowest harvest Index. Wairimu had the highest harvest index at treatment 2.5mls/L while KAT B1 produced the lowest harvest index. In treatment 5mls/L Wairimu dwarf produced the highest harvest index while GLP 2 and KAT B1 produced the lowest harvest index.

Table 4.3.10 Effect of foliar fertilizer application rate on harvest index of bean varieties

Bean variety	0 mls/L	2.5mls/L	5mls/L	Means
Wairimu dwarf	0.36Ce	0.52Bc	0.60Aa	0.49a
KAT B9	0.55Aa	0.46Be	0.33Cg	0.45b
GLP 1004	0.38Cc	0.53Ab	0.43Bc	0.45b
KAT X56	0.47Ab	0.45Bf	0.41Ce	0.44c
Wairimu	0.36Ce	0.54Aa	0.42Bd	0.44c
Piriton	0.37Cd	0.50Cd	0.40Bf	0.42d
Katram	0.37Ad	0.44Ag	0.44Ab	0.42d
GLP 2	0.15Cg	0.43Ah	0.40Bf	0.33f
KAT B1	0.16Cf	0.38Bi	0.40Af	0.32g
Means	0.35C	0.47A	0.43B	
C.V= 4.94	**LSD in the columns=0.005; on rows 0.003**			

Means in the same row followed by different upper case letters (A ,B, C) or in the same column followed by the different lower case letters (a, b ,c d e….g) are significantly different at (P < 0.05) using Fisher's LSD.

4.3.11 Regression of grain yield versus yield components

The correlations among the traits are shown in table (4.3.11). A significant positive correlation (p< 0.13; r= .449**) was observed between plant biomass and grain yields (Table 4.2.11). Likewise, a positive correlation was observed between girth and grain yied (p<0.000; r= .839**) stem girth and biomass (p<0.000; r= .761**) Chlorophyll and grain yield , (p<0.000; r=.849**), chlorophyll and biomass, (p<0.001; r= .635**) chlorophyll and stem girth (p<0.000; r= .834**).

Table 4.3.11 Regression of grain yield versus yield components

	Grain yield	Above ground biomass	Stem girth	Chlorophyll
Grain yield	1			
Above ground biomass	.449**	1		
Stem girth	.839**	.761**	1	
Chlorophyll	.849**	.635**	.834**	1

Where * * denotes highly significant relationship

4:4 Field experiment

4.4.1 Effects of different concentrations of foliar fertilizer application on Leaf area Index

Bean varieties' LAI increased with increasing concentration of foliar fertilizers (Table 4.4.1) Overall, Wairimu and Wairimu dwarf had significantly ($P<0.0001$) the highest leaf area index and were not significantly ($p<0.05$) different from each other. This was followed by Piriton and KAT B9 which were not significantly different from each other. Wairimu had the highest LAI in all treatments while KAT B9 produced the lowest.

Table 4.4.1 Effects of different concentrations of foliar fertilizer application on Leaf area Index

Bean variety	0 mls/L	2.5mls/L	5mls/L	Means
Wairimu	0.06Ca	0.08Ba	0.09Aa	0.08a
Wairimu dwarf	0.06Ca	0.07Ba	0.08Aa	0.07a
Piriton	0.04Cb	0.05Bc	0.06Ab	0.05b
KAT B9	0.03Cb	0.04Bc	0.05Ab	0.04b
Means	0.05C	0.06B	0.07A	
LSD in columns= 0.01 in rows=0.004, C.V= 8.89				

Means in the same row followed by different upper case letters (A, B ,C)or in the same column followed by the different lower case letters (a, b ,c) are significantly different at ($P < 0.05$)

4.4.2 Effect of different concentrations of foliar fertilizer application on stem girth

There was a significant (P<0.0001) increase in stem girth with increasing foliar fertilizer concentration (Table 4.4.2). Overall, Wairimu had the largest stem girth followed by Wairimu dwarf. Stem girth of KAT B9 and Piriton were not significantly (P<0.05) different from each other. Wairimu had the highest increase in stem girth in all levels of foliar fertilizer application followed by Wairimu dwarf, Piriton and KAT B9 in that order.

Table 4.4.2 Effect of different concentrations of foliar fertilizer application on stem girth

Bean genotype	0 mls/L	2.5mls/L	5mls/L	Means
Wairimu	0.87Ca	1.06Ba	1.27Aa	1.06a
Wairimu dwarf	0.80Cb	0.97Bb	1.13Ab	0.97b
Piriton	0.60Cc	0.80Bc	1.00Ac	0.80c
KAT B9	0.60Cc	0.80Bc	1.00Ac	0.80c
Means	0.71C	0.90B	1.10A	
C.V=5.33	**LSD in columns=0.04; in rows=0.02**			

Means in the same row followed by different upper case letters (A B C) or in the same column followed by the different lower case letters (a, b ,c) are significantly different at (P < 0.05)

4.4.3 Effects of different concentrations of foliar fertilizer on number of pods per plant

There was a significant interation (P<0.0001) between bean varieties and foliar fertilizer application as the number of pods increased with the increase in foliar application as shown in Table 4.4.3. Overall, wairimu had the highest number of pods per plant followed by Wairimu dwarf, Piriton and KAT B9 in that order. In treatment zero (control) Wairimu and Wairimu dwarf produced the highest number of pods per plant but were not significantly different from each other. This was followed by Piriton which had significantly higher number of pods than KAT B9. Wairimu had the highest number of pods in all levels of fertilizer application.

4.4.4 Effect of different concentrations of foliar fertilizer on pod length

Pod length increased with the increase in concentration of foliar fertilizer application (Table 4.4.4). Overall, the highest pod length was produced by KAT B9 followed by Wairimu dwarf. The shortest pod lengths was produced by Wairimu and Piriton but were not significantly different from each other. KAT B9 had the longest pod length across all the treatments followed by Wairimu dwarf. At treatment zero, Wairimu dwarf increased in pod length above all other varieties except KAT B9 but was not statistically different from Piriton.

Table 4.4.3 Effects of different concentrations of foliar fertilizer on number of pods per plant

Bean genotype	**0 mls/L**	**2.5mls/L**	**5mls/L**	**Means**
Wairimu	16.00Ca	21.00Ba	28.33Aa	21.77a
Wairimu dwarf	16.00Ca	21.00Ba	21.33Ab	19.44b
Piriton	10.33Cb	13.66Bb	27.66Aa	17.21c
KAT B9	8.66Cc	12.66Bc	18.66Ac	13.32d
Means	12.74C	17.08B	23.99A	
C.V=6.05	**LSD in columns=1.06 ; in rows=0.91**			

Means in the same row followed by different upper case letters (A, B, C)or in the same column followed by the different lower case letters (a, b ,c,d) are significantly different at (P < 0.05)

Table 4.4.4 Effect of different concentrations of foliar fertilizer on pod length (cm)

Bean variety	**0 mls/L**	**2.5mls/L**	**5mls/L**	**Means**
KAT B9	9.67Ca	10.30Ba	11.23Aa	10.40a
Wairimu dwarf	8.73Cb	9.26Bb	9.83Ab	9.27b
Wairimu	7.77Cc	8.77Bd	9.86Ab	8.80c
Piriton	8.56Cb	8.96Bc	9.23Ac	8.92c
Means	8.68	9.32	10.04	
C.V=1.94	**LSD in columns 0.17; across rows 0.15**			

Means in the same row followed by different upper case letters (A, B ,C) or in the same column followed by the different lower case letters (a, b ,c, d) significantly different at (P < 0.05)

4.4.5 Effect of different concentrations of foliar fertilizer on empty dry pod weight

There was significant (P<0.0001) increase in empty dry pod weight with the increase in concentration of foliar as shown in Table 4.4.5. Overall, KAT B9 had the highest increase in empty pod weight followed by Wairimu dwarf and Piriton which were not significantly different from each other**.** Wairimu had the lowest empty pod weight. KAT B9 had significantly higher weight of dry pod weight across all levels of foliar treatment while Wairimu had the lowest empty pod weight across all levels of treatment. In treatment zero (control) KAT B9 had the highest empty pod weight followed by Wairimu dwarf and Piriton which were not significantly (p<0.05) different from each other. Wairimu had the lowest empty pod weight.

Table 4.4.5 Effect of different concentrations of foliar fertilizer on empty dry pod weight (g)

Bean genotype	0 mls/L	2.5mls/L	5mls/L	Means
KAT B9	0.77Ca	0.90Ba	0.96Aa	0.87a
Wairimu dwarf	0.60Cb	0.70Bb	0.90Aa	0.73b
Piriton	0.62Cb	0.73Bb	0.89Ab	0.75b
Wairimu	0.50Cc	0.60Bc	0.80Ab	0.63c
Means	0.62C	0.73B	0.89A	
C.V=7.83	**LSD in columns=0.09; across rows=0.07**			

Means in the same row followed by different upper case letters (A, B ,C) or in the same column followed by the different lower case letters (a, b ,c) are significantly different at (P < 0.05)

4.4.6 Effect of different concentrations of foliar fertilizer on grain yield (kg/ha)

Grain yield increased with the increasing concentration of foliar fertilizer (Table 4.4.6). Overall, Wairimu variety had the highest grain yield followed by Wairimu dwarf, Piriton and KAT B9 had the lowest grain. Wairimu had significantly the highest grain yield across all treatments followed by Wairimu dwarf, Piriton, and KAT B9 in that order

Table 4.4.6 Effect of different concentrations of foliar fertilizer on grain yield (kg/ha

Bean variety	0 mls/L	2.5mls/L	5mls/L	Means
Wairimu	1212.88Ca	1344.71Ba	1765.02Aa	1440.87a
Wairimu dwarf	1197.77Cb	1294.48Bb	1610.66Ab	1367.64b
Piriton	1192.88Cc	1291.82Bc	1608.44Ac	1364.38c
KAT B9	1144.00Cd	1180.88Bd	1260.57Ad	1195.15d
Means	1186.90C	1277.97B	1561.17A	
C.V= 0.55	**LSD in columns=1.62; in rows=1.40**			

Means in the same row followed by different upper case letters (A, B, C) or in the same column followed by the different lower case letters (a, b ,c, d) are significantly different at (P < 0.05)

4.4.7 Effect of different concentrations of foliar fertilizer application rate on biomass per hectare

Application of foliar fertilizer at different concentrations resulted to significant ($p<0.05$) increase of above ground biomass of bean varieties as shown in Table 4.4.7. Overall, KAT B9 had the highest biomass production followed by Wairimu dwarf, Wairimu and Piriton in that order while Piriton had the lowest biomass production. KAT B9 had the highest above ground biomass in all levels of treatment followed by Wairimu dwarf, Wairimu and Piriton in that order.

Table 4.4.7 Effect of different concentrations of foliar fertilizer on biomass production per hectare

Bean variety	0 mls/L	2.5mls/L	5mls/L	Means
KAT B9	1330.80Ca	1389.91Ba	1426.04Aa	1382.25a
Wairimu dwarf	1326.71Cb	1274.66Bb	1322.66Ab	1308.01b
Wairimu	1197.15Cc	1206.35Bbc	1224.88Cc	1209.46c
Piriton	1215.55Cd	1234.22Bd	1260.44Ad	1236.73d
Means	1267.55	1276.28	1308.50	
C.V=0.35	**LSD in columns=0.98; in rows=0.85**			

Means in the same row followed by different upper case letters (A, B ,C) or in the same column followed by the different lower case letters (a, b ,c ,d) are significantly different at (P < 0.05)

4.4.8 Effect of different concentrations of foliar fertilizer on harvest index

Increasing the concentration of foliar fertilizer application increased HI of bean varieties significantly (P<0.0001) with Wairimu having the highest harvest index in all levels of fertilizer application while KAT B9 had the lowest as shown in Table 4.4.8 Overall, Wairimu had the highest harvest index followed by Wairimu dwarf, Piriton and KAT B9 in that order.

Table 4.3.8 Effect of different concentrations of foliar fertilizer on harvest index

Bean variety	0 mls/L	2.5mls/L	5mls/L	Means
Wairimu	1.01Ca	1.11Ba	1.44Aa	1.18a
Wairimu dwarf	0.90Cc	1.05Bb	1.21Ac	1.05b
Piriton	0.98Cb	1.04Bb	1.27Ab	1.09c
KAT B9	0.85Cd	0.85Bc	1.09Ad	0.93d
Means	0.94	1.01	1.25	
C.V=1.09 LSD in columns =0.01; in rows=0.01				

Means in the same row followed by different upper case letters (A, B ,C) or in the same column followed by the different lower case letters (a, b ,c ,d) are significantly different at (P < 0.05)

4.4.9 Regression of grain yields versus yield components of different bean varieties

The correlations among the traits are presented in the Table 4.4.9. A highly significant positive relationship (p<0.000; r= .804**) was observed between pod length and biomass per plant. A positive significant relationship (p<0.014; r=.409*) was also observed between biomass and grain yield. Likewise, number of pods per plant showed a significant positive relationship with biomass ($p<0.000$; $r=.589^{**}$). Similarly, number of pods and grain yield showed a highly significant positive relationship ($p<0.000$; $r=.834^{**}$).

Table 4.4.9 Regression of grain yields (kg/ha) versus yield components of different bean varieties

	Grain yield	Pod length	Plant biomass	Number of pods
Grain yield	1			
Pod length	.097	1		
Plant biomass	.804**	.759**	1	
Number of pods	.834**	.189	.589**	1

Where * and ** denotes significant and highly significant codes respectively

CHAPTER FIVE

5.0 DISCUSSION

5.1.0 Soil physiochemical properties

The low pH in the experimental sites could be attributed to increased concentration of hydrogen ions in the soil as explained by (Arthur, 2009). According to Whalen *et al.* (2000), most agricultural crops produce well in the pH range of 5.6 to 7.5 in sandy soils. However, the percentage of Organic Carbon was observed to be low (0.41%) in SEKU and 0.52 in Kalro compared with the global outlook of 1.1-2.5% (Whalen *et al.*, 2000). Landon (2014) rated soil containing organic carbon > 20 % as very high, 10–20 % high, 4–10 % medium, 2–4 % low and < 2 % very low. With reference to these ranges, the percent organic carbon of the study area was very low. The initial total nitrogen content in SEKU (0.08 %) and in Kalro (0.83) was very low. Landon (2014) rated percent total N content in soil > 1.0 as very high, 0.5–1.0 high, 0.2–0.5 medium, 0.1–0.2 low and < 0.1 very low. With reference to these ranges, the total N content of the study area was very low (0.08) due to the low organic matter content since nitrogen is a key component of organic matter. The available P content of the study area was medium in both sites Buchholz *et al.* (2004) provided available P ranges as: < 3 mg kg^{-1}-very low, < 10 mg kg^{-1}-low, between 10 - 20 mg kg^{-1}-medium, > 20 mg kg^{-1} high. The cation exchange capacity (CEC) (3.82 cmol+ kg-1 of soil) of the study area was very low and could be explained by the low pH and soil organic matter content. Arthur (2009) reported that low CEC value could be due to low pH (5.62). According to the rating given by Landon (2014), CEC value (i.e. in cmol+ kg^{-1}) > 40 is very high, 25–40 is high, 15–25 is medium, 5–15 is low and < 5 is very low.

5.2 LABORATORY EXPERIMENT

5.2.1 Comparison of the amount of water imbibed by different bean varieties in different times under laboratory conditions

The significant difference on the amount of water imbibibed by different bean varieties at different times is in agreement with earlier study conducted by (Borji *et al.*, 2007) who reported that the differences in water imbibition among the seed varieties is related to seed coat thickness, number of seed coat pores, size of micropyle and hilum. This could also be attributed to differences in the nature of the seed coat among the bean varieties.

5.2.2 Effect of maximum water imbibition time on germination of different varieties under laboratory conditions

The significant differences in germination time between bean varieties which imbibed water rapidly and reached their maximum imbibition capacity after a short time and those which imbibed water slowly and reached their maximum water imbibition late could be due to difference in the level of seed dormancy existing among the bean varieties as explained by (Shaoa *et al.,* 2007). This is in agreement with the study conducted by (Baskin,2005) who reported that seeds that imbibe water slowly are associated with physical dormancy as a result of hard seed coat which doesn't fully permit water uptake. Similar findings were also reported by Borji *et al.,* (2007) who attributed differences in water imbibition by different varieties to differences in hardness of the seed coat.

5.2.3 Comparison of germination time between imbibed and unimbibed seeds in different bean varieties under laboratory conditions

The difference in germination time observed between imbibed and unimbibed seeds could be due to the role played by water in causing biochemical changes within the seed and activating enzymes as explained by (Nonogaki *et al.,* 2010). Similar results were reported by (Abebe and Modi, 2009; Manz *et al*., 2005) who observed that moisture absorption was important for start of active germination of seed.

5.3 GREEN HOUSE AND FIELD EXPERIMENTS

5.3.1 Effect of foliar fertilizer application rate on LAI under green house and field conditions

The increase in LAI with the increase in foliar fertilizer application rate across the treatments could be attributed to increase in nitrogen content in bean plant tissues which is responsible for increased growth in plants' leaves. This concurs with the findings of Werner and Newton, (2005), who found out that LAI increases with the increasing nitrogen fertilizer application. Similar results were reported by (Chaillou *et al.,* 2003) who found out that LAI increases with the increase in nitrogen fertilizer application.

5.3.2 Effects of foliar fertilizer application on chlorophyll content of different bean varieties under green house and field conditions

Increase in chlorophyll content of the leaves with the increase in foliar fertilizer application observed in the current study could be attributed to the effects of nitrogen contained in foliar fertilizer which helps in the synthesis of chlorophyll molecule as explained by (Pilbram *et al.,* 2009).) This study agrees with the earlier findings of (Sabo *et al.,* 2002) who found out that there is a strong linear positive correlation between nitrogen level in the plant and chlorophyll content in the leaf.

5.3.3 The effect of foliar fertilizer application rate on number of pods per plant under green house and field conditions

The differences in number of pods in the current study could be attributed to differences in individual beans' ability to fix nitrogen even without fertilizer application to genotypical differences among the varieties as explained by (Akter *et al.,* 2014). Number of pods increased with the increasing foliar fertilizer application. The study agrees with findings of (Ranđelović, 2009; Yildirim *et al*., 2008) and who found that application of foliar fertilizer increases the number of pods per plant. Similar findings were reported by (Sharaf *et al*., 2009) who found that foliar fertilization with boron led to increase in the number of pods and plant seeds.

5.3.4 Effect of foliar fertilizer application rate on 100 grains weight under green house and field conditions

There was reduction in the weight of seeds as the yields of beans increased.The relationship was inverse probably due to substantial diversion of photoassimilates to the pods which may affect the weight of mature seeds. This study concurs with studies conducted by (Schmitt *et al.,* 2001) and (Binford *et al*., 2004) who reported that foliar applications of N-P-K show decreases in weight of mature bean seeds

5.3.5 Effect of foliar fertilizer application rate on grain yield under green house and field conditions

The significant differences in grain yields in different varieties without foliar fertilizer application could be associtaed with genetic differences in nitrogen fixation in the varieties used. This is in agreement with findings by (Akter *et al.,* 2014) who found that beans fixed substantial nitrogen without fertilizer application. The increase in grain yield with the increasing foliar application rate could also be attributed to the fact that when foliar fertilizers are applied to legumes they respond to it faster than the soil applied solid fertilizers (Oko *et al.,* 2003). This is supported by an earlier study conducted by (Ali *et al.,* 2007) who reported that foliar application of nitrogen increased seed number per pod with consequent increase in yields compared to the control (where nitrogen fertilizer was not applied). Other studies (Schon and Blevins, 1990; Ranđelović, 2009; Aaid, 2012) reported an increase in grain yield with increasing rates of foliar fertilizer application. The results also show the effect of photosynthate partitioning where varieties which had higher empty pod weight showed lower grain yields and those with lower empty pod weight showed higher grain yields underscoring the difference in varietal difference in photoassimilate partitioning in agreement with results by (Grussak, 2002) who observed differences in photosynthates partitioning among different crop species. The higher number of pods was positively correlated with higher grain yield in agreement with results by (Ali and Shakor, 2012; Peymaninia *et al*., 2012) who observed a positive correlation between number of pods ad grain yield. Besides, there may have been synergistic effects from the micronutrients contained in the foliar fertilizer as supported by the study conducted by (Imtiaz *et al.,* 2006) who revealed that by supplying beans with micro nutrients either through foliar fertilizer or seed treatment increased the yield as well as macro nutrient use efficiency (MUE).

5.3.6 Effect of foliar fertilizer application rate on empty pod weight and biomass Production of bean varieties under green house and field conditions

Results of empty pod weight showed that those varieties which recorded the highest grain yield had the lowest pod weight thus showing inverse relationship between grain yield and empty dry pod weigh. This may be due to differences in bean varieties in transferring the photo-assimilates from the source to the sinks. The increase in dry pod weight may also be due to progressive increase in the concentration of nutrients from the leaves to the sinks of the bean varieties. This study was in agreement with earlier work by (El-Habbasha, 2007) who reported increasing empty pod weight with increasing foliar fertilizer application. Similar findings were reported by (Odeleye *et al*., 2007) who found that nitrogen foliar fertilizer on bean varieties led to an increase in empty dry weight of its pods.

The increase in biomass production may be attributed to nitrogen and micro nutrients ability to stimulate vegetative biomass production. The results concurs with the study carried by (Mitova and Stancheva, 2013) who reported that biomass production is associated with increase in concentration of nitrogen in plant tissues leading to increased vegetative growth among the bean varieties as a result of foliar fertilizer application. The results were also in agreement with the study conducted by (Kushwaha, 2001; Kimithi *et al.,* 2009) who reported an increase in biomass due to increasing nitrogen foliar fertilizer application.

5.3.7 Effect of foliar fertilizer application rate on harvest index under green house and field conditions

There was a significant difference of harvest index among the varieties without fertilizer application. This could be attributed to the differences of the bean genotypes in fixing the atmospheric nitrogen through their root nodules and transferring the assimilates to grain relative to other plant parts as observed by (Akter *et al.*, 2014). Varieties which had high harvest index had low biomass and high grain yield. Harvest index was higher in varieties which put photosynthates to grain rather than vegetative parts. Increase in foliar fertilizer application encouraged vegetative growth rather than the grain yield. This agrees with the results obtained by (Urzúa, 2005) who observed increased harvest index due to increase in grain yield at the expense of biomass production in some crop varieties.

5.3.8 Correlation between grain yield and yield components under green house and field conditions

The significant positive correlation observed in pod length and biomass, grain yield and biomass, number of pods and biomass, number of pods and grain yield agrees with earlier findings by Duarte and Adams, 1972; Prakash and Ram, 1981; Helvacýoglu and Sehirali, 2001; Yorgancilar *et al.,* 2003 who found that bean seed yield per hectare was positively correlated with number of pods per plant, pod length, plant biomass, number of seeds per pod and seed yield per plant.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The study evaluated selected bean varieties based on their imbibition rate and the effects of foliar fertilization in order to establish their genetic potential to adapt in ASALs of South Eastern Kenya region. The study revealed significant variability among the bean varieties for most of traits studied. It was confirmed that under laboratory conditions, imbibed seeds offer more advantage over unimbibed seeds as they germinate significantly earlier compared to un-imbibed seeds. On the basis of yield of the bean varieties under green house conditions Wairimu Dwarf produced the highest grain yield compared to all other varieties followed by Wairimu, Piriton, KAT B9 and GLP 1004, KATRAM = KAT 56, KAT B1, GLP 2 in that order while under field conditions Wairimu had the highest grain yield followed by Wairimu dwarf, Piriton, and KAT B9 in that order. On the basis of relationship between bean grain yield and yield components of bean varieties under green house and field conditions the study revealed positive significant correlation between grain yield and selected yield components under green house conditions on the following traits: biomass and grain yields,stem girth and grain yield,stem and biomass, chlorophyll and grai yield,chlorophyll and biomass,chlorophyll and girth.Under field conditions the study revealed a positive significant correlation in the following traits: Pod length and biomass, biomass and grain yield, number of pods per treatment and biomass, number of pods per treatment and grain yield**.**

6.2 Recommendations

1. Based on findings of this study Wairimu,Wairimu dwarf, Piriton and KAT B9 imbibes water faster compared to other varieties and therefore can be recommended for ASALs where rainfall is low and variable.

2. Foliar fertilizer application should be encouraged among farmers in ASALs for the purpose of increasing yields of beans.

3. There is need to develop bean varieties which are ecologically adaptive to ASALs interms of yield productivity. This can be done through plant breeding.

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