INFLUENCE OF LIME AND FERTILIZER APPLICATION ON GROWTH AND YIELD OF DRY BEAN (*Phaseolus vulgairs* L.)

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This is my original work and has not been submitted for an award of a degree in any university

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DEDICATION

To my beloved husband Mr. Joseph Ezbon Idri and my children Payi, Lusi, David, and Ludi for their love, patience, understanding, and prayers during this study. May the almighty God bless you all.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA: Analysis of variance

CGIAR: Consultative Group for International Agricultural Research

AL^{3+}: Aluminium ion

CV: Coefficient of variation

^0C: Degree centigrade

DNA: Deoxyribonucleic acid

EC: Electrical conductivity

FAO: Food and Agriculture Organization of the United Nations

KALRO: Kenya Agricultural and Livestock Research Organization

LSD: Least Significant Difference

RNA: Ribonucleic Acid

SSA: Sub-Saharan Africa

ABSTRACT

Dry bean (*Phaseolus vulgaris* L.) is an important legume crop in the world. The crop is widely cultivated in both developed and developing countries. In Kenya, dry bean is a staple food crop, which comes second after maize as a source of calories, and its production is partially constrained by soil acidity and infertility. The study evaluated the effects of liming, farmyard manure, and inorganic fertilizers on the growth, nodulation, and yield of dry beans. The experiment was set up in a randomized complete block design with a split-plot arrangement, conducted over two rainy seasons at two locations, Kenya Agricultural and Livestock Research Organization (KALRO)-Embu and Mwea in Embu County and Kirinyaga County respectively. Two improved bean varieties namely KATB1 and TASHA were tested. The amendments used comprised the application of agricultural lime (5 t ha^{-1}), goat manure (10 t ha^{-1}), phosphorus (40 kg ha^{-1}), potassium (60 kg ha^{-1}), and nitrogen (20 kg ha^{-1}) both singly and in combination while control plots had no external amendments. Data was collected on plant height, nodulation, pest incidence, disease incidence**,** shoot biomass, yield, and yield components. Soil samples (before planting and after harvest) and manure samples were taken and tested for total nitrogen, potassium, available phosphorus, calcium, magnesium, organic carbon, and pH. After harvest, plant tissue was taken and analyzed for P, N, and K content. Application of Lime, goat manure, P, N, and K had no significant effects on all the chemical properties of soil in Embu and Mwea, except that, the application of goat liming significantly increased soil magnesium in Mwea. Significant effects of agricultural lime and goat manure were detected on all plant parameters. A single application of lime and goat manure in combination with NPK fertilizers recorded taller plants and a higher number of formed nodules at vegetative and flowering growth relative to control and NPK treatments in both sites. Application of goat manure singly recorded a higher number of pods per plant and higher shoot biomass relative to control and NPK treatments. Seed weight and grain yield were higher in plots amended with sole lime and manure than in control plots and plots amended with NPK treatments. Application Lime increased the grain yield four-fold. Nitrogen, P, and K treatments showed no significant effects on plant height, nodule number, pod number, and shoot biomass. TASHA and KATB1 varieties had no differences in grain yield components in the two sites and seasons. The KATB1 variety recorded a higher number of seeds per pod, pod weight, pod number, and shoot biomass in KATB1 than the TASHA variety in Embu and Mwea during the long rains. During the long rains, variety and soil amendment interactions significantly affected bean shoot biomass and grain yield in Mwea. KATB1 variety recorded higher shoot biomass and grain yield weight in plots treated with lime followed by plots treated with manure compared to control and P, K, and N treatment. The application of the treatments had no significant effects on root rot and bean fly incidences during the experiment. A positive relationship was identified between yield and seed weight linear relationship (R^2 ranged between 0.663 and 0.889). The results demonstrate that a single application of lime and manure and their combination with NPK significantly affected all the collected data except, pest and disease incidents that were not significates affected. As per that, lime and goat manure can be used to develop nutrient and low pH management options to improve dry bean productivity

Keywords: Grain yield, nodules, NPK, pH, *Phaseolus vulgaris*, plant height.

CHAPTER ONE: INTRODUCTION

1.1 Background information

The dry bean (*Phaseolus vulgaris L.*), known as the common bean, is an essential legume crop, representing about 50% of the legumes utilized globally (Mwajuma *et al.*, 2017). Wild dry beans originated in Mesoamerica and were domesticated in Mexico and the Southern part of America (Arenas *et al.*, 2013). The crop was found in Mexico's Valleys. In the year 1504, traders introduced the crop to England from which the crop reached Africa. Dry beans are a main source of food nutrients in southern and eastern regions of Africa. The crop is rich in folic acid, protein, fiber, complex carbohydrates, vitamins, and some micronutrients (Broughton *et al.*, 2003). Dry beans strongly support food security and nutrition for poor producers and consumers and help in decreasing the risk of some diseases such as diabetes, heart attack, high glucose levels, and cancer.

Dry bean is grown worldwide on about 23 million hectares with production of about 12 million metric tonnes per year, by which about 2.5 and 5.5 million metric tonnes are produced in African countries and Latin America, respectively (Broughton *et al.*, 2003 In Africa, the crop is cultivated by smallholder farmers mainly concentrated in the central and east African regions, where it is mostly grown by women. Kenya is the principal producer of dry beans in terms of cultivation followed by Uganda and Tanzania (Katungi *et al.*, 2010). In terms of production, Uganda occupies the first place followed by Kenya and Tanzania. In terms of local consumption, about 200 million people in 24 countries in Sub-Saharan Africa consume dry beans, the consumption reaching up to 66 kg/year/person in Rwanda, Burundi, and Kenya (CGIAR, 2012). In Kenya, dry bean is a staple food crop, which comes second after maize as a source of calories. The crop is grown mainly during long and short rainy seasons in Central, Western, Eastern Rift Valley, and Nyanza districts (Muthamia *et al.*, 2013).

In Africa, the usual annual production of dry beans is always lower than in the world (Graham *et al*, 1997). The low yield is due to biotic and abiotic constraints and poor agronomic practices. Abiotic constraints include excessive and erratic rainfall, high temperatures, soil infertility, soil salinity, soil acidity, and drought (Oster *et al.*, 1998; Mwang'ombe *et al.*, 2007). Biotic constraints include diseases such as anthracnose, root rot, and angular leaf spot and insect pests such as bean flies and white flies (Allen *et al.*, 1996). Soil acidity and low soil fertility are considered some of the major constraints to the productivity of dry beans in Kenya.

Dry bean productivity in Africa is consistently low when compared to global production. (Graham *et al.*, 1997). The low production is because of abiotic, biotic constraints and poor cultural practices. Important abiotic constraints include soil acidity, high temperatures, irregular and excessive rainfall and soil salinity, drought, and soil infertility (Oster *et al.*, 1998; Mwangombe *et al.*, 2007). The biotic limitations include diseases such as anthracnose, root rot, angular leaf spot, white mold, and insect pests such as stem maggots, bruchids, and bean flies (Allen *et al.*, 1996). Infertility and acidity of the soils are considered the major constraints to dry bean production in Kenya.

1.2. Problem statement

Dry bean production in most African regions is generally low due to soil infertility as a result of continual cultivation, without replenishing nutrients, and low soil pH. The annual grain yield is lower than 0.65 t ha^{-1} compared to the expected grain yield of 1.2 t ha^{-1}, resulting in a big gap yield of about 0.55 t ha^{-1} (FAO, 2010 In Kenya, the annual production of dry beans remained at an average of 0.524 t ha^{-} for about 30 years as reported by FAO, (2010). In Nyeri County, dry bean yield averaged 0.22 ton/ha for an intercropping system and 0.30 ton/ ha for a monocropping system (DAO Nyeri, 2010). This is partly due to soil infertility and acidity. Mwea in Kirinyaga County of central Kenya is characterized by different types of soils namely, sandy soil, black cotton, red volcanic soils, and loamy soils. In some areas, soil is characterized by poor water-holding capacity and low organic matter. Therefore, plant nutrients such as carbon, P, K and N are low. As a result, soil fertility in the area is low for optimal growth of the crops (Kanake, 1986). In Embu County, due to hydrogen ion saturation, high aluminum, and lack of Ca and Mg, soils are humic nitisols with high acidity (Benvindo *et al.*, 2014). Low soil pH in the area is responsible for the low microbial diversity in the soils, which leads to reduced breakdown of organic residues and release of nutrients. Additionally, soil acidity disturbs crop development at all stages of growth, it reduces the persistence of rhizobia strain in soil and inhibits root–hair infection, nodulation, and nitrogen fixation (Wood *et al.*, 1984). Soil microorganisms are also affected by high aluminum levels in acidic soils, mostly the bacteria responsible for nitrogen fixation (Peoples *et al.*, 1995).

1.3 Justification of the Study

Studies done by Ann (2017) showed that farmyard manure improves the nutrient content of the soils, soil structure, water retention, and soil aeration, and reduces acidity by discharging negatively charged sites to bind H^+ in acidic soil. The common method used to raise soil pH is through liming of acidic soil (Bolan *et al.,* 2003). Liming might also reduce aluminum and iron toxicity by raising soil pH and causing negative charges on soil particles (Mandal, 1998). Therefore, liming of acidic soils is advisable.

Chemical fertilizers release necessary nutrients such as N, K, and P into the soil and make them available for plant uptake, thus they improve growth and yield. However, over-application of some of these fertilizers can cause acidification harm to the soil (Ojeniyi *et al.,* 2006). Dry beans are an important food crop and the main source of carbohydrates, protein, and necessary micronutrients in southern and eastern parts of Africa especially Kenya, it is essential to develop nutrient and low pH management options to improve its productivity. This can be achieved through the surface application of Agricultural lime to lower soil pH and the application of fertilizers to improve plant nutrients in soil. Thus, it is essential to assess the effects of agricultural lime, organic manure, and inorganic fertilizers on dry bean growth, nodulation, and grain yield.

1.4 Study objectives

The study was set up to develop low soil pH and soil nutrient management strategies for improving common bean productivity in both Kirinyaga and Embu counties, Central Kenya. The specific objectives of the study were:

i. To assess the influence of agricultural lime on soil pH, dry bean growth, root nodulation and grain yield
ii. To assess the influence of organic and inorganic fertilizers on soil pH, dry bean growth, root nodulation and grain yield

1. 5. Hypotheses

I. Liming raises soil pH and improves dry bean growth, root nodulation, and grain yield.
II. Application of organic fertilizers raises soil pH and improves dry bean growth, root nodulation, and grain yield

CHAPTER TWO: LITERATURE REVIEW

2.1 Biology, environment, and importance of common bean

Dry bean (*Phaseolus vulgaris* L.), is an annual herb crop from the Leguminosae family and *Phaseolus* genus. The crop has about 80 cultivated and wild varieties and genetically is a diploid (2n = 2X = 22), either self or cross-pollinated. It has dense foliage with three lengthened flyers (Menbere *et al.*, 2017). Dry bean has white to violet-purple flowers, pods are straight or curved about 10-25 cm long, and slender in shape. Its seeds are generally kidney-like in shape, with dissimilar colors and sizes (6 to 15 mm long), mainly black, white, red, brown, and spotted (Sinha *et al.*, 1999). The germination period of the seeds normally is about five to eight days depending on environmental factors, and the variety (Amanullah and Muhammad, 2011).

Dry bean has varied habits of growth, namely indeterminate, runner or climbing, and bush type which is a favorite among African farmers (Chirwa *et al.*, 2011). The crop has a pronounced taproot, which quickly grows to one-meter deep with horizontal roots commonly confined to the top 61 centimeters of the soil. Dry bean fixes less than 12 kg of nitrogen ha^{-1} which is very low compared to other legumes (Hossain *et al.*, 2017).

Dry bean is ready for harvesting within 60-80 days after sowing, when all pods have turned yellow and dried, and the moisture content of the seed is 15-16.0%. When the seed moisture content is less than 12.0%, winnowing could cause damage to the seed and will be rejected by seed companies, seed canners, and growers (Amanullah & Muhammad, 2011).

Many varieties of dry beans are cultivated in Kenya. These comprise TASHA, KATB1, Mwitemania, Canadian Wonder, Rosecoco, and KK 15 (Katungi et al., 2009). The bean breeding program at the University of Nairobi has released newer varieties namely, Kenya Sugar, Miezi Mbili, New Rosecoco, Kabete Super, Kenya Umoja, Kenya Wonder, and Super Rosecoco (Kimani, 2014).

The dry bean is a tropical American native that was brought to Africa by traders from Brazil and is a major food crop in the warm regions of the world. The crop is adapted to warm weather and this makes it vulnerable to low temperatures at all stages of its growth (Gebre *et al.*, 2014). The crop is generally grown in the highlands of tropical central and eastern Africa and in the south and north where it is cultivated as an irrigated winter crop. The optimum temperatures for crop growth ranges from 20^{0}C to 24^{0}C. Temperatures below 20^{0}C decrease plant growth, whereas temperatures of 15 ^{0}C to 20^{0}C after the flowering stage, delay the maturity, damage the plant tissues, and affect the filling of pods. Amanllah and Muhammad (2011) reported that high temperatures cause rapid growth. The crop develops well at an altitude range of 800 to 2300 m above sea level, with rainfall ranging between 800 and 2000 mm annually. Irregular, excessive rain and long droughts increase disease occurrences, cause flower abortion, and decrease grain yields, while drought is needed during the harvest period (Yonts *et al.*, 2018). Dry bean grows well in moderately fertile soil with sufficient organic matter, with a pH above 5.5, free of weeds, and well-drained (Wortmann *et al.*, 1998).

Dry bean is globally available in big markets as fresh seeds, dried and canned. Its production in Africa is partially in 10 countries and Kenya has the most cultivated land (FAO, 2018). Africa produces about 2.6 metric tonnes of dry beans annually. As reported by FAO (2018), Uganda is the first in terms of production followed by Kenya and Tanzania. In central Africa, the crop is mostly cultivated for family consumption and generally grown as a mono-crop or intercrop with two or more crops such as cassava, maize, and banana (Allen *et al.*, 2007). The crop is also alternately sown with maize and sorghum to improve the yield and to be alternatively used when the main crop fails. In southern and eastern regions of Africa, the common bean is used in many recipes; fresh, green pods, and dry grain. It can be cooked in different dishes; such as a stew of immature fresh, pods stew, dry grains stew, and beans mixed and boiled with staple crops like sorghum and maize.

In Congo and Rwanda, the daily rate of dry bean consumption ranges from 200 to 300 kg/day. In Ethiopia, the consumption rate at the farm level ranges from 1.0 to 16.0 kg /person/ year and it is mainly cultivated for home consumption and canning (Ferries and Kaganzi, 2008). Kenya produces about 380,000 metric tonnes of dry beans annually while its demand is about 749,000 tonnes per year, the scarcity of 379,000 tonnes mostly imported from Ethiopia, Tanzania, and Uganda (Muthomi *et al.*, 2013). In Kenya, the crop is planted on around one million hectares by 1.5 million growers, mostly in the midlands and highlands of the Eastern, Central, Nyanza, Rift Valley, and Western regions that produce about 18.0%, 33.0% 20.0% and 13.0%, respectively

(USAID, 2010). Generally, the crop is intercropped with crops such as coffee, maize, and banana to improve soil fertility (Edie et al., 1981).

In Western Kenya, the consumption rate of dry beans is high, about 14.0 to 66.0 kg /year. About 70% of the crop is used for family consumption, with the remaining 30% being sold as fresh grain, canned grain, and dried grain (Spilsbury *et al.,* 2004; Chirwa, et al., 2011).

2.2 Major Factors limiting bean production

Dry bean production is limited by biotic and abiotic factors (Frahama *et al.,* 2014). These include soil infertility, low pH, diseases and pests, extreme temperatures, poor cultural practices, excessive rainfall, and dry spells (Asrat *et al.*, 2013). Low soil fertility as a result of low organic manure use, nutrient deficiencies, poor agronomic practices, removal of nutrients during harvest, overuse of farmland, soil salinity, and low soil pH, is a common constraint in African farms (Beebe *et al*., 2012). Inanga (2006) reported that salinity of the soils reduces the potential of water at the root zone as well as reduces water uptake by plants, which leads to depression in shoot transport of nutrients.

Insect pests such as bean fly, African bollworms, aphids, red spider mites, pod-sucking bugs, and bollworms and diseases such as anthracnose, root rot, rust, and angular leafspot are the most common abiotic factors. They lead to 75% to 99% grain losses, mainly at seedling growth and pod filing (Beebe *et al.*, 2011).

Common bean is delicate to hot weather that badly damages the seedlings, and flowers and affects pod growth and filling. Temperatures above 20^0C at night can cause pollen infertility and reduce fertilization (Yadav *et al.,* 2011). Drought conditions and the absence of rain affect about 60.0% of common bean productivity in Central America, Mexico, Eastern Kenya, Ethiopia, Northern Uganda Tanzania, and Southern Africa by creating a favorable environment for the development and spread of plant diseases (Beebe *et al.,* 2011).

In tropics and subtropics, where temperatures and relative humidity are high, stored dry beans experience about 50% losses in terms of seed value and seed quantity (Kenney *et al.*, 2011). These losses are commonly caused by storage pests such as flour mites, dry bean weevils, and bruchids

(Abate *et al.*, 1996). The seed embryo might be damaged by rodents and reduce germination rate and seed value (Tuda et al., 2004).

2.3 Impact of acidity on common bean growth, nodule formation, and yield

About 30% of the land in the tropics and sub-tropics is covered with acidic soils (Kochain, et al., 2004). Eswara (1997) reported that about 28.9 % of African lands are covered with low-acidity

Soil acidity is a critical factor restricting the production of dry beans globally (Dejene, *et al.*, 2015). In Eastern parts of Africa, 52% of soils are covered by acidity with an average pH of 5.2 (Graham *et al.*, 2003). Soil acidity limits crop growth by reducing nutrient uptake and yield (Giller *et al.*, 2006). In Kenya, 13% of farming land has been determined to be acidic with high levels of Al^{+3} and Fe^{+} and a pH range from 3.9-5.5, resulting in high phosphorus adsorption and deficiency of essential elements in the soil solution (Kanyanjua *et al.*, 2002; Owino *et al.*, 2015). Discharging of hydrogen, aluminum, and manganese ions into the acidic soils, leading to toxicity causing root damage, and affecting crop development. Acidity disturbs root initiation and lowers the availability of essential nutrients namely, Nitrogen, Potassium, and phosphorus, that are required for crop development (Benvido and Mugwe, 2018). It also reduced the uptake of some nutrients such as Mg, Fe, and Ca (Crawford *et al.*, 2008). Soil acidity also disturbs soil microorganisms that are responsible for enhancing soil quality and fixing nitrogen in the soil. Low pH limits *Rhizobium* survival in the soil and decreases nodule development hence affecting crop growth as well as yield. Studies done by Benvido and Mugwe (2018) in Embu County, showed that soils in Embu are acidic and, hence are characterized by low levels of nitrogen, potassium, and phosphorus in the soil which result in poor growth of plants and low production. For the dry bean to grow robustly on acidic soils, it requires a nutrient management plan to reduce the acidity and related phytotoxicity and eliminate deficiencies of some nutrients in these soils (Joachim *et al.*, 2013).

2.4 Effects of Inorganic and Organic Fertilizers on dry beans development, nodulation, and grain yield

Low soil fertility associated with low organic matter content and absence of important nutrients in the soil, is the major factor limiting dry bean productivity. Low organic matter content in the soil decreases the soil's water-holding ability and affects the soil structure, resulting in low yield (Islam *et al.*, 2016). Deficiencies of essential growth minerals such as boron, phosphorus, sulfur, nitrogen, magnesium, potassium, calcium, iron, and molybdenum in the soil lead to poor germination, root formation, and plant growth. Consequently, they prolong maturity, delay flowering, and cause extreme flower and pod abortion. It also results in underdeveloped seedlings, deformation, discoloration of the seeds, reduced seed weight, and yield loss (Allen *et al.*, 2007). Shanyn (1999) reported that the deficiency of calcium is uncommon because it is usually sufficient in soil and overuse of it limits the accessibility to other nutrients in the soil. The absence of calcium in the soil commonly appears on fruits as blossom-end rot and makes new leaves irregular in shape (Aleksandrov *et al.*, 2014).

Manganese deficiency causes the death of terminal buds and discolored spots on the leaves. Lack of iron and copper in the soil appears on newly developed plant leaves as necrosis and chlorosis (Korshunova *et al.*, 1999). Lack of boron results in short roots, and fruit failure. Zinc deficiency leads to a light, yellow color at the leaf tips and mid veins and plants appears short and distorted which may lead to plant death. In addition, it delays pod formation and plant maturity (Aleksandrov *et al.*, 2014). The common symptoms of nutrient deficiencies in dry beans may include yellow, bright green leaf deformation and discoloration of seeds, dwarf seedlings, and 100% yield loss (Singh *et al.*, 2003).

Verde *et al.*, (2018) reported that nitrogen, phosphorus, and potassium are the key nutrients needed by legume crops for root expansion, plant development, and filling of pods. Nitrogen is the major component of amino acids and proteins; it is needed for RNA and DNA production. Therefore, it is required for the support of plant tissues and growth. As reported by Thung and Rao, 1999, 60.0% of common bean production in central, eastern, and southern Africa is constrained by nitrogen deficiency. This results in a 40% decrease in production related to nitrogen-fertilized farms (Singh, 1999). Common symptoms of lack of nitrogen are; underdeveloped plants, yellowing of older leaves with pink color, and green leaves edges (Rajendran *et al.*, 2009).

Phosphorus is the main essential mineral nutrient after nitrogen and it must be taken directly from the soil solution (Verde *et al.*, 2018). Phosphorus is the most movable and obtainable nutrient in the soil and its absence is called ‘‘the bottleneck of world hunger’’ and is the most nutrient constraint of farming in most African lands (Henry and Smith, 2006). Elias *et al.*, (2016) reported that in tropical soils, lack P nutrients is generally a result of the solid adsorption of phosphorus by aluminum oxides, hydroxides, iron, and other shapeless materials. Phosphorus improves root formation and growth. It also improves flowering and fruit ripening and maturity. Whereas, its deficiency results in very short plants, poor root formation, slow growth, purple or reddish with necrotic tissues, gloomy yellow-green leaves, burnt leaf tips, and low fruit yield (Sompong *et al*., 2010). Lack of phosphorus in the soil is the main constraint of dry bean nodulation and nitrogen fixation that results in 40% grain yield losses in the world (Bargaz *et al.,* 2012). It is reported that sufficient phosphorus increases P uptake and utilization and, as a result, increases root initiation, plant growth, and nodule formations (Vance, 2001; Bargaz *et al.,* 2012).

Potassium is a very active mineral nutrient in the soil; it is an essential nutrient for plant development (Askegaard *et al.,* 2004). The nutrient increases plants' tolerance to biotic and Abiotic pressures, such as winter hardiness, frostiness, drought, pests, and diseases (Haile, (2009). Symptoms of potassium deficiency appear by drying of tips of the old leaf, and necrosis at the leave margins. Plants grown in this environment are extremely vulnerable to pathogens and diseases (Aleksandrov *et al*., 2014).

Farmyard manure is known for its valued soil nutrients when applied in a suitable amount with the right agricultural methods. The quality of organic materials used will have an impact on how readily available organic manure is in the soil, both its dry leaves and roots or animal manure (Abera *et al.,* 2005). The application of organic fertilizers as a substitute for chemical fertilizers as a source of nutrients for crop planting has received world concern due to the harmful effects of chemical fertilizers on the environment effects, fast nutrient loss of supplied fertilizers, high prices of chemical fertilizers (Gichangi *et al.,* 2009). By Roy et al. (2014), the possibility of ground and surface water resources degrading increases as a result of the accumulation of nitrogen, micronutrients, phosphorus, and nitrogen in soils. Research done by Liang (2011) showed that adding manure to the soil improves its chemical, physical, and biological characteristics by increasing its organic matter content.

Farmyard manure contains nitrogen, potassium, phosphorus, and micro and macronutrients that are needed by plants. The nutrient content of manure depends on animal type, variety of feeds and rations, assemblage and storage, environment, and methods of application (Verde et al., 2013). Farmyard manure recovers the soil's physical structure by increasing soil particle diffusion and capacity to hold water, and reducing soil compaction and surface erosion (Liang et al., 2011). Moreover, it raises the populations of soil microorganisms, enhances plant vigor, and decreases disease occurrence (Albiach *et al.,* 2000). Studies done by Kidanda (1999) indicated that farmyard manure application is one of the techniques used in tropical regions to restore soil fertility. Manure is the most common organic fertilizer used to improve crop production in central Kenya by about 80 % of households (Verde *et al.,* 2013; Mugwe et al., 2007). It discharges nutrients necessary for crop development and complexes with iron ion (Fe^{2+}) and aluminum ion (Al^{3+}) accordingly dropping their negative influence on crop development (Haynes *et al.,* 2001).

According to Gichangi *et al.* (2009), goat manure is second only to cow manure in accessibility for most small farmers. Goat manure improves phosphorous uptake by plants (Ojeniyi *et al.,* 2019). This is probably due to the special effects of various processes such as the complexation of toxic iron ions through organic acids, rise in soil pH, and blockage of phosphorus sorption sites by organic substances discharged by decaying organic materials (Elias et al., 2009). Studies done by Gichangi, *et al.,* (2009) showed that goat manure supplied high nitrogen to the soil and sufficient quantities of some other nutrients necessary for promoting healthy plant development and sustaining plant quality and production. A study done by Islam *(*2016) demonstrated that dry beans had better performance at all growth stages including germination, nodulation, flowering, and grain production under fields amended with organic fertilizers. Verbe *et al.,* (2013) narrated that, both chemical and organic fertilizers have several benefits for the soil; improve soil structure, increase availability of nutrients, and improve nutrient use efficiency due to improvement in the activity of soil microbes. Moreover, the application of fertilizers decomposes dangerous elements; balances the supply of nutrients, increases the capacity of the soil to hold water, enhances root initiation and crop growth, and increases grain yield.

2.6 Effects of liming on dry beans nodule formation, growth and yield

Application of agricultural lime to acidic soils is not commonly practiced by African farmers due to insufficient awareness of liming and its benefits to the soil and low accessibility to liming material due to high prices (Gitari et al., 2015.). Kisinyo *et al.,* (2012) stated that when lime is applied to the surface of an acidic soil, calcium and magnesium ions in liming material remove iron, aluminum, and hydrogen ions from the soil colloids, resulting in a reduction in soil acidity. Liming reduces the toxicity of magnesium (Mn^{2+}), iron (Fe^{2+}), and aluminum (Al^{3+}), improves soil properties as well increases accessibility of soil nutrients by plants (Kisinyo *et al.,* 2005). Moreover, liming increases microbial activities that break down organic residues and add organic manure to the soil as a result it improves the structure of the soil and reduces the leaching of nutrients in light-textured soils (Caires *et al.*, 2008). Liming of acidic soils has been advocated as the suitable technique to produce favorable pH for the growth of leguminous crops by decreasing the toxicity of Mn^{2+}, $Al^{3+,}$ and Fe^{2+} ions which cause root injury and make nutrients some nutrients unavailable, thus leading to reduced plant growth.

Kassa *et al.*,(2014) reported that the application of 0.40 t ha^{-1} of agricultural lime to an acidic soil under a dry bean crop lifted the soil pH from 5.3 to 6.2 and made phosphorus and other nutrients available for plant uptake, resulting in enhanced plant growth, nodulation and grain yield. Otieno *et al.,* (2018) in research on surface application of agricultural lime conducted in Western Kenya soils, reported that liming raised soil pH by about 2.2 and enhanced nutrient uptake by soybean. Additionally, it enhanced symbiotic nitrogen fixation and increased release of nitrogen from combined organic matter (Kisinyo et al., 2015). Organic matter dissolves the acidic elements of the soil by consuming protons and thus precipitating Mn^{2+} and Al^{3+}(Kisinyo *et al.*, 2005). Liming correct soil acidity and improve soil productivity. Common liming materials are hydrogen, oxides, carbonates, and silicates of Ca or Ca- Mg mixture. Lime dissolved slowly in moist soils and released Ca^{2+} and hydroxide HO- Relaesed OH^- will react with Al^{3+} from the surface of the acidic soil and solid $AL(OH)^{3+,}$ or it reacts with H^+ to form H_2O (Uchida *et al.*, 2000) Therefore, lime application removes toxic H^+ and AL^{3+} through reactions with OH. Extra hydroxide from liming material raises pH and makes the nutrients needed for nodule formation and plant growth (Zafar *et al.*, 2011). Buni (2013) indicated that over-limiting of soil could raise pH above 6, causing soluble phosphorus to form a compound with calcium, resulting in phosphorus and other soil micronutrient deficiencies and low yield.

CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of the research sites

The experiment was conducted in two sites: Kenya Agricultural and Livestock Research Organization (KALRO) - Embu and (KALRO) - Mwea. Mwea is located at a longitude of 37^{o} 27' 20'East and a latitude of 00 37'South (Figure 3.1). The area is characterized by warm weather with a temperature range between 18^{0}C to 30^{0}C and annual precipitation of 1679 mm. The rains fall into two seasons; long rains in mid-March to July, and a short season beginning from October to mid-January. The short drought spell is always from mid-June to mid-July (County K, 2014). The most common soils in Mwea are black cotton soils, sandy soils, red soils, and loam soils with low N, K, and P nutrients (Sakari *et al.*, 2017).

Embu positioned in South-Eastern Kenya, between longitude 0^{0} 8' 35''South and longitude 37°27′02″ east and latitudes 0^{0} 08' (Abuli, 2016). The area has a tropical climate with average temperatures ranging from 18°Cto 28°C and annual precipitation of 1500 mm. The rainfall is bimodal, with two distinct rainy seasons: a long season from mid-March to mid-July and a short season from mid-October to mid-January with a brief dry spell in between (County. K, 2014).

Embu occupies the most fertile soils with good environment for crop production (Embu County, 2014). Acidic humic nitrosols dominate the soils (Benvido, *et al.*, 2014). The soil acidity in the area has led to low populations of soil microorganisms and related to reduction in the decomposition of organic materials which results in low levels of macronutrients, like phosphorus and nitrogen, that essential for plant production (Benvido, *et al.*, 2014).

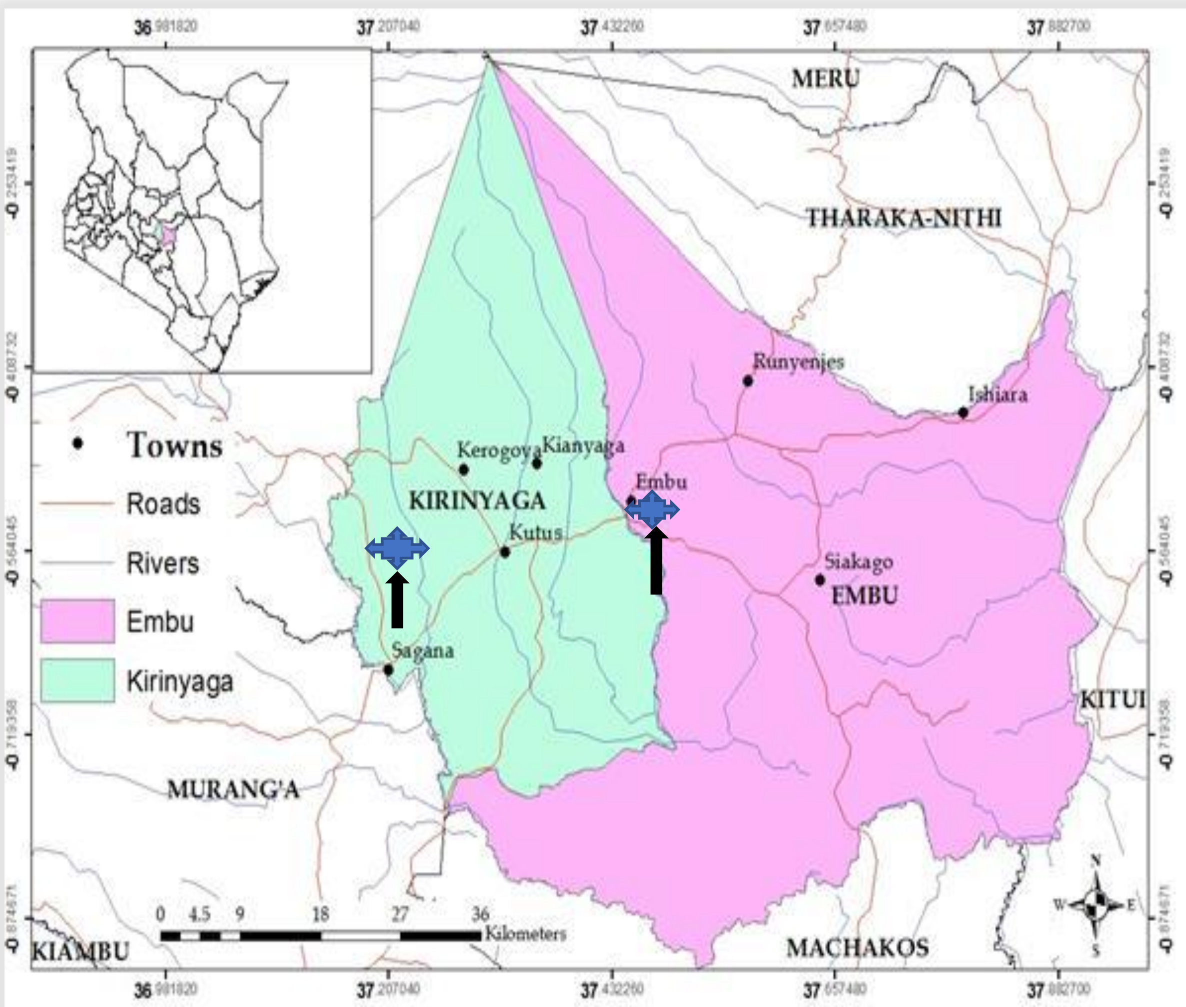

Figure 3. 1: Geographic map of the research sites (indicated by the arrows) in Embu and Kirinyaga Counties – Central Kenya

3.2. Treatments and the experimental design

The experiment was carried out in two seasons; long rains from end of March to end of August 2018 and short rains from mid- October 2018 to Mid-January 2019. In Embu, during the long rains the average rainfall received during the long rains was about 43.2 mm and temperature ranged from 20.9 ^{0}C to 18.1^{0}C, while during the short rains average rainfall received was about 46.3 mm and average temperature ranged from 14^{0}C to 25^{0}C

In Mwea County, the average precipitation during the long rains was about 325.0 mm, and the average temperature was 22.70C to 19.7^{o}C. The average rainfall was 192.8 mm and the average temperature ranged from 29.8^{0}C to 32^{0}C during the short rains

The soil amendments used were:

i. Control (No-amended)
ii. Phosphorus - 40 kg P/ha
iii. Potassium- 60 kg K /ha-
iv. Nitrogen - 20 kg N /ha
v. Lime, 5 tonnes/ha
vi. Manure, 10 tonnes/ha
vii. 10 tonnes manure/ha + 5 tonnes lime/ha
viii. 20 kg N/ ha + 40 kg P/ha + 60 kg K/ ha + 5 tonnes lime/ha
ix. 20 kg N/ ha + 40 kg P/ha + 60 kg K/ha + 5 tonnes lime/ ha + 10 tonnes manure /ha
x. 20 kg N/ha + 40 kg P/ha + 60 kg K/ ha + 10 tonnes manure/ha

Potassium, Phosphorus, and Nitrogen were obtained from; muriate of potash (60% K), triple super phosphate (46% P_2O_5), and urea (46% N), respectively. Agricultural lime was used for liming whereas goat manure was used as farmyard manure.

The amendments were set up in a randomized complete block design in a split-plot arrangement, with three replications. Two improved varieties of dry beans (KATB1 &TASHA) were allocated into the main plots. Lime treatment and the other fertilizers were consigned to sub-plots. The trial plot sizes were 2.0 m x 2.0 m, split by 0.5 m paths. In addition, 1.0-meter paths alienated the blocks. Goat manure and agricultural lime were supplied at a rate of 10 tonnes/ha and 5 tonnes/ ha, respectively, and the treatments were mixed within the plot before planting.

3.3. Crop management practices

The trial was carried out in two locations during the long and short rains; the first planting was done during the long rains on May 25th, 2018 at KALRO-Embu and May 29th, 2018 at KALRO-Mwea. In November 2018 and January 2019, the second planting was done at KALRO-Mwea and KALRO-Embu, respectively. In Mwea, during the short rains, the rainfall was not enough and the trial received additional sprinkler irrigation three times a week for 12 weeks. During this period total of 14.10 inches of irrigation water was used.

Bean seeds were planted in a spacing of 20.0 cm between holes and 40.0 cm between rows. Two bean seeds were planted in a hole. After seed emergence, emerging plants were thinned to one per hole to reduce competition for resources among the plants. Regular hand weeding was carried out every 21 days to maintain weed-free conditions in the plots. The plants were protected from aphids, root rot, and bean fly b application of Malathion 50% pesticide EC at the rate of 30.0 ml per 20.0 liters of water per hectare. The first spray was done two weeks after planting and thereafter every two weeks for two months.

3.4. Collection of the data

3.4.1. Manure and soil sampling and analysis

Soil samples from each plot were taken using soil rogue at a depth of 0-30 cm before planting, mixed to get 0.5 kg of homogeneous sample for the field. After harvest, three samples of soil were taken per plot at the same depth, mixed to get 0.5 kg of homogeneous sample per plot, and manure sample was also taken. The samples were tested for total nitrogen, potassium, available phosphorus, calcium, magnesium, organic carbon and pH using standard laboratory procedures (Benvido *and* Mugwe, 2018) at the Kenya Agricultural and Livestock Research Organization (KALRO) Kabete.

Soil samples were tested for total nitrogen using Kjedahl method (Page *at el.*, 1982). Other nutrients elements (K, P, Mg and Ca) were tested using Mehlich double acid method (Mehlich, *et al.*, 1962). Calorimetric method was used to test the total organic carbon (Anderson and Ingram, 1993). Soil pH was determined in 1:1 (w/v) soil – water suspension with pH- meter (Mehlich et al., 1962). (Table 3.1)

Table 3.1: Goat manure's chemical characteristics

Nutrients	%P	%K	%N	%Mg	%Ca	%Comg/Kg	Fe Mg/Kg	Zn mg/kg	Mn mg/Kg
Content	0.27	0.76	1.63	0.o6	0,27	18.3	2087	46.7	645
Adequate Range	4.1	1.9	4.9	0.9	1	20.5	5605	52.8	700

N= Nitrogen; K= potassium; P= Phosphorus; Mg= Magnesium; Ca= calcium; Co= Cobalt; Zn=Zinc; Fe= Iron; Mn= Manganese

Table 3.2: chemical characteristics Embu and Mwea soils

location	PH	N%	org. c %	P.pm	K%	Ca%	Mg%	Mn%	Co%	Iron%	Zinc%	Sodium%
Embu	4.7	0.2	1.6	30.0	0.2	0.4	1.6	1.5	1.9	34.5	24.2	0.5
Mwea	.0	0.1	1.2	250.0	1.4	10.8	2.9	0.7	1.7	63.5	2.7	0.7

pH= potential hydrogen; N= Nitrogen; K= potassium; P= Phosphorus; Mg= Magnesium; Ca= calcium; Co= Cobalt; Zn=Zinc; Fe= Iron; Mn= Manganese; Na= Soduim

3.4.2. Evaluation of agronomic parameters

Data were assembled on plant emergence percentage, initial vigor, plant height, stand count, days to 50% flowering, and days to 75% maturity. Emerged seeds per plot were counted to assemble data for emergence percentage. At two weeks after emergence, the plant vigor was measured and scored on an early vigor scale of 1, 2, ------ 9 representing excellence, very good, good, intermediate, poor, and stunted, respectively. Several emerged seeds per plot were counted to measure plant stand count. The heights of three plants in the center of plots were measured using a ruler, from the plant top to the end of the stem. Days to 50% flowering per plot were noted by assessing days taken for 50% of the plants in each plot to flower. Days to 75% maturity were established by the days taken for 75% of the plants in each plot to reach maturity.

3.4.3. Evaluation of Nodulation

Data for number of nodules formed per plant was collected at vegetative and at days to 50% flowering stages. Three plants were carefully uprooted from each plot, carefully removed and counted. The count nodules per plot were divided by three to get average number of nodules formed per plant.

3.4.4. Evaluation of root rot incidence

Data for root rot incidence was recorded at two and three weeks after emergence by counting the number of plants with the disease symptoms and scored on a scale of 1, 3, 5, 7 and 9 indicating 0%, 10%, 25%, 50% and 75%-100 % of disease symptoms, respectively. Infected plants were scored on the same scale according to the number of infected plants per plot (Corrales, 1987).

3.4.5. Assessment of Bean Fly Incidence

Plants affected by bean fly and aphids were counted at 2, 4, 6 weeks after planting and pest incidence scored using a visual nine step scale of 1, 3, 5, 7 and 9 indicating 0%, less than 10%, between 10% and 25%, between 25% and 50% and more than 50% of the leaf area or plant part consumed by the pest, respectively (Schoonhove and Pastor- Corrales, 1987). (Schoonhove and Pastor- Corrales, 1987).

3.4.6. Evaluation of yield and yield components

Pod number, pod weight, number of seeds per pod, one hundred seed weight, and grain yield per unit area were determined. Pods number and pod weight were taken at harvest when all the pods had dried. Three plants were selected per plot and the number of pods of the selected plants was counted. Several seeds from three selected pods were counted. A hundred seed weight was determined by weighing one hundred dried seeds, sampled randomly from the total harvest of the plots for each treatment, using an electronic balance. At harvest, three plants were sampled, sun-dried, and weighed to determine biomass weight. The yield was determined by harvested plants from the middle rows of a 2 m x 2 m plot to avoid border effects. The pods in each plot were removed and threshed, and the seeds were sun-dried to a moisture content of 12%. The dried seeds per plot were weighed to determine yield per plot.

3.4.7. Analysis of the plant tissue

During harvest three plants were removed and dried up in an oven at 40^0C. At KALRO- Kabete Laboratory, the dried plants were examined for N, K, and P nutrients using digestion in a tube with H_2O_{2-} salicylic acid -H_2SO_4- and selenium. Using distillation and titration with 0.3N HCl, total nitrogen was examined. Potassium was measured by flame photometer while phosphorus was verified colorimetrically by spectrophotometer (Walinga *et al.,* 1989)

3.5. Data analysis

All the assembled data were subjected to analysis of variance (Gomez and Gomez, 1984) using Genstat 15th edition computer software. The means of the treatments were compared using the protected Fisher's least significant difference (LSD) test at $P \leq 0.05$ Regression analysis were performed to determine the relationships between yield and yield components.

CHAPTER FOUR: RESULTS

4.1. Effects of liming and fertilizers on chemical characteristics of the soil

Application of lime, farmyard manure and inorganic fertilizers showed no significant effects on all soil chemical properties at Embu site (Table 4.1). A similar observation was made in Mwea site except for Mg content which was significantly affected by application of lime and fertilizers. In Mwea application of lime and farmyard manure significantly increased Mg% relative to no-amendment control and inorganic fertilizers. Nitrogen, P and K fertilizers had no effect on Mg content relative to no amendment (Table 4. 1)

Table 4.1: Effect of lime and fertilizers on the chemical characteristics of soil at KALRO-Mwea and KALRO-Embu sites in 2018-2019

Amendments	%N	pH	%P	%OC	%Mg	%K	%Ca
Mwea							
Control	0.20	5.00	215.0	2.10	3.10	1.20	7.80
Nitrogen	0.20	5.30	200.0	1.80	3.00	1.10	7.70
Phosphorus	0.20	5.60	178.0	1.90	2.70	1.10	7.10
Potassium	0.20	5.60	207.0	2.00	2.90	1.00	6.60
Manure	0.20	5.90	237.0	1.90	4.00	1.00	8.90
Lime	0.20	6.00	230.0	1.80	4.30	1.00	8.90
P-value	0.90	0.50	0.70	0.90	<0.004	0.40	0.70
LSD(5%)	NS	NS	NS	NS	0.80	NS	NS
CV%	4.10	4.50	26.6	5.10	7.70	6.60	24.20
Embu							
Nitrogen	0.20	5.20	38.30	2.30	2.70	0.80	2.00
Potassium	0.20	5.70	41.70	2.20	2.20	0.80	1.70
Phosphorus	0.20	5.00	35.00	2.30	2.40	0.80	1.70
Manure	0.20	5.30	41.70	2.20	2.50	0.80	2.10
Lime	0.20	5.70	41.70	2.10	2.80	0.80	4.70
P-value	0.80	0.10	0.20	0.70	0.20	0.80	0.10
LSD (5%)	NS	NS	NS	NS	NS	NS	NS
CV%	4.10	2.10	5.20	2.00	3.10	5.80	16.60

Keys: N= Nitrogen; pH= potential of hydrogen; P= Phosphorus; LSD = Least Significant Difference; OC= organic carbon; Mg=Magnesium; K= Potassium; Ca= Calcium; P-value= probability value; NS= Not Significant; CV= Coefficient of Variation.

4.2 Effects of fertilizers and lime on dry bean growth parameters

Interaction of Soil amendments and bean varities showed no significant effects on percent emergence, plant vigor, days to 50% flowering and days to 75% maturity in both sites and both seasons (Table 4.2). However, during long rains, soil amendments showed significant effects on plant height at vegetative and flowering stages in both sites. In Embu, the increase in plant height was 8.4 cm and 9.5 cm relative to the control non amended at vegetative and flowering stages, respectively. In Mwea, lime increased plant height by 12.2 cm and 11 cm compared to control at vegetative and flowering stages, respectively (Table 4.2).

During the short rain, application of fertilizers and lime showed significant effects on plant height at all stages in both sites (Table 4.2). All the treatments with lime had significantly higher plant height than zero- soil amendments and plots received nitrogen, phosphorous and Potassium fertilizers. (Table 4.2).

During the long rains in Mwea, KATB1 and TASHA varieties showed no significant effect on the percent emergence at the vegetative stage and the plant height at the flowering stages (Table 4.3). Relative to KATB1, the TASHA variety flowered and matured significantly earlier. The same observation was noted in Embu but the TASHA variety had significantly lower seedling emergence than KATB1. The two bean varieties showed no significant variation in days to 50% flowering (Table 4.3). The interaction of varieties with the fertilizers showed no significant effects on all the measured plant growth attributes (Table 4.3).

Table 4.2 Effects of soil amendments on the dry bean plant growth parameters during the long and short rains at KALRO-Embu and KALRO-Mwea sites during the long and short rains (2018-2019)

Parameters	%Emergence		Plant height (cm) at vegetative		Plant height (cm) at flowering		Days to 50% flowering		Days to 75% maturity	
Treatment/site	Embu	Mwea	Embu	Mwea	Embu	Mwea	Embu	Mwea	Embu	Mwea
Long rains-2018										
Control	94.00	93.20	8.90	10.8	10.0	11.60	47.30	49.80	76.20	77.20
Nitrogen (N)	96.80	76.0	9.60	9.60	8.70	11.20	43.70	49.70	75.70	76.20
Phosphorus (P)	96.70	89.0	9.40	14.10	11.20	13.50	44.80	49.30	75.70	77.00
Potassium (K)	95.00	86.80	10.90	11.60	10.00	10.50	45.30	48.50	75.80	77.70
Manure (M)	94.70	84.20	13.50	19.00	17.80	20.60	44.00	49.30	75.70	77.50
Lime (L)	97.20	83.70	17.20	23.00	19.50	22.60	44.70	49.30	76.20	79.30
Manure+ Lime	95.70	81.30	17.30	17.10	17.50	17.20	44.00	51.20	76.00	76.80
NPK+M	94.70	83.50	15.80	16.70	13.70	17.60	44.00	49.70	75.50	790.00
NPK+M+L	94.30	88.20	16.20	14.90	18.50	15.30	44.50	47.50	75.20	78.8
NPK+L	92.70	88.80	14.50	17.60	15.20	17.30	44.00	49.20	75.30	77.30
P-value	0.80	0.10	<.001	<.001	<.001	<.001	0.60	0.40	0.80	0.70
LSD (5%)	NS	NS	4.00	3.10	2.80	3.60	NS	NS	NS	NS
Short rains- 2018-2019										
Control	87.30	92.3	24.39	22.30	27.60	23.20	36.70	39.80	75.70	80.80
Nitrogen (N)	90.20	91.8	28.11	17.10	28.20	18.50	37.00	41.00	76.00	67.80
Phosphorus (P)	90.30	91.70	25.44	23.70	26.60	24.80	36.50	40.70	75.50	81.70
Potassium (K)	88.20	90.20	21.50	19.80	23.70	22.20	36.20	40.20	75.50	81.20
Manure (M)	9.010	93.0	41.33	29.20	40.20	30.80	36.30	40.20	75.30	81.20
Lime (L)	90.20	94.80	43.56	29.10	40.40	29.00	36.50	40.20	75.50	81.20
Manure+ Lime	88.80	93.00	39.39	27.50	37.70	31.20	36.70	40.20	75.70	67.00
NPK+M	87.50	97.70	31.0	25.10	30.80	25.30	37.50	39.50	76.50	80.50
NPK+M+L	87.80	91.80	37.28	26.80	36.80	26.20	36.70	4.10	76.00	82 .00
NPK+L	90.30	92.30	43.11	24.60	39.40	28.50	35.30	40.5	74.30	81.50
P-value	0.90	0.70	<.01	<.001	<.001	<.001	0.70	0.50	0.60	0.50
LSD (5%)	NS	NS	8.50	6.80	6.20	6.50	NS	NS	NS	NS

Table 4.3: Plant growth attributes of KATB1 and TASHA bean varieties grown in KALRO-Embu and KALRO-Mwea sites during the long and short rains (2018-2019)

Attribute	%Emergence		Plant height (cm) at vegetative stage		Plant height (cm) at flowering stages		Days to 50% flowering		Days to 75% maturity	
Varieties /location	Mwea	Embu	Mwea	Embu	Mwea	Embu	Mwea	Embu	Mwea	Embu
Long rains-2018										
KATB1	90.90	95.80	16.20	13.20	19.80	14.30	47.60	43.10	72.70	73.00
TASHA	80.10	94.50	14.70	13.40	19.00	14.10	51.10	46.20	82.60	78.40
P-value	0.10	<0.01	0.10	0.90	0.40	0.90	<0.001	0.30	<.001	<0.001
LSD (5%)	NS	1.20	NS	NS	NS	NS	0.50	NS	0.50	1.80
CV%	4.70	0.40	3.60	6.40	5.80	11.40	0.30	6.40	0.20	0.70
Short rains 2018-2019										
KATB1	93.90	95.30	24.90	35.10	26.10	34.20	39.50	33.60	80.50	72.60
TASHA	91.80	83.10	24.10	31.90	25.80	32.10	41.20	39.50	76.50	78.60
P-value	0.50	0.10	0.90	0.10	0.90	0.30	0.10	<0.001	0.60	<.001
LSD (5%)	NS	NS	NS	NS	NS	NS	NS	1.20	NS	0.70
CV%	3.30	4.20	20.10	3.800	17.30	5.10	1.90	1.00	9.10	0.20

Key: P-value= probability value; CV= Coefficient of Variation; NS= Not Significant; least significant Difference; CV= Coefficient of Variation.

4. 3: Effects of liming and fertilizers on nodulation of common bean

Soil amendments significantly affected number of nodules formed per plant at vegetative and flowering stages in the two locations and seasons (Table 4.4). Plots treated with manure and lime had a higher number of nodules per plant compared to control and plots treateted with single nitrogen, phosphorous and potassium fertilizers. sole application of manure and lime recorded a higher number of nodules per plant than plots treated with combinations of manure or lime with nitrogen, phosphorous and potassium fertilizers. No variations in nodule numbers per plant were observed between control nitrogen, phosphorous and potassium amended plots and among manure and lime treatments (Table 4.4). In both seasons, the average nodule number per plant was 15.5 at the vegetative stage and 19.5 at the flowering stage in Mwea while in Embu the average recorded was 13.10 and 17.40 at the vegetative and flowering stages, respectively. Single applications of manure and lime increased the number of nodules by 1.80 to 5.at vegetative and flowering stages at both locations

KATB1 and TASHA varieties showed no significant variation in number of nodules per plant at the vegetative growth and flowering stages in both locations and seasons (Table 4.5).

Table 4.4: Effect of liming and fertilizers application on nodule number per plant at vegetative and flowering stages in KALRO-Embu and KALRO-Mwea sites during the long and short rains (2018-2019)

Attributes	Nodules number per plant at the vegetative growth stage		Nodules number per plant at the flowering stage	
Amendments /location	Embu	Mwea	Embu	Mwea
Long rains-2018				
Control	7.70	7.21	7.30	7.30
Nitrogen (N)	7.10	6.81	5.40	11.50
Phosphorus (P)	6.21	7.71	5.70	11.50
Potassium(K)	8.21	9.71	9.50	14.70
Manure (M)	20.21	29.10	21.40	31.30
Lime (L)	16.00	24.10	25.70	21.70
M+L	16.30	22.80	19.40	20.30
NPK+ M	10.00	18.90	9.30	19.50
NPK +L	15.201	14.60	12.50	19.20
NPK+ L+ M	11.80	17.21	14.70	24.80
P-value	0.002	<.001	<.001	<.001
LSD (5%)	7.2.01	6.60	9.30	8.60
CV%	51.8.01	35.90	60.90	40.20
Short rains-2018-2019				
Control	4.21	4.700	14.31	9.01
Nitrogen	3.81	3.51	13.3	8.3.0
Potassium	10.70	6.70	17.5	13.01
Phosphorus	8.51	9.71	16.7	12.21
Manure (M)	20.50	24.71	27.8	27.20
Lime (L)	18.50	24.80	25.5	31.21
M+L	24.70	18.73	23	22.30
NPK+ Manure	19.01	19.32	25.2	23.31
NPK+ Lime	14.31	20.81	25.7	25.80
NPK+ Manure+ Lime	19.81	20.00	28.3	24.30
P-value	<.001	<.001	<.001	<.001
LSD (5%)	5.51	6.00	4.82	5.21
CV%	32.61	33.81	18.81	22.51

Key: LSD= Least significant difference; P-value= Probability value; K= Potassium; P= Phosphorus; M= Manure; L= Lime; CV= Coefficient of variation; N= Nitrogen

Table 4.5: Effect of dry bean variety on nodule number per plant at vegetative growth and flowering stages at KALRO- Mwea and KALRO-Embu sites during the long and short rains (2018-2019)

Attributes	Nodules number per plant at vegetative growth		Nodules number per plant at flowering	
Amendments /location	Mwea	Embu	Mwea	Embu
Long rains-2018				
KATB1	16.21	12.61	18.51	16.40
TASHA	15.42	11.20	17.82	9.71
P-Value	0.81	0.60	0.40	0.20
LSD (5%)	NS	NS	NS	NS
CV%	24.50	22.91	5.30	36.01
Short rains-2018-2019				
KATB1	16.21	14.51	20.41	21.91
TASHA	14.50	14.42	19.12	21.51
P-Value	0.21	0.90	0.61	0.80
LSD (5%)	NS	NS	NS	NS
CV%	6.42	9.70	10.91	8.30

Key: P-value= probability value; LSD= Least Significant Difference; CV = Coefficient of variation; NS= Not significant.

4.4 Effects of fertilizers and liming on root rot incidence and bean fly infestation on dry bean

Soil amendments showed no significant effects on root rot and bean fly incidence in Mwea and Embu during both seasons (Table 4.6). During the long rains, the incidence of bean fly varied from 37.7% to 45.4% in Embu while in Mwea it ranged from 5.7% to 10%. Root rot incidence varied from 23.8% to 30.7% in Embu and from 10.8% to 13% in Mwea (Table 4.6). During the short rains, root rot incidence ranged from 1.2% to 8.2% in Embu and 9% to 14% in Mwea and bean fly occurrence ranged from 13.7% to 25.2% in Mwea. However, in Embu, the range was from 1.8% to 14.7% (Table 4.6).

KATB1 and TASHA varieties were not significantly different in root rot and bean fly incidence during the two rainy seasons in both sites. During the long rains, the average bean fly incidence was 8.3% and 41% in Mwea and Embu, respectively. During the short rains, average bean fly infestation recorded was 7.3% in Embu and 19.5% in Mwea (Table 4.6). The average root rot incidence recorded during the long rains was 26.7% in Embu and 12% in Mwea, while during the short rains, the average recorded was 4 % in Embu and 12% in Mwea (Table 4.7).

Table 4.6: Effects of liming and fertilizers on root rot incidence and bean fly infestation on dry beans in KALRO-Mwea and KALRO-Embu sites in the long and short rains (2018-2019)

Attributes	Root rot %		Bean fly %	
Amendments /locations	Mwea	Embu	Mwea	Mwea
Long rains-2018/				
Control	11.50	25.50	8.81	40.50
Nitrogen (N)	11.20	30.71	9.71	43.11
Phosphorus (P)	11.70	23.71	9.70	37.81
Potassium (K)	13.00	28.20	8.81	40.30
Manure (M)	12.50	23.80	5.71	37.71
ZDFYLime (L)	10.80	29.40	6.82	38.71
M+L	12.20	30.00	9.23	45.31
NPK+ M	12.71	25.21	10.00	41.21
NPK+ L	12.31	23.81	5.72	40.80
NPK+ M+L	11.71	27.00	8.21	44.41
P-value	1.00	0.70	0.80	0.90
LSD (5%)	NS	NS	NS	NS
CV%	34.71	29.50	0.80	25.71
Short rains-2018-2019				
Control	9.72	4.21	18.50	7.71
Nitrogen (N)	14.31	4.82	20.30	8.01
Phosphorus (P)	9.00	3.53	14.81	6.31
Potassium (K)	13.32	8.22	23.72	14.72
Manure (M)	13.80	1.20	20.72	1.82
Lime (L)	13.23	4.21	20.51	7.22
M+L	12.71	4.51	20.00	7.81
NPK+ M	14.21	4.12	25.20	7.80
NPK+ L	10.71	2.72	17.30	4.50
NPK+ M+L	11.0 0	4.21	13.70	7.00
P-value	0.60	0.40	0.60	0.41
LSD (5%)	NS	NS	NS	NS
CV%	29.30	99.10	94.80	75.91

Key: N= Nitrogen; L= Lime; P= =Potassium; K= Phosphorus; M= Manure; NS= Not Significant; LSD= Least Significant Difference; P-value= Probability value; CV = Coefficient of Variation. %= percentage

Table 4.7: Root rot incidence and bean fly infestation in two dry bean varieties grown in KALRO-Mwea and KALRO-Embu sites in the long and short rains (2018-2019)

Attributes	Root rot incidence %		Bean fly% infestation	
Varieties /location	Mwea	Embu	Mwea	Embu
Long rains-2018				
KATB1	13.11	23.71	1.20	36.22
TASHA	10.81	29.71	15.3	45.82
P-Value	0.60	0.30	<0.04	0.20
LSD (5%)	NS	NS	11.80	NS
CV%	33.50	21.00	40.60	17.10
Short rains-2018-2019				
KATB1	11.91	0.80	19.11	1.31
TASHA	12.51	7.50	19.90	13.31
P-Value	0.70	0.10	0.80	0.10
LSD (5%)	NS	NS	NS	NS
CV%	13.60	75.90	19.00	75.90

Key: CV = Coefficient of Variation; NS Not Significant; P-value Probability value; LSD= Least Significant Difference, %= percentage

4.5. Effects of fertilizers and liming on yield and yield components of dry bean

During the short rains, pod number, shoot biomass, and grain yield were affected significantly by application of fertilizers and lime treatments in the Mwea and Embu (Table 4.8). The same was observed during the long rains in both sites except for the number of pods per plant that was not affected significantly by the applied treatments. During the long rains, all treatments with manure and lime recorded a high count of pods formed per plant compared to zero treatment in both locations. Potassium, phosphorus, nitrogen and manure treatments recorded significantly more pods per plant compared to lime treatment. Soil amendments showed no significant effects on seed count and pod weight during the long and short rains in both locations (Table 4.8). application of both Lime and manure singly plus lime treatments showed significant effects on shoot biomass and grain yield in Embu and Mwea sites during the two rainy seasons (Table 4.8).

TASHA and KATB1 varieties were not significantly different in yield components in both sites and seasons (Table 4.9). TASHA and KATB1 varieties significantly affected the number of seeds per pod and the number of pods per plant in both the Mwea and Embu sites. In the long rains, the KATB1 variety recorded higher pod weight, pod number, seed count per pod, biomass, and grain yield than TASHA in both locations (Table 4.9).

During the long rains, variety and soil amendment interactions significantly affected bean shoot biomass and grain yield in Mwea. KATB1 variety recorded higher shoot biomass and grain yield weight in plots treated with lime followed by plots treated with manure compared to control and phosphorus, Nitrogen and potassium treatment (Table 4.10).

Table 4.8: Yield and yield components of dry bean as affected by application of manure, lime, P, K, and N fertilizers in KALRO-Mwea and KALRO-Embu sites in the long and short rains (2018-2019)

Attributes	Pod count plant^{-1}		Pod weight (g)		Seed plant^{-1} (g)		Shoot biomass (g)		Grain yield (kg ha^{-1})	
Amendments /locations	Mwea	Embu	Mwea	Embu	Mwea	Embu	Mwea	Embu	Mwea	Embu
Long rains-2018										
Control	9.80	10.91	2.70	4.90	3.81	3.50	9.51	9.20	534.00	615.00
Nitrogen (N)	11.31	12.91	2.70	5.11	4.22	3.31	12.00	10.6	698.00	1010.00
Phosphorus (P)	10.32	12.22	3.20	5.43	3.73	4.00	10.72	9.90	1526.00	165.14
Potassium (K)	10.01	11.41	3.00	5.10	3.84	400	9.71	9.81	97.00	1030.00
Manure (M)	17.51	17.80	2.70	5.21	3.81	3.70	14.30	14.60	2222.00	2680.00
Lime (L)	13.20	15.20	2.81	5.61	4.01	3.81	13 .00	13.71	2815.00	3451.01
M+L	13.52	15.51	2.72	5.62	3.70	3.92	14.52	14.71	1882.00	1855.00
NPK+ M	13.00	13.70	3.20	5.31	4.22	3.92	13.81	14.42	1260.00	1572.00
NPK+ L	13.70	14.21	3.20	5.30	3.80	3.92	14.00	13.71	1355.00	158.100
NPK+M+L	13.31	13.61	2.70	4.80	4.30	3.81	14.00	13.42	1128.00	1379.00
P-value	<.001	<.001	0.90	0.80	0.70	0.40	<.001	<.001	<.001	<.001
LSD (5%)	1.60	1.90	NS	NS	NS	NS	1.20	1.50	109.1	507.20
Short rains-2018-2019										
Control	11.91	2.21	4.60	3.32	2.31	5.51	4.00	310.00	126.91	10.22
Nitrogen (N)	13.91	2.53	5.12	3.81	2.00	6.80	4.32	589.00	235.52	10.71
Phosphorus (P)	12.91	2.71	5.20	3.81	2.00	12.00	10.01	1152.00	460.83	12.22
Potassium (K)	12.53	2.52	5.11	4.22	2.31	8.20	6.00	516.00	206.31	10.73
Manure (M)	14.82	2.52	5.20	3.32	2.31	17.71	14.31	1770.00	708.00	11.52
Lime (L)	13.32	2.23	5.61	3.71	2.00	22.00	18.00	2218.00	887.21	12.20
M+L	15.00	2.31	5.71	4.00	2.31	14.00	12.71	1192.00	476.80	12.00
NPK+M	14.40	3.00	5.30	3.31	2.50	11.50	6.31	912.00	364.80	10.71
NPK+ L	13.90	2.52	4.91	3.31	2.00	10.21	8.00	1278.00	511.31	11.71
NPK+M+L	12.20	2.31	4.82	3.81	2.31	9.32	7.00	1014.00	405.70	10.71
P-value	0.20	0.90	0.60	0.30	0.60	<.001	<.001	<.001	<.001	0.90
LSD (5%)	NS	NS	NS	NS	NS	1.40	1.10	184.40	220.30	NS

Table 4.1: Grain yield and yield components of TASHA and KATB1 varieties in KALRO-Mwea and KALRO-Embu sites in the long and short rains (2018-2019)

Attributes	Pod count plant^{-1}		Pod weight (g)		Seed count pod^{-1}		Seed weight g plot^{-1}		Shoot biomass (g)		Yield kg ha^{-1}	
Varieties/locations	Mwea	Embu	Mwea	Embu	Mwea	Embu	Mwea	Embu	Mwea	Embu	Mwea	Embu
Long rains-2018												
KATB1	11.51	14.30	3.91	5.70	2.71	1.82	501.00	566.00	11.71	9.31	1254.00	501.41
TASHA	11.00	12.72	3.41	4.62	2.33	2.6	527.00	642.00	11.71	8.82	938.00	375.22
P-value	0.70	0.20	<0.01	0.2	<0.01	<0.0	0.70	0.60	0.90	0.20	0.1	0.10
LSD (5%)	NS	NS	0.1	NS	1.1	0.8	NS	NS	NS	NS	NS	NS
CV%	10.00	1.50	1.10	4.4	12.5	9.7	11.70	24.30	4.60	3.20	13.5	13.50
Short rains-2018-2019												
KATB1	12.61	14.63	4.01	5.93	2.71	4.21	609.70	708.00	13.00	12.51	1524.00	1770.00
TASHA	12.61	12.92	3.80	4.64	3.11	3.40	541.90	638.00	12.11	12.31	1355.00	1596.00
P-Value	0.10	0.20	0	0.40	0.30	0.40	0.20	0.60	0.60	0.20	0.40	0.10
LSD (5%)	1.10	1.90	0.7	0.80	0.20	0.50	120.80	137.30	0.80	1.50	302.10	343.20
CV%	2.60	3.90	4.8	4.50	2.50	3.70	6.00	5.80	1.70	3.40	6.00	5.80

Key: NS= Not significant, CV%= Percentage of coefficient of variation, LSD= Least significate difference, P.value= probability value

Table 4. 2: The interactive effects of soil amendments and varieties on dry bean shoot biomass and grain yield in the Mwea site during the long rains

	Shoot biomass (g)			Grain yield (kg ha^{-1})		
Amendments /Varieties	KATB1	TASHA	Means	KATB1	TASHA	Means
Long rains-2018						
Control	4.71	6.31	5.52	388.00	244.00	316.00
Nitrogen (N)	6.32	7.31	6.81	654.00	523.00	589.00
Phosphorus (P)	11.33	12.73	1201	1329.00	975.00	1152.00
Potassium (K)	8.00	8.31	8.22	566.00	466.00	516.00
Manure (M)	18.31	17.00	17.70	2046.00	1494.00	1770.00
Lime (L)	23.74	20.30	22.01	2344.00	2092.00	2218.00
L+M	14.00	14.00	14.00	1600.00	784.00	1192.00
NPK+ M	12.1	11.00	11.52	1125.00	699.00	912.00
NPK+L	10.30	10.00	10.24	1447.00	1110.00	1278.00
NPK+ L+M	8.71	10.00	9.31	1037.00	992.00	1014.00
Means	11.70	11.70		1254.00	938.00	
P-value variety	0.035			NS		
P-value T	<.001			<.001		
P-value VxT	0.03			<.001		
CV% V	4.60			13.50		
CV% Vx T	10.40			14.40		

Key: N= Nitrogen; LSD= Least Significant Difference; P=Phosphorus; NS= Not Significant; K= Potassium; T= Treatment (soil amendment); V=Variety; CV= Coefficient of Variation; L= Lime; M= Manure; P-value= Probability value

4. 6: Effects of soil amendments on the content of P, K, and N in common bean plant tissues

Application of soil amendment displayed no significant effects on Plant nutrient in Mwea and Embu (Table 4.11). The average percentage of potassium, nitrogen, and phosphorus nutrients in plant tissues varied from 0.10% to 0.4%, 0.50% to 0.7%, and 0.10% to 0.3%, respectively (Table 4.11).

Table 4. 3: Effect of soil amendments on the content of K, P, and N in dry bean plant tissues in Mwea and Embu sites

Site	Mwea	Embu	Mwea	Embu	Mwea	Embu
Amendments /nutrients	K%		N%		P%	
Control	0.40	0.31	1.00	0.71	0.11	0.11
Nitrogen	1.00	1.61	1.42	1.10	0.40	0.22
Phosphorus	0.91	1.52	2.11	1.00	0.42	0.22
Potassium	0.52	1.52	1.71	1.42	0.31	0.22
Manure	0.71	1.10	1.43	0.91	0.32	0.22
Lime	1.41	1.91	1.54	1.40	0.51	0.33
P-value	0.10	0.40	0.50	0.70	0.30	0.10
LSD (5%)	NS	NS	NS	NS	NS	NS
CV %	26.60	32.30	53.30	53.00	23.60	55.60

Keys: K = Potassium; P = Phosphorus; LSD = least significant difference; CV= Coefficient of Variation; P-value= Probability value; NS= Not significant,

4.7. Linear regression analysis for grain yield and yield component correlation

Shoot biomass, pod count, pod weight, seed count, and seed weight were all positively related to grain yield in Embu (Figure 4.1). Grain yield and shoot biomass (R^2=0.345), seed weight (R^2=0.663), pod count (R^2=0.0487), and pod weight/g (R^2=0.0146) were found to have a positive linear relationship. Shoot biomass, pod weight, pod count, and seed weight were all related positively to grain yield in Mwea (Figure 4.2). Significant and positive linear relationships were shown between grain yield and shoot biomass (R^2=0.012), seed weight/g (R^2=0.889), pod count (R^2=0.452), and pod weight (R^2=0.0121) (Figure 3).

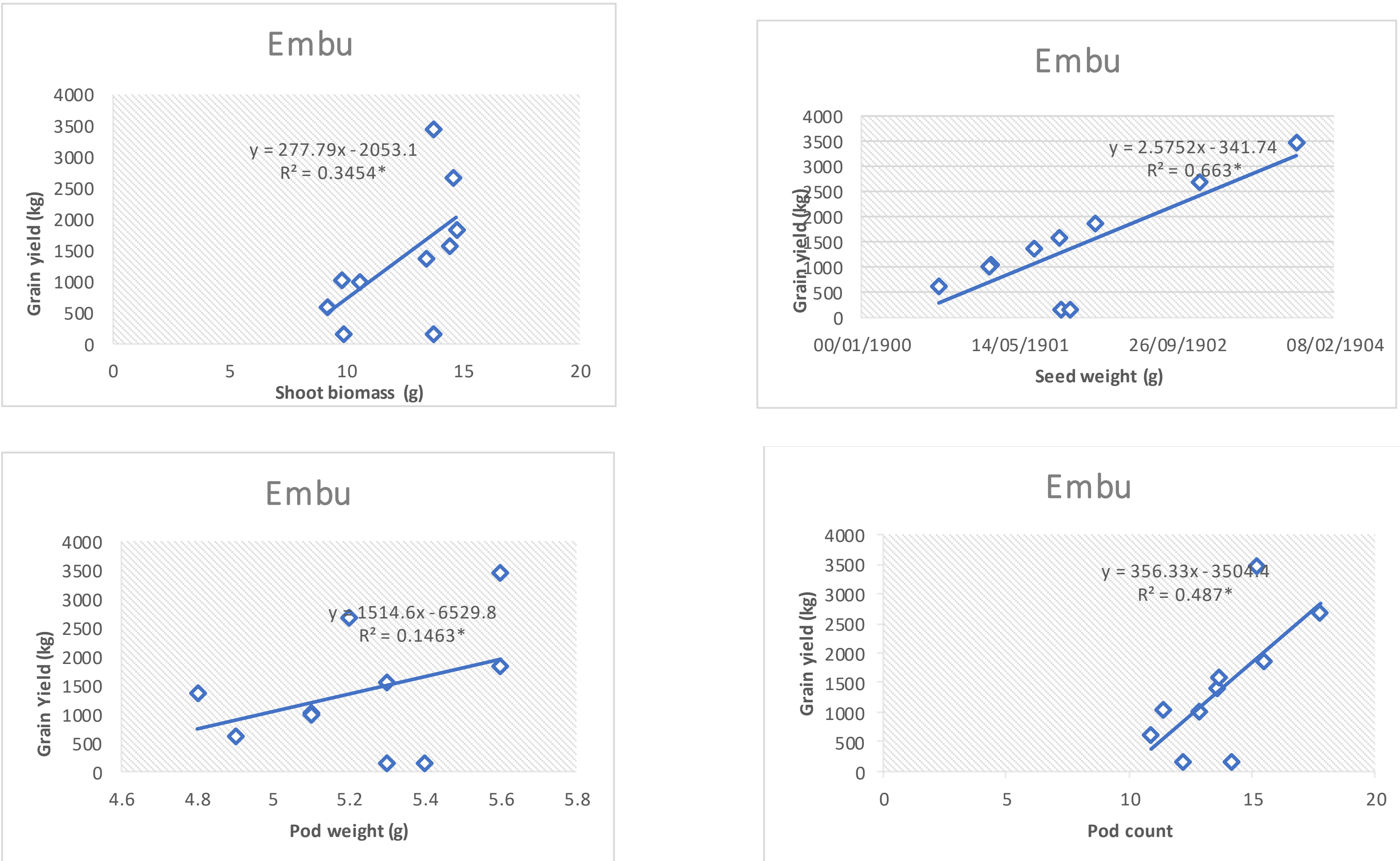

Figure 4.1: Relationship between grain yield and shoot biomass, pod weight, pod number, and seed weight at the Embu site

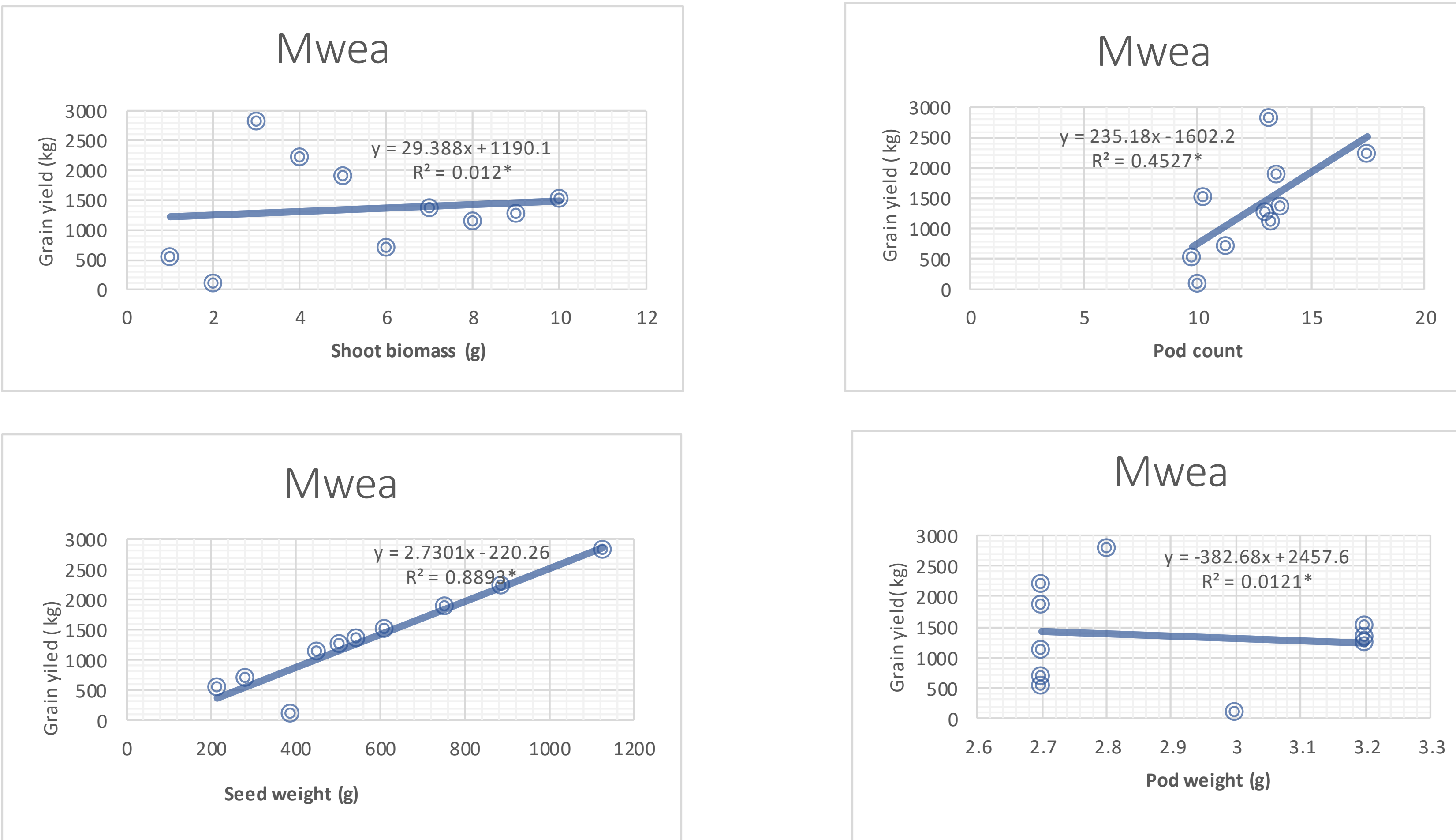

Figure 4. 2 **Relationship between yield and biomass, number of pod, pod weight and seed weight per plot in - Mwea**

CHAPTER FIVE: DISCUSSION

5.1. Effects of soil amendments on chemical properties of soils at Embu and Mwea sites

Agricultural lime, goat manure, and K, P, and N fertilizers showed no significant effects on the chemical properties of Embu soils. This suggests that the rates of the amendments applied were too low to effect significant change in the soil. This observation agrees with Ayalew (2011) who reported that the effects of fertilizers on soil nutrient availability increased with an increase in the application dose. In contrast, farmyard manure and liming increased Mg% significantly in Mwea. This could be due to the fact that application of manure and lime might have provided soil with additional Mg. Worldwide meta-analyses have demonstrated that the application of manure and lime increased potential of hydrogen (pH) of the soil by an average of 13% and 15%, respectively (Zhang *et al.*, 2023). This is similar to the observation in the current study in Mwea by which soil potential of hydrogen (pH) was increased by manure (18%) and lime (20%). In Embu, the increase under manure and lime treatments were 1.9% and 9.6%, respectively. The non-significant effect in this experiment, could be due to the fact that application of lime and manure treatments were done on a short-term basis. Long-term studies on the effects of manure and lime applications in the study sites would be desirable.

5.2 Effect of the treatments on dry bean plant height and biomass

Manure and lime-treated plants were taller and had more biomass than non-treated plants in both KALRO-Embu and KALRO-Mwea. Liming enhanced the pH of the dry bean rhizosphere by 20% in Mwea and 9.6% in Embu and may have improved the uptake of nutrients, root growth, and overall shoot biomass. Liming material may have provided the soil with calcium and magnesium that displaces Iron ion, hydrogen ion Al ion and Mangese on from soil colloids and raise soil protentional hygen. As a result, the released calcium and magnesium will be available for plant uptake and promote plant growth. The finding in the current study agrees with the study by Otieno *et al.,* (2018) on soybean in Western Kenya which stated that taller plants and high shoot biomass were recorded under lime treatment. The significant increase in shoot biomass and plant height under manure treatment could be related to the numerous potential benefits of farmyard manure to the soils. It ameliorates the properties of the soil by reducing soil compaction and erosion, and increasing organic matter content and soil water retention (Rasoulzaden and Yaghoubi 2010; Liang *et al.,* 2011). Organic manure is a major source of important nutrients such as P, K, and N. Phosphorous and K are essential for early stages of plant development, root initiation, and healthy plants. The present study results are in agreement with the findings described by Edmeades (2003) and Abera *et al., (*2005) that the high availability of phosphorus, nitrogen and potassium nutrients in manure is due to extra discharge of K, P, and N nutrients from manure during mineralization. Biomass was increased significantly by manure and agricultural lime treatments relative to the other amendments in Mwea and Embu. The significant increase noted in this research could be due to the favorable conditions for crop growth produced by organic matter and Ca released by manure and lime respectively. Lime discharges phosphorus (P) for easy plant use and reduces aluminum levels in the soil resulting in well-developed roots and an increase in shoot biomass. This agrees with Onwuka et al. (2009) who found that application of 2.0, 4.0, 6.0, and 8.0 megagrams of $CaCO_3/ha^1$ raised soil pH from 5.00 to 8.00. Studies done in Western Kenya showed that application of $CaCO_3$ significantly elevated pH and increased shoot biomass and yield (Okalebo *et al.,* 2009). Significant increase in plant height due to manure application may be attributed to the many potential benefits of manure to the soil. Farmyard manure improves soil properties by reducing soil compaction, increasing organic matter and water retention of the soil as well reducing its erosion (Rasoulzadeh and Yaghoubi, 2010; Liang *et al.,* 2011). Organic manure is a good source of important plant nutrients such as N, K, P and other micro nutrients that are required by plants for emergence, root development and growth (Verde *et al.,* 2013). Edmeades (2003) and Abera *et al.,* (2005) observed high available N, K and P under sole manure due to release of N, K and P from manure through mineralization.

Shoot biomass was significantly increased by lime and manure application compared to the other treatments in Embu and Mwea. The significant increase in shoot biomass with application of farmyard manure and lime observed in this study could be due to the favorable environment produced by the lime and organic manure and Ca released from the lime that increases soil Ph. Addition of lime to acidic soils result into the release of Phosphorus (P) for easy plant uptake and decrease in Al^{3+} levels in the soil. Onwuka *et al.* (2009) reported that the application of 2, 4, 6 and 8 mega grams of $CaCO_3/ha^1$, raised the soil pH from 5.02 to 8.04, while another study in Western Kenya, reported that application of $CaCO_3$ (Okalebo *et al.*, 2009) significantly raised soil pH and biomass yield. These research findings are also in agreement with Otieno *et al.* (2018) who reported that the highest soybean shoot biomass was in plots treated with lime and manure.

5.3 Effect of fertilizers and lime on common bean nodule formation

Liming significantly increased nodule number/plant in Mwea and Embu. This could be due to the fact that lime material improved soil acidity by increasing soil potentialhHydrogen (pH), and improved availability and uptake of nutrients especially P and micronutrients that activate initiation, growth, and activation of nodules (Zafar *et al.*, 2011). Furthermore, lime may release additional Ca^{2+} into the soil which may have formed positive conditions (raised soil pH) for rhizobia bacteria attachment to root hairs and the development of infection threads during nodule formation (Bambara and Ndakidemi, 2010). Studies done by Morón *et al.*, (2005) indicated that low soil potential hydrogen (pH) delays nodule formation by limiting the expression of rhizobia genes involved in nodule formation. Moreover, low soil potential hydrogen (pH) disturbs the exchange of signals between root hairs and bacteria necessary for the formation of infection threads (Otieno *et al.*, 2018).

Farmyard manure significantly increased the nodule number of plants in Mwea and Embu sites. Manure may have improved nodule development by releasing nutrients from manure which assisted the initiation of nodules. Additionally, during mineralization, manure always releases nitrogen into the soil for plant access (Muthomi *et al.*, 2009). Similarly, Otieno *et al.*, (2018) reported that sole application of manure and agricultural lime significantly increased the number of nodules per plant. Manure raised soil pH by adding base cations and organic matter which led to the depletion of hydrogen ions as a result of organic matter decomposition (Zhang *et al.* 2023).

Single application of phosphorus, potassium and nitrogen fertilizers displayed no significant effects on nodule formation. Low nodule formation under N treatments could have been due to high levels of nitrate released into the soil. Similar reports have been made by Otieno *et al.*, (2018) in their research on soybean in acid soils of Western Kenya and Ferguson and Mathesius (2003).

5.4 Effect of liming and fertilizer application on common bean grain yield and yield components

The pod count per plant and the grain yield were significantly increased by lime and manure applications. The increase in pod number and grain yield with liming could be due to the fact that liming neutralized soil acidity, increased availability of Phosphorus and other nutrients for plant uptake and it improves soil properties by reducing Al^{3+} toxicity, and increases the availability of phosphorus and other nutrients for uptake by plants (Kisinyo et al., 2005). This observation agrees with the findings by Abebe (2009) who observed that lime treatment increased bean pod number. In similar studies, Malik *et al.*, (2006) and Bhuiyan *et al.*, (2008) reported increases in soybean pod count per plant in experimental plots that were amended with lime. A high number of pods in plots treated with manure could be due to the availability of K, N, and P nutrients and micronutrients for plant use.

Increase in grain yield under plots treated with manure treatment could be due to increase in soil potential hydrogen (pH) that result to availability of P for plant uptake. In addition, manure improves the soil structure and the activities of microorganisms that comprise crop residue and improve soil structure and reduce nutrient leaching. These results are correlated with the results observed by Umoetok *et al.* (2007) and Verde et al. (2013), who reported high grain yield under lime and manure applications. This may be as a result of manure application that could improve soil physical and biological properties and increase soil water holding capacity as well improve nutrient uptake (Verde *et al.*, 2013).

Sole application of lime increased grain yield. This could be attributed to the fact that liming raises soil pH by suppressing aluminium ion toxicity, thereby improving the accessibility of phosphorus and some extra nutrients for plant uptake. This leads to improvement in plant growth, flower development, crop maturity, and grain filling. Furthermore, liming provides soil with more Ca and Mg which improves crop growth and grain production (Chiezey and Odunze, 2009). This fining is in agreement with Umoetok *et al.*, (2007) and Verde *et al.*, (2013), who stated that higher grain production of soybean was recorded under lime amended plots. Accordingly, farmyard manure is a good source of N, P, and K nutrients and also supplies the soil with micronutrients that are required by plants. Liming reduces soil acidity making the nutrients reachable by plants for easy uptake, and provides soil with more Mg and Ca^{2+}.

5.5 4 Effects of liming and fertilizers application on root rot rate and bean fly infestation on dry bean

Application of soil amendments had no significant effects on bean fly and root rot incidence in both sites and seasons. This could be due to the fact that lime could have improved soil pH in the dry bean rhizosphere, thus promoting root development. In addition, lime may have supplied soil with extra nutrients that improved crop growth. Manure application may be attributed to the many potential benefits of manure to the soil. Farmyard manure improves soil properties by adding organic matter to the soil, reducing soil compaction and erosion, and increasing water retention (Rasoulzadeh and Yaghoubi, 2010; Liang *et al.*, 2011) which may lead to a reduction in bean fly incidence and rot root.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Liming and application of fertilizers had no significant effects on soil chemical characteristics in both sites, except in Mwea where farmyard manure and lime amendments significantly increased Mg% content. Surface application of agricultural lime and manure singly and in combination increased the number of nodules per plant, plant height, grain yield, and yield components of dry beans. Sole applications of K, N, and P had no significant effects on dry bean growth, nodule formation, and yields. Soil amendments showed no significant effects on root rot occurrence and bean fly in Mwea in both seasons

6.2 Recommendations

1. Lime and goat manure can be used to develop nutrient and low pH management options to improve dry bean productivity
2. Carry out a similar trial long-term (4 rainy seasons) using a large number of dry bean varieties across a broad range of sites
3. Carry out a similar trial in regions with high levels of bean fly and root rot infestation

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APPENDICES

Appendix 1: ANOVA table for plant height of common beans at the vegetative growth in Embu during the long rains in 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	16.47	8.23	0.25	
Rep.Mainplot stratum					
Variety	1	0.77	0.77	0.02	0.892
Residual	2	65.52	32.76	2.78	
Rep.Mainplot.Subplot stratum					
Treatment	9	611.3	67.92	5.76	<.001
Variety.Treatment	9	46.68	5.19	0.44	0.904
Residual	36	424.72	11.8		
Total	59	1165.47			

Appendix 2: ANOVA table for the height of common beans at the flowering stage. Embu- Long Rain 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	27.3	13.65	0.52	
Rep.Mainplot stratum					
Variety	1	0.6	0.6	0.02	0.894
Residual	2	52.3	26.15	1.57	
Rep.Mainplot.Subplot stratum					
Treatment	9	881.93	97.99	5.88	<.001
Variety.Treatment	9	233.73	25.97	1.56	0.165
Residual	36	599.73	16.66		
Total	59	1795.6			

Appendix 3: ANOVA table for dry bean nodule count per plant at vegetative. Embu- Long Rain 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	340.9	170.45	2.31	
Rep.Mainplot stratum					
Variety	1	33.75	33.75	0.46	0.569
Residual	2	147.7	73.85	1.96	
Rep.Mainplot.Subplot stratum					
Treatment	9	1246.82	138.54	3.68	0.002
Variety.Treatment	9	380.42	42.27	1.12	0.372
Residual	36	1354.07	37.61		
Total	59	3503.65			

Appendix 4: ANOVA table for nodule count per plant at the vegetative stage of dry bean. Embu-Long rain 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	25.2	12.6	0.06	
Rep.Mainplot stratum					
Variety	1	663.56	663.56	3	0.225
Residual	2	441.73	220.87	3.49	
Rep.Mainplot.Subplot stratum					
Treatment	9	2675.58	297.29	4.7	<.001
Variety.Treatment	9	583.72	64.86	1.03	0.439
Residual	35	2213.06	63.23		
Total	58	6395.45			

Appendix 5: ANOVA table for dry bean seed weight per plot - Embu-long rain 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	110262	55131	0.26	
Rep.Mainplot stratum					
Variety	1	85277	85277	0.4	0.593
Residual	2	430711	215356	9.17	
Rep.Mainplot.Subplot stratum					
Treatment	9	887976	98664	4.2	<.001
Variety.Treatment	9	171281	19031	0.81	0.61
Residual	36	845880	23497		
Total	59	2531388			

Appendix 6: ANOVA table for biomass weight of dry bean - Embu-long rain 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	6.9333	3.4667	4	0.2
Variety	1	3.2667	3.2667	3.77	0.192
Residual	2	1.7333	0.8667	0.96	
Rep.Variety.Treatment stratum					
Treatment	9	1150.4	127.8222	140.87	<.001
Variety.Treatment	9	14.7333	1.637	1.8	0.101
Residual	36	32.6667	0.9074		
Total	59	1209.733			

-Appendix 7: ANOVA table for grain yield h^{-1} of dry beans- Embu- long rain 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	36568	18284	0.52	0.657
Variety	1	239023	239023	6.83	0.121
Residual	2	69989	34995	8.82	
Rep.Variety.Treatment stratum					
Treatment	9	2881606	320178	80.66	<.001
Variety.Treatment	9	121811	13535	3.41	0.004
Residual	36	142893	3969		
Total	59	3491890			

Appendix 8: ANOVA table for dry beans height at vegetative growth. Embu-short rain 2018-219

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	1478.18	739.09	45.65	0.021
Variety	1	149.36	149.36	9.23	0.093
Residual	2	32.38	16.19	0.31	
Rep.Variety.Treatment stratum					
Treatment	9	3785.96	420.66	8.09	<.001
Variety.Treatment	9	155.75	17.31	0.33	0.958
Residual	36	1872.47	52.01		
Total	59	7474.1			

Appendix 9: ANOVA table for height dry bean at flowering stages - Embu-short rain 2018-219

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	556.13	278.07	9.61	0.094
Variety	1	64.07	64.07	2.21	0.275
Residual	2	57.87	28.93	1.03	
Rep.Variety.Treatment stratum					
Treatment	9	2213.19	245.91	8.76	<.001
Variety.Treatment	9	132.28	14.7	0.52	0.848
Residual	36	1010.84	28.08		
Total	59	4034.38			

Appendix 10: ANOVA table for the number of nodules /plant at the vegetative stage of dry bean. Short Rain 2018-2019

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	1478.18	739.09	45.65	0.021
Variety	1	149.36	149.36	9.23	0.093
Residual	2	32.38	16.19	0.31	
Rep.Variety.Treatment stratum					
Treatment	9	3785.96	420.66	8.09	<.001
Variety.Treatment	9	155.75	17.31	0.33	0.958
Residual	36	1872.47	52.01		
Total	59	7474.1			

Appendix 11: ANOVA table for the number of nodules of dry bean plant at the flowering stage - Short rain 2018-2019

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	42.16	21.08	0.64	0.608
Variety	1	2.44	2.44	0.07	0.81
Residual	2	65.43	32.72	1.95	
Rep.Variety.Treatment stratum					
Treatment	9	1757.28	195.25	11.64	<.001
Variety.Treatment	9	247.63	27.51	1.64	0.141
Residual	36	603.75	16.77		
Total	59	2718.69			

Appendix 12: ANOVA table for pods numbers per dry bean plant - Embu Short rain 2018-2019

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	8.937	4.469	1.59	0.386
Variety	1	42.224	42.224	15.01	0.061
Residual	2	5.626	2.813	1.1	
Rep.Variety.Treatment stratum					
Treatment	9	233.52	25.947	10.15	<.001
Variety.Treatment	9	31.906	3.545	1.39	0.23
Residual	36	92.03	2.556		
Total	59	414.243			

Appendix 13: ANOVA table for seed weight of dry bean per plot - Embu-Short rain 2018-2019

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	11569	5784	0.38	0.725
Variety	1	72593	72593	4.75	0.161
Residual	2	30541	15271	0.5	
Rep.Variety.Treatment stratum					
Treatment	9	6031309	670145	22.15	<.001
Variety.Treatment	9	215097	23900	0.79	0.627
Residual	36	1089176	30255		
Total	59	7450285			

Appendix 14: ANOVA table for dry bean shoot biomass weight - Embu-short rain 2018-2019

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	4.448	2.224	1.23	0.448
Variety	1	0.535	0.535	0.3	0.64
Residual	2	3.604	1.802	1.11	
Rep.Variety.Treatment stratum					
Treatment	9	271.15	30.128	18.57	<.001
Variety.Treatment	9	10.113	1.124	0.69	0.711
Residual	36	58.393	1.622		
Total	59	348.243			

Appendix 15: ANOVA table for dry bean grain yield ha^{-1} -Embu- short rain 2018-2019

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	72306	36153	0.38	0.725
Variety	1	453705	453705	4.75	0.161
Residual	2	190884	95442	0.5	
Rep.Variety.Treatment stratum					
Treatment	9	37695679	4188409	22.15	<.001
Variety.Treatment	9	1344354	149373	0.79	0.627
Residual	36	6807352	189093		
Total	59	46564280			

Appendix 16: Analysis of variance (ANOVA) table dry beans height at vegetative stage - Mwea. Long rain 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	42.629	21.315	6.76	0.129
Variety	1	31.828	31.828	10.09	0.086
Residual	2	6.309	3.155	0.45	
Rep.Variety.Treatment stratum					
Treatment	9	729.621	81.069	11.55	<.001
Variety.Treatment	9	18.607	2.067	0.29	0.972
Residual	36	252.675	7.019		
Total	59	1081.67			

Appendix 17: ANOVA table dry bean plant height at the flowering stage - Mwea. Long rain 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	12.981	6.49	1.14	0.467
Variety	1	2.128	2.128	0.37	0.603
Residual	2	11.394	5.697	0.61	
Rep.Variety.Treatment stratum					
Treatment	9	989.978	109.998	11.69	<.001
Variety.Treatment	9	108.303	12.034	1.28	0.282
Residual	36	338.771	9.41		
Total	59	1463.557			

Appendix 18: ANOVA table for nodule count per plant at the vegetative stage of dry bean -Mwea. Long rain 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	33.7	16.85	0.11	
Rep.Mainplot stratum					
Variety	1	8.82	8.82	0.06	0.831
Residual	2	298.63	149.32	4.67	
Rep.Mainplot.Subplot stratum					
Treatment	9	3371.08	374.56	11.72	<.001
Variety.Treatment	9	358.68	39.85	1.25	0.299
Residual	36	1150.33	31.95		
Total	59	5221.25			

Appendix 19: ANOVA table for the number of nodules per dry bean plant at flowering stage = Mwea .long rain 2018-

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	44.1	22.05	2.39	
Rep.Mainplot stratum					
Variety	1	8.82	8.82	0.96	0.431
Residual	2	18.43	9.22	0.17	
Rep.Mainplot.Subplot stratum					
Treatment	9	2705.82	300.65	5.63	<.001
Variety.Treatment	9	455.68	50.63	0.95	0.497
Residual	36	1920.8	53.36		
Total	59	5153.65			

Appendix 20: ANOVA table for shoot biomass weight of dry bean - in Mwea-long rain 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	10.533	5.267	1.84	0.352
Variety	1	0.017	0.017	0.01	0.946
Residual	2	5.733	2.867	1.92	
Rep.Variety.Treatment stratum					
Treatment	9	1378.017	153.113	102.58	<.001
Variety.Treatment	9	32.15	3.572	2.39	0.031
Residual	36	53.733	1.493		
Total	59	1480.183			

Appendix 21: ANOVA table for seed weight of dry bean - in Mwea-long rain 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	339032	169516	4.65	
Rep.Mainplot stratum					
Variety	1	10192	10192	0.28	0.65
Residual	2	72861	36430	0.49	
Rep.Mainplot.Subplot stratum					
Treatment	9	1766271	196252	2.62	0.019
Variety.Treatment	9	874973	97219	1.3	0.272
Residual	36	2696309	74897		
Total	59	5759638			

Appendix 22: ANOVA table for grain yield per h of dry bean - Mwea- long rain 2018

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep.Variety stratum					
Rep	2	228548	114274	0.52	0.657
Variety	1	1493893	1493893	6.83	0.121
Residual	2	437433	218716	8.82	
Rep.Variety.Treatment stratum					
Treatment	9	18010038	2001115	80.66	<.001
Variety.Treatment	9	761321	84591	3.41	0.004
Residual	36	893082	24808		
Total	59	21824314			

Appendix 23: ANOVA table for dry bean height of dry bean at vegetative stages - Mwea-short rain 2018-219

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP.VAR stratum					
REP	2	462.08	231.04	0.95	0.513
VAR	1	7.59	7.59	0.03	0.876
Residual	2	486.27	243.14	7.26	
REP.VAR.TRT stratum					
TRT	9	839	93.22	2.78	0.014
VAR.TRT	9	298.49	33.17	0.99	0.465
Residual	36	1206.24	33.51		
Total	59	3299.67			

Appendix 24: ANOVA table for dry bean height at flowering - Mwea-short rain 2018-219

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP.VAR stratum					
REP	2	130.43	65.22	0.32	0.757
VAR	1	1.67	1.67	0.01	0.936
Residual	2	405.83	202.92	6.49	
REP.VAR.TRT stratum					
TRT	9	876.6	97.4	3.12	0.007
VAR.TRT	9	408.33	45.37	1.45	0.203
Residual	36	1125.07	31.25		
Total	59	2947.93			

Appendix 25: ANOVA table for the number of nodules per plant at the flowering stage of dry bean - Mwea short rain 2018-2019

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP.VAR stratum					
REP	2	118.03	59.02	6.2	0.139
VAR	1	40.02	40.02	4.2	0.177
Residual	2	19.03	9.52	0.36	
REP.VAR.TRT stratum					
TRT	9	3693.02	410.34	15.4	<.001
VAR.TRT	9	137.15	15.24	0.57	0.811
Residual	36	958.93	26.64		
Total	59	4966.18			

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP.VAR stratum					
REP	2	130.43	65.22	0.32	0.757
VAR	1	1.67	1.67	0.01	0.936
Residual	2	405.83	202.92	6.49	
REP.VAR.TRT stratum					
TRT	9	876.6	97.4	3.12	0.007
VAR.TRT	9	408.33	45.37	1.45	0.203
Residual	36	1125.07	31.25		
Total	59	2947.93			

Appendix 26: ANOVA table for pods number per dry bean plant - Mwea Short rain 2018-2019

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP.VAR stratum					
REP	2	0.033	0.017	0.02	0.984
VAR	1	0	0	0	1
Residual	2	2.1	1.05	0.53	
REP.VAR.TRT stratum					
TRT	9	288.733	32.081	16.22	<.001
VAR.TRT	9	22.667	2.519	1.27	0.285
Residual	36	71.2	1.978		
Total	59	384.733			

Appendix 27**:** ANOVA table for dry bean seed weight- Mwea-short rain 2018-2019

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP.VAR stratum					
REP	2	42632	21316	1.8	0.357
VAR	1	69088	69088	5.84	0.137
Residual	2	23658	11829	8.51	
REP.VAR.TRT stratum					
TRT	9	4251391	472377	340.02	<.001
VAR.TRT	9	43202	4800	3.46	0.004
Residual	36	50014	1389		
Total	59	4479986			

Appendix 28: ANOVA table for dry bean grain yield per ha $^{-1}$ Mwea- short rain 2018-2019

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP.VAR stratum					
REP	2	266452	133226	1.8	0.357
VAR	1	431802	431802	5.84	0.137
Residual	2	147863	73932	8.51	
REP.VAR.TRT stratum					
TRT	9	26571193	2952355	340.02	<.001
VAR.TRT	9	270011	30001	3.46	0.004
Residual	36	312588	8683		
Total	59	27999910			