ASSESSMENT OF ADVANCED COMMON BEAN (*Phaseolus vulgaris L.*) LINES FOR NUTRIENT UPTAKE, PHOSPHORUS EFFICIENCY AND YIELD IN LOW PHOSPHORUS SOIL TYPES OF KAKAMEGA COUNTY

BY

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Declaration

Declaration by the Candidate

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DEDICATION

This thesis is dedicated to my husband Boaz Wesonga

and

my two daughters Esther and Nicole.

ABSTRACT

Common bean (*Phaseolus vulgaris* L.) is an important source of food protein and cash in Kakamega County. Production is constrained by soil phosphorus which is mainly due to low phosphorus content of soils, export of phosphorus in crop produce, soil erosion and fixation by oxides in acidic soils. A study was conducted to evaluate bean genotypes in two sites in KARI Kakamega (34^{0}32’ and 34^{0}57’E, 0^{0} 07’ and 0^{0}15’N); this site has rhodic-nitisol in which P availability is limited by active iron and the second site was Kabras (34^{0}52’E and 0^{0}52’N) with nito-rhodic ferralsols in which P availability is limited by Iron (Fe) and aluminium (Al) oxides. Assessment of germination/emergence, plant count at harvest was taken to determine the plant tolerance as affected by low soil P. Shoot P and N uptake, phosphorus use efficiency (PUE), yield and economic analysis components were done using two levels of phosphorus, P0 (control) and P30 (30 kg ha^{-1} P) and 13 common bean lines with two local checks (GLP2, GLP585) in a randomized block design. Data for germination stand count, harvest, and yield were subjected to analysis of variance using the SAS software programme. Nutrient uptake and nutrient efficiency were subjected to student t- test. The means were separated using least significant difference (LSD) (protected) test. The pH of the soils was found to be 4.90 and 5.38 for Kabras and KARI site respectively implying, that the soils are acidic. The available P was low (2.45 ± 0.96 ppm and 7.69± 0.96 ppm for Kabras and KARI, respectively). The total nitrogen (%) was also low with 0.13 ± 0.02 and 0.2 ± 0.02) for Kabras and KARI Kakamega sites. Kabras site had soils which have good physical characteristics but are chemically poor while KARI Kakamega site had soils which are considered fertile but have low level of ‘available’ phosphorus. The germination and emergence of the different common bean lines varied between the sites with a weak inter-genotypic relationship between applied P on the stand count at both germination and harvest. There was varying response of genotypes in performance in terms of shoot biomass P uptake, PUE, N uptake, yield and marginal rate of return (MRR) in treatments with addition of P. No significant difference ($p<0.05$) was observed between lines CC13, CC547, MLB-48-89A, FEB195, A774, 286/6 and DOR755 for phosphorus uptake but it was higher compared to local checks. Lines 217-2, 222/1, AB136, and RWR221 had low uptake as the local checks ($p<0.05$). The inter-genotypic difference for nitrogen uptake was strong in the biomass and in the grain. Lines such as FEB195, DOR755, CC13, 3MS8-3, A774, UBR(95), and CC547 had a high uptake compared to the mean and local check but lines 217-2, 222/1, 286/6, AB136, RWR221, and MLB-48-89A had a lower uptake together with local check GLP585. Yield (tons/ha) increased with applied P with Kabras site having average of 0.479tons/ha and KARI had 0.548 tons/ha. There was however a weak inter genotypic significance ($p<0.05$) within the lines for yield both at KARI and Kabras sites. The highest net present value of benefits (PNB) for all the varieties was obtained from variety FEB 195 (Kshs 64,650 ha^{-1}) at KARI site with application of phosphorus , while the lowest(D) was from the local Check G585) at Kabras site. The varieties had a normal trend at both sites but KARI had a high return to land compared to Kabras. Genotypes DOR755, CC13, FEB195, UBR(95), A774 and CC 547 were outstanding in all parameters tested. Therefore, these genotypes can be recommended for use in low- phosphorus environments as well as breeding materials.

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LIST OF ACRONYMS

AGRA	Alliance for Green Revolution in Africa
AND	Andean origin
AYT	Advanced yield trials
CAL	Calima color
CIAT	Centro Internacional de Agricultura Tropical
DAP	Di ammonium phosphate
GLP	Grain Legume project of nation bean program Kenya
KARI	Kenya Agricultural Research Institute
MAG	Mesoamerican genotype
MLB	Mulungu bred genotype
MoA	Ministry of Agriculture
MR	moderately resistant reaction,
N	Nitrogen
P	Phosphorus
PAR	Photo synthetically active radiation
PUE	Phosphorus use efficiency
PYT	Preliminary yield trials
RR	Resistant reaction,
RWR	Rwanda Rubona genotype
SS	Susceptible reaction
TSP	Triple super phosphate
VT	Varietal trials

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CHAPTER ONE

1.0 INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is the most important food legume crop grown in the world (Wortmann *et al*., 1998; Buruchara, 2006). The per capita consumption varies depending on consumer preferences but can be as high as 66 kg/capita/year in parts of western Kenya (Broughton *et al*., 2003). Green leaves, green pods, and immature and/or dry seeds may all be eaten as they are very rich in iron and zinc (Kimani *et al*., 2006). Dry leaves, threshed pods and stalks are fed to animals, or burnt to make local salt (Buruchara, 2006).

Beans as legumes contribute a great deal to improving and sustaining soil fertility due to their ability to fix nitrogen. Research (Buruchara, 2006) shows that senescing leaves could contain substantial amounts of N of up to 90 kg N ha^{-1} which when added to soil in leaf fall enrich the soil with N. They are hence used in crop rotations, and intercropped with maize or sugarcane or planting as sole crop during short rain season. The crop is also an important source of income especially for women who grow it both for subsistence and for sale (Government of Kenya, 2011). However, beans are ranked second after maize in food crops and area expansion in Kenya is driven by domestic consumption demand rather than export demand as production remains below domestic consumption levels (Katungi *et al*., 2009).

The world production of beans currently stands at 20 million tons with the world leader being Brazil, followed by India and then China (FAOSTAT, 2008). Production in Africa is estimated at 2.8 million tons on 4.8 million hectares (FAOSTAT, 2008). East Africa accounts for over 75% of the total production in Africa, with Kenya's current production of 535 000 tons (FAOSTAT, 2008). In 2007, production was about 417,000 metric tons while demand was estimated at 500,000 metric tons (FAOSTAT, 2010).The deficit of 15% is offset by imports from neigbouring Uganda (Mauyo *et al*., 2007) and Rwanda, through informal border trade or relief supply to the World Food Programme (David *et al*., 1999).

However, even though Kenya is ranked high in bean production, it is ranked among last five countries in Africa in production per unit area (FAOSTAT, 2008). Low soil fertility has been documented as one of the major abiotic constraints to common bean production (Katungi *et al*., 2009, Odendo *et al*., 2004), and can lead to losses of up to 1.3 million tons per year. Others include acidic soils with aluminium and manganese saturation (Rutunga, 1997), low available nitrogen and phosphorus and low exchangeable bases (Wortmann *et al*., 1998). Gradual depletion of nutrients in the highlands of western Kenya which support the most rural population according to population census 2009, through export in crop produce, leaching and soil erosion (Vanlaulwe *et al*., 2005) also cause an annual nutrient depletion exceeding 40 kg N ha $^{-1}$, 6.6 kg P ha $^{-1}$, 33.2 kg K ha $^{-1}$ (Smaling *et al*., 1997). These highlands are also dominated by acid phosphorus-fixing soils in the order of Ferralsols, Acrisols and Nitisols (Deckers, 1993; Sanchez *et al*., 1997). Fertilizer additions of phosphorus for food crops is not enough compared to the rate of removal in the harvested crops (Brady and Weil, 2008), and their application in small scale farming systems is limited by their high cost (Blevins, 1999).

1.1 Problem Statement

Numerous measures have been used to restore soil fertility in western Kenya (Nziguheba, 2007) but nutrient balance carried out show that N and P balances were negative (Smaling *et al*., 1997). Whereas productive agriculture requires a large amount of fertilizers, (Dreschsel *et al*., 1996) it has been reported that there is very low use of mineral fertilizer of up to 0.4 kg ha^{-1} , yet it is estimated that beans remove 12.5 kg P/ha. Use of soluble fertilizers to overcome P limitation has been possible but their application in small scale farming systems is limited by their high cost (Ndufa *et al*., 2007). The common practice of improving soil fertility however is therefore the application of organic manure. This leads to low bean production because the organic matter alone is limited by insufficient quantities and poor qualities of organic resources available on farms (Lunze *et al*., 2007). Although much has been done in breeding beans for resistance to biotic constraints such as diseases and other pests, less has been done in the abiotic stress area. Bean production is constrained by low phosphorus; the need for bean varieties that are capable of acquiring phosphorus from limiting soil environments is of obvious importance. This therefore was the main basis of this study to identify bean lines which can tolerate low P in the soil or respond to added P.

1.2 Justification

The ability of common bean to acquire phosphorus from phosphorus-limiting environments has been reported to vary among genotypes and this ability is heritable (Yan et al., 1995a) both with wild and domesticated genotypes (Lynch, 1995). In Kenya several varieties especially red kidney group were found to tolerate low P stress (Lunze *et al*., 2007). Unfortunately, they are susceptible to the prevailing root pathogens, while known resistant varieties are associated with undesirable characteristics such as late maturity, black seed colour, and small seed size (Rusuku *et al*., 1997; Otsyula *et al*., 1998).

1.3 Objectives

1.3.1 Overall objective

To assess nutrient uptake, use efficiency and yield of advanced common bean lines in low phosphorus soil types of Kakamega County.

1.3.2 Specific Objectives

1) To determine the common bean variability in terms of phosphorus and nitrogen uptake under limiting phosphorus soils of Kakamega County
2) To evaluate the phosphorus use efficiency (PUE) of advanced common bean lines in low phosphorus soils of Kakamega County
3) To evaluate the yield difference of advanced common bean lines as influenced by low phosphorus soils of Kakamega County
4) To assess economic returns of growing the advanced common bean lines under standard farming options in low phosphorus soils of Kakamega County.

1.4 Hypotheses

1.4.1 General hypothesis

Phosphorus uptake and use efficiency, nitrogen uptake and yield of advanced common bean lines are influenced by low P conditions in soils

1.4.2 Working hypotheses

H_{o1}: Phosphorus uptake of advanced plant common bean lines is not affected by soil low P status.

H_{A1}: Phosphorus uptake of advanced common bean lines is affected by soil low P status.

H_{o2}: Nitrogen uptake of advanced common bean lines is not affected by soil low P status.

H_{A2}: Nitrogen uptake of advanced common bean lines is affected by soil low P status.

H_{o3}: Yield of advanced common bean lines are not influenced by soil low P status.

H_{A3}: Yield of advanced common bean lines are influenced by soil low P status.

Ho_4: Returns to land obtained from growing advanced common bean lines is not influenced by soil low P status.

H_{A4}: Returns to land obtained from growing advanced common bean lines is influenced by soil low P status.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Production trends of common bean

The commercial production of beans is well distributed worldwide with countries in Asia, Africa, Europe Oceania, South and North America all among the largest producers of dry beans. China produces by far, the largest amount of green beans, almost as much as the rest of the top ten growers altogether (Fig. 1) (FAOSTAT, 2008). During the year 2007 alone, 18.3 million tons of dry common beans and 6.6 million tons of green beans were produced worldwide with the broad beans (*Vicia faba*) producing 3.7 million tonnes (Kaplan,2008).

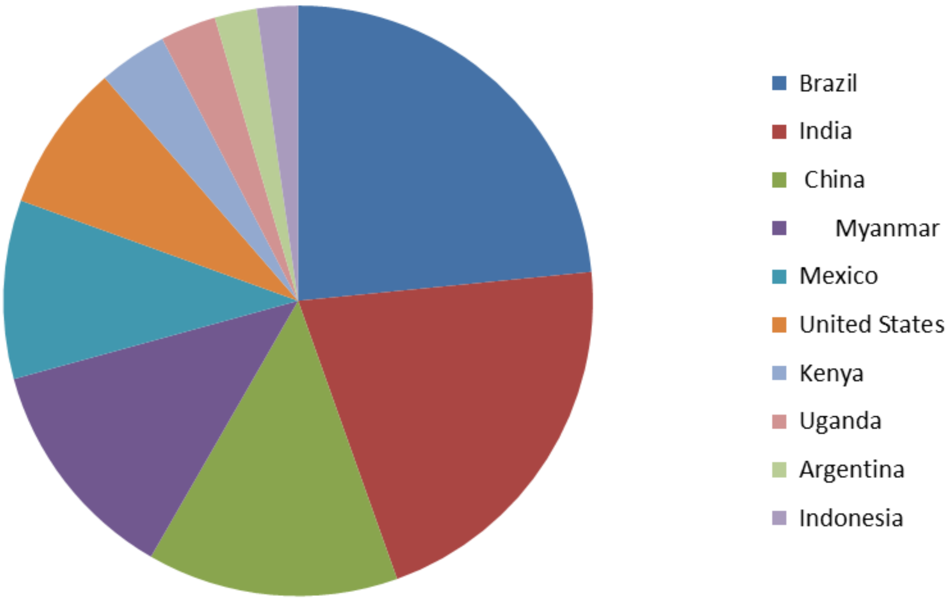


Fig 1. World Production of beans as at 2008 (*Source: Food and Agricultural Organization of United Nations: Economic and Social Department: The Statistical Division*).

Despite a relative growth in area for common bean since 2001, this growth does not seem to have been sufficiently large to increase production over the previous averages in Kenya

(Table1) due mostly to poor yield. Kenyan common bean production has been volatile with many spikes and dips that cancel out, leaving on average, a zero growth in production (Katungi *et al*., 2009)

Table 1. **Top 10 producers of common bean in terms of area in Africa in 2000-2007**

Country	**Average area (Ha)**	**Average production (tons)**
Kenya	910478	412381
Uganda	794375	478625
Tanzania	373125	285414
Rwanda	340055	231882
Angola	290391	92786
Burundi	2493735	229607
DR Congo	205958	110404
Malawi	197605	87593
Ethiopia	188000	143414
Madagascar	82096	77273

(*Source*: *Food and Agricultural Organization of United Nations: Economic and Social Department: The Statistical Division, 2008*)

2.2 Taxonomy of Common Beans

Common bean (*Phaseolus vulgaris* L.) belongs to the Angiosperms phylum (flowering plants with the grubs enclosed in a carpel or in several carpels united into an ovary). Out of 30 species of *Phaseolus* reported from the Americas only five, namely, common bean (*Phaseolus vulgaris* L.), year bean (*Phaseolus polyanthus* Greenman), scarlet runner bean (*Phaseolus coccineus* L.), tepary bean (*Phaseolus acutifolius* A, Gray) and lima bean (*P. lunatus* L.) are known to be domesticated (Debouck, 1999; 2000). The common bean (*P. vulgarius*) possesses by far the widest adaptation of all *Phaseolus* spp. with over 85 percent of the cultivated species worldwide (Singh, 2001). Common bean (*Phaseolus vulgaris L)*,belongs to the division Magnoliophyta, class Magnoliopsida, order fabales, family Leguminosae, sub-family Papilionoideae /Fabaceae /Lotoideae (pulse family characterized by edible seeds and pods) order Leguminales and tribe phaseoleae (Chazan, 2008).

Botanically, the common bean is classified in sub- phylum as a dicotyledon (embryo with two cotyledons, parallel veined leaves and the stem with the vascular bundles arranged irregularly and cambium usually present). Common beans are diploid (2n = 2x = 22) and self-pollinated crop though cross-pollination is possible if the stigma contacts with pollen coated bees when extended (Katungi *et al*., 2009).

It possesses complete, papilionaceous flowers with 10 stamens, and an ovary with a long, coiled style and a hairy introrse stigma; the stigma is situated laterally along the inner arc of the curved style, where it intercepts pollen dehiscing from its own anthers. The crop is highly polymorphic, showing considerable variation in growth habit from determinate bush to indeterminate, extreme climbing types; vegetative characters, flower colour and size, shape and colour of pods and seeds (Katungi *et al*; 2009).

Seeds are non-endospermic and vary greatly in size and colour from the small black wild type to the large white, brown, red, black or mottled seeds of cultivars, which are 7-16 mm long (Katungi *et al*., 2009). The bushy type bean is the most predominant type grown in Africa (Buruchara, 2006).

There are two major commercial classes of common bean, snap and dry beans (Singh, 2001). Snap beans are also known as string or green beans and are mainly grown for their pods, while dry beans are mainly grown for their seed.

2.3 Origin and genetic diversity

Common beans are intricately woven into the fabric of human history. The first 'permanent cultures' evolved when hunter-gatherers and nomadic people began tilling the earth and developing systems of agriculture, and beans were among the first cultivated crops (Ehler, 2011).

The oldest-known domesticated common beans in the Americas were found in Guitarrero Cave, an archaeological site in Peru, and dated to around the second millennium BCE (Chazan, 2008; Kaplan, 2008). By the second millennium BC cultivated, large-seeded broad beans appeared in the Aegean, Iberia and transalpine

Europe (Hopf *et al*., 2000). Beans were introduced in Africa over four centuries ago from Latin America (Allen and Edje, 1990).). In sub-Saharan Africa beans were introduced long ago by Portuguese traders with a lot of concentration in densely populated eastern Africa, the lakes region, and highlands of southern Africa (CIAT Website, 2001). In Kenya beans appeared for the first time about four centuries ago in 1643 (Chazan, 2008). Production is mainly in highland and midlands.

The traditional growing areas include: Burundi, Rwanda Democratic Republic of Congo and to a lesser extent in south-western highlands of Uganda, western highlands of Ethiopia, Kenya and Malawi (Katungi *et al*., 2009).

Nine major commercial seed types/market classes are grown in Africa (Plate 1).These include the Calima (Rose coco or red mottled) and the reds (large and small), which together account for about fifty percent of the production, primarily because of their high market demand. Others are the navy beans, cream-coloured, brown tan, yellow types, purples, white and black beans (Buruchara, 2006).

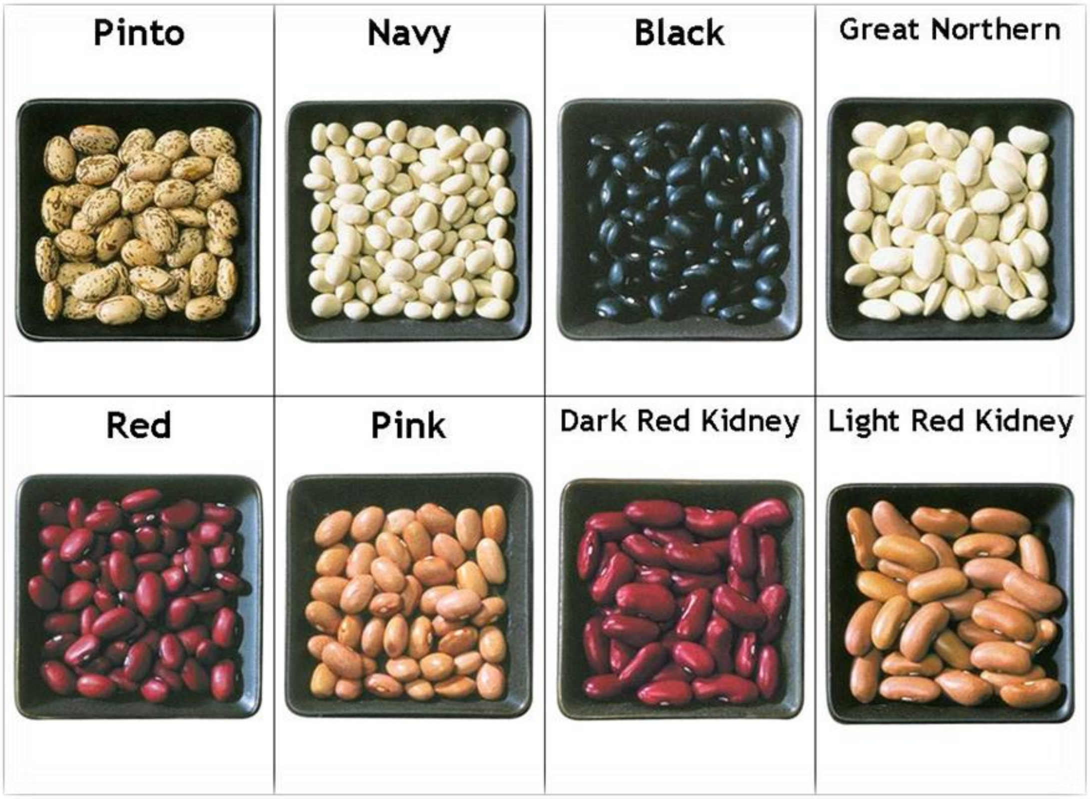


Plate 1. Pictorial presentation of different market classes of common beans (*Source: Gelin, 2007*).

2.4 Production of Beans

About 75% of the annual cultivation occurs in four regions in Kenya namely; Rift valley, Western, Nyanza, and Eastern Province (Katungi *et al*., 2009). However in terms of output, the Rift valley contributes the biggest share, accounting for 33% of the national output followed by Nyanza and Western province accounting for 22 % each. Output from Eastern parts of the country and the Coast is constrained by adverse climatic conditions (Karanja, 2006).

Although Kenya has two seasons for common bean, a significant number of farmers grow the crop once a year because of adverse climatic conditions. The Rift valley and the Western regions allocate land to common beans once a year, during March-May season (also referred to as long rains) while farmers in the Central and Eastern regions grow twice a year but only 70 % of the farmers in the Eastern region grow it in the long rains. Most farmers in these two regions grow common bean in short rains (October to December) (Katungi *et al*., 2009).

Production in the region averages 400-600 kg ha^{-1} per season which is a yield deficit of 20 to 30 % of genetic potential of improved beans (Wortmann *et al*., 1998). This is mainly due to continuous cultivation of land without rotation leading to decline in soil fertility and an increase in pests and diseases. The diseases are estimated to be the second largest constraint after low soil fertility (CIAT, 1995).

Based on this, research needs to identify and use genotypes adapted to soils with inadequate nutrient supply and low pH associated nutritional disorders as a component of integrated soil fertility management approach to improving bean productivity in the region.

2.5 Phosphorus availability in soils

The phosphorus content of soil ranges from 200 to 2000 kg ha^{-1} in upper 15 cm of soil with an average of 1000 kg ha^{-1} (Brandy and Weil, 2008). Other factors which influence the content of soil phosphorus include type of parent material from which the soil is derived, degree of weathering and climatic conditions. Soil phosphorus levels are affected by erosion, crop removal and phosphorus fertilization (Griffith, 2010).

Soil phosphorus can be classified in two broad groups: organic (20-22 % with phytic acid (inositol hexaphosphate) as a major component. The remainder is found in the inorganic fraction containing 170 mineral forms of P (Schachtman, *et al*., 1998).

The organic phosphorus may be found in plant residues/organic materials, manures/humus, and microbial tissues. Soils low in organic matter may contain only 3 percent of their total phosphorus in the organic form, but high organic matter soils may contain 50 percent or more of their total phosphorus content in the organic form. Inorganic forms of soil phosphorus consist of apatite (the original source of all phosphorus), complexes of iron and aluminum phosphates (Al-P, Ca-P, and Fe-P), and phosphorus adsorbed on clay particles (Schachtman *et al*., 1998). The solubility of these phosphorus compounds and the transformation of one form of phosphate into another is controlled mainly by soil pH (Furihata *et al*., 1992).Through adequate phosphorus fertilization and good crop/soil management, soil solution phosphorus can be replaced rapidly enough for optimum crop production.

Total phosphorus amounts in the soil may be high but in forms that are only available outside of the rhizosphere (Schachtman, *et al*., 1998). Application of P to the soil is necessary to ensure plant productivity, but the recovery of applied P by crop plants in a growing season is very low, because in the soil more than 80 % of the P becomes immobile and unavailable for plant uptake because of adsorption, precipitation, or conversion to the organic form (Holford, 1997). The low levels of available P in the bulk soil limits plant uptake and impacts negatively on plant growth hence low yield. If the amount removed is more than 350 mg P kg^{-1} of soil (phosphorus fixing capacity of about 700 kg P ha^{-1}) from solution then this soil is considered to be high phosphorus-fixing soils (Fig 3) (Brady and Weil, 2008) P-sorption increases as temperature increase (Griffith, 2010). Phosphorus absorption by the plant is decreased by low soil temperature and poor soil aeration. Excessive soil moisture or soil compaction reduces the soil oxygen supply and decreases the ability of the plant roots to absorb soil phosphorus. Compaction reduces aeration and pore space (Soil volume) in the root zone. This reduces phosphorus uptake and plant growth (Griffith, 2010).

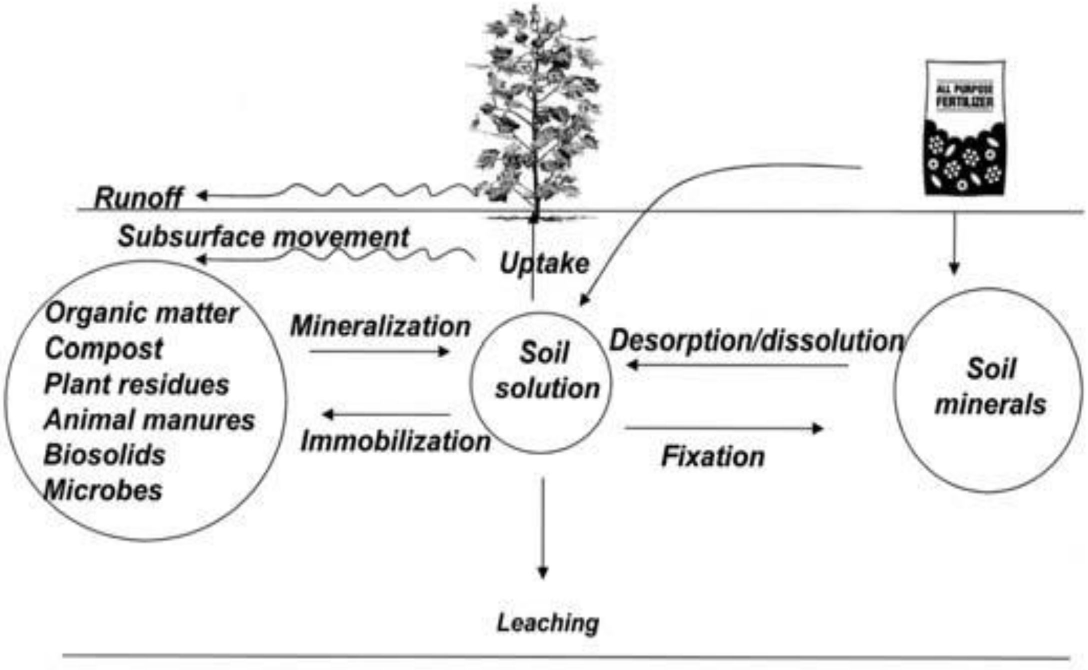


Fig 2. Simplified diagram of phosphorus cycle in soils (*Source: http://www.uaex.edu)*.

Large humic molecules can adhere to the surfaces of clays and metal hydrous oxide particles, masking the phosphorus fixation sites and preventing them from interacting with phosphorus ions in solution (Fig 3).

Soil pH has a profound influence on the amount and manner in which soluble phosphorus becomes fixed (Furihata *et al*., 1992). At low pH, soils have greater amounts of aluminum in the soil solution, which forms very strong bonds with phosphate. As pH drops from greater than 8.0 to below 6.0, calcium phosphate compounds increase in solubility (Griffith, 2010). Phosphate fixation is at its lowest (and plant availability is highest) when soil pH is maintained in the 6.0 to 7.0 range.

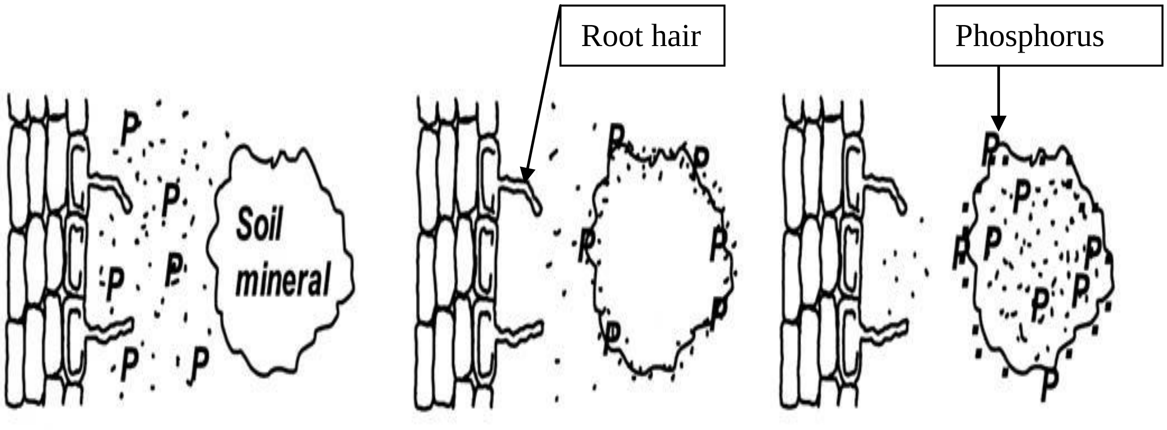


Fig 3. **Schematic representation of how phosphorus (phosphates) is tied up by soil minerals. (*Source: http://www.uaex.edu)*.**

Soils high in active fractions of organic matter exhibit low levels of phosphorus fixation. Organic matter increases P availability and is thus also a source of phosphorus through mineralization reaction (Griffith, 2010).

Through adequate phosphorus fertilization and good crop/soil management, soil solution phosphorus can be replaced rapidly enough for optimum crop production. Heavy applications of organic materials such as manure, plant residues, or green manure crops to soils with high pH values not only supplies phosphorus, but on decomposition they provide acidic compounds which increase the availability of mineral forms of phosphorus in the soil. More efficient utilization of fertilizer phosphorus is generally obtained by applying the fertilizer shortly before planting the crop. Banding of fertilizer for row crops is also much more likely to increase the efficiency of fertilizer phosphorus on soils of high phosphorus-fixing capacity than on soils of low phosphorus-fixing (Griffith, 2010).

2.5.1 Phosphorus and plant growth

Phosphorus has a vital role in the life processes of plants such as photosynthesis, synthesis and break down of carbohydrates and the transfer of energy within the plant.
These processes usually run from the beginning of seedling growth through to formation of grain and its maturity (Marschner, 1995).
P is moved mainly by diffusion which is slow (10^{-12} to 10^{-15} m^2 s^2). High plant uptake rates create a zone around the root that is depleted of P. Plant root geometry and morphology are important for maximizing P uptake, because root systems that have higher ratios of surface area to volume will more effectively explore a larger volume of soil (Lynch and Beebe, 1995).

In certain plant species, specialized roots (proteoid) exude high amounts of organic acids (up to 23 %t of net photosynthesis), which acidify the soil and chelate metal ions around the roots, resulting in the mobilization of P and some micronutrients (Marschner, 1995). The form in which P exists in solution changes according to the soil pH. Below pH 6.0, most P will be present as the monovalent $H_2PO_4^-$ species, whereas H_3PO_4 and $HPO_4^{\ 2-}$ will be present only in minor proportions (Tisdale *et al.*,, 1990).

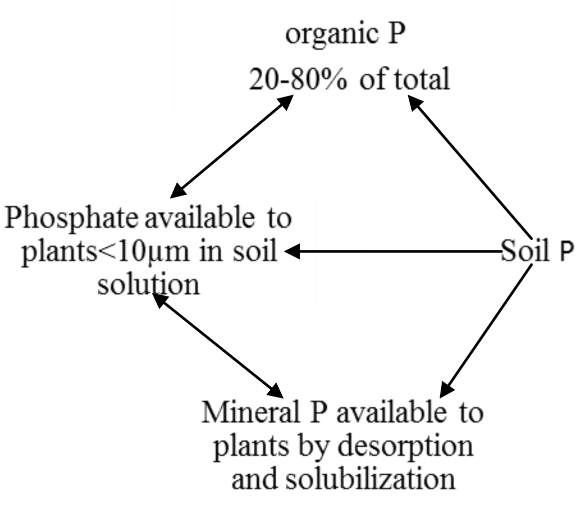


Fig 4. **Plant acquisition of soil phosphorus (*Source:Modified from Richardson, 2009).***

Conversely, when plants have an adequate supply of P and are absorbing it at rates that exceed demand, there is conversion of P into organic storage compounds (e.g. phytic acid), a reduction in the P uptake rate from the outside solution (Lee *et al*., 1990), and P loss by efflux, which can be between 8 and 70 % of the influx (Bieleski and Ferguson, 1983). Crops that acquire and /or use P more efficiently reduce the use of phosphate fertilizers and can yield with lower inputs (Hammond *et al*., 2009).

2.5.2 Effect of low phosphorus levels on plant growth

When the supply of P is limited, plants grow more roots, increase the rate of uptake by roots from the soil, and re-translocate P from older leaves. There is also a reduction in leaf expansion and leaf surface area, as well as the number of leaves. Shoot growth is more affected than root growth, which leads to a decrease in the shoot root dry weight ratio. Nonetheless, root growth is also reduced by P deficiency, leading to fewer roots mass to reach water and nutrients (Blevins, 1999).

Generally, inadequate P slows the processes of carbohydrate utilization, while carbohydrate production through photosynthesis continues. This results in a buildup of carbohydrates and the development of a dark green leaf color. In some plants, P-deficient leaves develop a purple color, tomatoes and maize being two examples. Since P is readily mobilized in the plant, when a deficiency occurs the P is translocated from older tissues to active meristematic tissues, resulting in foliar deficiency symptoms which appear on the older (lower) portion of the plant (Smith *et al*., 2003). However, such symptoms of P deficiency are seldom observed in the field other than loss of yield. Other effects of P deficiency on plant growth include delayed maturity, reduced quality of forage, fruit, vegetable, and grain crops, and decreased disease resistance.

P deficiency affects the plant capability to produce carbohydrates and also limit the formation of amino acids and proteins that are the building blocks of new cells (Smith *et al*., 2003).

2.5.3 How phosphorus deficiency can be corrected

Phosphorus can be added to the soil through supply of fertilizer rates that are just enough to be taken up by plants or by localized (band) placement to minimize reactions with the bulk of the soil and enhance availability (Griffith ,2010). Effectiveness of these fertilizers is determined by the properties of both the phosphorus salt and the soil being fertilized and the reactions which occur between the phosphorus fertilizer and various soil constituents (Sanchez *et al*., 1997).

Cycling of organic matter such as manures, green manures and plant residues can increase phosphorus availability. During the microbial breakdown of these materials, phosphorus is released slowly and can be taken up by plants before it reacts with the soil. The organic compounds also protect phosphorus from fixation by forming organic complexes (chelates) with Al, Fe, and Mn ions, thereby limiting the reaction of these ions with phosphorus (Brady and Weil , 2008, Nziguheba *et al*., 2006).

Enhancement of mychorrhizal symbiosis (mutual beneficial association/symbiosis between certain fungi and the roots of higher plants) is another way of controlling phosphorus in soils. This can be done through inoculation using the right inoculums or through crop rotation, organic matter addition and minimum tillage (Smith and Read, 1997). Mycorrhizae are also important for plant P acquisition, since fungal hyphae greatly increase the volume of soil that plant roots explore (Dar *et al.*, 1997).

In low pH soils, soil P availability for plant uptake can be enhanced by liming which in agriculture is the application of any Ca and/or Mg-containing material or compound commonly applied as $CaCO_3$, $Ca(OH)_2$ or CaO, that is capable of reducing soil acidity to achieve and maintain a soil pH of 6.0-6.5 (Tisdale *et al*., 1990).

2.6 Nitrogen availability in soils

Nitrogen exists in soils in two forms, organic and inorganic and constantly changes from one form to another (Espinoza *et al*., 2010). The inorganic form includes ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), nitrous oxide (N_2O), Nitric Oxide (NO,) and elemental nitrogen (N_2) with the first three being of greatest importance to plants but NO and N_2O being lost by denitrification (Maathuis, 2009). The atmospheric nitrogen is fixed in soils by various free-living and symbiotic bacteria (Fig 6) and the amounts fixed are generally inadequate for the sustained high yields of crops in commercial farming. The total soil nitrogen ranges from 0.02 % in sub soil to more than 2.5 % in peats This soil nitrogen fluctuate both space and time due to precipitation, temperature, wind, soil type and pH (Maathuis, 2009).

The organic forms of soil nitrogen occur as consolidated amino acids or proteins, free amino acids, amino sugars and other complex compounds (Harrison, 2003). Nitrogen is lost from the soil through leaching (soluble NO_3 as it moves below root zone), denitrification (loss of NO_3 when soils are saturated with water for 2 or 3 days), volatilization (N lost as NH_3 gas when soil pH is greater than 7.3, the air temperature is high, the soil surface is moist, and there is a lot of residue on the soil), crop removal, soil erosion and runoff. It has been estimated that 50–70 % of the nitrogen provided to the soil is lost (Hodge *et al.*, 2000).

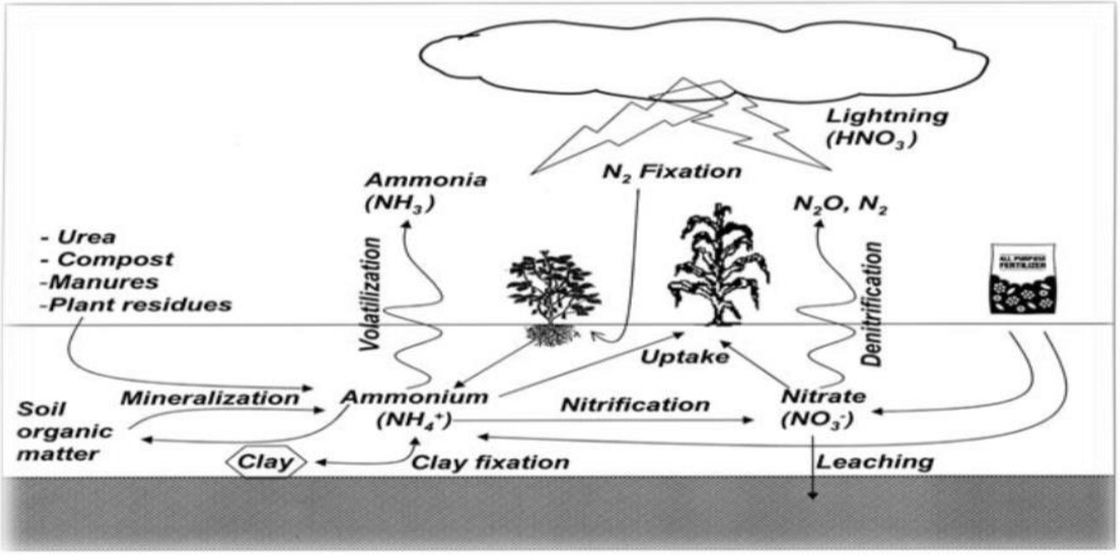


Fig 5. **The nitrogen cycle** ***(Source: http://www.uaex.edu).***

Nitrogen loss through crop removal depends on the type of the crop and consequently its N requirement. For instance, it has been estimated that daily nitrogen uptake from all sources by an average bean crop reaches a daily peak of 5 kg/ha at end of 3 months (Weiss, 1983). Incorporating some organic materials into the soil may tie up nitrogen(C: N ratio of >20:1) into unavailable forms by the microorganisms that decompose the organic fertilizers and can induce nitrogen deficiencies (a process called immobilization) (Barbarick, 2006). If the organic residue has a C: N less than about 20:1 (high nitrogen content), then the microorganisms will obtain adequate nitrogen for their needs and will convert the excess organic nitrogen to ammonium ($NH_4^{+)}$ (mineralization).

NO_3^- or NH_4^+ --> microbial activity --> organic N (unavailable nitrogen)

Immobilization could tie up the nitrate (NO_3^-) and ammonium (NH_4^+) for a number of months before being released by mineralization of the organic nitrogen found in the residue and microbial tissue.

Atmospheric nitrogen (N_2) is basically an endless source of N, but this nitrogen cannot be used directly by most plants. Legumes form a highly specific symbiotic association (mutually beneficial) with specific bacteria in root nodules to convert atmospheric N_2 to a form available to plants. It is catalyzed by nitrogenase enzyme as is affected by soil (pH) right type of inoculum and weather factors.

Incorporation or injection of manure and fertilizer can help to protect against N loss through erosion or runoff. Where soils are highly erodible, conservation tillage can reduce soil erosion and runoff, resulting in less surface loss of N. Consequently, using inoculation for an N source and N fertilizer as starter dose of 30-100 kg/ha is often recommended (Sanchez 1997; FAO, 2008).

2.6.1 Importance of nitrogen to plant growth

Nitrogen is essential for plant growth where by plants usually contain between 1 and 5 % by weight of this nutrient. Nitrogen is required for all organisms to live and grow because it is the essential component of DNA, RNA, and protein (Harrison, 2003). Nitrogen is an integral part of chlorophyll, which is the primary absorber of light energy needed for photosynthesis. The basic unit of chlorophyll's structure is the porphyrin ring system composed of four pyrrole rings, each containing one nitrogen and four carbon atoms. Single magnesium atom is bonded in the centre of each poryphyrin ring.

Nitrogen is a constituent of all protein and nucleic acids. The nitrate form is reduced to NH_4-N using energy provided by photosynthesis which combines with various organic compounds, including glutamate, with the amide glutamine as a product (Tisdale *et al.*, 1990).

Plants absorb nitrogen in the ammonium (NH_4^+) or nitrate (NO_3^-) forms as inorganic nitrogen sources and amino acids under particular conditions of soil composition. The rate of nitrate uptake is usually high and it occurs by active absorption and is favored by low-pH conditions. Plant uptake of NH_4^+ proceeds best at neutral pH values and is depressed by increasing acidity (Meyer and Stitt, 2001).

Nitrate uptake occurs at the root level and two nitrate transport systems have been shown to coexist in plants and to act coordinately to take up nitrate from the soil solution and distribute it within the whole plant (Tsay *et al.*, 2007) across several cell membranes and distributed in various tissues.

Adequate supply of nitrogen has been associated with vigorous vegetative growth and a dark green colour. When nitrogen supplies are adequate, and conditions are favorable for growth, proteins are formed from the manufactured carbohydrates. Less carbohydrate is thus deposited in the vegetative portion, more protoplasm is formed and because protoplasm is highly hydrated, a more succulent plant results.

2.6.2 Effect of low levels of nitrogen and plant growth

When nitrogen supplies are insufficient, carbohydrates will be deposited in vegetative cells which will thicken. If soil levels are less than adequate, common beans may respond to nitrogen (N), phosphorus (P), potassium (K) and zinc (Zn) (CIAT Website, 2001). An imbalance of nitrogen or excess of this nutrient in relation to other nutrients such as phosphorus, potassium, and sulfur can prolong the growing period and delay crop maturity.

2.6.3 Nitrogen metabolism

The high protein content of legume seeds explains the particular importance of nitrogen metabolism in grain legume physiology. In bean seeds, a protein content of 20% to 24 % implies a nitrogen content of approximately 4%, which in turn means that every 1000kg of yield implies a need for 40 kg of N, not including amounts needed to replace losses caused by leaching or residual N in other tissues (Hammond *et al*., 2009).

2.7 Nitrogen and phosphorus (N-P) interactions in legumes

Nutrient interactions occur if crop response to two factors together does not equal the sum of the responses to each factor separately; otherwise the two factors are considered to be working independently of each other and have no interactions between them (Blevins, 1999).

When growth is limited by deficiency of a second nutrient, such as sulfur or nitrogen, P transporters fail to be induced by P deprivation (Smith *et al*., 1999), thereby restricting uptake of inorganic phosphate (Pi) that cannot be effectively utilized.
Leguminous plant that might be expected to replenish soil nitrogen supplies is hard hit by phosphorus deficiency because low phosphorus inhibits effective nodulation and retards the biological nitrogen fixation process (Brady and Weil, 2008).

Adequate supplies of other plant nutrients tend to increase the absorption of phosphorus from the soil. Application of ammonium forms of nitrogen with phosphorus increases phosphorus uptake from a fertilizer as compared to applying the phosphorus fertilizer alone or applying the nitrogen and phosphorus fertilizers separately (Griffith, 2010). This has been attributed to stimulated uptake of $H_2PO_4^-$ or HPO_4^{2-} to balance a greater cation uptake, to enlarged sinks in the higher protein of NH_4^+ nourished plants, and to effects on the phosphorus-carrier complex (Smith *et al*., 2003).

Also the nitrogen increases the tops and roots growth, altering plant (Tisdale *et al*., 1990).

Nitrogen and phosphorus interactions may also take place on the interface between the plant (rhizoplane) and soil (rhizosphere) where soil micro-organisms are usually more abundant and active than elsewhere in the soil. As major nutrients, N and P are intimately involved in plant metabolism and growth; hence there are numerous points of interactions between N and P dependant processes (Troeh *et al*., 1993). Sufficient P supply to plants may prevent elevation of amino acids (with exception of arginine) levels which occurs in P deficient plants associated with the degradation of protein.

2.8 Common bean agronomy

In Africa, common bean cultivation is concentrated at altitude above 1000 m asl. These are the cooler highlands and the warmer mid-elevation areas of East, Central and Southern Africa. However, crop area in low elevation area (<1000m asl) has also been increasing following population pressure (Katungi *et al*., 2009).

Ferralsols is the major soil type in bean production areas of eastern and southern Africa (Table 2), but is generally low in nutrients. Beans grow well in a soil pH range of 5.5-6.8 and are susceptible to acid soils because of their high calcium requirements for nodulation (Sanchez *et al*., 1997). In aluminium saturated soils, calcium and magnesium deficiencies often occur and below pH 5.2, manganese toxicity symptoms such as stunting, chlorosis and puckering of the leaves usually occur. Above pH 6.8-7.0 manganese deficiencies `causing retardation of growth and chlorosis of leaves are evident (Wortmann *et al*., 1998). The temperature range of 10 and 35^0 C is adequate for growth but optimum growth averages of 16 to 24^0C are required. Below 10^0C growth of beans stops and the plant is killed by frost because they require a frost free season of about 120-130 days. Reduction in photosynthetic efficiency has been observed when night temperatures are 10^0 -18^0C (Wortmann *et al*., 1994). Dry, hot weather, short periods of soil water saturation, and cold weather, will all result in sloughing off of nodules, so it may be difficult to achieve high common bean yields Mean rainfall exceeds 400 mm during the 3 months following the main sowing dates for bean in 65% of production areas. Moisture deficits severely constrain bean production in some other areas, frequently resulting in complete crop loss (Wortmann *et al*., 1994).

Table 2. Percentage (%) of bean production areas found in association with major soil types in Eastern Africa

Soil type	Eastern Africa
Acrisol, ferric	2.8
Cambisol,chromic	6.9
Ferralsol, humic	3.4
Ferralsol, orthic	16.7
Ferralsol, rhodic	1.3
Lithosol	3.2
Luvisol,ferric	4.5
Nitisol,dystric	7.7
Nitisol,eutric	11.7
Nitisol,humic	28.8
Andosol mollic	6.1
Other	6.7

Source. Abiotic constraints *(In: Atlas of common bean production in Africa)*

2.8.1 Constraints to bean production

Even though common bean is adaptable to different cropping systems and has a short growing cycle, it is susceptible to many biotic and abiotic constraints (Table 1) (Wortmann *et al*., 1998). Low soil fertility and drought are among the abiotic stresses that are most widely distributed. On average 22 kg N, 2.5 kg P, and 15 kg K/ha are lost annually and losses can be as high as 112 kg N, 3 kg P, and 70 kg K/ha in the intensely cultivated highlands of western Kenya (Van den Bosch *et al*., 1998). Farmers in Kakamega district who can afford nutrient inputs continue to cultivate their farms with increased use of acidifying fertilizers such as Di-ammonium phosphate (DAP) and Urea (Odendo et al.,2006).

Availability of N is low and moderately low on 60% and 30 % of the bean production areas. Potassium is moderately deficient on 40 to 45 % of the area. Aluminium and Manganese toxicities are constraints of moderate importance and cause losses of 200 and

100kg/ha for sole crop of bean if the typical soil pHs were 4.5-5.0 or 5.0-5.5, respectively (Wortmann *et al*., 1998).

Deficiencies in soil nitrogen, phosphorous (P) and zinc (Karen *et al*., 2006), and toxicities of aluminium and manganese are particularly disastrous. Low P soils are a major constraint to bean production in regions of Africa where farmers lack access to sufficient P fertilizer, resulting in an estimated loss of 356,000 tons yr^{-1} (Wortmann *et al*., 1998, Yan *et al*., 1995a).

Among the biotic stresses, many species of insect pests attack beans both before and after harvest. In Kenya, the major pests include the bean fly (*Ophiomyia phaseoli, O.spencerella, O. centrosematis;* Diptera: Agromyzidae), foliage beetles (*Ootheca* sp; Coleoptera: Chrysyomelidae), black aphid (*Aphis fabae*; Homoptera: Aphididae) (Byabagambi *et al*., 1999, Wortmann *et al*., 2006)

Weeds are also an important constraint to bean production due to competition for light, water, space and nutrients (Wortmann *et al*., 1993). Good weed control may be achieved by a single weeding three weeks after planting. However, major losses in the tropics result when farmers lack sufficient labour for timely hand weeding (Wortmann *et al*., 1998).

Diseases are also major constraints to bean production and may be fungal, bacterial or viral in nature. In Kenya, 20 diseases on beans are listed (Byabagambi *et al*., 1999) but only 10 of these are considered important. They include common bacterial blight (*Xanthomonas campestris* pv. *phaseoli* , angular leaf spot *Phaseoriopsis griseolsa,* rust (*Uromyces appendiculatus* Pers), bean common mosaic virus (BCMV), and floury leaf spot *Mycovellosiella phaseoli* which are more important in the low altitude high temperature areas (Gelin,2007). Halo blight (*Pseudomonas syringae* pv. *Phaseolica* ,anthracnose (*Colletotrichum lindemuthianum* , aschochyta blight *Phoma exigua* var. *diversipora* and root rots *(Rhizoctonia solani, Pythium* sp. *Fusarium* spp.) are considered more important in the high altitude and low temperature (Opio *et al*., 2001) Bean root rot disease which is caused by several fungus, including *Fusaruim salani* ,Sacc.F. sp *phaseoli*), *Pythium* ssp, and *Rhizoctonia solani* can lead to complete yield loss when susceptible varieties are used and the environmental conditions are favorable for pathogen development (Otsyula *et al*., 1998).

2.8.2 Common bean in human nutrition

A typical composition of common bean per half cup edible portion is protein 8 g, fat <1 g, carbohydrate 20 g, dietary fiber 8 g, Mg 60 mg, Iron 2g, Sodium 1mg, Copper <1mg, carotene trace, thiamin <1mg,folic acid 128 mg, Manganese<1mg (The bean institute, 2010). The essential amino acid composition per 100 g edible portion is: tryptophan 210 mg, lysine 1540 mg, methionine 240 mg, phenylalanine 1130 mg, threonine 860 mg, valine 990 mg, leucine 1640 mg and isoleucine 890 mg (Wortmann *et al*., 2006).

Consumption of common bean is high mostly because it is relatively inexpensive compared to meat (Katungi *et al*., 2009) and for the poor, it plays a strategic role in alleviating malnutrition.

In Eastern Africa beans are consumed either as cooked or boiled dry grains, prepared in a wide range of recipes. The form of preparation influences the varieties preferred for domestic use. Varieties with thin soft seed coats are associated with less cooking time and give soft gravy (Broughton *et al*., 2003).

In Kenya, beans are commonly consumed as boiled dry beans (either as stew or *Githeri*-a Kikuyu name for mixture of beans and maize), making the varieties with soft grain when cooked, and thin skins more preferred. The dried common beans require processing before they are eaten to degrade the toxic compound, lectin phyto-haemaglutinin, which would otherwise cause severe gastric upset (Ferris and Kaganzi, 2008). The fresh form of grain is the most preferred because of its fresh flavour, good taste, and requires considerably little time to cook (approximately 40 min). However, fresh beans are difficult to keep, and as such they are consumed for a short time only in season before beans dry. Beans are low in sugar, which prevents insulin in the bloodstream from spiking and causing hunger. And when substituted for meat in diet, there is the added bonus of a decrease in saturated fat (Kovacs, 2011).

Beans are also high in antioxidants, a class of phyto-chemicals that incapacitate cell-damaging free radicals in the body implicated for cancer and aging (Kovacs, 2011).

Bean pigmentation and size are also important in consumers' acceptance of a particular bean. Many consumers prefer large brownish/purple or reddish colour seeded beans. Reddish colour is normally preferred because of the red colour it imparts to the food after cooking (Wortmann *et al*., 1998). The palatability of leaves is also an important consideration in varieties grown (Hillocks *et al*., 2006). It is important for staggering food supply where the leaves, pods, green grains and dry beans can also be consumed as boiled green leaves and green immature pods.

2.8.3 Varieties grown and their spatial distribution

A high degree of diversity (in terms of growth habits, seed shape, size and colour) exists but the most common bean varieties grown in Africa are of bush type with small to medium sized seeds. Bush type common bean is preferred to the climbing type because of it low cost production requirements and convenience for market production type. They are also less labour intensive and do not need stakes, are early and uniform maturing, which makes them attractive for market-oriented producers (Wortmann *et al*., 2006). The crop's quick maturity and tolerance of shading have encouraged its widespread cultivation under multiple cropping systems. The climbers dominate the highland areas, where population density is high and land is limiting (Blair *et al.*, 2004). They are potentially high yielding (capable of giving two to four times the yield of bush varieties) (Wortmann *et al*., 1998).

The diversity of common bean seed types in Africa has been reported as massive but varies across the region (Wortmann *et al*., 1998,). It is highest (more than 10 varieties) in pure stand. An inspection of the characteristics of the varieties developed and released reflects a research agenda that was highly influenced by biophysical constraints and user preferences back home. Multi-disease resistance stands out as a common feature of most varieties developed and released in the region. Tolerance to low soil fertility is also emphasized in Kenya because of declined soil fertility (Hillocks *et al*., 2006). Farmers evaluate the potential varieties using their own selection criteria which include total yield, drought tolerance, marketability, taste and cooking time.

Variety traits like high yields, early maturity, good taste, low flatulence and fast cooking are popular among many varieties, reflecting their importance in variety acceptance (Singh, 2001). Spatial distribution of seed types in Eastern and Southern Africa (ESA) is a result of many factors but market forces and agro-ecological conditions are major.

Wortmann *et al* (1998) estimated an aggregate area share of about 50 percent for pure reds and red mottled in Eastern Africa. With the economic growth steadily increasing in most of the sub Saharan African countries, the commercialization of common bean is expected to grow rapidly in the medium term. However, the current preferred market varieties are less tolerant to the important biophysical constraints (drought and poor soils, diseases) and the predicted effects of global warming on the climate in the region could alter the variety distribution trends. The reds and red mottled beans are the most common types due to market preferences. Large genotypic differences also occur in ability to partition P to grain, thereby producing higher grain yield under P-limiting conditions (CIAT, 1995).

2.9 Economic importance of growing common beans

Economic importance refers to a systematic approach to determining the optimum use of scarce resources, involving comparison of two or more alternatives in achieving a specific objective under the given assumptions and constraints. It takes into account the opportunity costs of resources employed and attempts to measure in monetary terms the private and social costs and benefits of a project to the community or economy.

Bean is an important source of cash for small-scale farmers in Africa whether as part of total farm income or for providing a marketable product at critical times when farmers have nothing else to sell such as before the maize crop is harvested (Wortmann *et al*., 1998). Although several varieties of beans have arisen from decades of research (Bean Improvement for low fertility soils in Africa, BILFA) they play an important role in choosing the variety to grow but the different varieties have not generated the desired impacts amongst the target populations due to low or lack of adoption mainly because of availability, price and preferences in terms of seed colour, size or cooking time (Rachier *et al*., 1999).

Return to land is also an economic indicator in choice of an enterprise in situations where land is relatively scarcer than labour or where there are fewer opportunities for the farmer to hire out labour or to engage in off-farm employment. Land in such circumstances is viewed as the most limiting resource and hence farmers should strive to optimize return to land by planting varieties that give high yields and use fewer resources (Ng'eno *et al*., 2010).

The marginal rate of return (MRR) is an indicator of what farmers expect to gain, or on average, in return of the investment when they decide to choose the varieties to grow. Thus for each shilling invested with the local check the farmer can recover plus 6.25 and 1.43 respectively. As a guideline, an MRR below 100% is considered to be too low and is therefore unacceptable to farmers (CIMMYT, 1988). This is because such a return would not offset the cost of capital and other transaction costs while providing an attractive gross margin to serve as an incentive. The results show that the most economically viable option of growing certain varieties was not necessarily the one with highest net benefits or yield.

The marginal rate of return of investing in the technology is also used to show how net benefits accruing from an investment increases as the amount invested increases (Odendo et al., 2006).

This study focuses some attention on evaluation of the economics of the tested common bean varieties at the two sites with and without applied of P.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The study area

The study was carried out both on-farm and on-station in Kakamega district. The on-station experiment was laid down at the Kenya Agricultural Research Station- Kakamega Regional Research Station which is found on longitude 34^0 32’ and 34^0 57’ E and latitude 00^0 07’ and 00^0 15’ N of the equator. It is located within Kakamega Municipality, 1.5 km south-east of the town centre. The on-farm site was in Kabras which lies on longitude 34^0 $52^{'}$ E latitude 00^0 52’N one km away from the Kakamega- Webuye highway. The soils range from rhodic nitisols (nitisols which are not strongly humic and have a red to dusky red argic B horizon) within the station to highly weathered ferralsols

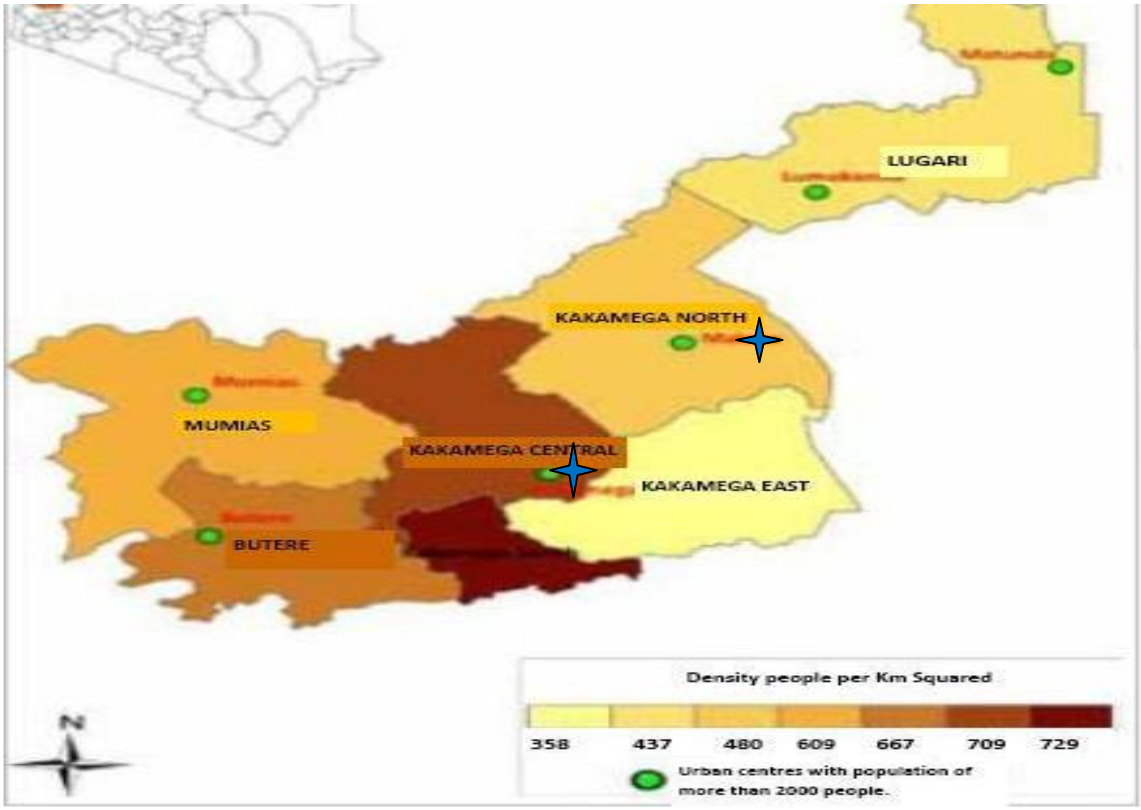


Fig 6. **Map of Kakamega County showing the two study sites (*Source: http//.www.google.co.jp/url?, 2013)***

The characteristics of the 2 study sites can be summarized as below.

Table 3. **A brief profile of the two study sites, (KARI and Kabras)**

Characteristics	**KARI**	**Kabras**
Area (km^2)	1	427.3
Altitude (m asl)	1585	1638
Mean annual rainfall(mm)	1850	1700
Average temperature(^{o}C)	21(high 27, low 14)	18(high29, low 18)
Crops	Maize, beans, cassava, sorghum, Finger millet, sweet potatoes, bananas	Maize, beans, Finger millet, sweet potatoes, sugarcane

3.2 Materials: Origin and characteristics

The improved common bean lines used in this study were from the advanced yield trials (AYT) which had been bred for bean root rot. Recommendations from study by Otsyula (2010) indicate that the bean varieties developed be tested in all bean growing areas where *Pythium* root rot is an important constraint.

The genotypes selected for evaluation consisted of thirteen (13) breeding lines from CIAT- Kawanda Agricultural Research Station in Uganda (Table 3). These materials are advanced lines generated from previously selected root rot materials as breeding parents (Otsyula, 2010). Two check varieties were used: a local released and popular variety GLP585 and GLP2 which is a cultivar that was released by Grain Legume Project at National Horticultural Research Station, Thika in 1984. It is susceptible to low soil P, N and low soil pH, but well adapted, high yielding cultivar. (Kimani, 2006)

Table 4. Characteristics of advanced series common bean (*Phaseolus vulgaris* L.) lines

S/ No	Cultivar	Resistance status to *Root rot)*	Seed size	Geneology	Seed colour
1	GLP2 (check)	SS	Large	Rosecoco Uganda bred.	Calima
2	DOR755	RR	Small	MAG	Red
3	CC 13	MR	small	Land race	Cream mottled
4	217/2	MR	Small	Landrace	Black
5	222/1	RR		Landrace	red
6	297/6	RR	small	Landrace	cream
7	3/MS 8-3	RR	Small	Land race	Red
8	AB- 136	RR	Small	Land race	Red
9	A774	RR	small	MAG	Navy
10	FEB 195	RR	small	MAG	Red
11	RWR 221	RR	Small	Rwanda origin	Red
12	UBR (95)2	RR	Small	Landrace	Cream
13	CC 547	MR	small	Landrace	Cream Mottled
14	MLB-48-89A	RR	small	- from DRC	Grey
15	GLP585 (check)	MR	Small	A240 x Inyumba	Red

RR= Resistant reaction, MR= moderately resistant reaction, SS= Susceptible reaction

Large = 45-50 grams/100 seeds, Medium = 35-40 grams/ 100 seeds, small = 15-25 grams/100 seeds

Those indicated as landraces are breeding lines from the CIAT Africa regional breeding program of university of Nairobi, Kabete Campus. These are advanced lines generated from previously selected tolerant bean improvement for low fertility soils in Africa (BILFA) materials as breeding parents (Lunze *et al*., 2002).

3.3 Evaluation methodology

Evaluation was done at two fertilizer levels: moderate and nil. The moderate level corresponded to the fertilizer level at which a well-adapted control variety under the level performs at 40 to 50% of its normal unfertilized performance (Lunze *et al.*, 2007). All test materials were evaluated under a single level only. All other growth constraints were carefully controlled.

Phosphorus fertilizer was applied at the rate of 0 and 30 kg P ha^{-1}. Triple superphosphate (TSP) fertilizer contains 19% to 23% total phosphorus (44 to 52 % P_2O_5); 95 to 98 % of which is water soluble and nearly all of which is classified as available. The superphosphate TSP is a neutral fertilizer in that it has no appreciable effect on soil pH (Tisdale, 1990). The application of TSP treatment was done only once at planting banded within furrows and incorporated with the soil before planting.

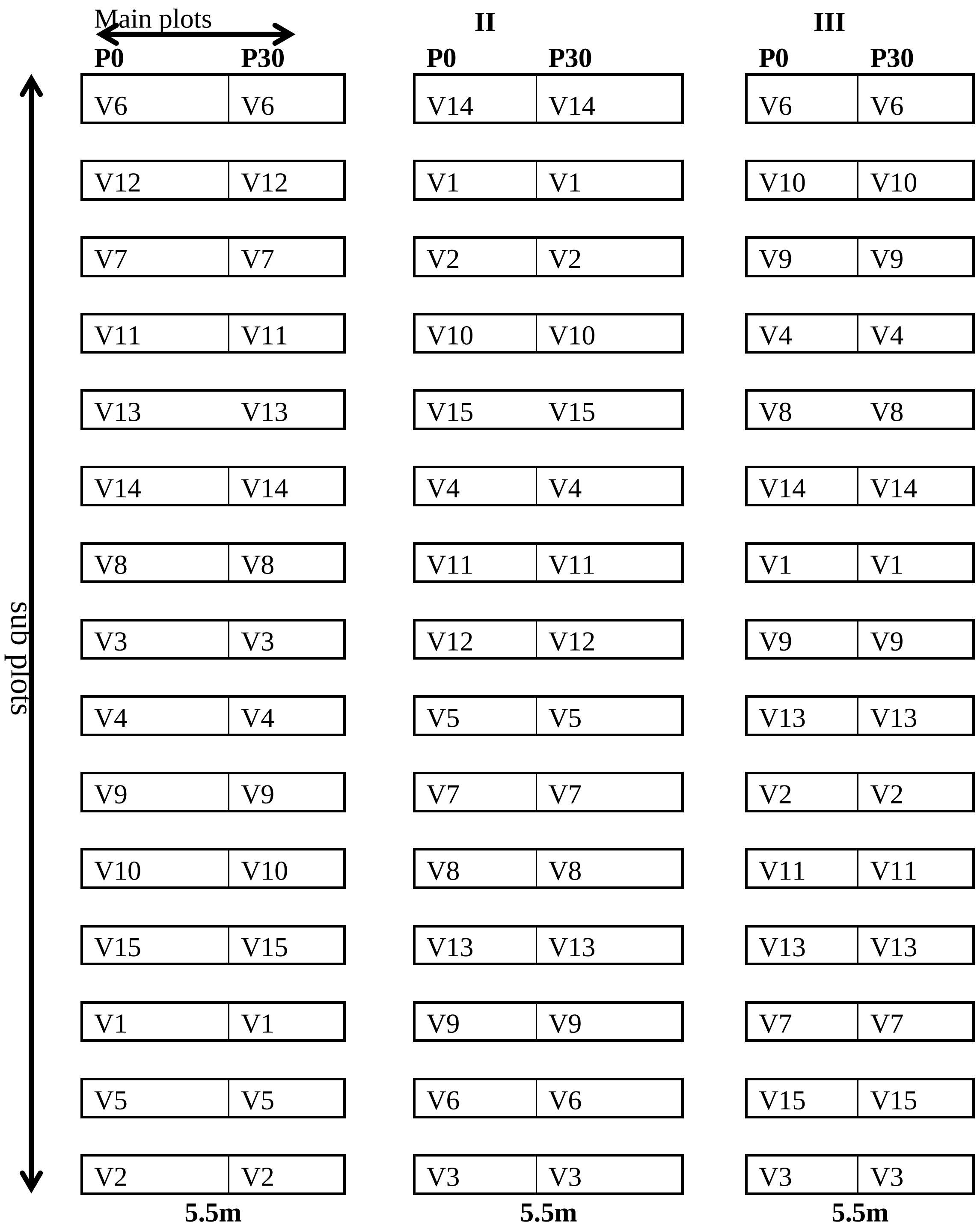
3.4 Field study

3.4.1 Experimental design and treatment allocations

The experiment was laid out in a split plot design (Fig 7) which consisted of fifteen (15) advanced common bean lines as sub factor and two phosphorus rates (0 kg P ha^{-1} and 30 kg P ha^{-1}) as main factor. The treatments were replicated three times

3.4.2 Soil sampling and pre-laboratory analysis

Soil sampling was done prior to the setting of experiment from the two sites on the top 0-20 cm soil. Augering was done to a depth of 30 cm and the auger contents put in a clean polythene bucket. These were then mixed thoroughly. A sub sample was taken of about 500 g (one cupful) and the remaining soil discarded. The soil was then air dried by spreading it out in a shallow tray in a well-ventilated place protected from rain and contamination. The soil lumps were crushed gently using pestle and mortar so that the gravel and roots are separated from the mineral soil



Main plots		II		III	
P0	**P30**	**P0**	**P30**	**P0**	**P30**
V6	V6	V14	V14	V6	V6
V12	V12	V1	V1	V10	V10
V7	V7	V2	V2	V9	V9
V11	V11	V10	V10	V4	V4
V13	V13	V15	V15	V8	V8
V14	V14	V4	V4	V14	V14
V8	V8	V11	V11	V1	V1
V3	V3	V12	V12	V9	V9
V4	V4	V5	V5	V13	V13
V9	V9	V7	V7	V2	V2
V10	V10	V8	V8	V11	V11
V15	V15	V13	V13	V13	V13
V1	V1	V9	V9	V7	V7
V5	V5	V6	V6	V15	V15
V2	V2	V3	V3	V3	V3
5.5m		**5.5m**		**5.5m**	

Fig 7. **Field layout**

P0= Without Phosphorus, P30= with 30 kg P ha^{-1}, V1…V15= common bean lines. I, II and III are the blocks. The total field plot was 38 m by 18.5 m

The soil was then sieved through a 2 mm sieve for pH, particle size analysis and extractable P and exchangeable bases analysis and 60 mesh soils for organic carbon and total N analysis (Okalebo *et al*., 2002)

3.4.3 Planting

Each line was grown in a plot 5.5 m x 2 m to give 6 rows of treatment 0 kg P ha^{-1} and 6 rows of 30 kg P ha $^{-1}$ with 126 plants in each plot. All agronomic practices such as weeding and pest control were done according to standard agricultural practices.

3.5 Laboratory and data analysis

3.5.1 Soil characterization

Composite soil samples from the two sites were analyzed for pH (1:2.5water), Total Nitrogen, total P and particle size analysis as outlined in working manual (Okalebo *et al*., 2002). Total nitrogen (N) was determined by khjeldah method. Total phosphorus (P) was determined by calorimetric without pH adjustment using ascorbic acid

3.5.2 Common bean stand count from the two sites at germination and harvest.

The number of plants that had emerged 10 days after planting in each plot was recorded as the stand count at germination. The number of plants surviving up to harvest was counted and expressed as percentage of emerged. The data obtained from the field was subjected to analysis of variance using SAS.

3.5.3 Determination of nutrient uptake of the common bean lines from the two sites

Common bean sampling was done at 50 % podding by cutting two stems of beans per plot. The biomass of sampled plants was weighed and then dried at 60^0C and the dry weight taken. The biomass was then ground and a composite sample taken for each variety from the three replicates to make one sample. This was then analyzed to determine the N and P contents in the biomass when the plant was at its peak of nutrient uptake (See calculations in equation 1). The means were then subjected to student t-test and separated by least significant difference (LSD).

A sample of the grains was taken and ground. The ground samples were also made into composite samples to obtain 30 samples. One representative sample was from each treatment and replicate. The results were also subjected to student t-test. The nutrient use efficiency (NUE) for each variety was then determined using the yield (tons ha^{-1}) from both treatments and the uptake from the treatment with TSP application (see calculation in equation 2).

% Nutrient = Concentration x 0.005/weight of sample used

Uptake (kg ha^{-1}) = %N * Yield (kg ha^{-1}) ……………………………………………. (**1**)

Nutrient use efficiency was determined using the following formula:

(Yf-Yo)/ Uf………………………………………………………………. (**2**)

Where: Yf, Yo are yields of fertilized and unfertilized crops, respectively
Uf is the P uptake in fertilized crops. (*Source, Hammond et al., 2009)*

3.5.4 Determination of yields

Harvesting was done when the beans were mature and dry. The yield as grains harvested from plot (5.5m x2m) was weighed, recorded in grams and converted into tons per hectare (See calculation 3**)**. The yield in grams (observed) was converted into tons

$$\text{Yield tons ha}^{-1} = \frac{\text{yield in tons (observed (g)/1000000}}{\text{Plot area (m}^2\text{)}} \quad \text{…………………………. (}\mathbf{3}\text{)}$$

The yields were then subjected to analysis of variance using SAS. The means were separated using LSD. Yield was also used to determine the economic analysis of growing the beans in the two sites for different bean varieties.

3.6 Marginal analysis of growing different bean lines in two sites

The variable costs (Table 5) used in this study are from those adopted from the bean section, KARI Kakamega. Enterprise budget was developed and used to compare costs and benefits accruing from different genotypes of advanced common bean lines grown at the two sites with and without application of P. The first step was the calculation of net benefits. Field prices and costs were used to calculate present value of benefits (PNB) which reflects all costs farmers incurred to have inputs on their fields and the actual prices received from output(Gittinger, 1995). Return to land was devised from the net present value (NPV) of each treatment summed over the cropping seasons.

Table 5. Variable costs (Kshs ha^{-1}) for common bean at the two sites

Activity	Quantity/ha	Unit cost	Total
Cost of bean seed	40kg	100	4,000
Land preparation x2		2500	5,000
TSP	30kg	125	3,750
Planting	25MD	100	2,500
Labour	110MD	100	11,000
Total expenditure			26,250

MD –Man day where an adult works for 8 hours

The marginal rate of return was used to show how net benefits accruing from an investment increase as the amount invested increases. Farmers are interested to obtain a given increase in net benefits.

The highest NPV (that is return to land) was identified and then MRR is calculated by dividing the marginal return (difference between the option with the highest return to land and any other option, such as without application of P by the marginal costs (difference between the gross costs of the option giving the highest return to land and the one being compared with) times 100% (Equation 4)

$$\text{MRR}_{(A\text{-}B)}\ (\%) = \frac{\Delta \text{PNB}_{A\rightarrow B}}{\Delta \text{PCV}_{A\rightarrow B}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(4)}$$

Where: A=use of fertilizer, B= no use of fertilizer

$\Delta PNB_{A\rightarrow B}$ = the change in present value benefits (PNB) due to change from A to B, $\Delta PCV_{A\rightarrow B}$ change in present value of total costs (PCV) due to change from A → B

3.7 Statistical model used for split plot design

$$Y_{ijk}=\mu+R_i+V_j+RV_{(ij)}+B_k+V_jB_k+RVB_{ijk}$$

Where:

Y_{ijk} = Yield,

μ = mean yield,

R_i = replicate effect,

V_j = variety,

RV_{ij}= error term for variety,

B_k = Block effect,

V_jB_k = Interaction between variety and block effect

RVB = error term for blocks and interaction between variety and blocks

3.8 The ANOVA

All stand counts at germination and harvest, yields were subjected to analysis of variance (ANOVA) using SAS package (Littell et al., 1996) and the means were separated using least significant difference (LSD) test at 5% probability level. The nutrient uptakes and nutrient use efficiencies were subjected to student t-test and means separated using LSD test at 5% probability levels (Table 4).

Table 6. **The ANOVA model table**

Source	Degrees of freedom	Mean squares
V	14	-
Error(a)	30	$EMS_a = S^2_a$
B	2	-
VB	28	-
Error(b)	60	$EMS_b = S^2_b$
Total	134	

Where V= Variety, B = Fertilizer

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Site soil physical and chemical characteristics

The pH of the soils was 4.90 for Kabras and 5.38 for KARI implying, that the soils are acidic (Table 7). The readily available P was and 2.45 ± 0.96 ppm and7.69± 0.96 ppm for Kabras site and KARI, respectively. These soils are classified as having low in P (0 – 20 ppm is classified as low) (Nelson *et al.*, 1995). The total nitrogen (%) was 0.13 ± 0.02 and 0.2 ± 0.02) for Kabras and KARI indicating low N(less than 0.2%).

Table 7. **Characteristics of soil from the two study sites**

Parameter	KARI Kakamega	Kabras
pH (H_2O)	5.38	4.90
Total N (g kg^{-1})	0.13	0.23
Olsen P (mg kg^{-1})	7.69$\underline{+}$ 0.96	2.45$\underline{+}$ 0.96
Organic carbon (%)	2.6	1.98
Exch K (cmol kg^{-1})	6.94	1.72
Exch Ca (cmolkg^{-1})	1.6	3.52
Mg (cmol kg^{-1})	3.70	0.67
Sand %	62	70
Silt %	21	9
Clay %	17	21
Textural class	Sandy loam	Sandy clay loam
Classification	Rhodic Nitisols	Nito-Rhodic ferralsols
		(***Source: Lunze, 2007***)

Ferralsols (nutrient poor soils) and Nitisols (nutrient rich soils) were the soils used in this study. These soils make up 30.1% of major soils on which common bean is undertaken in East Africa. It is also typical of land used for bean production in Kakamega County by resource poor farmers where although production is achieved the yield is constrained by low available nutrients especially P. Nito-rhodic ferralsols found in Kabras have good physical properties but are chemically poor. These soils are highly weathered soils due to high rainfall, characterized by low cation exchange capacity of < 10 cmol (+) kg^{-1} clay, low exchangeable bases, and low pH. In such soils, available phosphorus becomes limited due to fixation by sesquioxides which occupy much of upper horizons as a result of intensive weathering (Tabu *et al*., 2005). The rhodic-nitisols soils found in KARI are considered fertile soils in spite of their low level of “available “phosphorus and their normally low base status. They are rich in iron(4% or more), CEC is high and less strongly weathered (FAO, 2001) However, for increased bean yield, soil fertility amendment strategies including application of organic matter, phosphate fertilizer or liming may enhance bean yield under similar climatic conditions. Bean production by resource poor farmers without means to ameliorate soil fertility problems, using bean varieties adapted to low phosphorus soils may be important in improving the yields.

(Buresh *et al*., (1997) observed that the quantities of P reserve to replenish solution P concentration are the main factors which will govern the P supply to plants. This therefore implies that the soil at the two sites need prioritization in increasing P which is available to crop within one growing season i.e. P in soil solution and labile P (Nziguheba, 2006)

4.2 Stand count of common bean lines at 10 days after planting with and without applied P

The germination and emergence of the different bean lines varied between the sites and with or without applied P (Fig 8a and b**).** At KARI there was a significant difference (p<0.05) within the lines, within fertilizer treatments and within interaction of the lines and fertilizer. Line CC547, UBR(95), D0R755and A774 had highest number of plant stand compared to the mean while line 217-2 had lowest number of 56 plants as compared to the local check variety GLP585. The local check GLP2 was outstanding with the highest stand count.

At Kabras no significance difference (p<0.05) was observed between treatments and with interaction of fertilizer and lines. Between the test lines, DOR755, CC547, A774, FEB 195, 3MS-8-3 and UBR(95) were outstanding as compared to the mean of 96 plants for the site and a mean of 98 and 94 plants for treatments with and without applied P respectively was observed. Lines AB136, 222/1 and 217-2 had lowest stand count of plants compared to the local checks GLP2 and GLP585. At both sites the inter-genotypic variation was weak within treatments without applied P but more pronounced with P application. The stand count at KARI was low as compared to Kabras with line 217-2 having the lowest stand count.

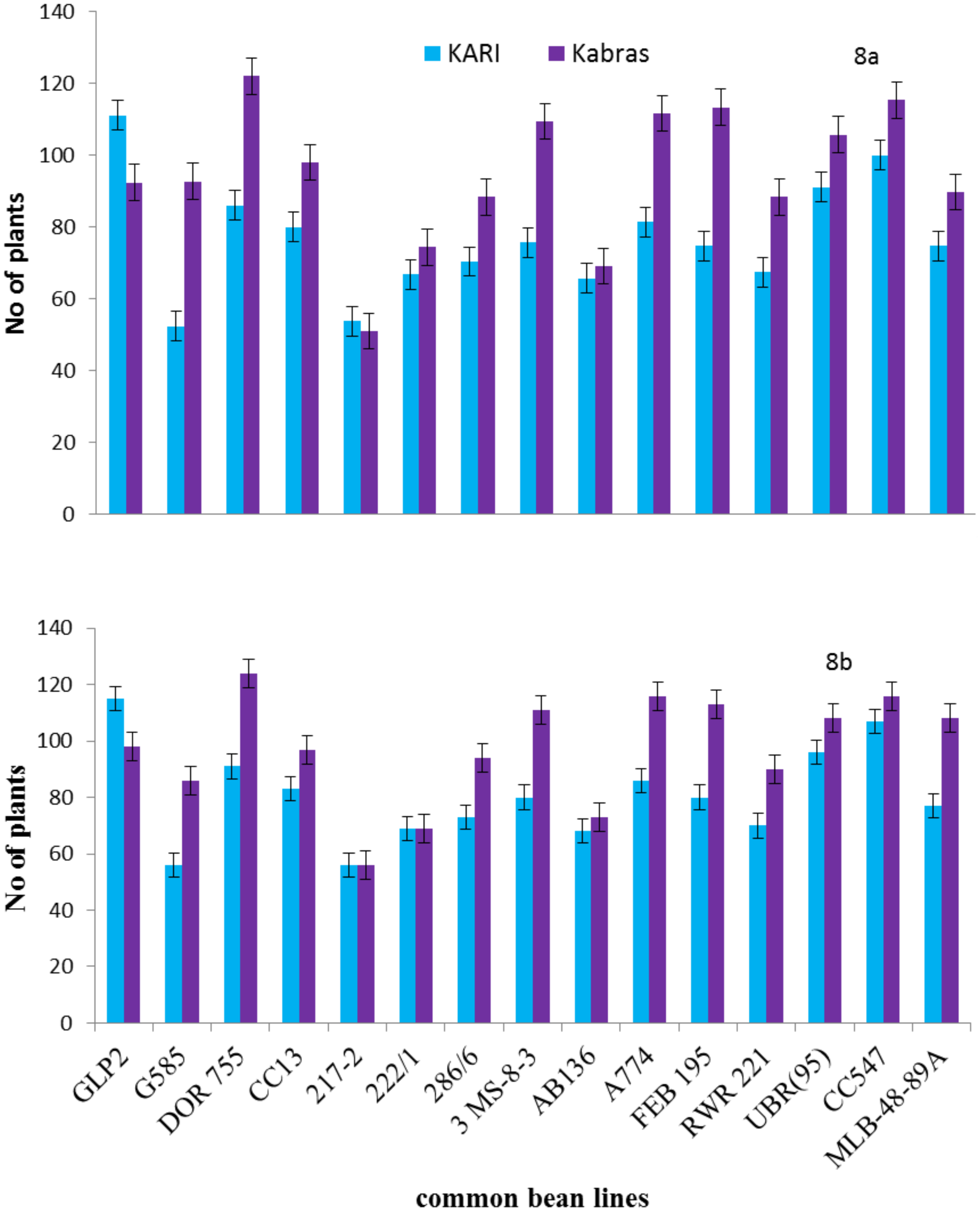


Fig 8a, 8b. **Stand count at germination of bean varieties. a- planted with applied P, b- without applied P.** *LSD (5%): KARI phosphorus=1.9, variety=5; Kabras phosphorus=5, variety=14 CV (%): KARI=5.48; Kabras=12.5*

The results indicate that the soil conditions did not affect stand count of bean lines because despite the high acidity and low soil P and N in the soils at the two sites the beans emerged. No significant difference between interaction of variety and fertilizer at both sites indicate that the applied P did not influence the germination/emergence of the different bean varieties. There was a weak inter-genotypic significance, without applied P implies that P has a role to play in the initial stages of bean germination/emergence. Wortmann *et al*., (1998) indicated that whereas common bean crop may not be sensitive to soil type it should be reasonably fertile, well-drained and with conditions that favour germination and emergence. The nutrient sinks in the seed were most critical in rapid establishment of leaf area. Although Lynch and Brown, (2008) argued that the low P conditions may result in a change in the angle of basal roots, generating a shallower root phenotype, this is a mechanism the bean crop employs to allow it to forage for available inorganic phosphate (Pi) in the top soil.

4.3 Stand count of common bean lines at harvest

At harvest, there was a significant difference ($p< 0.05$) within, between treatments, and with interaction of fertilizer and variety at KARI (Fig 9a and b). Lines CC547, UBR (95), FEB 195, DOR755 and A774 had a stand count higher than the mean of 49 plants. The lines with lowest stand count were RWR221, 217-2 and AB 136. The local check GLP585 had a moderate performance but GLP 2 was outstanding.

At Kabras site a significant difference ($p<0.05$) was observed within treatments but not between treatments and interactions. Within the treatments, the test lines A774, FEB195, MLB-48-89A, DOR755, CC13, and 3MS-8-3 were outstanding above the mean while lines UBR(95), RWR221, AB136, 217-2, and 222/1 had a stand count less than the mean. The local check GLP585 performance was poor while GLP2 was outstanding compared to the test lines.

From the two sites, though the plant population declined at harvest the trend was the same for all treatments with Kabras site having 50 plants and KARI site having 49 plants. Between treatments and within treatments at both sites the number of plants was the same.

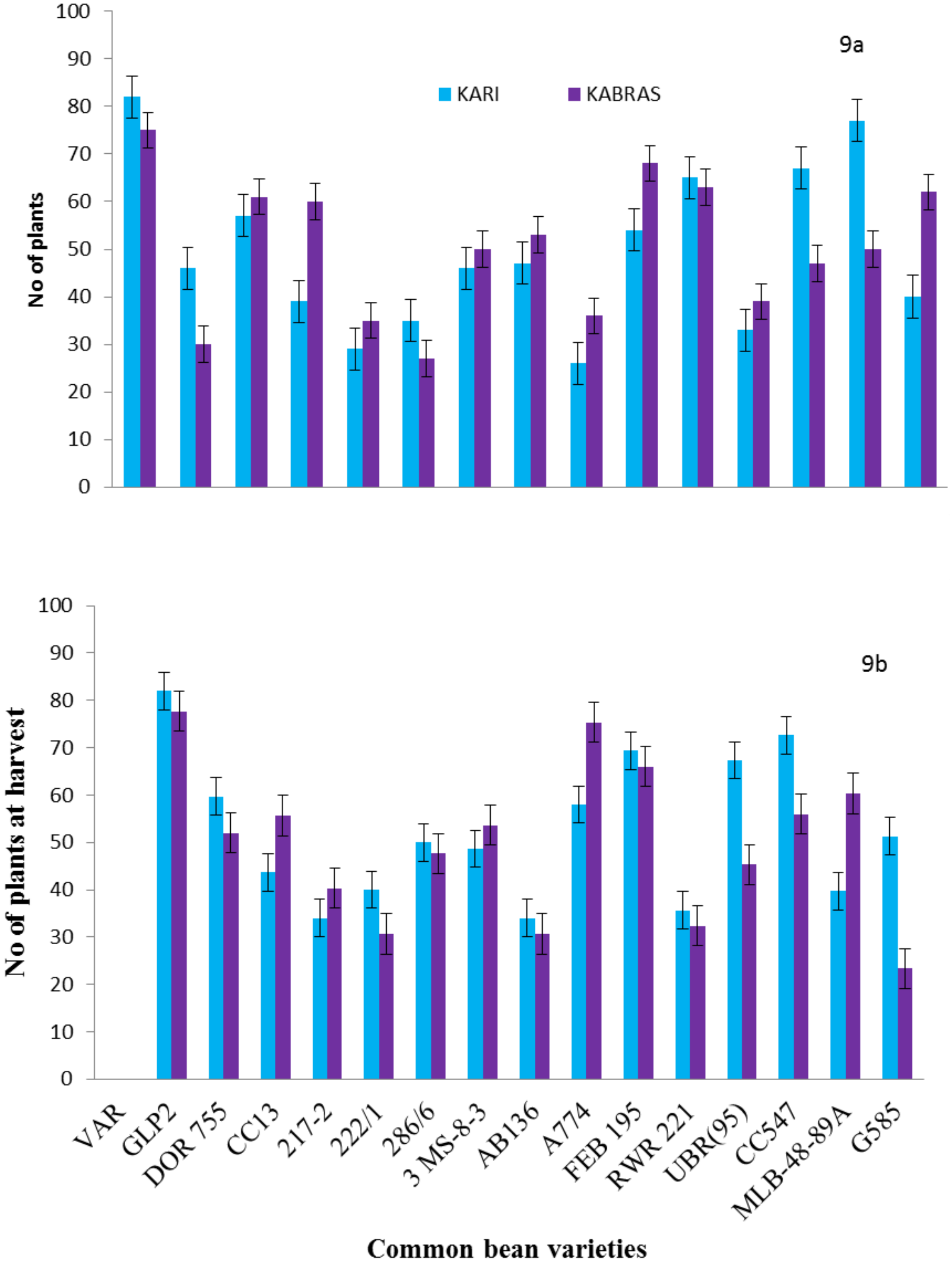


Fig 9a, 9b. Stand count at harvest a-with applied P and b-without application of P.

LSD (5%): KARI phosphorus=6, variety 16; Kabras phosphorus=5, variety=14

CV (%): KARI=27.29; Kabras 23.63

There was a significance difference noted in varieties but not in interactions of variety and fertilizer. Lines which had a high stand count at germination also followed the same trend, DOR755, UBR(95), FEB195, A774, except the local checks whose stand count went low with time.

Results from this study corroborate the hypothesis that common bean differs in their ability to thrive in P-limiting environments (Yan *et al*., 1995b). At low nutrient availability, plants partition large fraction of resources to the root system and as a result, leaf growth and expansion become restricted such that there is a decline in above ground biomass and eventually decline in yield (Poorter *et al.,* 2000). Therefore, the genotypes that thrived at deficient phosphorus level may be termed as efficient, probably because, soil P is somehow sufficient for them or they invest large part of the assimilate to the roots for enhanced soil exploration to support shoot biomass production (Marschner, 1995, Nielsen *et al*,2001). Leaves are also their own sink and transportation of carbon only depends on P availability to provide the energy through the ATP molecule. The stress conditions however reduce partitioning of these resources to the roots. The leaves may fall (defoliation) but the root capacity becomes excess. This phenomenon allowed some lines to survive to harvest while others did not (Plate 2).

Plate 2. Study plot at KARI-Kakamega 28 days after planting
a-with applied P and b-without applied P. ***(Source: Author, 2009)***

4.4 Phosphorus uptake(kg ha^{-1}) of common bean lines in biomass and grain at the two sites

At KARI there was significant difference ($p<0.05$) in phosphorus uptake in the biomass and grain with applied P but no significance difference ($p<0.05$) in biomass without applied P (Fig 10). The lines varied for uptake in the biomass with lines 222/1 and AB136 being not different ($p<0.05$) from the local checks GLP2 and GLP 585 whose uptake was poor. Lines that showed outstanding ($p<0.05$) uptake in biomass compared to the local checks were DOR755, CC13, 3MS8-3, FEB195, UBR(95) and CC547. In the grain the trend was similar with 222/1 and AB136, RWR 221 having a poor uptake together with the local checks ($p<0.05$). Test lines CC547, FEB195, UBR(95), A774, 3MS8-3, CC13,and DOR 755 were outstanding($p<0.05$) compared to the local checks.

At Kabras site there was no significant difference ($p<0.05$) for P uptake in biomass and grain. The lines however varied for their P uptake (Fig 11). Lines RWR221, UBR(95) 217-2, AB136, AND 222/1 did not show a significant difference($p<0.05$) with local checks and their uptake was low. The other lines A774, FEB195, CC547, DOR755, were outstanding compared to the local checks at $p<0.05$. The inter-genotypic difference ($p<0.05$) for P uptake in the grain was weak. No significant difference ($p<0.05$) was observed between lines CC13, CC547, MLB-48-89A, FEB195, A774, 286/6 and DOR755 but it was higher compared to local checks. Lines 217-2, 222/1, AB136, and RWR221 had low uptake as the local checks ($p<0.05$).

From the two sites, the uptake in the bean lines was higher at KARI site as compared to Kabras site. The lines with applied P had a higher uptake compared to those without applied P.

Critical tissue P concentration for common bean below which normal plant growth may not occur is 0.2% (Thung, 1991). The non-significant difference (0.05%) between no applied P and applied P treatments in as far as biomass P concentration is concerned may be due to the following reasons. First is that, there might have been dilution effect (Thung, 1991), (Machado and Furlani, 2004) where phosphorus is distributed within a bigger biomass in plants as exhibited in applied P treatment. Second, it is possible that Al and Fe oxides which are typical constituents in acidic soils (Hinsinger, 2001) may fix much of the phosphorus at applied P, thus rendering it unavailable for the bean plants.

However, tissue P concentration increased with increase in soil P availability, therefore, shoot P concentration was more pronounced at applied P treatment.

Plant P uptake depends not only on P available in the soil but also on plant adaptation and properties such as root architecture (Yan *et al*., 1995), possession of adventitious roots (Miller *et al*., 2003; Lynch et al., 2011) and exudation of anions in the rhizosphere (Hinsinger,2001). An increase in P uptake with increase in P availability among genotypes is in line with the study by Valizadeh (2002) where shoot biomass and P uptake were positively correlated at both low and high P supply for bean genotypes. The differences in P uptake among the genotypes across P treatments show the diversity in efficiency with which bean plants are able to absorb phosphorus from the soils of varying availability

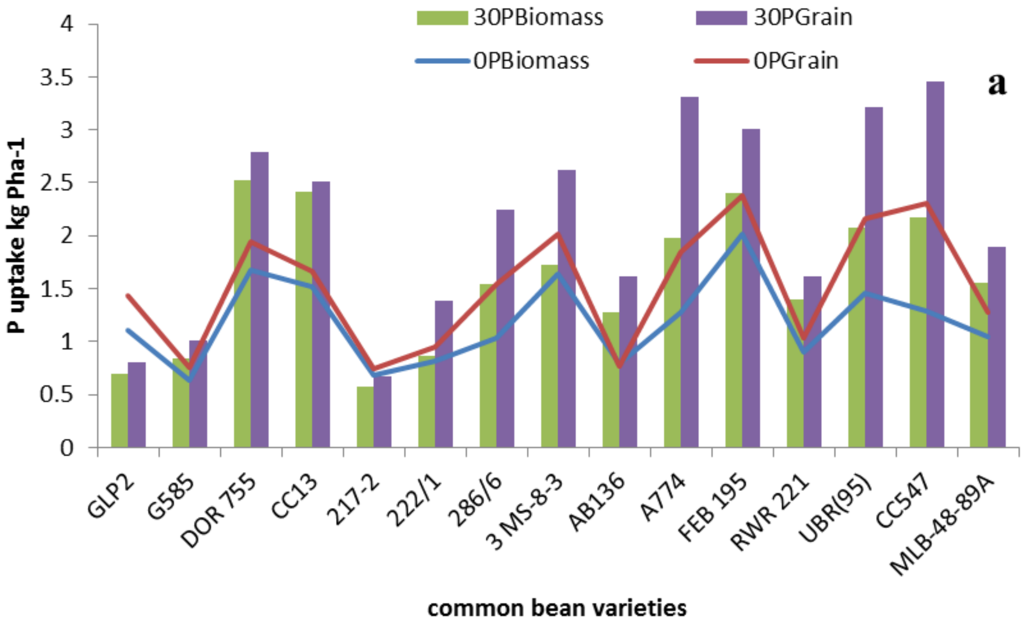


Fig 10. A comparison of phosphorus uptake in biomass and grain at KARI.

CV (%): KARI Biomass =19.3, grain=19.5; LSD (5%): KARI variety 0.58, 0.77 Phosphorus 0.21, 0.28;

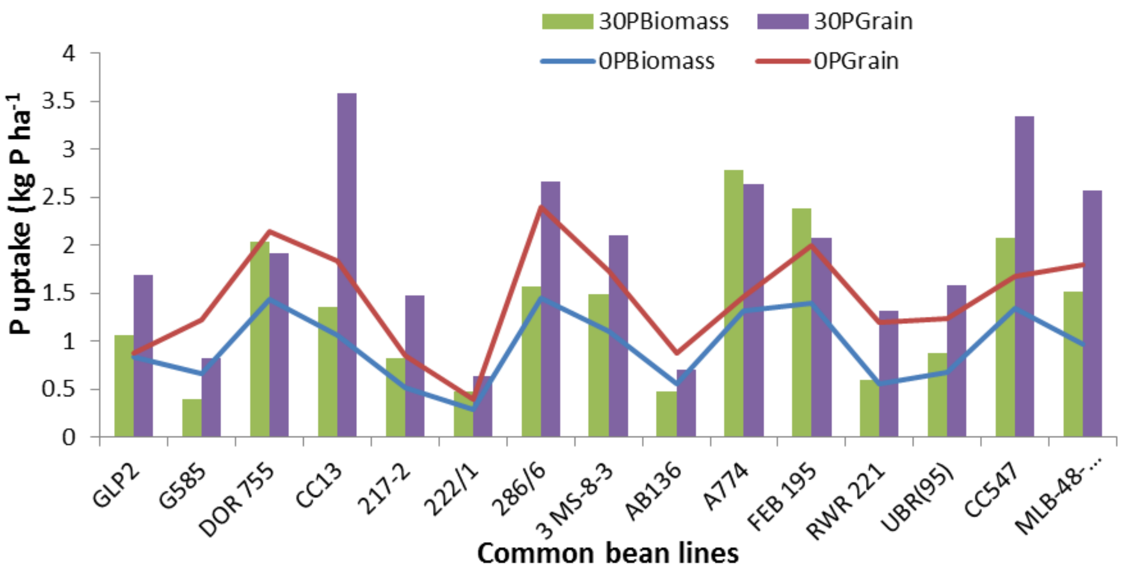


Fig 11. A comparison of phosphorus uptake in biomass and grain at Kabras.

CV (%) Kabras biomass=27.1, grain= 27 LSD (5%) variety 0.66, 0.98, Phosphorus 0.23, 0.36 kg P/ha

Phosphorus use efficiency (PUE) kg kg^{-1} was calculated using yield in applied P treatment lines. There was a varied ($p<0.05$) PUE in the lines at KARI as compared to Kabras (Fig12). Outstanding lines at KARI with PUE above mean included DOR755, CC13, 217/2, 286/6, AB136, A774, FEB195, RWR221, UBR(95), MLB-48-89. At Kabras lines DOR755, 217/2, 286/6, AB136, A774, RWR221, MLB-48-89A had a PUE higher than the mean and also compared to local check. The uptake at KARI site was high compared to Kabras site.

A significant difference between the sites in PUE is an indication that whereas there exists a difference in the genotypes acquisition of P, there is a superior ability to acquire phosphorus from the environment, and phosphorus use efficiency (PUE), or superior ability to convert phosphorus into biomass or yield once it is acquired. Thus, P uptake is the good indicator with respect to P acquisition as it combines both shoot biomass and shoot P content. Common bean genotypes are easily identified by these two parameters and hence may not be favored in selection (Schachtman *et al.*, 1998; Fageria and da Costa, 2000).

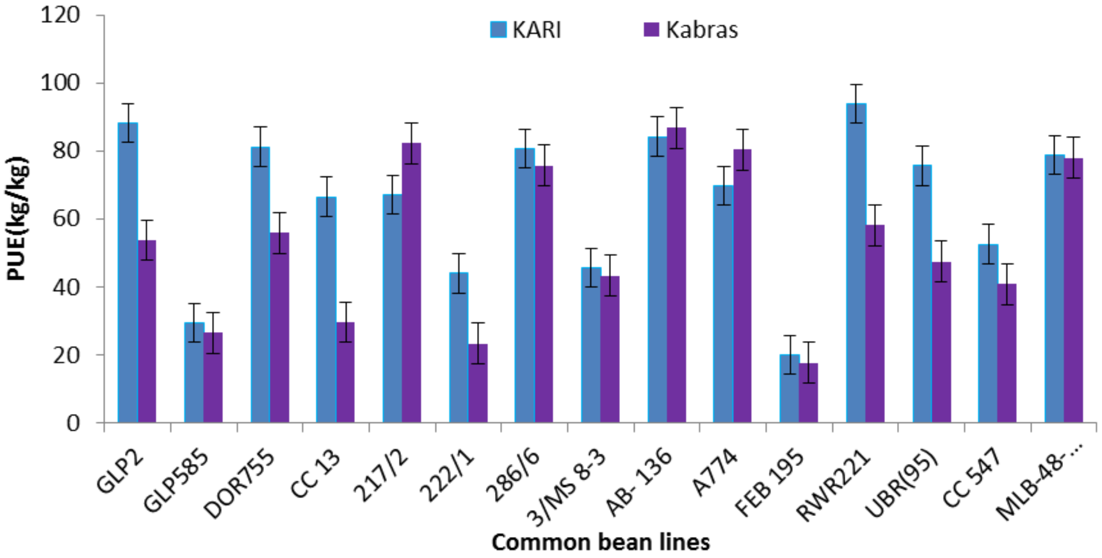


Fig 12. Phosphorus use efficiency (PUE) kg kg^{-1} of common bean lines at the two sites. *CV (%): KARI= 33.9; Kabras =43.65 Standard error KARI=5.7; Kabras=6.0*

4.5 Nitrogen uptake of common bean lines in biomass and grain at the two sites

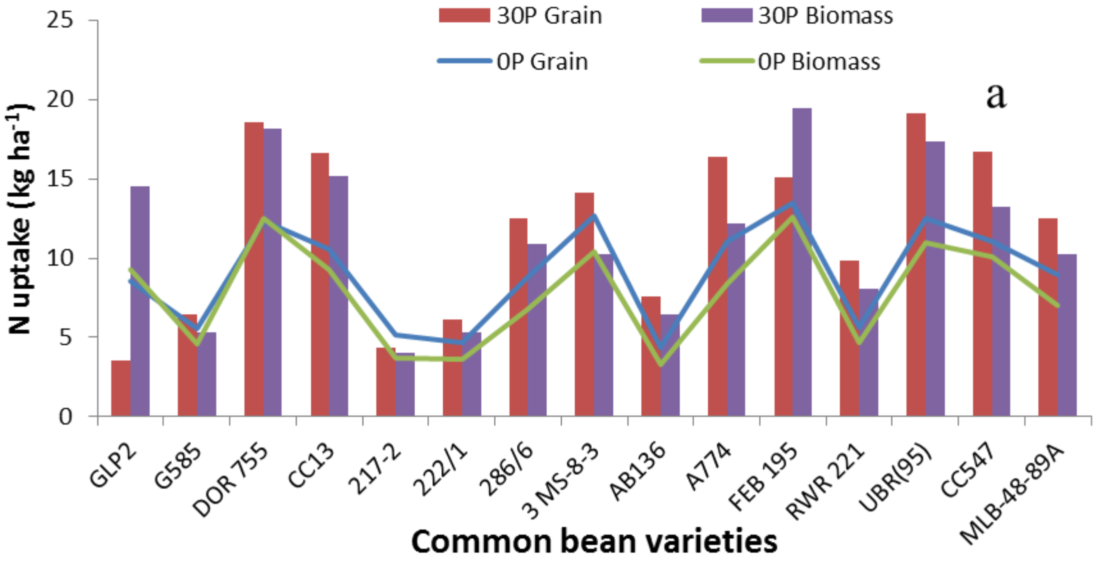
From the results there was a significance difference within varieties ($p<0.05$) for nitrogen uptake in biomass and grain with applied P, in biomass without applied P but no significant difference ($p<0.05$) for uptake without applied P in grain at KARI (Fig 13a). The inter-genotypic difference was strong in the biomass and in the grain. Lines such as FEB195, DOR755, CC13, 3MS8-3, A774, UBR(95), and CC547 had a high uptake compared to the mean and local check. Lines 217-2, 222/1, 286/6, AB136, RWR221, and MLB-48-89A had a lower uptake together with local check GLP585.GLP2 had an average uptake.

At Kabras, there was no significant difference ($p<0.05$) for treatments without applied P for both biomass and grain uptake (Fig 13b). Treatments with applied P showed a significant difference ($p<0.05$) in uptake both for biomass and grain. The inter genotypic difference was however high with lines FEB195, CC547, A774, 3MS8-3, 286/6, and MLB48-89A having high uptake compared to local check. The lowest were 217-2, 222/1, AB136, RWR221, and UBR(95). The inter-genotypic difference ($p<0.05$) for nitrogen uptake within treatments was weak in the grain. Lines 286/6, MLB48-89A, CC547, FEB195, and CC13 had a high uptake in grain as compared to local checks. LinesDOR755, 222/1, 3MS8-3, A774, UBR(95), RWR221 had low uptake and were similar with local checks.

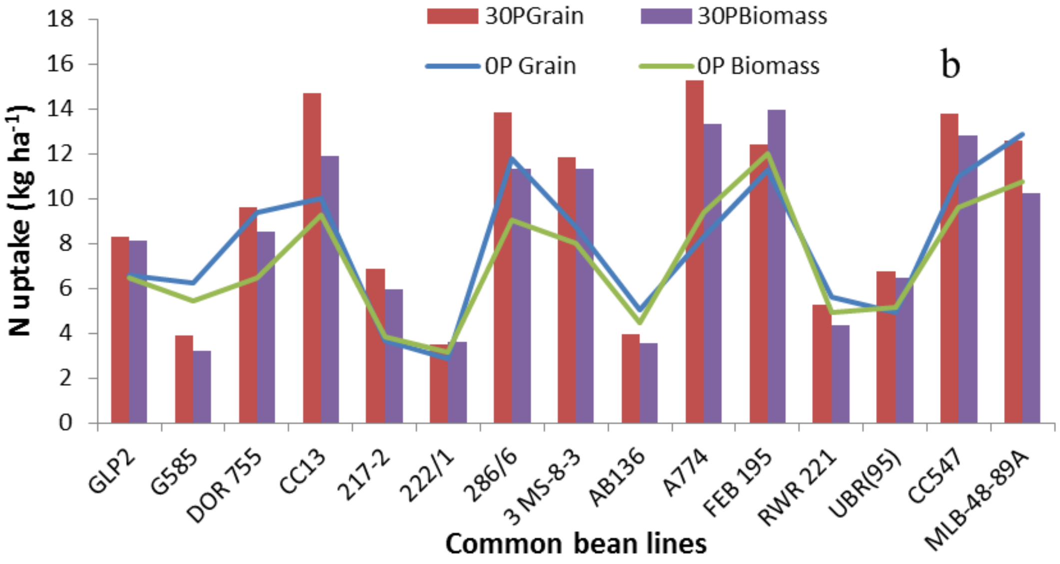
From the two sites, uptake increased with application of P but generally KARI had a higher uptake in lines as compared to Kabras site. The local checks had lower uptake in both locations as compared to the other varieties.

A significant difference at both sites in grain indicates that uptake is influenced by the soil type, and species (Hodge *et al.*, 2000). A non-significant($p<0.05$) difference in the biomass at podding is in line with findings of Masclaux *et al*., (2001) who observed that nitrogen uptake and assimilation during the grain filling period is generally insufficient for the high demand of the seeds, and the progressive and numerous remobilization steps, occurring successively in the different plant organs, are needed to route nitrogen to the seeds. N remobilization is also environment dependent and favoured under limiting nitrate supplies (Lemaître *et al*., 2008), this was evident when the mean of 11.9g kg^{-1} was observed at KARI with application of fertilizer as compared to 9.5 g kg^{-1} at Kabras site and 9.02 g kg^{-1} without applied P as compared to 7.87 g kg^{-1} at KARI and Kabras respectively. This may be attributed to an efficient uptake and use of soil available N and possibly accounts for the low response to P application, as soil N uptake is less dependent on availability (Abaidoo *et al*., 2007), Several varieties had a near equal uptake within the treatments (DOR 755, CC 13, 3MS-8-3, FEB 195, and CC547). This shows that there was a sub-optimal N supply at high P supply which might have also triggered other nutrient deficiency, especially nitrogen and potassium, leading to less assimilate allocation to the seeds (Kajumula and Muhamba, 2012). .

The common bean lines only relied on the N available in the soil (Stress condition) of 0.13kg kg^{-1} for KARI and 0.23 kg kg^{-1} for Kabras since no N was applied.



CV(%): KARI biomass 16.4,grain= 21.1; LSD(5%):biomass 3.37, grain 4.75 kg/ha;



CV(%)Kabrasbiomass= 16,grain= 19.3 LSD(%) biomass = 2.7, grain = 3.59kg/ha

Fig 13a and b. A comparison between nitrogen uptake (kg ha^{-1}) of common bean in biomass and grain grown at KARI; a and Kabras b.

4.6 Grain yield (tons ha^{-1}) of common bean lines grown at two sites

The yield showed a significant difference ($p<0.05$) within the treatments, between treatments but no significant difference with interaction of fertilizer and varieties (Table 8)

Table 8. Grain yield (tons ha^{-1}) of common bean lines grown at KARI Kakamega with and without applied P

	Common bean lines															
Phosphorus applied (kg ha^{-1})	GLP 2	GLP 585	DOR 755	CC 13	217/2	222/1	286/6	3/MS 8-3	AB 136	A774	FEB 195	RWR 221	UBR(95)	CC 547	MLB-48-89A	MEAN
0P	0.485	0.238	0.636	0.621	0.197	0.243	0.439	0.651	0.227	0.588	0.834	0.288	0.667	0.606	0.411	0.481
P30	0.758	0.288	0.863	0.788	0.242	0.303	0.621	0.666	0.364	0.818	0.894	0.439	0.909	0.788	0.561	0.616
Variety mean	0.621 bcd	0.272 f	0.749 a	0.704 a	0.219 a	0.272 f	0.530 cde	0.658 cd	0.295 f	0.702 ab	0.863 a	0.363 ef	0.787 ab	0.697 abc	0.485 de	**0.548**
CV (%)	5.48															
LSD (5%)	0.168															
P	*															
Variety	*															
P x variety	ns															

Means with the same letter along same row are not significantly different at 5% probability level.

at KARI. Lines FEB195, UBR(95), DOR755, CC13 A774, CC547 and 3MS8-3 had a high yield compared to the local checks and above the mean. There was weak variation within yield for these lines. Lines 286/6, MLB48-89A, RWR221, AB136, 222/1 and 217-2 had low yield together with the local checks.

At Kabras site yield was significantly different ($p<0.05$) within treatment but it was not significant ($p<0.05$) between treatments and with interactions (Table 9). Lines MLB48-89A, CC547, FEB195, 286/6, A774, CC13, 3MS8-3, and DOR755 had a yield above the mean (0.479 tons ha^{-1}) and compared to local checks. Other lines UBR(95), 217-2, RWR221, AB136 and 222/1 had low yield together with local checks.

At both sites the yield increased with applied P. There was a weak inter genotypic significance ($p<0.05$) within the lines both at KARI and Kabras.

The high number of pods per plant with increase in P levels (Plate 3) conforms to the results by Yan *et al*.(1995b). Response of bean genotypes to higher P levels indicates that P is pertinent for increased bean productivity. Although grain yield was high within P levels treatments, genotypes differed in the degree of response to higher P levels, suggesting that bean genotypes differ both within and between P treatments for low fertility tolerance, especially phosphorus deficiency.

Plate 3. A photograph of DOR 755 of common bean grown with and without P at Kabras. ***(Source: Author, 2010)***

R= replicate, P= plot number, (+P or –P) = with or without applied P respectively

Table 9. Grain yield (tons ha^{-1}) of common bean lines grown at Kabras with and without applied P

	Common bean lines															
Phosphorus applied (kg ha^{-1})	GLP 2	GLP 585	DOR 755	CC 13	217/2	222/1	286/6	3/MS 8-3	AB 136	A774	FEB 195	RWR 221	UBR(9 5)	CC 547	MLB-48-89A	MEAN
0P	0.454	0.182	0.499	0.667	0.348	0.182	0.697	0.606	0.212	0.742	0.712	0.242	0.379	0.788	0.697	0.494
P30	0.364	0.318	0.606	0.561	0.227	0.167	0.682	0.515	0.288	0.530	0.697	0.318	0.303	0.651	0.742	0.465
Variety mean	0.409c	0.249de	0.553b	0.614ab	0.288cde	0.174e	0.689ab	0.561b	0.249de	0.636ab	0.705a	0.280cde	0.341cd	0.719a	0.719a	0.479
CV (%)	24.4															
LSD (5%)	0.138															
P	ns															
Variety	*															
P x variety	ns															

Means with the same letter along same row are not significantly different at 5% probability level.

Under low P availability, bean genotypes suffer from reduced photosynthesis rate Boutraa *et al*., 2009;Hernández *et al*., 2007, thus leading to low grain yield, unlike for those at high P levels. In most cases, grain yield is the ultimate goal of the grower; therefore, it is an important criterion in adopting a genotype for low soil fertility situations. Bean genotypes which sustain low P levels may be considered efficient and thus worthy of further investigation for inclusion in crop improvement programs. Therefore, such genotypes as CC547, FEB195, A774, DOR755 and CC13 may be considered for inclusion in breeding Apart from the different varieties of common beans Lunze *et al*., (2007) tested a number of beans in Kakamega where he concluded that low tolerance was also related to bean color with the red mottled and red kidney groups having pronounced low tolerance but little tolerance in small red and white/navy seed types. Rachier *et al*., (1999) while carrying out a study in Uganda also confirmed that small grain types have a more P efficiency than check varieties with large- grain types.

The identification of bean genotypes tolerant to low P soils can be difficult due to constraints to growth and yield caused by a small genotypic adaptation to low P. However, towards efforts for obtaining bean cultivars more productive under conditions of low inputs in a sustainable agriculture, there is the challenge of making compatible P efficiency.

4.7 Economic analysis of common bean lines grown as pure stand using 30 kg ha^{-1} P supplied as TSP at two sites

At KARI, the lines which gave a high return to land include DOR755, UBR(95), CC547, 286/6, and A774 (Table10). The local check GLP2 gave a high return but GLP585 had a negative return to land same as 217-2, 3MS-8-3. This indicates that a farmer engaging in growing these lines has to source for more money elsewhere to obtain a profit.

At Kabras site, most of the lines showed a negative return to land except A774,CC547, 217-2, and CC13 but this was low. The local check GLP2 had a low return 43% while GLP585,had no return to land together with other lines such as DOR755, 222/1, 286/6, AB136, RWR221, FEB195 and MLB-48-89A.

With application of P from the two sites, the highest net present value of benefits (PNB) for all the varieties was obtained from variety FEB 195 (Kshs 64,650 ha^{-1}) at KARI , while the lowest(D) was from the local Check G585) at Kabras site. The varieties had a normal trend at both sites but KARI had a high return to land compared to Kabras.

Table 10. **Marginal rate of return (MRR) of common bean lines at KARI and Kabras**

	MRR (%)	
VAR	KARI	KABRAS
GLP2	625	143
DOR 755	505	D
CC13	345	183
217-2	D	223
222/1	63	D
286/6	383	D
3 MS-8-3	D	143
AB136	263	D
A774	516	465
FEB 195	60	D
DRWR 221	305	D
UBR(95)2	548	100
CC547	385	263
MLB-48-89A	300	D
G585	D	D

From the enterprise budget computed for the varieties of common beans grown without applied P, the bean with the highest return was FEB195 with Kshs 60,800 when grown at KARI while genotype 222/1 had a negative return/loss at Kabras. The enterprise budget from the two sites followed a similar trend for all the varieties with KARI site having higher returns to land than Kabras site.The negative returns can be explained by the low yield levels.

From the results farmers are expected to gain more from the different bean varieties if they grow them at KARI as compared to Kabras but with applied P. Returns to land indicate that it would be profitable to grow all varieties using fertilizer except for genotypes 217-2, 3MS-8-3 at KARI, and genotypes DOR 755, 222/1, 286/6, AB 136, FEB 195, MLB-48-89A and UBR(95)2 at Kabras where the returns to land would be too low in almost all varieties. It would however be profitable to grow varieties A774 and CC 547 in both locations. The local check G585 showed negative returns to land at both sites which can be explained by the low yield levels a factor that can be related to the low soil fertility as was seen in Kabras site.

4.8 Genotypic similarities of common bean lines for adaptation to low P, N and P use efficiency, yield and MRR

Cluster analysis which considered similarities for traits other than yield under low P, placed the 15 genotypes in 4 groups (Table 11). Cluster I consisted of genotypes DOR755, CC13, A774, FEB 195, CC 547,and UBR(95); these genotypes had high germination and harvest stand count ,high N and P uptake, high PUE, high MRR. MLB-48-89A, 286/6, 3MS-8-3 had average performance for all traits considered and were put in cluster II.

Table 11. **Genotypic similarities of common bean lines grown at 2 sites**

Cluster	Genotype	Notable characteristics	Mean Yield (kg ha^{-1})
I	DOR755, CC13, A774, FEB195, CC 547, UBR(95)	High germination and harvest stand count ,high N and P uptake, high PUE, high MRR,	693.9
II	MLB-48-89A, 286/6, 3MS-8-3	Average performance	606.8
III	AB136, RWR 221, 222/1	Low P uptake, low PUE at Kabras and negative MRR at Kabras	272.4
IV	217-2,GLP 2, G585	Very low uptake, but high PUE at Kabras & low NUE, negative MRR at Kabras	343.5

Genotypes AB136, RWR 221, 222/1 were in the third cluster; P uptake, PUE at Kabras and yield were generally low and gave a negative MRR at Kabras. 217-2, GLP 2 and

G585 had low nutrient uptake and nitrogen use efficiency but high PUE at Kabras. The MRR was however negative and these were grouped in cluster IV.

From this clustering, it can be noted that yield is a quantitative character, i.e., influenced by many genes with the effects of individual genes normally unidentified, its expression depending upon interaction of many physiological component processes (Fageria *et al*., 2007) as can be seen from Cluster I. Early establishment could have allowed the crop to explore the soil for available nutrients especially N and P (Ma *et al*., 2001; Bates and Lynch, 2000). The lateral root development may have been enhanced in localized zones of the soil that are rich in Pi (Jackson *et al*., 1990). This provides a very valuable mechanism for acquiring more P by these species, particularly when combined with changes in root morphology as occur with cluster roots. This led to a high return to land.
Cluster II having average performance indicate there adaptability to low P and have the potential to perform well if the soil fertility is improved. These varieties will allow the farmer to break-even but not give profits to attract the farmer to engage in their growing.
Cluster III had all notable characteristics as low which led to low yield. The farmer will make a loss in engaging in planting of these varieties at the two locations as they give no returns to the investments incurred. Low nutrient use efficiency in the genotypes could have been the reason for their poor performance.
The last cluster (IV) consisted of the local checks and one test genotype (217-2). All noted characteristics were very low.

P uptake despite its lower initial biomass and nutrient accumulation had an impact on grain yield demonstrating a rapid translocation of assimilates to grain in those lines.
The most grain yielding lines FEB 195 at KARI and MLB-48-89A at Kabras), presented the low seed P concentrations, suggesting a relationship between productivity and P utilization by grain. More efficient P utilization should be achieved by genotypes which retain P in the vegetative tissues, maintaining the rate and duration of photosynthesis and minimizing grain P concentration. Some studies have noticed the genotypic variability for responses to P fertilization of bean yield (Yan *et al*., 1995a).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Soil fertility problems for common bean production can be overcome by growing crop plants which are adapted to low fertility condition in circumstances where other soil amendment strategies are not readily practical. However, this is not possible until these adapted crop genotypes are developed. This study revealed that common bean genotypes do not differ in emergence but available P had an effect on stand count at harvest. This later affected all other parameters that were tasted which included phosphorus uptake. Although some genotypes exhibited an outstanding performance in terms of shoot biomass P uptake and yield, fertility improvement would still be very important if economical bean production is to be undertaken in places with soils of low P concentration as the one used in this study. The soils in the sites used in this experiment were deficient in phosphorus and represents typical soils to which common bean are grown in Kakamega District. Genotypes DOR 755, CC13, A77A, FEB 195, CC547 and UBR(95) were outstanding in terms of stand counts, P and N uptake, and grain yield under low P treatment. They can therefore be considered for incorporation into breeding program for low soil fertility tolerance. Moreover, these genotypes exhibited a good potential to give higher economic yield when P fertilizers are used.

The following conclusions can be made from this study:

1. The bean lines showed different patterns of growth and of P and N accumulation under the different soils.

2. The responses of the different genotypes to the P supply reflect with the same magnitude on seed yield indicating P is a contributing factor to bean yield.

3. A sub-optimal supply of nutrients may limit the expression of the yield potential of lines, reducing the genotypic variability of responses to P levels.

5.2 Recommendations

Common bean lines from Cluster I had all desired characteristics to be considered in a breeding programme as they combine strengths of genotypes for different adaptation to low soil fertility, N and P acquisition, utilization efficiency, yield and return to land hence will offer an opportunity for proper screening of the genotypes.

Growth of P efficient common bean genotypes needs moderate levels of P rather than residual P found in the soil and is necessary for maintaining yield stability in sites extremely deficient in P such as those at Kabras. To improve sustainable agricultural production, it is also necessary to grow crops that can remove the nutrient applied to soil efficiently, and therefore require less fertilizer.

The net benefits of the different varieties at the two sites was more inferior than expected while looking at the yield with some showing negative net benefits and return to land. Nevertheless some data of the varieties was indicative of varieties that could be recommended to farmers.

5.3 Future Research

Future research should focus on the following:

1) Genotypic variability for responses to P fertilization of bean lines calls for fertilizer recommendation which are quantified depending on the soil type, in order to obtain the maximal potential of a specific cultivar
2) Grain yield alone is not sufficient enough to evaluate efficiency of P use of bean genotypes: as yield integrates many edaphic and climatic variables which would likely conceal the efficient germplasm.
3) Studies to ensure that tolerance to low P is compatible with N_2 fixation are needed, since attempts to select bean genotypes tolerant to low P are likely to be affected by the symbiosis established with rhizobia

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APPENDICES

ANOVA TABLES

Appendix 1: Mean Squares for stand count at germination and at harvest, Nitrogen and Phosphorus uptake and yield of 15 common bean genotypes tested at KARI- Kakamega

Source of variation	Degrees of freedom	Stand count at germination	Stand count at harvest	Yield tons ha^{-1}
Variety	14	1687.26*	1798.39**	0.27**
Error	28	719.10	182.04	0.09**
Blocks	2	149.23	438.81	0.07
Fert	1	1195.38**	786.18*	0.41**
Fert *var	14	12.68ns	58.18ns	0.01ns
Error	30	19.40	182.04	0.02
Total	89			
Mean		80.33	49.44	0.548
SED		2.93	8.99	0.09
CV		5.48	27.29	25.9

Appendix 2: Mean Squares for stand count at germination and at harvest, nitrogen and phosphorus uptake and yield of 15 common bean genotypes tested at Kabras

Source of variation	Degrees of freedom	Stand count at germination	Stand count at harvest	Yield tons ha^{-1}
Variety	14	2251.56*	1277.84*	0.24*
Error	28	512.35	156.47	0.04
Fert	1	250.00ns	28.90ns	0.02ns
Fert *var	14	85.74ns	159.35ns	0.02ns
Error	30	145.08	141.62	0.01
Total	89			
Mean		96.40	50.86	0.48
SED		8.03	7.93	0.08
CV		12.49	23.62	24.44