EFFECTS OF PHOSPHORUS LEVELS ON YIELD AND YIELD COMPONENTS OF DROUGHT RESISTANT BEAN LINES IN SOUTHERN HIGHLANDS OF TANZANIA

BY

AIDA ALEX MAGELANGA

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ABSTRACT

The study on the effects of phosphorus (P) levels on yield components and yield of drought resistant common bean lines was carried out at Agricultural Research Institute- Uyole in the Southern Highlands of Tanzania, during the 2010/2011 cropping season. The institute is located at latitude 08^o 56’ S, longitude 033^o 06’ E and altitude of 1795 m above sea level. The overall objective of this study was to find out how to increase grain yield of drought resistant common bean lines through use of phosphatic fertilizers. This was done under screen house and field conditions. A split-plot experiment in a randomized complete block design (RCBD) with three replicates was used. The main-plots were three drought resistant common bean lines: MR 14125-3, MR 14125-6-1 and MR 14215-9-2; and a drought susceptible check variety, Bilfa Uyole. The sub-plots included four levels of P: 0, 30, 60 and 90 kg P ha^{-1}. Data were collected for growth, developmental and yield characteristics. The results revealed that P application of 60 and 90 kg ha^{-1} had significant effect on drought resistant bean lines compared to the control. However, application of 90 kg P ha^{-1} out-yielded the rest of the treatments producing 1972 kg ha^{-1}. The same level also gave the highest growth rate 17.99 g m^{-2} day^{-1} under field conditions. Line MR 14125-3 gave the highest number of pods per plant, number of seeds per pod and 100 seed weight, resulting to highest grain yield of 1292 kg ha^{-1}. From the study it is concluded that, in areas with low soil fertility and terminal drought, application of P at 90 kg ha^{-1} in common bean line MR 14125-3 has a potential for escaping drought hence giving high yields.

DECLARATION

I, Aida Alex Magelanga, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work and it has not been submitted for a degree award in any other institution.

______________________ ______________________

Aida Alex Magelanga Date

(MSc. Candidate)

______________________ ______________________

PROF. C. L. RWEYEMAMU Date

(First supervisor)

______________________ ______________________

PROF. A. J. P. TARIMO Date

(Second supervisor)

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DEDICATION

To my father Alexander Mkonomali Magelanga and my mother Atilia Carlo Fivawo who realized that, the best inheritance I could be given was to be sent to school.

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LIST OF ABBREVIATION AND SYMBOLS

%	percent
/	per
<	less than
>	greater than
±	plus or minus
≤	less or equal to
ANOVA	Analysis of Variance
ARI	Agriculture Research Institute
CV	Coefficient of Variation
CEC	Cation exchange capacity
CIAT	Centro International de Agriculturea Tropical
cm	centimeter
cm^{-2}	per centimeter squares
cmolc (+)kg^{-1}	cent mole concentration per kilogram
DAP	days after planting
DNMRT	Duncan’s New Multiple Range Test
E	East
FAO	Food and Agriculture Organization of the United Nations
Fig.	Figure
g	gram
ha	hectare
kg	kilogram
m	meter

$mgkg^{-1}$	milligram per kilogram
P	phosphorus
N	nitrogen
pH	Hydrogen ion concentration
s/n	serial number
SE	standard error
TSP	triple super phosphate
GM	Grand mean
Mc	moisture content
RCBD	Randomized complete block design
SHZ	Southern Highland Zone

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Common bean (*Phaseolus vulgaris* L.) is the world's most important food legumes for direct human consumption. The crop is also known by a number of other names such as dry, field, French, snap, navy or kidney beans. The crop forms an integral part of the diet of the people in many African and Latin American countries (Maghembe, 1999; Perla *et al*., 2003). With over 25% protein in seeds, common bean is a major source of protein in cereal- based diets of smallholder farmers (Peters, 1993). The common bean also is one of the best non-meat sources of iron, providing 23-30% of daily- recommended levels from a single serving (Schwartz *et al*., 1996). Some 12 million metric tons are produced annually worldwide, of which about 8 million tons are from Latin America and Africa (FAO, 2005). Africa produces 10-25% of the world production and Tanzania in particular produces 11%. In Tanzania the crop is mostly used as a side –dish and as a cash crop to both urban and rural communities.

Common bean grows in a wide range of climates, and is adapted to temperate and cool tropical climatic conditions. Major production occurs in areas where the temperature is around 21^{o}C (Laing *et al*., 1984). Higher temperatures (>30^{o}C) can cause flower and pod abortion which reduces yield (Fageria *et al*., 1997**).** The bean plant is intolerant of frost and a short exposure to 0^{o}C or below will kill its tissue (Wallace, 1980). In Tanzania, the crop grows very well in altitudes ranging from 800-2300 meters above sea level (m.a.s.l) with diverse cropping systems. Common bean is not suited to the very wet tropics, but does well in areas of medium rainfall in tropical and temperate regions. Adequate amounts early in the season is essential, but particularly so during the pod-filling period.

Common bean prefers medium textured, well-drained soils with pH ranging between 6.0 and 7.5 (Wortmann, 2006). It is also intolerant of poor soil aeration due to soil compaction and can tolerate a flooded soil for only about 12 hours. Soil fertility depletion particularly phosphorus (P) is one of the leading factors responsible for low crop yields. Phosphorus is one of the most significant determinants of plant growth (Wang *et al.*, 1998). Phosphorus is considered as one of the necessary elements for the complete function of plants, especially for blooming and seed setting as well as contribution to the growth of roots. It plays a beneficial role in legume by promoting extensive root development and thereby ensuring a good seed. Lack of this element is doubly serious since it may prevent other nutrients from being acquired by plants (Mengel and Kirkby, 2001).

Phosphorus (P) is an important nutrient for all crops in general and legumes in particular. It is a constituent of ATP and plays significant role in energy transformations in plants and also in various roles in seed formation (Hossain *et al.*, 2007). Plants need P for growth, utilization of sugar and starch, photosynthesis, nucleus formation and cell division, fat and albumen formation. Phosphorus compounds are involved in the transfer and storage of energy within plants. Energy from photosynthesis and the metabolism of carbohydrates is stored in phosphate compounds for later use in growth and reproduction.

1.2 Problem Statement and Justification

Despite the importance of the common bean in the Southern Highlands of Tanzania, it is reported that the average production ranges from 300-600 kg ha^{-1} compared with 1500-2500 kg ha^{-1} under research conditions (Mkuchu *et al*., 2003). Common bean yields are severely limited by abiotic and biotic stresses. Among the abiotic stresses, drought and low soil fertility are the primary constraints to crop production. About 60% of the bean crop is cultivated under the risk of intermittent or terminal drought (White and Singh, 1991).

The majority of the common bean production occurs under low input agriculture by resource-poor farmers. Common beans produced by these resource-poor farmers are more vulnerable to attack by diseases pathogens, insect pests and abiotic stresses including drought and low soil fertility (Miklas *et al*., 2006). Of all the environmental factors limiting bean production, drought plays greater role in yield reduction in most of the crop producing areas (Teri *et al*., 1990). Drought stress reduces common bean seed yield in most producing regions worldwide. Moreover, drought is the primary yield constraint to common bean production throughout Eastern and Southern Africa including Tanzania. Drought, whether intermittent or terminal in expression, can be confounded with high temperatures in certain locations, or aggravated by shallow soils and roots. Both quality and yield of beans are negatively affected by brief periods of water shortage (Haterlein, 1983). The effects of drought stress vary depending on the frequency, duration, and intensity and the growth stages affected. Drought occurring during flowering and grain filling periods is the most damaging for beans. Drought stress increases root shrinkage that consequently affects nutrient transport to the root surface due to reduced contact between root and soil. In common bean, excessive abortion of flowers, young pods, and seeds occurs because of drought stress during pre-flowering (10 to 12 days before anthesis) and reproductive periods. It interferes with pollination resulting in increased frequency of barren plants and incomplete seed setting. Moderate to high drought stress can reduce biomass, days to maturity, number of seeds per pod, harvest index, seed yield and seed weight in common bean (Ramirez-Vallejo and Kelly, 1998). In general, drought has the greatest impact on bean seed yield when it occurs during reproductive development. Morphological and phenological traits such as plant type, root systems and early flowering play a major role in adaptation of plants to specific drought conditions.

Much of the common bean production in Sub Saharan Africa, where three quarters of the crop is grown, takes place on steep, erosion-prone slopes with low soil fertility. Common bean production in tropical Africa occurs mostly under conditions of P deficiency (Wortman, 2006). Most important soil related constraint is the P deficiency, which limits 50% of bean production in tropical soils (Beebe *et al*., 1997). In Tanzania over 50% of cultivated soils are estimated to be deficient in P (Kalala and Semoka, 2010). A deficiency of P will slow overall plant growth. Studies conducted by Rodriguez *et al.* (1998) show that P deficiencies lead to a reduction in the rate of leaf expansion and photosynthesis per unit leaf area.

Moreover, P deficiencies occurring during late growing stages will affect both seed development and normal crop maturity. Mengel and Kirkby (2001) found that lack of this element has a double effect since it may prevent other nutrients from being acquired by plants. Adequate P results in rapid growth and earlier maturity, which is important in areas where frost and drought occur frequently. Phosphorus fertilization has been shown to increase water-use efficiency, drought tolerance, and shoot dry matter of many plant species under drought conditions. Moreover, fertilizers containing P have proved to be effective in terms of root development in the early stages of growth and after those growth stages, they have also positive effects on grain yield and quality (Bildirici and Yulmaz, 2005).

However, fertilizers are very expensive and their use is negligible in many developing countries, especially in Sub-Saharan Africa. Moreover, most farmers in bean growing areas are used to grow the crop towards the end of the rainy season, hence being faced with terminal drought. Thus, drought resistant varieties or cultivars are very important in common bean producing areas with erratic rainfall as in many parts of tropical Africa (Tesha, 1987).

Agricultural Research Institute-Uyole (ARI Uyole) has been evaluating drought resistant bean lines for adaptability in the Southern Highlands Zone. However, little has been done on the effect of P on yield and yield components. Identifying optimal P level for drought resistant beans will enable increased bean yield in marginal areas and improve food security for smallholder farmers. This is also advocated by the International Center for Tropical Agriculture (CIAT) scientists (Rao, 2001).

The present study aims at assessing the effect of P on growth and development of drought resistant bean lines and their effect on yield and yield components in the Southern Highlands of Tanzania, particularly in Mbeya region.

1.3 Objectives

1.3.1Overall objective

To increase yield of drought resistant common bean varieties through use of appropriate phosphatic fertilizer levels.

1.3.2 Specific objectives

(i) To determine the effect of different phosphorus levels on common bean growth and development

(ii) To identify the agronomic phosphorus level for common bean lines resistant to drought with respect to yield and yield components

(iii) To evaluate the interaction effect of phosphorus levels and drought resistant common bean lines on yield and yield components.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin of the Common Bean

Common bean is known to have originated in the highlands of Central America and the Andes. It was taken to Europe, Africa and Asia in the 16th century by the Spanish and Portuguese travellers. Common bean is now grown widely in many parts of the tropics, subtropics, and temperate regions (Purseglove, 1987). The crop is the most widely cultivated species in a group of more than 60 legume species referred to as pulse crops. Among the pulses (i.e., annual leguminous food crops that are harvested for seeds) the common bean is by far the most important (Singh, 1999).

2.2 Common Bean Taxonomy

Common bean is a species of the genus *Phaseolus* belonging to the Papilionaceae (fabaceae) family (Raemaekers, 2001). The genus is of American origin and comprises over 50 species (Debouck, 1991). Five of the species, namely, *P. acutifolious* A Gray tepary bean; *P. coccineus* L. runner or scarlet bean; *P.lunatus* L. lima, butter or Madagascar bean; *P. polyanthus* Greenman year-long bean and *P. vulgaris* L. common bean, haricot, navy, French or snap bean were domesticated (Debouck, 1999). Among these species the common bean is the most widely distributed and has the broadest range of genetic resources (Singh, 1999).

2.3 Botanical Description

Common bean may be of determinate or indeterminate growth habits. Studies conducted by Singh (1999) classified the bean growth habits into four major classes (type I =determinate upright or bush; type II = indeterminate upright bush; type III = indeterminate prostrate, non climbing and type IV = indeterminate strong climbers) and suggesting a key for their identification based on the type of terminal bud, stem strength, climbing ability and fruiting patterns. They have pinnately compound trifoliate leaves which are, somewhat hairy, and each has a well-developed pulvinus at the base (Summerfield and Roberts, 1984). The flowers are self compatible, and almost all of them can be self-pollinated and produce fertile seeds (Summerfield and Roberts, 1985). Flowers are highly variable in colour; they may be white, pink, or purple and give way to pods 8-20 cm long, each containing 4-6 seeds. The seeds can be ovoid, subpheric or kidney-shaped and the colour black, brown, yellow, white, brown, red, or reddish- brown, with mottling varying in colour and pattern (Raemaekers, 2001). Common beans have a taproot system with extensive lateral roots. The roots may grow to a depth of 1 m but the lateral root system is mainly confined to the top 25 cm of the soil profile. Common bean stems and branches are slender, twisted, angled and ribbed; in climbing forms they have more nodes which are further apart than in determinate bush types.

Growth and development of common bean is divided into vegetative and reproductive stages. The vegetative stages (V) are defined on basis of the number of nodes on the main stem, whereas the reproductive (R) stages are defined on the basis of pod and seed characteristics in addition to nodes (Fageria *et al.*, 1997). Common bean has an epigeal germination which is complete in 7-8 days after planting. Its flowering may be initiated as early as 10 DAP (Wallace, 1985) although it usually begins between 28 and 40 DAP. Amongst climbing varieties grown at high elevation, it can occur significantly later than bush beans. Physiological maturity occurs between 58 and 68

DAP in early cultivars or can continue up to 200 days amongst the climbing varieties that are used in cooler upland elevations (Graham and Ranally, 1997).

2.4 Benefits of Common Bean

The mature dry seeds of common bean are eaten worldwide as a pulse and the immature pods and seeds as a vegetable. In tropical Africa, common bean is primarily produced and consumed as a pulse. In temperate regions of the world, common beans is mainly grown for the green immature pods (French bean). Common bean is an important source of protein and calories in human diets (Smithson *et al*., 1993). In addition beans provide needed calories (up to 30% of dietary energy), folic acid, vitamin B, dietary fibre essential inorganic micronutrients (Fe, Zn, Ca, Mg and Cu), flavones, antioxidants and ant carcinogenic compounds. It may also be mashed or made into soup. In many parts of the world the dry seeds of common bean are canned, either alone or in tomato sauce. Beans are mainly utilized as side dish, eaten along with rice or thick porridge in rural and urban communities. The nutritional benefits and contribution of beans to healthy human diet is recognized by non-profit organizations targeting human ailments like cancer, diabetes and heart diseases (Haugen and Bennink, 2003).

Common bean is one of the major constituents in human diet, normally complementing cereals especially in developing countries, Tanzania inclusive (Escribano *et al*., 1997).The mature dried seed contains per 100 g of edible matter: 10 g water, 22.6 g protein, 1.4 g fat, 62 g carbohydrate, 4.3 g fibre and 3.7 g ash. The energy value is 1,453 KJ per 100g. The composition of green pods is: 91g water. 1.8 g protein, 0.2 g fat, 6.6 g carbohydrate, 1 g fibre and 0.7 g ash. The energy value is 126 KJ per 100 g. The fresh leaves are sometimes consumed; they contain, per 100 g, 3.6 g protein, 110mg vitamin C and a high content of the precursors of vitamin A. The energy content of leaves is 151 KJ per 100 g. Naturally, the chemical composition of the harvested plant parts depends on the genotypes and ecological factors. In the plant kingdom, the seeds of common bean are appreciated not only for their very high protein content (20-26%) but also for their potassium (average of 1.47%), iron (average of 92.9 ppm), vitamins (thiamine, niacin, folic acid) and fibres (Raemaekers, 2001). Common bean is also important for adding diversity and flavour to carbohydrate-rich meals, such as those based on maize and banana.

The major health benefit of common beans is their rich source of cholesterol lowering fiber. In addition to lowering cholesterol, the high fiber content of beans prevents blood sugar levels from rising too rapidly after meal, making the legume an especially good choice for individuals with diabetes, insulin resistance, or hypoglycemia. The common beans' contribution to heart lies also in the significant amounts of antioxidants, folic acid, vitamin B6 and Magnesium. Folic acid and B6 help lower levels of homocysteine, an amino acid that is an intermediate product in an important metabolic process called the methylation cycle. Elevated blood levels of homocysteine are an independent risk factor for heart attack, stroke or peripheral vascular disease, and are found in between 20-40 percent of patients with heart disease (Messina, 1999).

Common bean generates income to the growers after harvest as it is transported to urban centres where it fetches good prices (Mkuchu *et al*., 2003). Common beans also associate with Rhizobium and fixes atmospheric nitrogen in the soil. Fixation of atmospheric improves the soil nitrogen level benefiting the followed crop, which reduces production costs. If common bean residues are left on the field they improve both the soil structure and texture (Barret, 1990).

2.5 Effect of Climatic Conditions on Common Bean

2.5.1 Rainfall

Common bean is very sensitive to both drought stress and excessive rainfall. Water requirements are quite high during pod filling stage. In Tanzania common beans are grown in areas with rainfall ranging from 500-2000 mm and needs a frost free growing season and a relatively dry period during pod maturation. Early moisture stress at the stage of two trifoliate can have a lasting effect by reducing vegetative growth and affecting floral initiation so that crop maturity becomes more uneven. Excessive rain causes flower drop therefore very low or no grain yield at all. This has also been recorded at the Sokoine University of Agriculture where the common bean crop grown during the December 2011 to February 2012 resulted to no pod production at all (Rweyemamu, C. L. personal communication, 2012). Moreover, excessive rainfall more than 2000 mm increases incidences of diseases, which ultimately result in reduced yield and crop quality. In Tanzania, common bean production which is mostly under rainfed conditions, water deficit or too much rainfall limits yields which results into instability in bean grain yield.

2.5.2Temperature

Common bean is grown in wetter and cooler areas and prefers mean temperatures during the growing season between 15 and 23^{o}C. In Southern Highland Zone (SHZ) common bean sowing normally takes place at temperature between 13 and 23 ^{o}C. Common beans are very sensitive to high temperatures above 30^{o} at flowering time, showing increased abscission of flower buds, flowers and young pods, poor fertilization and seed development in pods. Common beans are also sensitive to low temperatures, which can limit production during early part of the season (Farlow, 1981). Growth stops below 10^{o}C and the plants are killed by frost.

2.5.3 Radiation

The common bean is a short day crop and penetration of light through the canopy is critical and depends to a large extent on orientation and distribution of leaves. The pulvinus of beans leaflets and the trifoliate leaf structure allow the bean plant to orient its leaves in relation to the sun and maximize canopy interception (Wien and Wallace, 1973). In areas such as Tanzania that are close to the equator, light is usually not a problem if appropriate common bean cultivars are grown.

2.5.4 Altitude

In tropical Africa the common bean is adapted to elevations of 1200-2200 m.a.s.l. In Tanzania, the crop is grown in medium to high altitude (1000-2400 m.a.s.l) zones under diverse climatic conditions and cropping systems. The major bean growing areas within the country are upland areas of Tanga, Arusha, Mbeya, Mbinga, Morogoro and Mara (Misangu, 1982).

2.5.4 Soil characteristics

Common bean prefers medium textured, well-drained soils over 0.5 m deep. The optimum pH is 6.0-7.5 but most common bean production in tropical Africa is at soil pH 5-6 and 20% takes place on soils with pH below 5. The crop can also be grown in most types from light sands to heavy clays and also to peat soils. The crop is sensitive to high concentration of Manganese, Aluminium and Boron (Purseglove, 1987). Application of optimum amounts of nutrients is important for optimum bean yield.

2.6 Importance of Phosphorus in Common Beans

Phosphorus is one of the most significant determinants of plant growth (Wang *et al*., 1998). Is an essential plant nutrient required for the general health and vigor of all plants. Growth and development of crops depend largely on the development of root system. Phosphorus enhances root development, which improves the supply of other nutrients and water to the growing parts of the plants, resulting in an increased photosynthetic area and thereby more dry matter accumulation. Robinson *et al*. (1981) reported the effect of phosphorus in stimulating root and plant growth, initiation of nodule formation as well as influencing the general efficiency of the rhizobium bacteria. It plays beneficial role in legumes by promoting extensive root developments and thereby increasing yields, enhancing nitrogen fixation and ensuring a good quality seed. Phosphorus fertilization improves quality of fruits, vegetable and grain crops and increases their resistance to diseases, drought and adverse environmental conditions. It is a major component of compounds whose functions relate to growth, root development, flowering, and ripening (Raboy, 2003). Is the main component in nucleic acids, which as units of DNA molecules are the carriers of genetic information and as units of RNA are the structures responsible for translocation of genetic information (Marschner, 1995).

2.7 Depletion of Phosphorus

Soil fertility depletion, particularly P, is one of the leading factors responsible for low crop yields in sub-Saharan Africa. Total P in soils is abundant, but is rarely available (Liu *et al*., 1994). Low total P and high rate of fixation result in low available P in soils (Palm *et al*., 1997). Only about 10% of added P is immediately available to plants, the rest rapidly converted into insoluble compounds or adsorbed on the soil particles (Mongi, 1974).

2.8 Drought and its Occurrence

Drought may be defined as "the inadequacy of water availability (including precipitation and soil moisture storage capacity) in quantity and distribution during the life cycle of a crop, thus restricting the expression of its full genetic yield potential". Drought is a multidimensional stress affecting plants at various levels of their organization (Yordanov *et al*., 2000). Drought can be imposed when a plant is unable to meet its evapo-transpirational demands. Drought environments are characterized by wide fluctuations in precipitation, quantity of precipitation, and its distribution within and across seasons. There are different types of drought; a drought may be meteorological when precipitation is significantly below expectation for the time of year and location. An agricultural drought is said to exist when water from all sources is sufficiently low enough to cause serious shortfalls in crop yield. A physiological drought occurs when water is present in the soil, but the plant cannot withdraw it due to lower osmotic potential of the soil caused by salts (Rauf, 2008). The effect of stress is usually manifested as a decrease in photosynthesis and growth (Yordanov *et al*., 2000). Drought stress is a worldwide production constraint of common bean (Teran and Singh, 2002). Pandey *et al*. (1984) reported that common beans are extremely sensitive to drought, and significant yield reductions due to drought are common in the tropics. There are two kinds of drought associated with limited rainfall; intermittent, and terminal drought.

Intermittent drought occurs due to climatic patterns of sporadic rainfall that causes intervals of drought and can occur at any time during the growing season (Schneider *et al*., 1997). The nature of this rainfall is unpredictable and leads to marginal yields in crops. In contrast, terminal drought occurs when plants suffer lack of water during later stages of reproductive growth or when crops are planted at the beginning of a dry season (Frahm *et al*., 2004). An example of terminal drought occurs when beans are planted during a short period of precipitation or toward the end of the rainy season without the option of irrigation.

2.9 Components of Drought Resistance

Drought resistance in modern farming is based on the plant ability to obtain water or to use water efficiently, when water is limited by drought. Drought resistance is also defined as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. Rather, drought resistance appears to result from a combination of mechanisms including a deeper root system, stomatal control and improved photosynthate remobilization under stress (CIAT, 2007; CIAT, 2008).

The two main components of drought resistance are drought avoidance and drought tolerance. In common beans, the mechanisms of drought avoidance include principally the development of an extensive root system and an efficient stomatal closure, while drought tolerance in agronomic terms means the ability of the crop to produce a satisfactory yield when subjected to water deficit (Madata, 1991). Drought tolerance in common beans encompasses all mechanisms that allow greater yield under soil moisture deficit (Maghembe, 1999), like thick cuticle with hairs, narrow leaves and deep roots. It is associated with many different morphological and physiological traits or responses including stomatal regulation, variation in leaf cuticle thickness, root morphology and depth, osmotic adjustment, antioxidant capacity, desiccation tolerance (membrane and protein stability), maintenance of photosynthesis and the timing of events during reproduction (Nguyen *et al*., 1997; Klueva *et al*., 1998). Mechanisms of drought tolerance, especially at low plant water status, involve processes at the cellular level, the most important being osmotic adjustment and protection of the membrane system. The osmotic adjustment can allow the maintenance of root or shoot growth under stress conditions, through a control on cellular turgor (Creelman *et al*., 1990).

Various morphological and phenological characteristics have been found to contribute to the drought resistance. Among the morphological characteristics includes leaf characteristics such as leaf angle movements (Kristin *et al*., 1997) and greater root growth (White and Castillo 1989). Another mechanism contributing to increased performance in bean under drought is the phenotypic plasticity, which allows shortening of the growth cycle.

2.10 Interaction of Phosphorus and Drought in Beans

Phosphorus fertilization improves tolerance to drought stress in many plants. Previous research results indicate that the superior performance of common bean genotypes under drought was associated with their ability to mobilize photosynthates to developing grain and to utilize the acquired P more efficiently for grain production. Several authors have shown that drought tolerance in common bean is related to depth of rooting (Sponchiado *et al*., 1989; White *et al*., 1990). Soil exploration by roots is associated with nutrient acquisition, especially for immobile nutrient such as

P (Fageria *et al*., 1997). Hence, the effect of phosphorus on root development is well established (Hossain and Hamid, 2007). Addition of N and P fertilizer enhances root development, which improves the supply of other nutrients and water to the growing parts of the plants, resulting in an increased photosynthetic area and thereby more dry matter accumulation. Genetic differences have been reported in common beans for root biomass and root to shoot ratio and root biomass distribution among distinct root types (Lynch and Beem, 1993).

At CIAT common bean researchers are actively testing the new drought resistant lines, while combining their drought resistance with other traits that farmers need for example efficient nutrient utilization. On the other hand, drought resistance in modern agriculture requires sustaining economically viable plant production despite stress.

The SH zone is dominated by highly weathered soils which have low content of plant nutrients including P. Continuous cropping coupled with inadequate use of inorganic fertilizers has led to low soil productivity in most smallholder farms. Due to the tropical soil characteristics, applied P end up being marginally effective because of fixation by Aluminium (Al) and Iron (Fe) oxides. The use of P efficient bean drought resistant cultivars if identified will be a very good alternative to the improvement of the bean crop in the area.

CHAPTER THREE

3.0 MATERIAL AND METHODS

3.1 Experimental Site

Field and screen house (under controlled conditions) experiments were conducted on-station at ARI- Uyole during the 2010/2011 growing season. The Institute is located in the Southern Highlands of Tanzania at latitude 08^{o} 56’ S, longitude 033^{o} 06 E and at an altitude of 1795 meters above sea level (masl). The area experiences a mono/unimodal rainfall pattern between November to May every year.

3.2 Weather

Weather data which included rainfall (mm), maximum and minimum temperature (^{o}C), relative humidity (RH %) and radiation (MJm^{-2}day^{-1}) under field experiment were recorded at ARI –Uyole meteorological station. Maximum and minimum temperature (^{o}C) and relative humidity (RH %) were also recorded for the screen house experiment.

3.3 Soil Sampling

Composite soil sample was collected randomly from the 0-20 cm depth in February 2011, 14 days before setting the experiment. Soil physical and chemical properties were determined at ARI-Uyole soil laboratory using analytical methods presented in

Table 1: Soil physical and chemical characteristics determined at the beginning of the experiment (February 2011).

Variable	Method of analysis	Reference
Physical characteristics		
Sand , silt and clay	Dispersal and hydrometric readings	Anderson and Ingram (1993).
Chemical characteristics		
Total nitrogen	Micro-Kjedahl digestion-distillation	Bremner and Mulvanay (1982)
Organic Carbon	Walkley and Black	Nelson and Sommers (1982)
pH in water (1:2.5)	pH	Maclean (1982)
Extractable P	Bray - Kurtz-1	Olsen and Sommers (1982)
Cation exchange capacity (CEC)	Ammonium acetate saturation	Chapman (1965)

3.4 Materials

Four common bean lines known to be resistant to drought were obtained from ARI-Uyole. These were MR 14125-3, MR 14125-6-1 and MR 14215-9-2; and a drought susceptible variety Bilfa Uyole that was used as a check. The selection of these drought resistant bean lines used was based on seed color, seed size and yield. These are the characteristics also used by farmers as selection criteria for bean varieties. Fertilizers used were:- Triple Super Phosphate (TSP) 46% P_2O_5 and Urea 46% N. Phosphorus levels applied were:- 0, 30, 60 and 90 kg P ha^{-1}. The recommended P level for beans in the area is 60 kg ha^{-1} as described by Kanyeka *et al*. (2007). Tap water was applied using buckets for irrigation where necessary.

3.5 Experimental Design

3.5.1 Field experiment

For the experiment conducted in the field at ARI-Uyole, a split-plot in a randomized complete block design (RCBD) with three replications was used. Four main plots (factor A) were assigned to bean lines which were MR 14125-3, MR 14125-6-1 MR

14215-9-2 and Bilfa Uyole while subplots (factor B) were assigned to P levels that were 0, 30, 60 and 90 kg P ha^{-1}.

The crop was spaced at 50 cm x 20 cm for inter-row and intra-row respectively. This resulted into 3.0 m x 2.5 m plot size and a total experimental area of 820.31 m^2 including the 1.0 m space between replications. Each plot had six rows, the outer one in each plot being guard rows while the inner four were used for data collection. There was an average of 15 stands per row.

3.5.2 Screen house experiment

Four pots each with 4 l volume represented a sub-plot. Among these four pots, three were used for data collection using destructive method. The experimental design used was as described in section 3.5.1. Spacing in pots was 20 cm between plants sown at a depth of 25 cm.

3.6 Agronomic Practices

3.6.1 Field experiment

3.6.1.1 Land preparation, planting, fertilizer application and weeding

Land clearing, ploughing and harrowing was done by hand hoe. Planting was done on 10 March 2011 by placing two seeds per hill at 25 cm depth in each row. Fertilizer application was done by banding at the rate of treatment applications. Seven days after planting (7 DAP) seedlings were thinned to one plant per hill. Spraying using selecron (Profenofos) insecticide at the rate of 720g/l was done to control bean stem maggot using a knapsack sprayer. Weeding was done three times using hand hoe to make sure that no weeds grew in the plots.

3.6.2 Screen house experiment

3.6.2.1 Land preparation, pot filling, watering and planting

Soil adjacent to field experiment was cleared and top soil (0-20 cm depth) was dug using hand hoe. This was filled into four L pots up to three quarter, watering was done to 50 % field capacity. Fertilizers were applied on planting holes as per treatment combinations. Planting was done on 11 March 2011 by sowing four seeds per pot at a depth of 0.25 m. At (7 DAP) seedlings were thinned to two seedling per hill at a spacing of 0.2m. Spraying was done as described in section 3.6.1.1. Watering was done twice a week, after flowering drought was induced by not watering up to harvesting. Weeding was done by hand pulling.

3.7 Plant Sampling

3.7.1 Field experiment

Plant sampling was done randomly for determination of growth and developmental characteristics. Five sampled plants were tagged from the central rows of each treatment from sub-plots at 21, 42 and 63 DAP. The soil around plants was watered for easy uprooting, and then the roots were carefully dug out of the soil with the aid of sharpened peg. The uprooted plants were washed thoroughly using tap water, and then rinsed with separate clean water. After air drying, data were recorded including; plant height (cm), number of leaves per plant, number of nodes per plant, number of branches per plant and root length (cm) were collected and recorded. Dried plants were then cut into shoots and roots portions packed in dry paper bags for drying.

3.7.2 Screen house experiment

Two plants per pot were uprooted at 21, 42 and 63 DAP. The potted plants were watered and carefully uprooted with the aid of sharp peg avoiding distorting the roots. Washing and data collection were done as described in section 3.7.1.

3.8 Harvesting

The plants were harvested at physiological maturity i.e. when 95% of the pods were dry and brown. At harvest, plants from an area of 1 m^2 in experimental rows in the field and two plants in pots were uprooted for determination of yield and yield components (seed yield per plant, number of pods per plant, number of seeds per pod and 100 seed weight).

3.9 Data Collection

3.9.1 Field experiment

3.9.1.1 Data on vegetative (V) and reproductive (R) stages

Vegetative (V) and reproductive (R) growth stages were collected based on LeBaron (1974), cited by Fageria *et al*. (1997).

(a) Days to crop emergence

This growth stage refers to number of days recorded at developmental stage from sowing to full developed node.

(b) Days to crop establishment

Days to crop establishment were recorded as developmental stage V3 when three nodes on the main stem including the primary leaf node and secondary branching began to show from branch of V1.

(c) Days to 50% flowering

Days to 50% flowering was measured as DAP to the time coinciding with initiation of developmental stage R6 (seeds at least 0.6 cm on long axis) when 50% of the plants had one or more flowers.

(d) Days to physiological maturity

Number of days to physiological maturity was determined at developmental stage R8 (when leaves started yellowing over half of the plant).

(e) Days to harvest maturity

The number of days to harvest maturity was determined as DAP to time when 95% of plants in each plot attained physiological maturity with developmental stage R9 i.e. at least 80% of pods were yellow and ripe. This was taken only when the pods were dry and brown.

3.9.1.2 Data on plant growth and developmental characteristics

Data on some growth characteristics were collected and mean values calculated accordingly.

(a) Number of leaves per plant

Number of leaves per plant was taken by counting total number of leaves from the tagged five plants and computed the mean value.

(b) Plant height (cm)

Plant height (cm) was taken by measuring distance from the soil surface to the tip of the main shoot using a 5 meter steel tape measure and mean value from five plants determined.

(c) Number of branches per plant

Number of branches per plant was taken by counting total number of branches from the tagged five plants and computed the mean value.

(d) Number of nodes per plant

Number of nodes per plant was taken by counting total number of nodes from the tagged five plants and computed the mean value.

(e) Root depth (cm) per plant

Root depth (cm) was determined by measuring length of the tap roots using a ruler from five uprooted field plants then computed the mean value.

(f) Shoot and root biomass (g) per plant

Oven dried samples of shoot and roots were weighed using an electronic balance and computed the mean value.

(g) Crop growth rate (g m^{-2} day^{-1})

Crop growth rate was done by calculating various mean changes in plant dry weights observed at three sampling intervals which were 21, 42 and 63 DAP. These were used to calculate crop growth rate as described by Jolliffe *et al*. (1982) using the following formula:-

CGR (g m^{-2} day^{-1}) = (N/A) (dW/dt)

Where:

CGR= Crop growth rate

N = number of plants

A = land area (plot size sampled)

W = total dry weight per plant

t = time

3.9.1.3 Data on yield and yield components

(a) Seed yield (kg ha^{-1})

Seed yield were taken by weighing total seeds harvested from an area of 1 m^2 from experimental lines sun dried and weighed the measurements converted to kg ha^{-1}.

(b) Number of pods per plant

Number of pods per plant was determined by counting total number of pods from five tagged plants per plot from the central rows.

(c) Number of seeds per pod

Number of seeds per pod was taken by counting total number of seeds from five sampled pods from field and the mean value was computed.

(d) 100 seed weight

100 seeds were taken and weighed from each plot taken as a representative sample.

3.9.2 Screen house experiment

Data collected for screen house experiment were similar to those described in section 3.9.1. However, two plants were used to determine the mean value.

3.10 Data analysis

Data were analyzed using ANOVA as described by Gomez and Gomez (1984) using the following statistical linear model:-

$$\mathbf{Y_{ijk} = \mu + p_k + \alpha_i + \delta_{ik} + \beta_j + A\beta_{ij} + E_{ijk}}$$

Where:

$\mathbf{Y_{ijk}}$**=** is the observed value of kth replicate of the ith level of factor A and the jth level of factor B, **μ =** is the general mean, $\boldsymbol{\alpha_i}$ **=** is the effect of ith level of factor A, $\boldsymbol{\beta_j}$ **=** is the effect for the jth level of factor B, **pk =** is the block effect for the kth block, $\boldsymbol{\delta_{ik}}$ = is the whole plot random error effect, for the ith, kth combination of block and factor A, $\mathbf{A\beta_{ij}}$ **=**is the e interaction of effect of the ith level of factor A with the jth level of factor B, **Eijk** is the subplot random error effect associated with the Y_{ijk} subplot unit. Means were compared using DNMRT at $P<0.05$ level.

CHAPTER FOUR

4.0 RESULTS

4.1 Soil Analysis

The physical and chemical properties of soil (Table 2) were observed to be clay loam in texture with a medium pH of 5.38. The soil available P was low (5.76 mg kg^{-1}) and the percent nitrogen was low (0.13%). The site had medium organic carbon (2.30%) with low cation exchange capacity (18.3 $cmol_c$ (+) kg^{-1}), as described by Landon (1990).

4.2 Weather Conditions

Rainfall received during the experimental period was not uniformly distributed and ranged from 2.4 in May to 237.8 mm in January. Mean monthly maximum air temperature ranged from 23.1 in April to 27.5 ºC in October, while the minimum temperature ranged from 9.7 in September to 14.3 ºC in November. The mean relative humidity was lowest in October (32%) and highest in February (64%). The Radiation was lowest in February (14.9 MJ m^{-2} day^{-1}) and highest in September (19.7 MJ m^{-2} day^{-1}) (Appendix 1). Under screen house conditions, mean monthly air temperature ranged from 30.5^{o}C in April to 31.3^{o}C in March while, the mean relative humidity was highest during April (81.7%) and the lowest in March (66.7%) (Appendix 2).

Table 2: Soil physical and chemical characteristics of soil in experimental site

Parameter	Unit	Reading	Interpretation
Physical characteristics			
Sand	%	40	
Silt	%	26	Clay loam
Clay	%	34	
Chemical characteristics			
Soil pH (1:25) H_2O	pH	5.38	Medium
Total Nitrogen	%	0.13	Low
Organic Carbon	%	2.30	Low
Extractable P	mg kg^{-1}	5.76	Low
CEC	($cmol_c$ (+) kg^{-1}	18.3	Medium

4.3 Field Experiment

4.3.1 Analysis of variance (ANOVA) summary

Summary of analysis of variance of the studied variables is presented in Appendices 3 and 4. Appendix 3 indicates that bean lines had significant effect in all variables except days to crop emergence, crop establishment, 50% flowering, physiological maturity, harvest maturity and seed yield in $kgha^{-1}$. Differences among Phosphorus levels in all variables measured except days to crop emergence and establishment were significant. There was no significant effect for the studied variables on interaction except number of seeds per pod ($P<0.05$) and 100 seed weight ($P<0.001$).

The results in Appendix 4 showed that bean lines were similar in various variables measured except the number of branches per plant ($P<0.01$) at 21 DAP. Similarly, there were no significant differences among the bean lines in variables studied except number of branches per plant ($P<0.01$), plant height ($P<0.01$) and root biomass ($P<0.05$) at 42 DAP. At 63 DAP; bean lines had no significant effect on the variables except plant height. Phosphorus levels were significant in all studied variables except number of nodes at 21 DAP. Interaction effect had no effect on both bean lines and P levels.

4.3.2 Effect of bean lines and phosphorus levels on vegetative (V) and reproductive (R) stages

Table 3 indicates the effect of bean lines and P levels applied on days to crop emergence, crop establishment, 50% flowering, physiological and harvest maturity.

4.3.2.1 Days to crop emergence (V1)

There were highly significant differences ($P<0.001$) among P levels. Plants emerged earliest in MR 14125-3 (11.25 days) followed by MR 14125-6-1 (11.83 days) and latest in Bilfa Uyole (12.42 days). Earliest emergence was observed with 90 kg P ha^{-1} (11.75 days) followed by 30 and 60 kg P ha^{-1}(11.92 days) and latest with 60 kg P ha^{-1}(12.17days).

4.3.2.2 Days to crop establishment (V3)

There were highly significant differences ($P<0.001$) among P levels on days to establishment. Earliest establishment was observed in Bilfa Uyole (23.67 days) followed by MR 14125-3 (23.92 days) and latest in MR 14125 -6-1 and MR 14215-9-2 (24.00 days). Effect of P on days to establishment showed that plants with 60 kg P ha^{-1} (23.58 days) were the first followed by plants with 30 (23.75 days) and latest with 90 kg P ha^{-1} (24.33 days).

4.3.2.3 Days to 50% flowering (R6)

There were highly significant differences ($P<0.001$) on number of days to 50% flowering among P levels. Early flowering plants were recorded in MR 14215 -9-2

(73.92 days) followed by MR 14125-6-1 (74.00 days) and latest in MR 14125-3 (74.50 days). Effect of P on days to 50% flowering showed that plants with 90 kg P ha^{-1} (72.25) were the first followed by 60 kg P ha^{-1} (73.42) and latest with 0 kg P ha^{-1} (76.00 days).

Table 3: Effect of bean lines and phosphorus levels on vegetative (V) and reproductive (R) stages

Bean lines	Days to crop emergence	Days to crop establishment	Days to 50% flowering	Days to physiological maturity	Days to harvest maturity
MR 14125-3	11.25	23.92	74.50	85.17	96.08
MR 14125-6-1	11.83	24.00	74.00	84.92	96.00
MR 14215-9-2	12.25	24.00	73.92	85.33	95.92
Bilfa Uyole	12.42	23.67	74.33	84.58	95.58
SE ±	1.24	0.41	0.98	1.10	0.25
CV%	10.40	1.70	1.30	1.30	0.30
Phosphorus (kg ha^{-1})					
0	12.17	23.92	76.00a	87.67a	98.92a
30	11.92	23.75	75.08a	85.17a	97.83a
60	11.92	23.58	73.42b	84.00b	95.08b
90	11.75	24.33	72.25b	83.17b	91.75b
GM	**11.94**	**23.90**	**74.19**	**85.00**	**95.90**
SE ±	0.66	0.75	0.59	0.68	1.00
CV%	5.50	3.10	0.80	0.80	1.00

Means in the same column followed by the same letter(s) are not statistically different ($P<0.05$) by Duncan's New Multiple Range Test.

4.3.2.4 Days to physiological maturity (R8)

There were highly significant differences ($P<0.001$) among P levels on number of days to physiological maturity of bean lines. Earliest maturity was observed in Bilfa Uyole (84.58 days), followed by MR 14125-6-1 (84.92 days) and latest in MR 14215-9-2 (85.33 days). The effect of P on days to physiological maturity showed that plants with 90 kg P ha^{-1} (83.17 days) were the earliest followed by 60 kg P ha^{-1} (84.00 days) and latest with 0 kg P ha^{-1} (87.67 days).

4.3.2.5 Days to harvest maturity (R9)

There were highly significant differences (P<0.001) among fertilizer levels on days to harvest maturity of bean lines. Generally, the earliest harvest maturity was observed in Bilfa Uyole (95.58 days) followed by MR 14215-9-2 (95.92 days) and latest in MR 14125-3 (96.08 days). The effect of P on days to harvest maturity showed that plants with 90 kg P ha^{-1} were the earliest (91.75 days) followed by 60 kg P ha^{-1} (95.08 days) and latest with 0 kg P ha^{-1} (98.92 days).

4.3.3 Effect of bean lines and phosphorus levels on some growth and developmental characteristics

Tables 4 – 6 present the effect of bean lines and phosphorus levels on the number of leaves, plant height, number of branches and nodes; root depth, root biomass and shoot biomass at 21, 42 and 63 DAP.

4.3.3.1 Number of leaves per plant

Bean lines showed high significant differences (P<0.01) on number of leaves per plant at 42 DAP. However P levels showed highly significant differences (P<0.001) at all growth stages tested (Table 4). At 21 DAP, higher number of leaves was observed in MR 14125-3 (4.00), line MR 14125-9-2, Bilfa Uyole and MR 14125-6-1 had similar response (3.00). At 42 DAP, MR 14215-9-2 had higher number (20.17) followed by MR 14125-3 (19.83) and lowest in Bilfa Uyole (16.75). At 63 DAP, MR 14125-3 had the highest number (40.90) followed by MR 14215-9-2 (32.60) and lowest in Bilfa Uyole (29.90). At 21 DAP, 90 kg P ha^{-1} showed more leaves (3.92) followed by 30 and 60 kg P ha^{-1} (3.00) and lowest with 0 kg P ha^{-1} (2.00). At 42

DAP, 60 kg P ha^{-1} had more leaves (21.58) followed by 90 kg P ha^{-1} (20.42) and lowest with 0 kg P ha^{-1}(12.33). At 63 DAP, 30 kg P ha^{-1} had more leaves (40.20) followed by 60 kg P ha^{-1} (38.70) and lowest with 0 kg P ha^{-1} (21.30). The high CV at 21 and 63 DAP could be due to the very low number of leaves in treatments with no P. Leaves being the sink for photosynthesis, due to low P in the roots the plants failed to absorb moisture and other nutrients hence resulted to reduced growth both vegetative and reproductive.

4.3.3.2 Plant height (cm)

Plant height were similar among bean lines at 21 DAP; however, were highly significant differences (P<0.01) were observed at 42 DAP. Also, highly significant differences (P<0.001) among P levels were observed at all growth stages (Table 4). At 21 DAP, the tallest plants were observed in MR 14125-3 (8.67 cm) followed by MR 14215-9-2 (7.58 cm) and shortest plants in Bilfa Uyole (6.00 cm). At 42 DAP, MR 14125-3 had the tallest plants (31.67 cm) followed by MR 14215-9-2 (25.25 cm) while Bilfa Uyole had the shortest plants (18.50). At 63 DAP, MR 14215-9-2 had the tallest plants (68.70 cm) followed by MR 14125-3 (49.40 cm), whreas Bilfa Uyole had the shortest plants (42.80). The effect of P levels on plant height indicated that at 21 DAP plants to which, 60 kg P ha^{-1} was applied were the tallest plants (8.08 cm) followed by 30 kg P ha^{-1} (7.92 cm) whereas plants that did not receive P were the shortest (5.50 cm). On the other hand, at 42 DAP plants that receive 90 kg P ha^{-1} were the tallest (27.25 cm) followed by 60 kg P ha^{-1} (26.50 cm) while plants receiving no P were the shortest (16.92 cm). At 63 DAP, plants that received 90 kg P ha^{-1} (63.20 cm) were the tallest followed by 60 kg P ha^{-1} (61.40 cm) and those that received no P were shortest (35.20 cm).

Table 4: Effect of bean lines and phosphorus levels on some growth characteristics at 21, 42 and 63 DAP

	Number of leaves per plant			Plant height (cm)			Number of branches per plant		
Bean lines	**21 DAP**	**42 DAP**	**63 DAP**	**21 DAP**	**42 DAP**	**63 DAP**	**21 DAP**	**42 DAP**	**63 DAP**
MR 14125-3	4.00	19.83a	40.90	8.67	31.67a	49.40b	2.70a	4.83a	6.00a
MR 14125-6-1	3.00	16.92b	31.50	6.83	20.67bc	53.80b	2.20bc	3.33c	5.83a
MR 14215-9-2	3.00	20.17a	32.60	7.58	25.25b	68.70a	2.60ab	4.00ab	5.92a
Bilfa Uyole	3.00	16.75b	29.90	6.00	18.50c	42.80bc	2.00c	4.08ab	6.50ab
SE ±	0.48	0.88	5.4	1.33	2.6	2.7	0.22	0.53	0.61
CV%	14.6	4.8	16	18.1	10.8	5	9.4	12.2	10.1
Phosphorus (kg ha^{-1})									
0	2.00c	12.33b	21.30b	5.50b	16.92b	35.20b	1.60b	2.75b	3.67c
30	3.00b	19.33a	40.20a	7.92a	25.42a	55.00b	2.80a	4.25a	6.33b
60	3.00b	21.58a	38.70a	8.08a	26.50a	61.40a	2.60a	4.50a	6.92ab
90	3.92a	20.42a	34.70a	7.83a	27.25a	63.20a	2.60a	4.75a	7.32 a
GM	**3.27**	**18.42**	**33.7**	**7.33**	**24.02**	**53.7**	**2.38**	**4.06**	**6.06**
SE ±	0.71	3.604	9.34	1.02	2.771	10.51	0.62	0.495	1.1
CV%	17.2	19.6	15.4	13.9	11.5	19.6	16.2	32.7	18.1

Means in the same column followed by the same letter(s) are not statistically different ($P < 0.05$) by Duncan's New Multiple Range Test.

4.3.3.3 Number of branches per plant

Difference among bean lines were significant ($P<0.05$) at 42 DAP but highly significant different ($P<0.01$) at 21 DAP in number of branches per plant. The effect of P levels were significantly different ($P<0.05$) at 21 DAP and highly significant different ($P<0.001$) at 42 and 63 DAP (Table 4). At 21 DAP, more branches were observed in MR 14125-3 (2.70) followed by MR 14215-9-2 (2.60) and less branches in Bilfa Uyole (2.00). At 42 DAP, MR 14125-3 had more branches (8.83) followed by Bilfa Uyole (4.08) and less in MR 14125-6-1 (3.33). At 63 DAP, Bilfa Uyole had the higher number of branches (6.50) followed by MR 14125-3 (6.00) whereas MR 14125-6-1 had the lowest number (5.82).

The effect of P on number of branches at 21 DAP showed almost a decreasing trend with increasing levels of fertilizer. Plants that had 30 kg P ha^{-1} produced the highest number of branches (2.80) whereas 60 kg P ha^{-1} and 90 kg P ha^{-1} produced 2.60 branches. Plants that did not receive any P recorded the smallest number of branches (1.60). However, at 42 DAP the number of branches per plant increased with increasing levels of P. Application of 90 kg P ha^{-1} had the highest number (4.75) followed by 60 kg P ha^{-1} (4.50) and lowest with 0 kg P ha^{-1} (2.75). Similarly, at 63 DAP, 90 kg P ha^{-1} produced the highest (7.33) followed by 60 kg P ha^{-1} (6.92) and lowest with 0 kg P ha^{-1} (3.67). The high CV value of 26 and 32.7% at 21 and 42 DAP respectively was mainly caused by the very low number of branches produced in treatments with no P application.

4.3.3.4 Number of nodes per plant

At 42 and 63 DAP, P levels showed highly significant differences ($P<0.001$) in number of nodes per plant (Table 5). At 21 DAP, the highest number of nodes was observed in MR 14125-3 (4.00), followed by MR 14125-6-1 and MR 14215- 9-2 (3.00) and the lowest in Bilfa Uyole (2.00). At 42 DAP, MR 14215- 9-2 had the highest number of nodes (9.75) followed by MR 14125-3 (9.42) where line Bilfa Uyole produced the lowest (7.42). At 63 DAP, MR 14215- 9- 2 had the highest number (12.00) followed by MR 14125-3 (11.83) and lowest in Bilfa Uyole (10.42). At 21 DAP the response of bean lines to P levels in number of nodes was similar. All levels of P (30, 60 and 90 kg P ha^{-1}) produced three nodes per plant whereas 0 kg P ha^{-1} produced two nodes. At 42 DAP, plants which received 90 kg P ha^{-1} had the highest number (10.17) followed by those that received 60 (9.58), and the lowest

(5.83) from the plants that did not get P. At 63 DAP, 90 kg P ha^{-1} had the highest (12.58) followed by 60 kg P ha^{-1} (12.50) and lowest was with 0 kg P ha^{-1} (8.00).

4.3.3.5 Root depth (cm)

Like other parameters measured, the root depth of bean lines were significantly influenced by levels of P at different DAP. At 42 and 63 DAP there were significant differences ($P<0.05$) among P levels on root depth (Table 5). However at 21 DAP P levels highly significantly ($P\leq 0.001$) influenced root depth of bean lines. The deepest roots were observed in Bilfa Uyole (12.20 cm) followed by MR 14215-9-2 (11.80 cm) and shallowest in MR 14125-6-1 (10.70 cm). At 42 DAP, MR 14215-9-2 had the deepest roots (19.50 cm) followed by MR 14125-3 (18.67 cm) and shallowest in MR 14125-6-1 (16.83 cm). At 63 DAP, Bilfa Uyole had the deepest roots (28.83 cm) followed by MR 14125-6-1 (27.75 cm) whereas line MR 14125-3 had the shallowest (24.25 cm). At 21 DAP, P levels showed deepest roots with 60 kg P ha^{-1} (14.00 cm) followed by 30 kg P ha^{-1} (12.60 cm) and shallowest with 0 kg P ha^{-1} (8.50 cm). At 42 DAP, deepest roots were observed with 60 kg P ha^{-1} (19.67) followed by 30 kg P ha^{-1} (19.33 cm) and shallowest with 0 kg P ha^{-1} (14.83 cm). At 63 DAP, 30 kg P ha^{-1} had the deepest roots (28.58 cm) followed by 60 kg P ha^{-1} (27.58 cm) and shallowest with 0 kg P ha^{-1}(23.83 cm).

Table 5: Effect of bean lines and phosphorus levels on some morphological and root characteristics at 21, 42 and 63 DAP

	Number of nodes per plant			Root depth (cm)			Root biomass (g plant^{-1})		
Bean lines	**21 DAP**	**42 DAP**	**63 DAP**	**21 DAP**	**42 DAP**	**63 DAP**	**21 DAP**	**42 DAP**	**63 DAP**
MR 14125-3	4.00	9.42	11.83	10.90	18.67	24.25	1.40	2.05a	6.18
MR 14125-6-1	3.00	8.33	11.00	10.70	16.83	27.75	1.40	1.81b	6.66
MR 14215-9-2	3.00	9.75	12.00	11.80	19.50	26.50	1.40	1.96ab	6.41
Bilfa Uyole	2.00	7.42	10.42	12.20	16.92	28.83	1.40	1.87b	6.34
SE ±	0.43	1.08	0.91	1.46	1.68	2.81	0.05	0.08	0.51
CV%	14.4	12.8	8	12.8	9.3	10.5	3.6	4.2	7.9
Phosphorus (kg ha^{-1})									
0	2.00	5.83b	8.00b	8.50c	14.83b	23.83b	1.30b	1.42b	5.76b
30	3.00	9.33ab	12.17a	12.60a	19.33a	28.58a	1.50a	2.01a	6.47a
60	3.00	9.58ab	12.50a	14.00a	19.67a	27.58a	1.50a	2.09a	6.65a
90	3.00	10.17a	12.58a	10.50b	18.08ab	27.33ab	1.50a	2.16a	6.72a
GM	**3.00**	**8.73**	**11.31**	**11.4**	**17.98**	**26.83**	**1.42**	**1.92**	**6.4**
SE ±	0.49	1.867	1.71	1.87	4.333	4.23	0.09	0.199	0.54
CV%	16.2	17.4	15.1	16.4	24.1	15.8	6.6	10.4	8.5

Means in the same column followed by the same letter(s) are not statistically different ($P< 0.05$) by Duncan's New Multiple Range Test.

4.3.3.6 Root biomass per plant (g)

At 42 DAP, there were significant differences ($P<0.05$) among bean lines and P levels on root biomass. P levels were highly significant different ($P<0.001$) at 21 and 63 DAP (Table 5). At 21 DAP, there were similar response (1.40 g) on root biomass in all bean lines. At 42 DAP, highest accumulation was in MR 14125-3 (2.05 g) followed by MR 14215-9-2 (1.96 g) and lowest in Bilfa Uyole (1.87 g). At 63 DAP, MR 14125-6-1 had the highest (6.66 g) followed by MR 14215-9-2 (6.41 g) and lowest in MR 14125-3 (6.18 g). At 21 DAP, effect of P on root biomass showed similar response at 30, 60 and 90 kg P ha^{-1} (1.50 g) and lowest with 0 kg P ha^{-1} (1.30

g). At 42 DAP, 90 kg P ha^{-1} had the highest (2.16 g) followed by 60 kg P ha^{-1} (2.09 g) and lowest with 0 kg P ha^{-1} (1.42 g). Similarly, at 63 DAP, 90 kg P ha^{-1} had the highest (6.72 g) followed by 60 kg P ha^{-1} (6.65 g) and lowest with 0 kg P ha^{-1} (5.76 g).

4.3.3.7 Shoot biomass per plant (g)

Table 6 presents the effect of P on shoot biomass of bean lines. There were highly significant differences ($P<0.001$) among P levels in all growth stages but bean lines had similar response. At 21 DAP, all bean lines showed similar response (3.30 g) on shoot biomass. At 42 DAP highest biomass was in MR 14125-3 (6.78 g) followed by MR14215-9-2 (6.12 g) and the lowest in MR 14125-6-1 (5.34 g). At 63 DAP, highest biomass was in MR 14125-3 (38.52 g) followed by MR 14215-9-2 (37.32 g) and lowest in MR 14125-6-1 and Bilfa Uyole (32.54 g). Effects of P levels at 21 DAP, 30 and 90 kg P ha^{-1} showed highest biomass (3.40 g) followed by 60 kg P ha^{-1} (3.30 g) and lowest with 0 kg P ha^{-1} (2.90 g). At 42 DAP, 90 kg P ha^{-1} had the highest biomass (7.28 g) followed by 60 kg P ha^{-1} (6.87 g) and lowest with 0 kg P ha^{-1} (3.85 g). At 63 DAP, 90 kg P ha^{-1} had the highest biomass (43.28 g) followed by 60 kg P ha^{-1} (38.50) and lowest with 0 kg P ha^{-1} (27.96 g) (Table 6).

Table 6: Effect of bean lines and phosphorus levels on shoot biomass at 21, 42 and 63 DAP

	Shoot biomass (g plant^{-1})		
Bean lines	**21 DAP**	**42 DAP**	**63 DAP**
MR 14125-3	3.30	6.78	38.52
MR 14125-6-1	3.30	5.34	35.57
MR 14215-9-2	3.30	6.12	37.32
Bilfa Uyole	3.30	5.95	32.58
SE ±	0.21	0.88	5.07
CV%	6.4	14.6	14.1
Phosphorus (kg ha^{-1})			
0	2.90b	3.85b	27.96c
30	3.40a	6.18a	34.26b
60	3.30a	6.87a	38.50ab
90	3.40a	7.29a	43.28a
GM	**3.29**	**6.05**	**36**
SE ±	0.29	1.3	5.71
CV%	8.8	19.5	15.9

Means in the same column followed by the same letter(s) are not statistically different ($P < 0.05$) by Duncan's New Multiple Range Test.

4.3.3.8 Crop growth rate (g m^{-2} day^{-1})

Growth analysis was done to evaluate the effect of bean lines and P levels on crop growth rate between 42 and 63 DAP and results are presented on Figure 1. The data indicate that mean growth rate at both growth stages increased with increasing levels of P (51.79 g m^{-2} day^{-1}). Mean growth rate at 42 DAP was slower (5.26 g m^{-2} day^{-1}) than at 63 DAP (57.05 g m^{-2} day^{-1}). Crop growth rate was preceded by MR 14125-3 with 30 and 60 at both growth stages and with 90 P levels at 63 DAP. Highest growth rate was observed in MR 14125-3 with 90 kg P ha^{-1} (17.99 g m^{-2} day^{-1}), followed by MR 14125-6-1 with 90 kg P ha^{-1} (17.46 g m^{-2} day^{-1}) and lowest in MR 14125-6-1 with 0 kg P ha^{-1} (0.26 g m^{-2} day^{-1}) at 42 DAP.

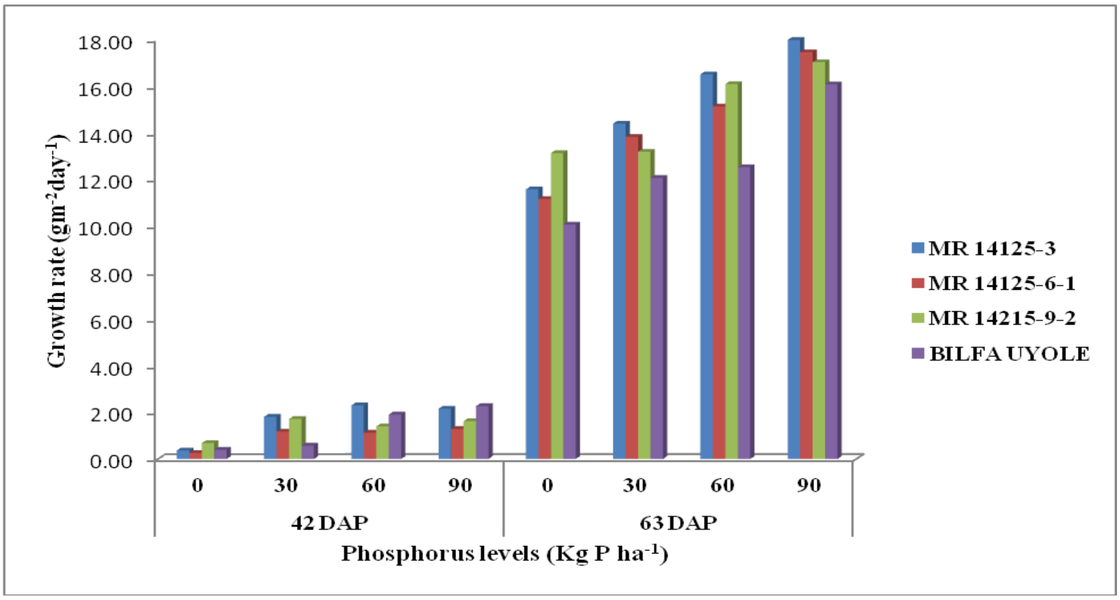

Figure 1: Effect of bean lines and P levels on crop growth rate at 42 and 63 DAP.

4.3.4 Effect of bean lines and P levels on seed yield and yield components

Results in Table 7 show the effect of bean lines and P levels on seed yield (kg ha^{-1}), number of pods per plant, number of seeds per pod and 100 seed weight.

4.3.4.1 Seed yield (kg ha^{-1})

Higher seeds yield was observed in MR 14125-3 (1292 kg ha^{-1}) followed by Bilfa Uyole (1258 kg ha^{-1}) and lowest in MR 14215- 9-2 (1178 kg ha^{-1}). However, differences in yield among bean lines were not significant. P levels, showed higher seed yield in treatments with 90 kg P ha^{-1} (1972 kg ha^{-1}) followed by 60 kg P ha^{-1}(1305 kg ha^{-1}) and lowest with 0 kg P ha^{-1} (629 kg ha^{-1}).

4.3.4.2 Number of pods per plant

The highest number of pods was observed in MR 14215-9-2 (26.42) followed by Bilfa Uyole (24.25) and lowest in MR 14125-6-1(20.42). The differences in pod number among the different lines were significant ($P \leq 0.05$). Effects of P levels showed that 60 kg P ha^{-1} gave the highest pod number (27.25) followed by 90 kg P ha^{-1} (26.58) and the lowest from 0 kg P ha^{-1}(16.00).

4.3.4.3 Number of seeds per pod

There were significant differences among bean lines and P levels in number of seeds per pod. The highest number of seeds was observed in MR 14125-6-1 (5.08) followed by Bilfa Uyole (4.50) and lowest in MR 14125-3 (4.25). The effect of P on number of seeds per pod showed that, 90 kg P ha^{-1} had the highest (5.08) followed by 60 kg P ha^{-1}(4.83) and lowest with 0 kg P ha^{-1} (4.17).

4.3.4.4 100 Seed weight (g)

Heaviest seeds were observed in MR 14125-3 (35.89 g) followed by MR 14215- 9-2 (24.13 g) and lighter seeds in Bilfa Uyole (22.92 g). These differences were significant ($P \leq 0.05$) P levels showed heaviest seeds in treatments with 60 kg P ha^{-1} (29.60 g) followed by 90 kg P ha^{-1} (29.54 g) and lighter seeds with 0 kg P ha^{-1} (23.07 g); however, significant differences among P levels were not observed.

Table 7: Effect of bean lines and P levels on seed yield and yield components

Bean lines	**Seed yield (kg ha^{-1})**	**Number of pods plant^{-1}**	**Number of seeds pod^{-1}**	**100 seed weight (g)**
MR 14125-3	1292.00	23.42ab	4.25b	35.89a
MR 14125-6-1	1216.00	20.42b	5.08a	23.46b
MR 14215-9-2	1178.00	26.42a	4.67ab	24.13b
Bilfa Uyole	1258.00	24.25ab	4.50ab	22.92c
SE ±	98.40	1.72	0.20	1.51
CV (%)	8.00	7.30	4.30	5.70
Phosphorus (kg ha^{-1})				
0	629.00c	16.00c	4.17c	23.07
30	1036.00bc	24.67b	4.42b	24.19
60	1305.00bc	27.25a	4.83ab	29.60
90	1972.00a	26.58ab	5.08a	29.54
GM	**1236.00**	**23.62**	**4.62**	**26.60**
SE ±	189.10	3.54	0.71	1.36
CV (%)	15.30	15.00	15.30	5.10

Means in the same column followed by the same letter(s) are not statistically different ($P<0.05$) by Duncan's New Multiple Range Test.

4.3.5 Interaction effect of bean lines and P levels on seed yield and yield components

Among the analysed variables, interaction effects were found significant except on seed yield (kg ha^{-1}) and number of pods per plant (Appendix 3).

4.3.5.1 Interaction of bean lines and P levels on seed yield (kg ha^{-1})

The data reveal significant response on seed yield among treatments (Figure 2). The mean yields in all bean lines increased at increasing P levels. Overall, the highest mean yields were produced at 90 kg P ha^{-1} (1972 kg ha^{-1}) whereas the lowest yield at 0 kg P ha^{-1} (629 kg ha^{-1}). The highest yield was produced by line MR14125-3 at 90 kg P ha^{-1} (2083 kg ha^{-1}) followed by Bilfa Uyole at the same rate (1973 kg ha^{-1}). The lowest yield was produced by MR 14125-6-1 at 0 kg P ha^{-1} (593 kg ha^{-1}).

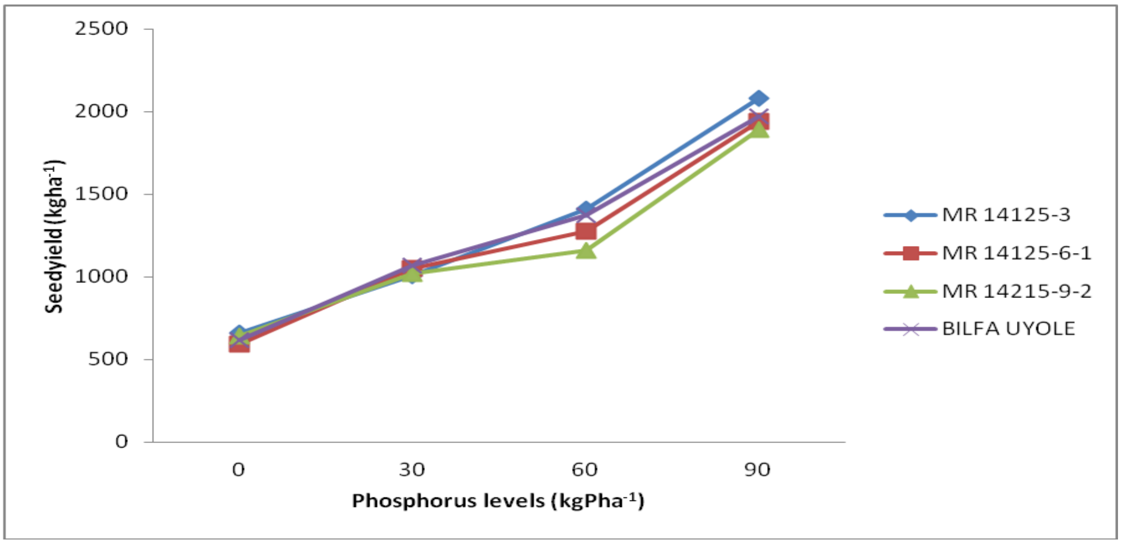

Figure 2: Interaction effect of bean lines and P levels on seed yield (k g ha^{-1})

4.3.5.2 Interaction effect of bean lines and P levels on yield components

Interaction effect show that mean pod number increased with increasing P levels and the highest mean pod number was produced at 90 kg P ha^{-1} (26.58). The highest number of pods was produced by line MR 14125-3 at 90 kg P ha^{-1} (30.00) followed by Bilfa Uyole at 60 kg P ha^{-1} (28.33) and lowest by MR 14125-6-1 at 0 kg P ha^{-1} (14.33). Similar mean values were produced for number of seeds per pod at 60 and 90 kg Pha^{-1} (5.08). The highest number of seeds was produced by line MR 14125-6-1 (6.00) at 60 kg P ha^{-1} followed by MR 14125-3 at 90 kg P ha^{-1} (5.67) and lowest by MR 14124-3 at 0 kg P ha^{-1} (3.33). The highest mean values for 100 seed weight were produced at 60 kg P ha^{-1} (29.60). The heaviest seeds were produced by MR 14125-3 at 90 kg P ha^{-1}(47.10) followed by the same line at 60 kg P ha^{-1}(46.97) and lighter seeds by MR 14125 6-1 at 0 kg P ha^{-1}(22.03).

4.3.6 Correlation analysis

Table 8 presents results of linear correlation (r) analysis conducted to study the degree of relationship among various growth and yield components. The findings showed that the number of branches per plant was highly significant and positively correlated with root length (r = 0.372***), root biomass (r = 0.389***), shoot biomass (r = 0.458***), seed yield (r = 0.638***), number of pods per plant (r = 0.673***) and number of seeds per pod (r = 0.341***). Also, the number of branches per plant was very highly significant and negatively correlated with number of days to 50% flowering (r = -0.594***) and physiological maturity (r = -0.702***). Root length was very highly significant and positively correlated with root biomass (r = 0.475***), shoot biomass (r = 0.221**), number of pods per plant (r = 0.265**), number of seeds per pod (r = 0.357***) while it was negatively correlated with days to 50% flowering (r =-0.196***) and physiological maturity (r = -0.283***). The data showed that root biomass was highly significant and positively correlated with shoot biomass (r = 0.587**) and also significant and positively correlated with pods per plant (r = 0.425*) and seeds per pod (r = 0.296*) and highly significant and negatively correlated with the number of days to 50% flowering (r =-0.325***) and physiological maturity (r =-0.479***). Shoot biomass showed very highly significant and positively correlated with seed yield (= 0.575***), number of pods per plant (r = 0.521**) and number of seeds per pod (r = 0.384***); highly significant and negatively correlated with number of days to 50% flowering (r = -0.522***) and physiological maturity (r = -0.541***).

The days to 50% flowering were highly significant and positively correlated with number of days to physiological maturity (r = 0.657**), while were very highly significant and negative correlated with seed yield (r = -0.713***), number of pods per plant (r = -0.432***) and number of seeds per pod (r = -0.381***). The number of days to physiological maturity was very highly significant and negatively correlated with seed yield (r = -0.696***), number of pods per plant (r = -0.577***) and number of seeds per pod (r = -0.334**). Seed yield showed very high significant and positively correlated with number of pod per plant (r = 0.465***) and significant with number of seeds per pod (r = 0.272*). The number of pods per plant was significant and positively correlated with number of seeds per pod (0.254*).

Results show that yield and yield components of common bean are highly associated with the performance of other growth parameters. Thus in order to have higher yields one have to manage the crop throughout the growth cyle.

Table 8: Linear correlation among growth variables and yield components

s/ n	Variables	1	2	3	4	5	6	7	8	9
1	Branches per plant	-								
2	Root depth (cm)	0.372***	-							
3	Root biomass (g/plant)	0.389***	0.475***	-						
4	Shoot biomass (g/plant)	0.458***	0.221**	0.587**	-					
5	Days to 50 % flowering	- 0.594***	-0.196***	-0.325***	-0.522***	-				
6	Physiological maturity	-0.702***	-0.283***	-0.479***	-0.541***	0.657**	-			
7	Seed yield ($kgha^{-1}$)	0.638***	0.141ns	0.431***	0.575***	-0.713***	-0.696***	-		
8	Pods $plant^{-1}$	0.673***	0.265**	0.425*	0.521**	-0.432***	-0.577***	0.465***	-	
9	Seeds pod^{-1}	0.341***	0.357***	0.296*	0.384***	-0.381***	-0.334**	0.272*	0.254*	-

ns not significant
* Significant at 0.05
** Significant at 0.01
*** Significant at 0.001

4.4 Screen House Experiment

Appendix 5 presents a summary of analysis of variance (ANOVA) for some vegetative, reproductive and yield variables. There were no significant differences among bean lines in all variables except days to crop establishment ($P<0.05$). Also, significant differences were noted on all P levels except days to crop emergence. There were no significant interaction between bean lines and levels of P in all variables studied.

Appendix 6 summarises ANOVA for some growth and root characteristics at 21, 42 and 63 DAP under screen house environment. At 21 DAP, there were no significant differences among bean lines in all variables studied except plant height ($P\leq 0.05$). At 42 DAP, significant differences among bean lines were noted in number of nodes per plant ($P<0.01$) and root length ($P<0.001$) only. On the other hand, at 63 DAP there were significant differences among bean lines in all variables except number of nodes and number of leaves per plant. Also, highly significant effects among P levels were noted in all variables except root length, number of leaves and root biomass at 21, 42 and 63 DAP respectively.

4.4.1 Effect of bean lines and P levels on vegetative and reproductive stages

Results in Table 9 indicate the effect of P levels applied on days to crop emergence, crop establishment, 50% flowering, physiological and harvest maturity of bean lines. The data show that bean lines had no influence on the variables studied except days to crop establishment. On the other hand, there were significant differences among P levels in all variables studied except days to crop emergence.

4.4.1.1 Days to crop emergence (V1)

Days to seedling emergence were similar among bean lines and P levels. However plants emerged earlier in lines MR 14215-9-2 (8.92 days), Bilfa Uyole (9.82 days) whereas they emerged latest in MR 14125-6-1(10.67 days). Application of P caused plants to emerge at different times. Application of 30 kg P ha^{-1} led to earlier seedling emergence (9.67 days) followed by 0 and 90 kg P ha^{-1}(10.08 days). The latest seedlings emergence (10.17days) was observed where 60 kg P ha^{-1} was applied.

4.4.1.2 Days to crop establishment (V3)

Days to crop establishment were significantly ($P \leq 0.05$) influenced by bean lines and highly significantly ($P \leq 0.001$) by Phosphorus. The earliest establishment was observed in line MR 14215-9-2 (20.33 days) followed by MR 14125-3 (20.92 days). Whereas, the latest was MR 14125-6-1(23.75 days). The effect of P on days to establishment showed that plants with 0 kg P ha^{-1} were the first (20.42 days) followed by plants with 30 kg P ha^{-1} and latest in plants with 90 kg P ha^{-1} (22.83 days).

4.4.1.3 Days to 50% flowering (R6)

The results indicate that there were high significant differences ($P<0.001$) on number of days to 50% flowering, among P levels. Generally, early flowering plants were recorded in line MR 14125-6-1 (65.42 days) followed by Bilfa Uyole (65.50 days) while the latest were observed in treatments with MR 14215-9-2 (65.82 days). Among P levels, early flowering was recorded in plants where 90 kg P ha^{-1} was applied (61.33 days) followed by 60 kg P ha^{-1} (63.83 days). The plants where no P was applied were the latest to flower (68.75 days).

4.4.1.4 Days to physiological maturity (R8)

Significant differences were noted among P levels on the number of days to physiological maturity. Bean lines that received 90 kg P ha^{-1} were the earliest to reach physiological maturity (70 days) followed by 60 kg P ha^{-1} (73.67 days) and latest 0 kg P ha^{-1} (78.50 days). The earliest physiological maturity were observed in treatments with MR 14125-6-1 (74.42 days), followed by MR 14125-3 (75.25 days) while the latest were those with MR 14215-9-2 (75.83 days).

4.4.1.5 Days to harvest maturity (R9)

There were high significant differences (P<0.001) among P levels in days to harvest maturity (Table 10). The earliest plants to attain harvest maturity were recorded from line Bilfa Uyole (83.92 days) followed by MR 14125-3 (84.75 days) and MR 14215-9-2 (85.50 days). Among P levels, bean lines with 90 kg P ha^{-1} were the earliest (80.33 days) followed by lines with 60 kg P ha^{-1} (82.83 days) and the latest with 0 kg P ha^{-1} (88.00 days) and differences were significant (P≤0.05).

Table 9: Effect of bean lines and P levels on vegetative and reproductive stages

Bean lines	**Days to crop emergence**	**Days to crop establishment**	**Days to 50 % flowering**	**Days to physiological maturity**	**Days to harvest maturity**
MR 14125-3	10.58	20.92b	65.58	75.25	84.75
MR 14125-6-1	10.67	23.75a	65.42	74.42	84.92
MR 14215-9-2	8.92	20.33b	65.83	75.83	85.50
Bilfa Uyole	9.83	22.92a	65.50	75.33	83.92
SE ±	1.40	0.91	0.73	0.93	0.78
CV%	14.00	4.10	1.10	1.20	0.90
Phosphorus (kg P ha^{-1})					
0	10.08	20.42b	68.75b	78.50b	87.92b
30	9.67	22.17a	68.42b	78.58a	88.00b
60	10.17	22.50a	63.83a	73.67a	82.83a
90	10.08	22.83a	61.33a	70.08a	80.33a
GM	**10.00**	**21.98**	**65.58**	**75.21**	**84.77**
SE ±	1.34	1.32	1.68	1.70	2.52
CV%	13.40	6.00	2.60	2.30	3.00

Means in the same column followed by the same letter(s) are not statistically different (P<0.05) by Duncan's New Multiple Range Test.

4.4.2 Effect of bean lines and phosphorus levels on some growth and developmental characteristics

Results on Tables 10-12 show the influence of bean lines and phosphorus levels on number of leaves, branches, nodes, plant height, root depth, root density, root and shoot biomass at 21, 42 and 63 DAP. The data show that there was an increase in all variables determined from 21 to 63 DAPS. The bean lines had no effect at all growth stages except plant height at 21 DAP and number of leaves at 63 DAP (Table 10). Phosphorus levels had significant effect on all studied variables at all growth stages. Table 11 shows that bean lines had no effect on number of nodes, root depth and root density but showed significant effect on number of nodes and root density at 42 and 63 DAP and root depth at 42 DAP. Phosphorus levels had effect on all variables except root biomass at 63 DAP and root depth at 42 DAP.

Results on Table 12 show that bean lines had no significant effect on studied variables on root and shoot biomass. Phosphorus levels showed effect on shoot biomass.

4.4.2.1 Number of leaves per plant

Number of leaves per plant differ significantly ($P<0.05$) among bean lines at 63 DAP. At 21 and 63 DAP; the levels of P differed highly significantly ($P<0.01$). At 21 DAP, MR 14125-3 recorded highest number of leaves (3.42) followed by MR 14125-9-2 (3.33) and the lowest by Bilfa Uyole (3.08). At 42 DAP, more leaves were observed in MR 14215-9-2 (6.92) followed by MR 14125-3 and Bilfa Uyole (6.67) and the lowest number in MR 14125-6-1 (6.58). At 63 DAP, more leaves were observed in MR 14125-3 (11.58) followed by MR 14215-9-2 (11.33) and the least in MR 14125-

6-1 (9.42). At 21 DAP, 90 kg P ha^{-1} resulted to more leaves (3.58) followed by 60 kg P ha^{-1} (3.41) and least from 0 kg P ha^{-1} (3.00). At 42 DAP, more leaves were observed with 30 and 60 kg P ha^{-1} (7.50) followed by 90 kg Pha^{-1} (6.83) and the least leaves from 0 kg P ha^{-1}(6.00). At 63 DAP, more leaves were observed with 60 kg P ha^{-1} (11.67) followed by 90 kg P ha^{-1} (11.33) and least leaves with 0 kg P ha^{-1} (8.67).

4.4.2.2 Plant height (cm)

There were high significant differences (P<0.001) among bean lines at 21 DAP and P levels in all growth stages. At 21 DAP, the tallest plants were observed in MR 14215-9-2 (57.20 cm) followed by MR 14125-3 (55.10 cm) and the shortest in Bilfa Uyole (40.00 cm). At 42 DAP the tallest plants were in MR 14125-3 (95.70 cm) and MR 14125-6-1(91.80 cm) while the shortest in Bilfa Uyole (80.30 cm). At 63 DAP the tallest plants were observed in MR 14125-6-1 (108.20 cm) and MR 14125-3 (108.00 cm). Similarly, the shortest plants were observed in Bilfa Uyole (94.70 cm). Among P levels applied, 21 DAP had the tallest plants (56.00 cm) where 60 kg P ha^{-1} was applied followed by 90 kg P ha^{-1} (54.80 cm). The shortest plants (39.90 cm) were observed where no P was applied. At 42 DAP, the tallest plants (101.70 cm) were observed where 30 kg ha^{-1} was applied followed by 90 kg ha^{-1} (97.20 cm) and the shortest (65.20 cm) where no P was applied. At 63 DAP growth stage, the tallest plants were observed where 30 kg P ha^{-1} (115.60 cm) was applied followed by 90 kg P ha^{-1} (112.90 cm) while the shortest (76.20 cm) were observed where no P was applied.

4.4.2.3 Number of branches per plant

There were highly significant differences ($P<0.01$) among P levels at 21 DAP and highly significant differences ($P<0.001$) at 42 and 63 DAP in number of branches per plant. However, no significant differences were observed among the bean lines. At 21 DAP, more branches were observed in MR 14125-3 (1.67) followed by Bilfa Uyole (1.42) and lowest in MR 14125-6-1 (1.25). At 42 DAP, more branches were observed in MR 14125-3 (2.50) and MR 14125-6-1 (2.08) while lowest in MR 14215-9-2 and Bilfa Uyole (1.80). At 63 DAP, more branches were recorded in MR 14125-3 (3.67) and Bilfa Uyole (3.58) while lowest in MR 14215-9-2 (2.83). At 21 DAP, the highest number of branches was observed with 90 kg P ha^{-1} (1.75) followed by 60 kg P ha^{-1}(1.58) and lowest with 0 kg P ha^{-1}(1.00). At 42 DAP, more branches were observed with 90 kg P ha^{-1} (2.41) followed by 60 kg P ha^{-1} (2.25) and lowest with 0 kg P ha^{-1} (1.41). At 63 DAP, branches were observed with 90 kg P ha^{-1} (4.41) followed by 60 kg P ha^{-1}(3.66) and lowest with 0 kg P ha^{-1} (2.25).

4.4.2.4 Number of nodes per plant

At 21 DAP, number of nodes per plant among P levels were similar, however there were highly significant differences ($P<0.01$) at 42 and 63 DAP. The bean lines showed highly significant differences ($P<0.01$) in number of nodes per plant at 42 DAP and highly significant differences ($P<0.001$) at 63 DAP. At 21 DAP, the highest number was observed in MR 14125-6-1 (3.42) followed by MR 14125-3 and MR 14215- 9-2 (3.25). Line Bilfa Uyole recorded the lowest number (3.08). At 42 DAP, the highest number was in MR 14125-3 (6.42), followed by MR 14125-6-1 (6.00) and the lowest in MR 14215- 9-2 (5.00). At 63 DAP, the highest number was observed in MR 14125-3 (8.75) followed by MR 14125-6-1 (7.67) and the lowest in MR 14215-

9-2 (7.17). Application of 90 kg P ha^{-1} at 21 DAP, showed the highest number of nodes (3.58) followed by 60 kg P ha^{-1} (3.41) and the lowest with 0 kg P ha^{-1} (2.92). At 42 DAP, the highest number was observed with 60 kg P ha^{-1} (6.42) followed by 30 (6.17), and the lowest with 0 kg Pha^{-1}(4 58). At 63 DAP, 60 kg P ha^{-1} resulted to the highest number (8.58) followed by 90 kg P ha^{-1} (8.08) and the lowest with 0 kg P ha^{-1} (6.50).

4.4.2.5 Root depth (cm)

There were highly significant differences ($P<0.001$) among bean lines at 42 DAP and P levels at 42 and 63 DAP on root depth. At 21 DAP, the deepest roots were observed in MR 14215-9-2 (13.17 cm) followed by MR 14125-3 (12.67 cm) while the shallowest in Bilfa Uyole (11.83 cm). At 42 DAP, the deepest roots were observed in MR 14125-6-1 and MR 14215-9-2 (18.42 cm) followed by MR 14215-9-2 (18.33 cm) and the shallowest in MR 14125-3 (16.00 cm). At 63 DAP, the deepest roots were observed in MR 14215-9-2 (21.25 cm) followed by Bilfa Uyole (20.83 cm) and the shallowest roots were in MR 14125-3 (19.67 cm). At 21 DAP, P level 60 kg P ha^{-1} caused the deepest roots (12.92 cm) followed by 90 kg P ha^{-1} (12.75 cm) and the shallowest with 0 kg P ha^{-1} (11.58 cm). At 42 DAP, the deepest roots were observed with 30 kg P ha^{-1} (19.50 cm) followed by 60 kg P ha^{-1} (18.50 cm) and the shallowest with 0 kg P ha^{-1} (15.08 cm). At 63 DAP, the deepest roots were observed with 90 kg P ha^{-1} (21.75 cm) followed by 30 kg P ha^{-1} (21.33 cm) and the shallowest with 0 kg P ha^{-1}(17.58 cm).

Table 10: Effect of bean lines and P levels on some growth characteristics at 21, 42 and 63 DAP

Bean lines	Number of leaves per plant			Plant height (cm)			Number of branches per plant		
	21 DAP	**42 DAP**	**63 DAP**	**21 DAP**	**42 DAP**	**63 DAP**	**21 DAP**	**42 DAP**	**63 DAP**
MR 14125-3	3.42	6.67	11.58a	55.10a	95.70	108.00	1.67	2.50	3.67
MR 14125-6-1	3.25	6.58	9.42b	49.80ab	91.80	105.00	1.25	2.08	3.08
MR 14215-9-2	3.33	6.92	11.33ab	57.20a	91.70	108.20	1.33	1.83	2.83
Bilfa Uyole	3.08	6.67	9.83ab	40.00b	80.30	94.70	1.42	1.83	3.58
SE ±	0.48	1.03	0.8	5.32	8.04	12.23	0.19	0.33	0.58
CV%	14.6	15.3	7.6	10.5	8.9	11.8	13.2	16	17.7
Phosphorus (kg ha^{-1})									
0	3.00c	6.00	8.67b	36.90b	65.20b	76.20b	1.00c	1.41b	2.25b
30	3.08bc	7.50	10.50a	54.40a	101.70a	115.60a	1.33bc	2.16a	2.83ab
60	3.41ab	7.50	11.67a	56.00a	95.30a	111.20a	1.58ab	2.25a	3.66a
90	3.58a	6.83	11.33a	54.80a	97.20a	112.90a	1.75a	2.41a	4.41a
GM	**3.27**	**6.71**	**10.54**	**50.5**	**89.9**	**104**	**1.42**	**2.06**	**3.29**
SE ±	0.41	1.05	1.81	8.64	17.87	18.92	0.44	0.46	0.67
CV%	12.5	15.6	17.2	17.1	19.9	18.2	11.1	19.8	18.7

Means in the same column followed by the same letter(s) are not statistically different (P< 0.05) by Duncan's New Multiple Range Test.

4.4.2.6 Root density (g cm^{-3})

The results indicate that bean lines had no significant effects in root density at all growth stages (Table 11). Phosphorus levels showed no significant effect at 63 DAP however, significant effect (P<0.05) was observed at 21 and 42 DAP. At 21 DAP heavier roots were observed in line MR 14125-3 (0.0018 g cm^{-3}) whereas the remaining lines had the same value (0.0017 g cm^{-3}). At 42 DAP, three lines including MR 14125-3, MR 14125-6-1 and MR 14215-9-2 had the same value (0.019 g cm^{-3}) of root density whereas Bilfa Uyole had lower value (0.018 g cm^{-3}). At 63 DAP line MR 14125-6-1 (0.0069 g cm^{-3}) had heavier roots whereas the remaining lines had the same value (0.0068 g cm^{-3}). The influence of P levels on root density indicates that at

21 DAP, 30 kg P ha^{-1} had heavier roots (0.0018 g cm^{-3}) while 60 and 90 kg P ha^{-1} had the same value (0.0017 g cm^{-3}) and 0 kg P ha^{-1} lighter roots (0.0016 g cm^{-3}). At 42 DAP 30 kg P ha^{-1} had heavier roots (0.0020 g cm^{-3}), 60 and 90 kg P ha^{-1} had the same value (0.0019 g cm^{-3}) and 0 kg P ha^{-1} lighter roots (0.0018 g cm^{-3}). At 63 DAP, the heaviest roots were observed with 60 kg P ha^{-1}(0.0069 g cm^{-3}) while 0, 30 and 90 kg P ha^{-1} had the same value (0.0068 g cm^{-3}).

4.4.2.7 Root biomass per plant (g)

The root biomass differed significantly ($P<0.05$) among P levels at 21 and highly significantly ($P<0.01$) at 42 DAP (Table 13). At 21 DAP, the highest biomass accumulation was realized in MR 14125-3 (1.32 g) followed by MR 14125-6-1(1.31 g) and lowest in Bilfa Uyole (1.27 g). At 42 DAP, the highest biomass was in MR 14125-6-1(1.45 g) followed by MR 14125-3 (1.44 g) and the lowest in Bilfa Uyole (1.36 g). At 63 DAP, the highest root biomass was recorded in MR 14125-6-1(5.18 g) followed by MR 14215-9-2 (5.14 g) whereas Bilfa Uyole recorded the lowest (5.08 g). At 21 DAP, P application showed the highest response in root biomass with 30 kg P ha^{-1} (1.33 g) followed by 60 kg P ha^{-1} (1.30 g) and the lowest with 0 kg P ha^{-1} (1.24 g). At 42 DAP, the highest accumulation was with 30 kg P ha^{-1} (1.45 g) followed by 60 and 90 kg P ha^{-1} which produced the same amount (1.42 g). The lowest response was observed from 0 kg P ha^{-1} (1.33 g). At 63 DAP, the highest accumulation was with 60 kg P ha^{-1} (5.15 g) followed by 90 kg P ha^{-1} (5.13 g) and the lowest with 0 kg P ha^{-1} (5.11 g).

Table 11: Effect of bean lines and P levels on some morphological and root characteristics at 21, 42 and 63 DAP

	Number of nodes plant^{-1}			Root depth (cm)			Root density (g cm^{-3})		
Bean lines	**21 DAP**	**42 DAP**	**63 DAP**	**21 DAP**	**42 DAP**	**63 DAP**	**21 DAP**	**42 DAP**	**63 DAP**
MR 14125-3	3.25	6.42a	8.75a	12.67	16.00b	19.67	0.0018a	0.0019a	0.0068
MR 14125-6-1	3.42	6.00ab	7.67b	12.00	18.42a	19.92	0.0017ab	0.0019a	0.0069
MR 14215-9-2	3.25	5.00b	7.17b	13.17	18.33a	21.25	0.0017ab	0.0019a	0.0068
Bilfa Uyole	3.08	5.75ab	7.42b	11.83	18.42a	20.83	0.0017ab	0.0018ab	0.0068
GM	3.25	5.79	7.75	12.42	17.79	20.42	0.0017	0.0019	0.0068
SE ±	0.48	0.61	0.25	0.96	1.1	1.4	0.00004	0.0001	0.0001
CV%	14.7	10.6	3.2	7.7	6.2	6.8	2.4	4.2	1.9
Phosphorus (kg ha^{-}1)									
0	2.91c	4.58b	6.50b	11.58	15.08b	17.58b	0.0016b	0.0018ab	0.0068
30	3.08bc	6.17ab	7.83a	12.42	19.50a	21.33a	0.0018a	0.0020a	0.0068
60	3.41ab	6.42a	8.58a	12.92	18.50a	21.00a	0.0017ab	0.0019a	0.0069
90	3.58a	6.00ab	8.08a	12.75	18.08a	21.75a	0.0017ab	0.0019a	0.0068
SE ±	0.42	1.04	0.97	2.12	2.48	2.38	0.0001	0.0001	0.0003
CV%	12.8	18	12.4	17.1	14	11.6	5.6	6.3	3.8

Means in the same column followed by the same letter(s) are not statistically different ($P < 0.05$) by Duncan's New Multiple Range Test.

4.4.2.8 Shoot biomass per plant (g)

There were significant differences ($P<0.05$) among P levels on shoot biomass at 21 and 42 DAP, and highly significant differences ($P<0.001$) at 63 DAP (Table 12). At 21 DAP, the highest biomass was observed in MR 14125-6-1 (2.77 g) followed by MR 14215-9-2 and MR 14125-3 (2.73 g) and lowest in Bilfa Uyole (2.63 g). At 42 DAP the highest biomass was in MR14215-9-2 (3.48 g) followed by MR 14125-3 (3.35 g) and the lowest in Bilfa Uyole (3.20 g). At 63 DAP, the highest biomass was in MR 14125-3 (15.62 g) followed by MR 14215-9-2 (15.34 g) and the lowest in MR 14125-6-1 and Bilfa Uyole (15.12). At 21 DAP phosphorus application caused the highest biomass with 60 kg P ha^{-1} (2.80 g) followed by 90 kg P ha^{-1} (2.72 g) and the least with 0 kg P ha^{-1} (2.64 g). At 42 DAP, the highest biomass was observed from 30 kg P ha^{-1}(3.46 g) followed by 60 kg P ha^{-1} (3.44 g) and the lowest was observed from

0 kg P ha^{-1} (3.06 g). At 63 DAP, 90 kg P ha^{-1} showed the highest biomass (16.62 g) followed by 60 kg P ha^{-1} (15.67 g) and the lowest was with 0 kg P ha^{-1} (13. 55 g).

4.4.3 Effect of bean lines and P levels on yield and yield components

Table 13 shows the influence of bean lines and P levels on seed yield per plant, number of pods per plant and number of seeds per pod. The results show that bean lines had no significant effect on seed yield per plant, number of pods per plant and number of seeds per pod. However, P levels showed significant effect in all variables studied.

4.4.3.1 Seed yield per plant (g)

Line MR 14215-9-2 had high seed yield (6.43 g) followed by MR 14125-3 (6.25 g) and Bilfa Uyole (5.97 g); whereas MR 14125-6-1 had the lowest seed yield (5.49 g). Application of P levels increased seed yield with 90 kg P ha^{-1} producing 8.94 g followed by 60 kg P ha^{-1} (7.39 g) and 30 kg Pha^{-1} (5.15 g) the lowest seed yield was obtained from 0 kg P ha $^{-1}$ (2.66 g).

4.4.3.2 Number of pods per plant

The highest number of pods per plant was observed in MR 14125-6-1 (3.33) followed by MR 14215-9-2 (3.17) while the lowest in MR 14125-3 (2.83). The number of pods per plant increased with increasing levels of P with 90 kg P ha^{-1} giving the highest number (4.42) followed by 60 kg P ha^{-1} (3.58), 30 kg P ha^{-1} (2.50) and the lowest from 0 kg P ha^{-1} (1.75).

Table 12: Effect of bean lines and P levels on root and shoot biomass at 21, 42 and 63 DAP

	Root biomass ($g\ plant^{-1}$)			Shoot biomass ($g\ plant^{-1}$)		
Bean lines	**21 DAP**	**42 DAP**	**63 DAP**	**21 DAP**	**42 DAP**	**63 DAP**
MR 14125-3	1.32	1.44	5.10	2.73	3.35	15.62
MR 14125-6-1	1.31	1.45	5.18	2.77	3.32	15.12
MR 14215-9-2	1.28	1.39	5.14	2.73	3.48	15.34
Bilfa Uyole	1.27	1.36	5.08	2.63	3.20	15.12
SE ±	0.03	0.05	0.09	0.07	0.15	0.52
CV%	2.4	3.7	1.8	2.6	4.4	3.4
Phosphorus ($kg\ ha^{-1}$)						
0	1.24c	1.33b	5.11	2.64b	3.06b	13.55c
30	1.33a	1.45a	5.12	2.69b	3.46a	15.37b
60	1.30ab	1.42a	5.15	2.80a	3.44a	15.67ab
90	1.29ab	1.42a	5.13	2.72ab	3.37a	16.62a
GM	**1.29**	**1.41**	**5.13**	**2.72**	**3.34**	**15.3**
SE ±	0.07	0.08	0.2	2.12	0.34	1.31
CV%	5.5	5.9	3.8	4.4	10.1	8.6

Means in the same column followed by the same letters(s) are not statistically different ($P<0.05$) by Duncan's New Multiple Range Test.

4.4.3.3 Number of seeds per pod

The highest seed number per pod was observed in MR 14215-9-2 (3.67) followed by Bilfa Uyole (3.42), MR 14125-6-1 (3.25) and the lowest in MR 14125-3 (2.83). Similar results were observed among P levels where the highest seed number (3.50) was observed from 60 and 90 kg P ha^{-1} while 0 and 30 had the same number of seeds per pod (3.08).

4.4.4 Interaction effect of bean lines and P levels on yield and yield components

Results in Appendix 5 indicate no significant effect on interaction among bean lines and P levels on seed yield per plant (g), number of pods per plant and seeds per pod. This implies that the performance of bean lines in these variables was not influenced by the different levels of P.

Table 13: Effect of bean lines and P levels on seed yield and yield components

Lines	**Seed yield per plant (g)**	**Number of pods plant^{-1}**	**Number of seeds pod^{-1}**
MR 14125-3	6.25	2.83	2.83
MR 14125-6-1	5.49	3.33	3.25
MR 14215-9-2	6.43	3.17	3.67
Bilfa Uyole	5.97	2.92	3.42
SE ±	1.42	0.40	0.41
CV%	18.9	13.00	12.30
Phosphorus (kg ha^{-1})			
0	2.66b	1.75b	3.08b
30	5.15ab	2.50b	3.08b
60	7.39a	3.58a	3.50a
90	8.94a	4.42a	3.50a
GM	**6.04**	**3.06**	**3.29**
SE ±	2.09	0.75	0.63
CV%	15.7	18.9	12.10

Means in the same column followed by the same letter(s) are not statistically different (P< 0.05) by Duncan’s New Multiple Range Test.

4.4.5 Correlation analysis

Table 14 presents results of simple linear correlation (r) analysis carried out to study the nature and degree of relationship between various growth and yield components. The results indicate that root length was very highly significant and positively correlated with number of pods per plant (r = 0.415***) while was highly significant and positively correlated with number of seeds per pod (r = 0.309**) and yield per plant (r = 285*). The study implies that yield components and yield of drought resistant bean are highly influenced by root length. The number of pods per plant was positively correlated with number of seeds per pod (r = 0.348**) and yield per plant (r = 0.685***). The number of seeds per pod was significant and positively correlated with yield per plant (r = 0.325*).

Table 14: Simple linear correlation (r) on some root characteristics and yield components

S/N	Variables	1	2	3	4	
1	Root density (gcm^{-3})	_				
2	Root length (cm)	0.018ns	_			
3	Podsplant^{-1}	0.044ns	0.415***	_		
4	Seeds per pod	0.080ns	0.309**	0.348**	_	
5	Yield plant(g)$^{-1}$	0.071ns	0.285*	0.685***	0.325*	_

ns not significant
* Significant at 0.05
** Significant at 0.01
*** Significant at 0.001

CHAPTER FIVE

5.0 DISCUSSION

The non significant effect ($P \leq 0.05$) of bean lines on various growth stages are indicated in Table 3 for field experiment and Table 9 for screen house experiment. However, crop establishment under screen house had significant effect ($P \leq 0.05$). The results on crop growth seem to have not been influenced by genetic differences among the bean lines. This is in contrary with findings by Yoshida (1981) in which there were genetic variation among genotypes of beans days to 50% flowering and maturity. However, early crop establishment is important for the plant to minimize soil evaporation. The significant effects ($P \leq 0.05$) caused by P application starting at 50 % flowering, to harvest maturity under field conditions, and those under screen house conditions were observed from crop establishment to harvest maturity. The results are similar to those reported by Jasrotia and Sharma (1998) and such findings may have been caused by the stimulatory effect of P application on growth hormones which induces early flowering. Further, the study shows that increasing P-levels reduces days to physiological maturity in common beans.

The application of 90 kg Pha^{-1} favours rapid plant growth, early fruiting and maturity which improve yield and quality of the produce. Similarly, Sabaghpour *et al.* (2003), found that early phenology (early flowering, early podding and early maturity) was the most important mechanism to escape terminal drought stress and this was associated with high initial growth vigour. This results into the crop escaping drought in areas prone to terminal drought. Jasrotia and Sharma (1998) also reported similar results that showed that P application significantly reduced number of days to physiological maturity. Beaver and Rosas (1998) found that selection for early flowering with a greater rate of partitioning and a shorter reproductive period permitted selection of small red bean breeding lines which had a week early maturity period without sacrificing the crop yield potential. Therefore, this could be a good point of consideration to synchronize bean production based on P application in order for the crop to escape terminal drought. However, researchers such as Tewari and Singh (2000) reported no significant effects of P application in number of days to 50 % flowering.

Results in Table 4 show significant differences ($P \leq 0.05$) among bean lines in number of leaves, plant height and number of branches at different growth stages under field condition. However, in the screen house experiment significant effect ($P \leq 0.05$) was observed in number of leaves at 63 DAP and in plant height at 21 DAP only (Table 10). The variation in plant height can be attributed to differences in the genetic makeup of the bean lines. The data under field conditions show that mean plant height increased at increasing rate, while it increased at a decreasing rate under screen house experiment. The decline in plant height may have been due to increase in temperature, leading to increased evapotranspiration and cell senescence during the growing season. Weather data under screen house indicated higher temperature (31.0 ^{O}C), which probably resulted in excessive water loss and hence insufficient soil moisture for plant growth. Consequently this decreased photosynthesis and translocation of photosynthates into plant parts which might have reduced growth and hence plant height (Ohashi *et al*., 2000).

Significant effects ($P \leq 0.05$) of P levels were also observed in the number of leaves, plant height and number of branches (Table 4 and 10) and stunted growth was observed at all growth stages in treatments with no P. These results are in agreement with reports by Camacho *et al.* (2002); Akinrinde and Gaizer (2006) who observed reduced plant height in sorghum (*Sorghum bicolor* (L.) Moench) and rice (*Oryza sativa*) under P deficiency. The results recorded on the P effect on number of branches are in agreement with (Baboo *et al*., 1998; Jasrotia and Sharma 1998) in which there was a linear increase in number of branches per plant as P levels increased. Significant improvement in number of branches per plant with 35.2 kg P ha^{-1} application was also revealed by Kanaujia *et al*. (1999).

Significant effects observed among bean lines on root biomass in this study are in agreement with those reported by Baligar *et al*. (1998). The authors also found that inter and intra-species difference in root dry matter accumulation is highly modified by environmental factors. Root elongation due to water stress during flowering indicates that the current bean lines used reacted to water stress by diverting assimilates to root development, hence resulting into root elongation which is a drought avoidance mechanism. This is supported by studies at CIAT on a drought resistant line, BAT 477 that had a deep root under drought stress permitting access to soil moisture at greater depths (Sponchiado *et al*., 1989; White and Castillo, 1992 and Kashiwagi *et al*., 2006).

The significant effects ($P \leq 0.05$) caused by P application shown in Tables 5 and 11 on root characteristics are in agreement with studies conducted by Nielsen and David (1996). These authors showed that root and shoot biomass increased due to increasing levels of P. Similar observations were reported by Lynch (1995) on the role of P in enhancing root development, which in turn improves the capacity of plants for phosphate acquisition. Phosphorus application in common bean is known to have a positive effect on enhancing root proliferation and thus helping in exploiting soil water and nutrients.

Lynch and Beebe (1995) observed that at early growth stages, plants use seed reserves for their establishment and little utilization of P to develop more roots, which can scavenge the nutrients around themselves. Thus higher root development would be an important trait for adapted genotypes in exploring large soil volume hence soil moisture. The effect of P on root development has also been reported by Hossain and Hamid (2007).

The significant effects ($P \leq 0.05$) of bean lines on root density at different growth stages observed throughout the soil profile in this study may have increased the diffusion area, thereby improving water availability and nutrient uptake. Maintenance of plant water status under water limitations can be partially attributed to root characteristics such as rooting depth and root length density (Subbaro *et al*., 1995). Thus, root depth may be considered as an alternative trait to screen for drought resistant common bean lines, as also observed by Sponchiado *et al*. (1989). Plants often maintain higher root length density than required by the surface area of the shoot, mainly to minimize effects of other stress factors such as soil pests and nutrient deficiency (Passioura, 1983).

The none significant effects ($P \leq 0.05$) recorded in this study on shoot biomass accumulation show that bean line MR 14125-3 maintained high biomass accumulation despite water stress under field conditions. Such behavior could be due to remobilization of photosynthates from vegetative shoot structures to pods and from pod wall to grain as an important mechanism of drought resistance. Significant increase in shoot dry weight at all growth stages with increasing P application have also been reported by several other authors Fageria *et al*. (1997); Fageria and Baligar (1997); Rana *et al*. (1998); Sushant *et al*. (1999); Arajuo *et al*. (2000) and Thung (1991).

The significant effects ($P \leq 0.05$) of bean lines on yield and yield components are in agreement with those reported by White *et al*. (1994). Water stress during flowering reduces yield through increased flower failure and to a lesser extent by reducing the number of seeds per pod. After flowering, water stress usually results into embryo abortion, pod abortion, poor pod development due to poor photosynthesis. A number of authors (Munoz-Perea *et al.,* 2006, Fageria, 2006 and Fageria, *et al*., 2010) have reported that reduction of grain yield in common bean grown under stress is usually due to excessive abortion of flowers, young pods and seed size (also referred to as seed weight) occuring during pre-flowering (10-12 days) before anthesis and reproductive periods. On the other hand Beebe *et al*. (2008) reported that, some common bean materials that were essentially selected for drought resistance were also found to have better yield potential in favorable conditions and frequently within a shorter growth cycle. It was further reported that the advantage of improved partitioning to grain that is selected under stress carries over into favorable environments.

Significant effects ($P \leq 0.05$) of P application on yield and yield components of the bean lines shown in the present study are in agreement with those results reported by Islam and Noor (1982). The current results show that plants grown without P fertilizer had the lowest pod yield. The reduction in pod number was mainly caused by failure of fertilization due to production of non-viable pollen grains under such conditions. Similarly, the number of pods per plant was significantly reduced by P deficiency probably due to increased flower abortion. This effect was more pronounced under screen house experiment where excessive temperature during and after flowering were recorded. Reduction of pod number at higher P levels in this study could be due to insufficient moisture which resulted into plants redirecting assimilates from reproductive to vegetative parts for survival. Generally, yield was mostly reduced at lower P levels and increased at higher P levels in all bean lines. Seed yield in common bean is a product of the stable yield components and these components are generally the product of sequential developmental processes. Fageria *et al*. (2010) reported that, the contribution of yield components in increasing grain yield was in the order of number of pods per plant > seeds per pod > 100 grain weight. Similarly, Fageria and Santos (2008) observed that, number of grain per pod and weight of hundred grains are important yield components. Further, it has been documented that grain yield in beans as affected by the above mentioned seed yield components is usually affected by available P to the crop. Studies conducted by Hussain (1983) showed that application of P to legumes would improve seed yield considerably. Thus, any reduction in these yield components directly affects overall grain production. The reduction in yield is largely due to reduction in number of pods per plant as reported by Lopez *et al*. (1990).

As already indicated, the root characteristics were highly and positively correlated with yield components such as number of pods per plant, number of seeds per pod, yield per plant and 100 seed weight. These results indicate that the common bean yield components studied and the grain yield are very much influenced by the root characteristics. This effect could be due to the improvement of P on root growth (Tables 5 and 11) that gives the crop a higher ability to explore resources such as moisture during the terminal drought conditions. Similar results have been reported (Nielsen and David, 1996; Lynch, 1995; Hisinger, 2001; Hossain and Hamid, 2007).

Application of 60 or 90 kg P ha^{-1} showed significant impacts in terms of crop performance such as growth, development and grain yield of drought resistant bean lines compared to plots that had no P fertilizer. The highest application rate 90 kg P ha^{-1} out yielded the other P levels applied.

Some lines like MR 14125-3 accumulated dry matter faster than the rest, indicating higher photosynthetic rates. The line also had higher number of pods and high 100 seed weight in interaction effect these resulted to higher seed yield.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The findings in this study suggest that there is great variability among drought resistant common bean lines in growth and yield characteristics as affected by P availability. This study clearly indicates that in areas with low P fertility and terminal drought, P application is a key nutrient to enhancing yields of common bean. Phosphorus level at 90 kg Pha^{-1} followed by drought condition towards flowering would significantly improve growth and developmental characteristics, mainly the number of branches, leaves and nodes , shoot and root biomass, days to flowering, physiological and harvest maturity. Low P levels towards flowering significantly reduced growth of drought resistant common beans lines in this study.

Furthermore, P levels had significant influence on yield and yield components of crop. The 90 kg Pha^{-1} out yielded the rest of the treatments applied due to increased number of pods per plant, seeds per pod and 100- seed weight. Under field condition, overall grain yield showed that application of 90 kg Pha^{-1} produced 1292 kg ha^{-1} which was higher by 213% compared with the control that had 629 kg ha^{-1}. The line MR 14125-3 responded better than the rest in terms of number of pods per plant, seeds per pod and 100- seed weight, resulting to the highest grain yield of 1292 kg ha^{-1}. The results also showed significant interaction effect of 90 kg Pha^{-1} by a common bean line MR 14125-3 with a yield of 2083 kg ha^{-1}, which was higher by 214% compared to the lowest (1890 kg ha^{-1}) that was produced by bean line MR 14215-9-2 under plots with no P. Consequently, low P applied (30 kg ha^{-1}) led to low yield and yield components including number of pods per pod, number of seeds per plant and 100 seed weight; and subsequently low grain yield.

Root characteristics such as root length and root density were very important as far as terminal drought is concerned. The increase in length and root density in this study was positively correlated with the reduction of terminal drought that resulted into increase in growth and yield. Similarly, 60 or 90 kg Pha^{-1} reduced the number of days to flowering and crop maturity. This could be recommended in areas with terminal drought. Overall, the highest crop growth rate was observed in line MR 14125-3 applied with 90 kg Pha^{-1} (17.99 g $m^{-2}day^{-1}$).

6.2 Recommendations

- Based on the present findings, common bean line MR 14125-3 is recommended for adoption in the study area and other areas where soil and environmental characteristics are similar to these of the SHZ. This line was superior to the rest of the materials used in the study in terms of growth and yield characteristics.

- Application of P fertilizer at 90 kg ha^{-1} may offer a large scope for obtaining higher yield of drought resistant common beans in areas prone to terminal drought.

- The results of this study were obtained from one site and only in one season (2010/2011). In order to validate the findings, it is recommended that the study be conducted in different agro-ecological environments and seasons.

- The study showed a positive response of bean yield to P application thus it is recommended that the study be repeated with higher P levels.

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APPENDICES

Appendix 1: Summarized mean monthly weather data for field experimental site

Months	Rainfall (mm)	Temperature (^{O}C) Maximum	Minimum	RH (%)	Radiation $MJm^{-2}day^{-1}$
September	0	25.8	9.7	35	19.7
October	0	27.5	12.7	32	19.6
November	13.7	27	14.3	41	17.5
December	114	24.6	14.1	58	16.2
January	237.8	23.8	13.8	62	16.2
February	168.5	23.8	13.8	64	14.9
March	154.7	23.8	13.4	62	16.7
April	182.7	23.1	12.6	60	17.1
May	2.4	23.4	11.5	58	18.9

Appendix 2: Summarized mean monthly weather data in a screen house

Months	Temperature (^{O}C)	Relative humidity (%)
March	31.3	66.7
April	30.5	81.7
May	31.2	81.5

Appendix 3: Summary of analysis of variance (ANOVA) for vegetative, reproductive and yield variables from field experiment

Variables	Bean lines	Phosphorus levels	Lines x phosphorus
Days to crop emergence (V1)	ns	ns	ns
Days to crop establishment (V2)	ns	ns	ns
Days to 50 % flowering (R3)	ns	***	ns
Days to physiological maturity (R8)	ns	***	ns
Days to harvest maturity (R9)	ns	***	ns
Seed yield per ha ($kgha^{-1}$)	ns	***	ns
Number of pods per plant	*	***	ns
Number of seeds per pod	*	*	*
100 seed weight (g)	***	***	***

ns = not significant
* = significant at P<0.05
** = significant at P<0.01
*** = significant at P<0.05

Appendix 4: Summary of analysis of variance (ANOVA) for some growth and root characteristics at 21, 42 and 63 DAP under field experiment

	Bean lines			Phosphorus levels			Lines x phosphorus		
Variables	21 DAP	42 DAP	63 DAP	21 DAP	42 DAP	63 DAP	21 DAP	42 DAP	63 DAP
Number of nodes per plant	ns	ns	ns	ns	***	***	ns	ns	ns
Number of branches per plant	**	*	ns	*	***	***	ns	ns	ns
Number of leaves per plant	ns	**	ns	***	***	***	ns	ns	ns
Plant height (cm)	ns	**	***	***	***	***	ns	ns	ns
Leaf area (cm^{-2})	***	ns	ns	***	***	***	ns	ns	ns
Shoot biomass (g)	ns	ns	ns	***	***	***	ns	ns	ns
Root biomass (g)	ns	*	ns	***	*	***	ns	ns	ns
Root length (cm)	ns	ns	ns	***	*	*	ns	ns	ns

ns = not significant
* = significant at P<0.05
** = significant at P<0.01
*** = significant at P<0.001

Appendix 5: Summary of analysis of variance (ANOVA) for some vegetative, reproductive and yield variables from screen house experiment

Variable	Bean lines	Phosphorus levels	Lines x phosphorus
Days to crop emergence (V1)	ns	ns	ns
Days to crop establishment (V2)	*	***	ns
Days to 50 % flowering (R3)	ns	***	ns
Days to physiological maturity (R8)	ns	***	ns
Days to harvest maturity (R9)	ns	***	ns
Seed yield (g/plant)	ns	***	ns
Number of pods per plant	ns	***	ns
Number of seeds per pod	ns	**	ns

ns = not significant
* = significant at P<0.05
** = significant at P<0.01
*** = significant at P<0.001

Appendix 6: Summary of analysis of variance (ANOVA) for some growth and root characteristics at 21, 42 and 63 DAP under screen house

Variable	Bean lines			Phosphorus levels			Lines x phosphorus		
	21 DAP	42 DAP	63 DAP	21 DAP	42 DAP	63 DAP	21 DAP	42 DAP	63 DAP
Number of nodes per plant	ns	**	***	**	***	***	ns	ns	ns
Number of branches per plant	ns	ns	ns	**	***	***	ns	ns	ns
Number of leaves per plant	ns	ns	*	**	ns	**	ns	ns	ns
Plant height (cm)	***	ns	ns	***	***	***	ns	ns	ns
Shoot biomass (g)	ns	ns	ns	*	*	***	ns	ns	ns
Root biomass (g)	ns	ns	ns	*	**	ns	ns	ns	ns
Root length (cm)	ns	***	ns	ns	***	***	ns	ns	ns
Root density (gcm^{-3})	ns	ns	ns	*	*	ns	ns	ns	ns

ns = not significant
* = significant at P<0.05
** = significant at P<0.01
*** = significant at P<0.001