RESPONSE OF THREE COMMON BEAN (*Phaseolus vulgaris* L.) VARIETIES TO MOISTURE STRESS AT DIFFERENT LEVELS OF PHOSPHORUS

BY

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA

ABSTRACT

In this study, two experiments were conducted, one (field experiment) at the Horticultural Unit of the Sokoine University of Agriculture (SUA) located at 6^{0} 5' S 37^{0} 39' E with an elevation of 524 m a.s.l. and the other (pot experiment) was conducted at the screen house of the Department of Crop Science and Production. The main objective was to study the response of the three common bean varieties i.e. SUA 90, Kablanketi and Canadian wonder, to the interaction of the two factors; moisture stress and different levels of phosphorus fertilizer. The source of phosphorus used was Triple Super Phosphate (TSP) and the source of water used for irrigation was tap water for the pot experiment and rain for the field experiment. Three levels of phosphorus used were 0 kgP/ha, 30 kgP/ha and 60 kgP/ha. The three moisture regimes applied were less than 21 cb, between 21 and 50 cb and between 51 and 60 cb of moisture tension in the soil. In Canadian wonder total plant biomass significantly increased with increasing P. Root biomass increased with increasing P application in SUA 90. From this study it was concluded that Canadian wonder is the most vigorous and tolerant variety of the three, it has a vigorous growth which enables it to tolerate low P and moisture stress. It was hence recommended that, common bean breeders should use this variety in breeding for tolerance to moisture stress and low P.

DECLARATION

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

22-10-2008

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The above declaration is confirmed by

22/10/2008

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Date

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LIST OF ABREVIATIONS

ATP	Adenosine triphosphate
cb`	centibars
CRD	completely randomised design
DAP	days after planting
DNA	Deoxyribonucleic Acid
LAI	Leaf area index
N_d	number of nodes per plant
N_L	number of leaves per plant
N_P	number of pods per plant
NS	Not Significant
N_S	number of seeds per pod
S_{DM}	seeds dry mass
SUA	Sokoine University of Agriculture
TDM	total plant dry matter
TSP	Triple Super Phosphate
WRoot	below ground dry mass
WShoot	above ground dry mass

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

The common bean (*Phaseolus vulgaris* L.) rank first among the grain legume crops grown in Tanzania, supplying 72% of the vegetable protein that is consumed in most rural and urban diets (Mwalyego *et al.*, 2002). Beans are the major source of proteins in most diets in developing countries (Ferguson *et al.*, 1989; Wortmann *et al.*, 1998). Their proteins are relatively cheaper than proteins derived from animal sources (Nchimbi, 1989). The crop is grown for food as well as for sale (Madata *et al.*, 2003).

Smallholder farming dominates agricultural production in Tanzania, where a large proportion of smallholder production is for subsistence. Low productivity of land and high variability of rainfall (leading to frequent drought) are among the weaknesses and threats of agricultural performance in Tanzania (TARP II SUA Project, 2004).

1.2 Problem Statement and Justification

Bean yields in Tanzania are low due to biotic, abiotic and socio-economic problems (Madata *et al.*, 2003). Biotic problems include diseases, insect pests and poor varieties. Abiotic problems are poor soils and unreliable weather whereas strong varietal preference is one of the socioeconomic problems (Ngowi and Minjas, 1989; Wortmann *et al.*, 1998; Madata *et al.*, 2003).

About 60% of bean producing regions in the world suffer serous drought conditions (Van Schoonhaven and Voysest, 1991). Tanzania is among the bean producing countries in Africa which suffer serious yield loss in food crops, nearly every year due to drought spells. Although irrigation is used to reduce water stress in a few regions, still water shortages and high irrigation costs often prevent irrigation at rates required to eliminate drought stress (Van Schoonhaven and Voysest, 1991).

Currently much of the cultivated land throughout the world is deficient in available phosphorus (Wasaki *et al.*, 1997). The major soil groups found in bean growing areas in Africa are alfisols, oxisols and inceptisols and are all known for their P deficiency (Ndakidemi *et al*, 1995; Wortmann *et al.*, 1998). Low phosphorus availability is a big problem in bean producing areas in Tanzania. Most soil P is inaccessible to plants due to its existence in various chemical forms such as Fe, Al , Ca or organic P. Availability of P is affected by nature of the soil parent materials i.e. contain no P at all, and pH of the soil where by in places receiving sufficient amount of rainfall the soil tend to be acidic due to high H^+ activity hence, rich in Al^{3+} and Fe^{3+} which fix P and render it unavailable to plants or in low rainfall areas the soil is alkaline and rich in Ca^{2+} which fix P as $CaPO_4$. It is often difficult to distinguish between direct effects of drought and interaction of drought with other factors such as low soil fertility e.g. Phosphorus but all cause serious yield loss in common bean production (Kalumuna *et al.*, 2002).

1.3 Objectives

1.3.1 Overall objective

The overall objective of this study was to understand the response of three common bean varieties SUA 90, Kablanketi and Canadian wonder to moisture stress and different levels of phosphorus fertilizer.

1.3.2 Specific objectives

The specific objectives were

i) To asses responses related to moisture stress tolerance in the three common bean varieties with respect to growth habits i.e. determinate, semi determinate and indeterminate.

ii) To asses responses related to different phosphorus fertilizer levels among the three common bean varieties.

iii) To determine the relationship between moisture availability and phosphorus use efficiency in common bean production.

iv) To determine the effect of moisture stress and phosphorus on yield and yield components of common beans.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Systematics of the Common Bean

The common bean belongs to the species *Phaseolus vulgaris*, genus *Phaseolus*, sub tribe Phaseolinae, tribe Phaseoleae, subfamily Papilionoideae and the family Leguminosae (Van Schoonhaven and Voysest, 1991). The genus *Phaseolus* includes approximately 35 species of which four are cultivated; *P. vulgaris* L, *P. lanatus* L, *P. coccineus* L and *P. acutifolius* L.

2.2 Botany of the Common Bean

Phaseolus vulgaris L. is a highly polymorphic species showing considerable variation in habit, vegetative characters, flower colour and size, shape and colour of pods and seeds (Purseglove, 1968). The bean plant has a fibrous root system comprised of a taproot, basal roots that emerge from the basipetal end of the taproot and adventitious roots that emerge from the subterranean portion of the hypocotyl (Duke, 1983). The main stem originates from the axis of seed embryo and starts at the insertion of the root system (Debouck, 1991). The stem has nodes and internodes with the first node found at the insertion of cotyledons and the first internode between the cotyledons and primary leaves. The leaves are alternate, green or purple, trifoliate and possess stipules, petiole and marked pulvinus at the base. Leaflets are ovate, entire, acuminate, 6-15cm long and 3-11 cm wide in the middle (Duke, 1983). Flowers are in lax, axillary and zygomorphic i.e. bilaterally symmetrical. The colours of the flowers are diverse, ranging from variegated, white, pink or purplish and are about 1cm long (Duke, 1983). Pods are slender, cylindrical or flat, green, yellow, purple or black in color depending on the cultivar. The pods are 8-20cm long and 1-1.5cm wide, which also depends on the cultivar. The pods are usually grabulous i.e. smooth surface but sometimes, puberulent pods exist and the beak of the pod is prominent. The seeds can be white, purple red, grey, tan or black often variegated. They are reniform, oblong or globose up to 1.5cm long. The 100 seeds weight varies between 17 and 100grammes depending on the cultivar (Voysest and Dessert, 1991). Surface texture of the seed may be shiny (brilliant) opaque or intermediate. Common bean has two general growth habits namely, determinate and indeterminate growth habits (CIAT, 1987). Some semi-indeterminate or semi climbing varieties also exists. Strong and erect stem branches, short internodes and terminal inflorescence are attributes typical to determinate growth habit (Debouck, 1991). Long internodes, weaker stems and sometimes with long guides for climbing are attributes typical to indeterminate growth habit. Semi-indeterminate growth habit possesses some intermediate attributes to those of the determinate and indeterminate growth habits.

2.3 Ecology of the Common Beans

The common bean grows well in areas with medium rainfall, 500 mm – 2000 mm of mean annual rainfall well distributed and followed by a dry weather season right after maturity for pods and seeds drying. Beans grow best in well-drained, sandy loam, silt loam or clay loam soils, rich in organic content, but are sensitive to concentrations of Al, B, Mn, and Na. Excessive water or poorly drained soils resulting into water logging injures bean plants within a few hours (Duke, 1983; White, 1987). Below pH 5.2, Mn toxicity may be a problem (Duke, 1983). Optimum pH range is 5.5 – 7.0. Drought or lack of enough rains causes water stress to common beans, resulting into serious yield reductions. There are both short-day and day-neutral cultivars (Duke, 1983). Most bean producing areas in Eastern and Southern Africa have favourable temperatures (15 °C – 23 °C) for bean growth for at least part of the year (Wortmann *et al.*, 1998).

2.4 Uses of Beans

Beans are highly nutritious food and low cost source of protein when compared to other sources like meat, fish and sardines (Ferguson 1989; Nchimbi 1989; Wortmann 1998). Green beans contain 6.2% protein 0.2% fat and 63% carbohydrates whereas dried bean contains 22.9% protein, 1.3% minerals (Duke, 1983). Bean leaves are an important relish in Tanzania and are always found sold in local markets (Madata, 2003). The green immature pods are cooked and eaten as vegetables while others are marketed fresh, frozen or canned. Mature, ripe beans are cooked. Beans generate income to the growers after harvest as it is transported to urban centres where it fetches good prices (Mkuchu, *et al.*, 2003).

2.5 Common Bean Production in Tanzania

The common bean is produced in higher and wetter areas in the country. The yields are still very low despite the importance of bean as a leader of all grain legumes in supplying the dietary protein in Tanzania. In the Southern Highlands of Tanzania it was reported the average bean production ranged from 300 - 600 kg/ha compared to 1500 - 2500 kg/ha reported in research stations (Mkuchu, *et al.*, 2003). The annual yield increase is very small while the area harvested is more or less stable.

Low soil fertility and poor agronomic practices are the major constraints to bean production in Tanzania.

Table 1: Bean production statistics in Tanzania 1991-2004

Year	Area harvested x 1000ha	Yield kg/ha	Production x 1000mtons
1991	420	643	270
1992	305	639	195
1993	320	614	205
1994	300	633	190
1995	340	676	230
1996	400	700	280
1997	340	676	230
1998	360	694	250
1999	360	708	255
2000	365	712	260
2001	365	712	260
2002	370	729	270
2003	370	729	270
2004	370	729	270

Source: FAO-STAT (2005)

2.6 Drought Tolerance in Common Beans

There are few bean lines that have good agronomic characteristics that have proven to be drought resistant or tolerant (Tarimo, *et al* 1994). Tepary bean (*Phaseolus acutifolius* A. Gray) has been suggested to be as a good source for drought tolerance genes for inclusion into bean breeding programmes (Tarimo, 1997; Szilagyi, 2003). Of the various physiological problems limiting bean production in developing countries, drought is rivalled in importance only by soil fertility problems (Van Schoonhaven and Voysest, 1991). Studying on water requirements in bean through use of weighing lysimeters Thung in Van Schoonhaven and Voysest (1991) came up with the finding that yield depends on adequate soil moisture. Usually the yield depression of bean will be negligible if no more than 55% to 65% of available water storage capacity in the soil volume, well explored by plant roots, is depleted. Near maturity up to 70% to 80% can be safely used (Van Schoonhaven and Voysest, 1991). Water stress during the reproductive stage reduces yield significantly (Van Schoonhaven and Voysest, 1991). Water stress at pre-flowering stage reduces number of pods per plant, seed per pod and individual seed mass (Tarimo, *et al* 1994). Plants are also stunted if water stress occurs during the vegetative growth period but yields are not reduced if adequate soil water was maintained during flowering.

2.7 Phosphorus in Common Beans

Phosphorus is the most deficient macronutrient element in acidic soils of the world where most bean production is undertaken (Thung, 1991). Phosphorus deficiency in bean cultivars is most common on volcanic ash soils and in highly weathered oxisols and ultisols of the world (Schwartz, 1978). The plants remain dwarfed and the stems are thin, with very short internodes. The upper leaves remain small and dark green while the lower leaves become yellow with necrosis on the edges. When P deficiency is serious, defoliation of leaves occurs earlier. The initiation of flowering is late and few flowers remain in the plant because of a high level of flower abortion. Roots develop slightly less in comparison with those plants without P deficiency. Plants that suffer from P deficiency have a P content of less than 0.2% in the upper leaves during floration, but the critical level of P in tissue varies between 8ppm and 15ppm (Bray II method), depending on the type of soil (Van Schoonhaven and Voysest, 1991).

Bildirici *et al.*, (2005) studied the effect of different N, P and rhizobium inoculation on yield and yield components of common beans under watery conditions and found that the number of pods per plant and grain yield in kg ha $^{-1}$ increased with increased P doses. Studies in beans and many other crops confirm the importance of root growth in permitting plants to explore a greater soil volume, thus extracting more moisture and suffer less drought effects (Nilsen and David, 1996; Van Schoonhaven and Voysest, 1991). Yan *et al.*, (1995) found that in common beans root biomass and length were enhanced markedly by P addition. The author also found that shoot biomass increased with increasing P levels. Low-P availability can dramatically alter the growth angle of basal roots and the production of adventitious roots, resulting in more shallow root systems, a disadvantage under water-limited environments (Ho, *et al.*, 2003).

Phosphorus 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 translation of genetic information (Marschner, 1997). Phosphorus is also known for its structural role in biomembranes in the cell systems as it acts as a bridge between the glycerides and other molecules such as amino acid, alcohol and amine. It is also involved in energy metabolism in the cell by forming an energy rich intermediate or coenzyme, principally Adenosine triphosphate (ATP). This intermediate is used in biochemical processes such as starch synthesis. Studies on response of common beans to a combination of the three factors; water stress, P doses and varieties are currently scarce. This study therefore combines the three factors i.e. water stress, P doses and varieties with different growth habits to elucidate interaction effects.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location and Duration

Two experiments were conducted, one at the Horticultural Unit of the Sokoine University of Agriculture (SUA) field located at 6° 5" S 37° 39' E; 524 m a.s.l. and another in a screen house of the Department of Crop Science and Production using pots.

The area has two rainfall seasons: long rains season which starts early in March and end late in May and short rains season which normally starts end of October and ends late in December.

The field experiment was set out on 26th October 2006 during the short rains season. The experiment prevailed for three months i.e. from late October 2006 to late February 2007. During this period the area received considerable amounts of rainfall with a peak amount in December (Fig. 1). This condition was accompanied by low evaporation (Fig. 2) and, high temperature (Fig. 3).

3.2 Materials

SUA 90, Kablanketi and Canadian wonder varieties were obtained from in the Department of Crop Science and Production. The source of phosphorus used was Triple Super Phosphate (TSP). The source of water used for irrigation was tap water for the pot experiment and the field experiment depended on rain.

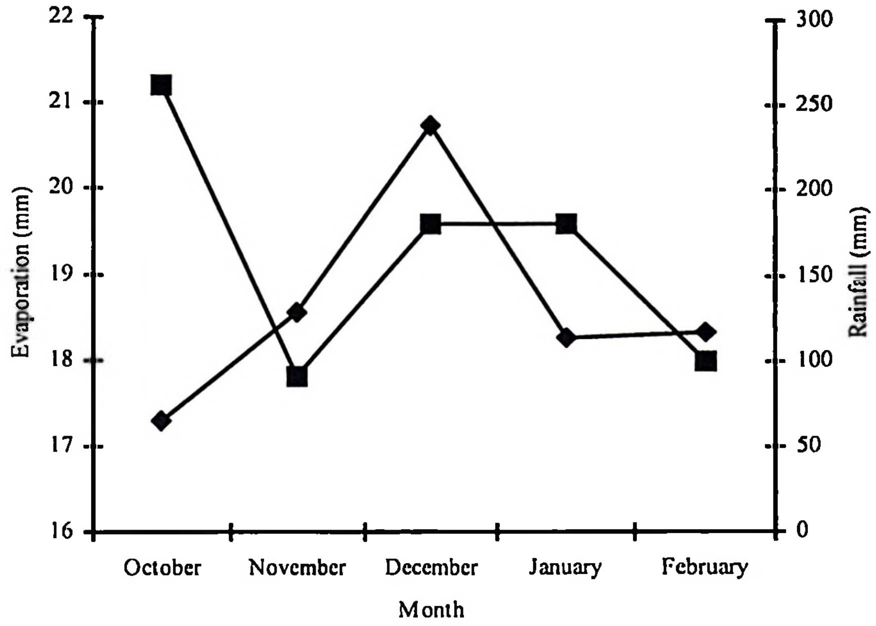

Figure 1: Monthly mean rainfall and evaporation from October 2006 to February 2007

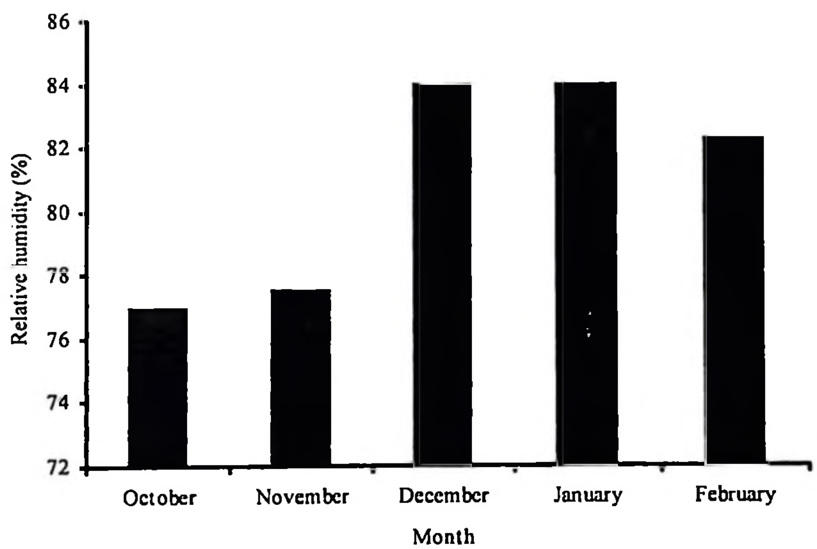

Figure 2: Monthly mean relative humidity from October 2006 to February 2007

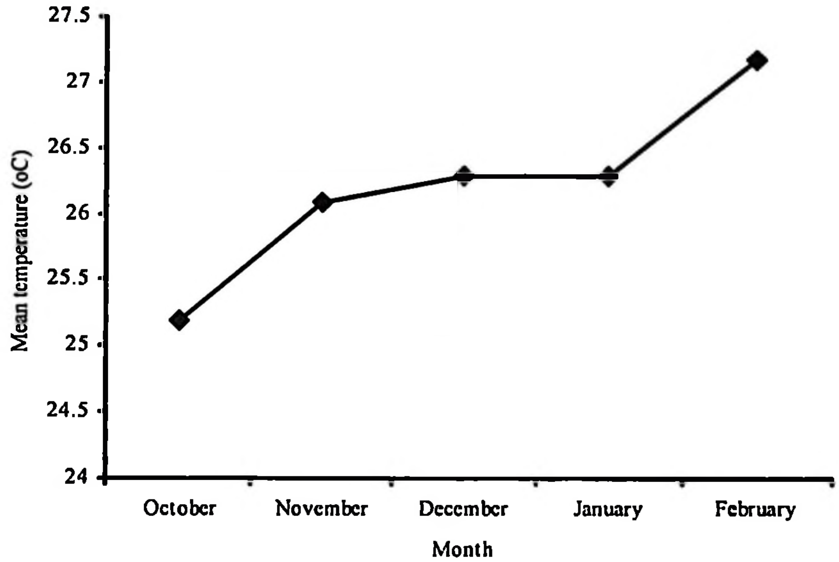

Figure 3: Monthly mean temperature from October 2006 to February 2007

3.3 Experimental Design and Layout

The field experiment was laid out in a Randomised Complete Block Design (RCBD), laid in a split – splits plots and replicated three times. The expeimental area was $1035m^2$. The plant spacing was 50 cm × 20 cm. The pot experiment was a split- split plot in completely randomised design (CRD) in a screen house using 4kg plastic pots with 2 seeds sown per pot and replicated three times. Moisture regimes were monitored using field tensiometers whereby the three soil moisture tension levels of $\geq$ 51 centibars, 21 – 50 centibars and $\leq$ 20 centibars were maintained. Phosphorus levels were monitored by basal application of three levels of P, i.e. 0 kgP/ha, 30 kgP/ha and 60 kgP/ha. The source of P was TSP.

The three water regimes were the main plot (factor A), the three phosphorus levels were the subplots (factor B) and the three bean varieties were the sub – sub plots (factor C) for the pot experiments.

3.4 Data Collection

3.4.1 Soil characteristics

Two soil samples were taken to the Soil Science Laboratory at SUA for characterisation. The first soil sample was taken from the experimental field at the Horticultural Unit. Physical and chemical characteristics were determined and summarised in Table 2. The second soil sample was taken from Magadu area for the pot experiment. Chemical and physical characteristics were determined and summarised in Table 3. The chemical characteristics determined were soil pH, extractable (available) phosphorus, exchangeable potassium, total nitrogen and organic carbon. The physical characteristic determined was particle size distribution.

Table 2: Horticultural garden soil characteristics

Characteristic	Measurement		Interpretation
Soil pH (1:2.5) (H_2O)		7.5	Alkaline
Particle Size Distribution	Clay (%)	17	
	Silt (%)	8.3	Sandy Loam
	Sand (%)	74.8	
Total Nitrogen (%)		0.039	Low
Organic Carbon (%)		0.805	Low
Bray I Extractable Phoshorus (mg/kg)		50.24	Medium
Exchangeable bases (Cmol(+)/kg)	Ca^{2+}	4.715	Medium
	Mg^{2+}	3.273	Medium
	K^{+}	0.39	Medium

Table 3: Magadu soil characteristics

Characteristic	Measurement		Interpretation
Soil pH (1:2.5) (H_2O)		6.5	Neutral
Particle Size Distribution	Clay (%)	36	
	Silt (%)	8	Sandy Clay
	Sand (%)	56	
Total Nitrogen (%)		0.1	Medium
Organic Carbon (%)		1.52	Medium
Bray I Extractable Phoshorus (mg/kg)		11.41	Low
CEC (Cmol(+)/kg)		13	Medium
Exchangeable bases (Cmol(+)/kg)	Ca^{2+}	6.43	Medium
	Mg^{2+}	2.78	Medium
	K^{+}	0.91	High
	Na^{+}	0.16	Low

3.4.2 Primary plant growth characteristics

The following primary plant growth characteristics were obtained; plant height, leaf area index (LAI), number of leaves per plant (N_L), number of nodes per plant (N_d), above ground (WShoot) and below ground dry mass (WRoot), and total plant dry matter (TDM).

3.4.3 Yield and yield components

Ten plants were sampled for yield and yield components data; number of pods per plant (N_P), number of seeds per pod (N_S) and seeds dry mass (S_{DM}).

3.5 Data Analysis

3.5.1 General model for data analysis

The general model for data analysis was;

$Y_{ijkl} = \mu + R_i + V_j + (RV)_{ij} + P_k + (RP)_{ik} + (VP)_{jk} + W_l + (RW)_{il} + (VW)_{jl} + (PW)_{ik} + (VPW)_{jkl} + (RVPW)_{ijkl}$.

Whereby,

Y_{ijkl} = response, μ = general mean of all observations, R_i = i^{th} replication effect, V_j = j^{th} variety effect, P_k = k^{th} phosphorus effect, W_l = l^{th} water stress effect, $(RW)_{ij}$ = main plot error, $(RP)_{ik}$ = sub plot error, $(RV)_{il}$ = sub – sub plot error, $(VP)_{jk}$ = interaction of variety and phosphorus levels, $(VW)_{jl}$ = interaction of variety and water stress, $(PW)_{ik}$ = interaction of water stress and phosphorus levels, $(VPW)_{jkl}$ = interaction effect among variety, phosphorus and water stress and $(RVPW)_{ijkl}$ = experimental error.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

This chapter explains the results of the two experiments; the first one that was conducted in the field (Field experiment) and the second one that was conducted in the screen house (Screen house experiment). In the field experiment, growth and yield responces to three P rates were studied while in the pot experiment, growth and yield response of the crop to three P rates and three moisture regimes in the soil were studied.

4.1.1 Field experiment.

4.1.1.1 Total plant biomass

Changes in total biomass (TDM) per plant within growth stages, 21, 42 and 63 days after planting (DAP) were not statistically significant among the bean varieties. Overall, TDM changes were only significantly different across P rates (Table 4a). TDM in SUA 90 increased from 7.3 g to 18.3 g, Kablanketi from 6.8 g to 38.3 g and Canadian Wonder from 5.6 g to 31.7 g at 0 kgP/ha. At 30 kgP/ha TDM in SUA 90 increased from 4.6 g to 20.4 g, Kablanketi from 7.7 g to 20.3 g and Canadian Wonder from 6.1 g to 28.6 g. At 60 kgP/ha SUA 90 TDM increased from 5.4 g to 27.1 g, Kablanketi from 4.8 g to 27.7 g and Canadian Wonder from 6.6 g to 35.0 g (Table 4a).

Table 4a: The effects of phosphorus on number of nodes and branches per plant, leaf area index and total dry mass of common bean varieties

Variety	Phosphorus rate (kgP/ha)	DAP	Plant Growth Characteristics			
			Number of Nodes per plant	Number of Branches per plant	Leaf Area Index (LAI)	Total Dry Mass
SUA 90	0	21	8	2	0.9	7.5
		42	19	5	1.5	14.6
		63	24	8	1.5	18.3
	30	21	9	2	1.1	4.6
		42	19	6	1.9	15.1
		63	19	8	1.8	20.4
	60	21	8	1	1.0	5.4
		42	17	5	1.4	19.7
		63	31	8	2.0	27.1
Kablanketi	0	21	7	2	1.2	6.8
		42	17	3	2.7	27.9
		63	33	4	2.9	38.3
	30	21	9	2	1.0	7.7
		42	25	3	2.3	16.1
		63	36	3	3.0	20.3
	60	21	8	1	1.2	4.8
		42	31	3	2.6	20.1
		63	36	3	3.1	27.7
Canadian Wonder	0	21	12	2	1.2	5.6
		42	38	4	2.4	23.1
		63	52	2	2.8	31.7
	30	21	9	1	1.5	6.1
		42	34	3	2.4	21.1
		63	46	3	3.0	28.6
	60	21	12	1	1.1	6.6
		42	37	3	2.5	25.4
		63	53	3	3.6	35.0
LSD (0.05)						
DAP			12.8	4.9	1.0	41.3
Variety			NS	NS	NS	NS
Phosphorus			NS	NS	NS	0.2
Variety × Phosphorus			NS	NS	NS	NS

At 21 DAP, TDM in Canadian wonder significantly increased with increasing P levels (Table 4a). Largest plant biomass were observed in treatments with 60 kgP/ha (6.6 g) compared with 5.6 g and 6.1 g in treatments with 0 kgP/ha and 30 kgP/ha, respectively (Table 4a). SUA 90 and Kablanketi did not show any definite responses with increasing levels of P at that growth stage (21 DAP). At 42 DAP, TDM increased with increasing P levels in SUA 90. Highest TDM was observed in

Table 4b: The effects of phosphorus on root and shoot dry mass, plant height and number of leaves per plant of common bean varieties

Variety	Phosphorus rate (kgP/ha)	DAP	Plant Growth Characteristics			
			Root Dry Mass (g/plant)	Shoot Dry Mass (g/plant)	Plant Height (cm)	Number of Leaves per plant
SUA 90	0	21	0.4	7.1	32.7	9
		42	1.4	13.2	40.0	19
		63	2.0	16.3	37.0	24
	30	21	0.4	4.17	32.0	8
		42	1.4	13.7	48.7	21
		63	2.0	18.4	51.0	19
	60	21	0.4	5.0	33.7	9
		42	2.1	17.7	40.3	16
		63	3.1	24.0	48.0	27
Kablanketi	0	21	0.5	6.33	34.7	7
		42	2.2	25.7	118.3	16
		63	2.7	21.7	135.1	73
	30	21	0.6	7.2	33.7	7
		42	1.8	14.4	142.7	21
		63	2.3	17.9	206.7	39
	60	21	0.5	4.31	36.3	8
		42	2.1	18.0	175.3	26
		63	2.9	24.9	213.3	34
Canadian Wonder	0	21	0.5	5.1	36.0	9
		42	2.6	20.5	155.0	32
		63	3.2	30.8	146.1	95
	30	21	0.6	5.5	36.0	10
		42	2.1	19.0	144.7	27
		63	2.8	25.8	190.0	41
	60	21	0.8	5.8	34.7	9
		42	2.6	22.8	169.3	28
		63	3.8	31.3	193.3	51
LSD (0.05)						
DAP			0.6	83.2	38.7	13.3
Variety			1.4	NS	38.7	NS
Phosphorus			0.2	NS	17.2	NS
Variety × Phosphorus			NS	NS	NS	NS

treatment with 60 kgP/ha (19.7 g) compared with 14.6 g and 15.1g in treatments with 0 kgP/ha and 30 kgP/ha, respectively (Table 4a). Kablanketi and Canadian wonder did not show any definite responses with increasing levels of P at 42 DAP.

At 63 DAP, TDM again increased with increasing P levels in SUA 90. Highest TDM was recorded from treatments with 60 kgP/ha (27.1 g) compared with 18.3 g and 20.4 g in treatments with 0 kgP/ha and 30 kgP/ha, respetively (Table 4a). Kablanketi and Canadian wonder did not show any definite responses to increasing levels of P at that growth stage.

These results show that beans with high levels of P (60kgP/ha) accumulated more TDM than those in the control or with 30kgP/ha, respectivelly. The source of variation in TDM was analysed using plant morphological characteristics.

4.1.1.2 Leaf area index (LAI)

As with TDM, leaf area index was not influenced by levels of P among the three bean varieties at 21 DAP (Table 4a). At 42 DAP, LAI increased to 3.6 at 60 kgP/ha in Canadian wonder, while in Kablanketi and SUA 90 responces were not apparent. At 63 DAP, LAI was significantly higher in treatments with high levels of P. In SUA 90, LAI was 2 at 60 kgP/ha (Table 4a) while in Kablanketi was 3.1 and Canadian wonder 3.6 at the same levels of P (Table 4a).

4.1.1.3 Shoot biomass

Overall, shoot biomass was similar among varieties and phosphorus levels. While not statistically significant shoot biomass was higher at higher P levels. For example, SUA 90 shoot biomass increased from 7.1 g to 16.3 g, Kablanketi from 6.3 g to 21.7 g and Canadian Wonder from 5.1 g to 30.8 g at 0 kgP/ha while at 30 kgP/ha SUA 90 shoot biomass increased from 4.2 g to 18.4 g, Kablanketi from 7.2 g to 17.6 g and Canadian Wonder from 5.5 g to 25.8 g. At 60 kgP/ha SUA 90 shoot biomass increased from 5 g to 24 g, Kablanketi from 4.3 g to 24.9 g and Canadian Wonder from 5.9 g to 31.3 g during the course of plant growth (Table 4b).

At 21 DAP, Canadian wonder's shoot biomass increased with increasing P levels although this was not a statistically significant change. Heaviest shoots were observed in treatments with 60 kgP/ha (5.9 g) compared with 5.1 g and 5.5 g in treatments with 0 kgP/ha and 30 kgP/ha, respectively (Table 4b). SUA 90 and Kablanketi did not show any definite shoot biomass responses with increasing levels of P at 21 DAP.

Shoot biomass showed similar trends of response to increasing P levels in SUA 90 at 42 DAP although this change was not significant. Highest shoot biomass was observed from treatment with 60 $kgPha^{-1}$ (17.7 g) compared with 13.2 g and 13.7 g in treatments with 0 kgP/ha and 30 kgP/ha, respectively (Table 4b). Shoot biomass was however highest (25.7 g/Plant) in treatments without P application (0 $kgPha^{-1}$) in Kablanketi. Similar observations were recorded in Canadian wonder where there were no clear responses of shoot biomass to increasing levels of P (Table 4b).

At 63 DAP, shoot biomass increased with increasing P levels in SUA 90 although this also was not a significant change. Heaviest shoots were observed in treatments with 60kgP (24 g) compared with 16.3 g and 18.4 g in treatments with 0 kgP/ha and 30 kgP/ha respectively (Table 4b). Kablanketi and Canadian wonder did not show any definite responses with increasing levels of P at that growth stage (63 DAP).

4.1.1.4 Root biomass

The increase in root biomass with growth stage (i.e. 21 DAP, 42 DAP and 63 DAP) was significant among all the three bean varieties. SUA 90 root biomass increased from 0.4 g to 2 g, Kablanketi from 0.5 g to 2.7 g and Canadian Wonder from 0.5 g to 3.2 g at 0 kgP/ha. At 30 kgP/ha SUA 90 root biomass increased from 0.4 g to 2 g, Kablanketi from 0.6 g to 2.3 g and Canadian Wonder from 0.6 g to 2.8 g. At 60 kgP/ha SUA 90 root biomass increased from 0.4 g to 3.1 g, Kablanketi from 0.5 g to 2.9 g and Canadian Wonder from 0.8g to 3.8 g (Table 4b).

At 21 DAP, Canadian wonder's root biomass increased with increasing P levels. Heaviest roots were observed in treatments with 60 kgP/ha (0.8 g) compared with 0.5 g and 0.6 g in treatments with 0 kgP/ha and 30 kgP/ha respectively (Table 4b). SUA 90 and Kablanketi did not show any definite responses with increasing levels of P at that growth stage (21 DAP).

At 42 DAP, root biomass increased with increasing P levels in SUA 90. Heaviest roots were observed in treatments with 60 kgP/ha (2.1 g) compared with 1.4 g and 1.4 g in treatments with 0 kgP/ha and 30 kgP/ha respectively (Table 4b). Kablanketi and Canadian wonder did not show any clear responses with increasing levels of P at 42 DAP.

At 63 DAP, root biomass increased with increasing P levels in SUA 90 once again. Heaviest roots were recorded in treatments with 60 kgP/ha (3.1 g) compared with 2 g in treatments with 0 kgP/ha and 30 kgP/ha (Table 4b). Kablanketi and Canadian wonder did not show any definite responses with increasing levels of P at 63 DAP.

4.1.1.5 Plant height

Plant height was not significantly influenced by P levels at 21 DAP among the three common bean varieties (Table 4b) However, plant height was significantly influenced by P levels at 42 DAP (P<0.05). In SUA 90, tallest plants were observerved from treatments with 30 kgP/ha. In Kablanketi, however, tallest plants (175.3 cm) were recorded from treatments with 60 kgP/ha. Similar observations were noted in Canadian wonder where tallest plants (169.3 cm) were recorded from treatments with 60 kgP/ha. Thus varietal differences exist among common beans varieties in response to increasing levels of P under field conditions (Table 4b).

Plant height was also significantly influenced by P levels at 63 DAP (P<0.05, Table 4b). In SUA 90, tallest plants came from plants which received 30 kgP/ha. In Kablanketi, however, tallest plants (213.3 cm) were corded from treatments with 60 kgP/ha. Similar observations were noted in Canadian wonder where tallest plants (193.3 cm) were recorded from treatments with 60 kgP/ha.

4.1.1.6 Number of leaves per plant

Number of leaves per plant was significantly influenced by P levels at 21 DAP among the three common bean varieties (P<0.05, Table 4b). Canadian wonder and SUA 90 had the largest number of leaves per plant (9) in treatments with 60kgP/ha. In Kablanketi the treatments with 30kgP/ha had the largest number of leaves per plant. Hence varietal differences exist among common beans in response to varying levels of P under field conditions (Table 4b).

Number of leaves per plant showed similar trends of response to increasing P levels in Kablanketi at 42 DAP. Largest numbers of leaves per plant was observed from treatment with 60 kgP/ha (26 leaves per plant) compared with 16 and 21 leaves per plant with 0 and 30 kgP/ha, respectively (Table 4b). Leaves per plant were however greater (32) in treatments without P application (0 kgP/ha) in Canadian wonder. Similar observations were recorded from SUA 90, where there were no clear responses in terms of number of leaves per plant with increasing levels of P. Instead, there were more leaves per plant (21) in treatments with 30 kgP/ha.

At 63 DAP, the number of leaves per plant was not significantly influenced by levels of P. Thus largest number of leaves per plant were observed in treatments without P (72) in Kablanketi and (94) in Canadian wonder.

4.1.1.7 Number of nodes per plant

The number of nodes per plant was not significantly influenced by P levels at 21 DAP among the three common bean varieties (Table 4a). Canadian wonder had the largest number of nodes per plant (12) in treatments with 60kgP/ha. For SUA 90 and Kablanketi, the highest responses were observed in treatments with 30 kgP/ha, with 9 nodes per plant each. Thus there are varietal differences in common bean response to increasing levels of P under field conditions (Table 4a).

At 42 DAP, the number of nodes per plant was significantly influenced by P application ($P<0.05$, Table 4a) in Kablanketi. This variety had the largest number of nodes per plant (31) at 60 kgP/ha compared with 17 at 0 kgP/ha and 25 at 30 kgP/ha. SUA 90 and Canadian wonder did not show any significant response to P application.

The number of nodes per plant was significantly increased by P application in Kablanketi and Canadian wonder at 63 DAP. The highest number of nodes per plant in Kablanketi was 36 in treatments with 30 kgP/ha and was maintained at 36 in treatments with 60 kgP/ha (Table 4a). In Canadian wonder the highest number of nodes per plant was 53 in treatments with 60 kgP/ha.

4.1.1.8 Number of branches per plant

The number of branches per plant was not influenced by the amount of P applied in all the three common bean varieties across the three growth stages analysed (Table 4a). SUA 90 at 63 DAP had similar number of branches per plant (8) at all the three levels of P applied. Kablanketi maintained three branches per plant at 42 DAP in all the three levels of P. Canadian wonder had a slight increase in the number of branches per plant at 63 DAP from 2 at 0 kgP/ha to 3 at 30 kgP/ha and 60 kgP/ha (Table 4a).

4.1.1.9 Grain yield and yield components

Grain yield per plant was not significantly influenced by P rates across the bean varieties although Canadian wonder showed an approximately linear response with increase in P levels (Table 5). SUA 90 appeared to have a large number of seeds per pod than Kablanketi and Canadian Wonder, particularly at 30 kgP/ha (Table 5). SUA 90 also showed some positive responces, although not statistically significant to P application in number of pods per plant (Table 5). Phosphorus levels did not have any significant influence on grain yield among the common bean varieties. The interaction effects among variety and phosphorus were not statistically significant among all the parameters analysed in this study.

Table 5: Effects of phosphorus levels on grain yield of common bean varieties

Bean Variety	Phosphorus rate (kgP/ha)	Yield Characteristics		
		Pods/ Plant	Seeds/ Pod	Yield (t ha^{-1})
SUA 90	0	17	5	1.1
	30	22	6	1.1
	60	21	4	1.1
Kablanketi	0	29	3	1.0
	30	14	3	0.9
	60	14	4	1.0
Canadian Wonder	0	18	5	1.1
	30	22	4	1.1
	60	19	4	1.2
LSD (0.05)				
Variety		NS	NS	NS
Phosphorus		NS	NS	NS
Variety × Phosphorus		NS	NS	NS

4.1.2 Pot Experiment

This experiment was conducted to study common bean responses to moisture stress at different levels of P levels.

4.1.2.1 Plant height

At 21 DAP treatments with less than 21 cb of moisture tension, and 0 kgP/ha had significantly taller plants in all varieties. Canadian wonder was the tallest (34 cm), followed by Kablanketi (30.7 cm) and SUA 90 (26.3 cm) (Table 6). Treatments with 30 kgP/ha, Canadian wonder was the tallest (35.3 cm) of SUA 90 (32.7 cm) and Kablanketi (24 cm) (Table 6). Under 60 kgP/ha, Kablanketi and Canadian wonder had similar height (28 cm) and slightly taller than SUA 90 (27.7 cm).

The effects of P applications among the varieties at 21 DAP in treatments with less than 21 cb moisture tension were not significant. In SUA 90, the treatments with 30 kgP/ha had the tallest plants compared with 0 kgP/ha (26.3 cm) and 60 kgP/ha (27.7 cm) (Table 6). In Kablanketi, treatments with 0 kgP/ha had the tallest plants (30.7 cm) compared with 30 kgP/ha (24 cm) and 60 kgP/ha (28 cm) (Table 6). In Canadian wonder, treatments with 30 kgP/ha had the tallest plants (35 cm) compared with 0 kgP/ha (34 cm) and 60 kgP/ha (28 cm) (Table 6).

Under the moisture tension of between 21 cb and 50 cb at 21 DAP, treatments with 0 kgP/ha had significant influence in plant heights among varieties. Canadian wonder had the tallest plants (39 cm) compared with SUA 90 (25 cm) and Kablanketi

Table 6: Effect of moisture, Phosphorus and their interactions to the three common bean varieties

Variety	Moisture Levels (cb)	Phosphorus rate (kgP/ha)	Date	Plant Growth Characteristics		
				Plant height (cm)	Number of Nodes per Plant	Number of Leaves per Plant
SUA 90	<21	0	21	26.3	4	4
			42	56.3	7	8
			63	64.7	9	11
		30	21	32.7	4	4
			42	75.0	10	9
			63	88.3	10	14
		60	21	27.7	3	3
			42	71.7	7	8
			63	94.3	11	12
	21 -50	0	21	25.0	4	4.
			42	55.0	7	7
			63	72.3	8	9
		30	21	35.0	4	4
			42	76.7	10	9
			63	90.7	14	15
		60	21	35.7	4	4
			42	78.7	9	8
			63	94.0	10	12
	51 – 60	0	21	26.7	4	4
			42	62.7	7	6
			63	74.0	9	9
		30	21	24.0	4	4
			42	58.7	11	9
			63	75.0	12	12
		60	21	33.7	4	4
			42	78.7	9	8
			63	89.7	9	12
Kablanketi	<21	0	21	30.7	4	4
			42	47.0	6	6
			63	53.0	8	10
		30	21	24.0	4	4
			42	36.3	7	6
			63	48.3	8	9
		60	21	28.0	4	4
			42	59.7	7	7
			63	89.3	10	12
	21 -50	0	21	23.0	4	4
			42	66.7	7	6
			63	84.7	9	10
		30	21	24.3	4	4
			42	58.7	7	6
			63	86.0	10	12
		60	21	44.7	4	4
			42	81.7	8	8
			63	111.3	13	13

Table 6 Continued

	51 – 60	0	21	29.0	4	4
			42	55.0	8	7
			63	64.3	9	11
		30	21	36.3	5	4
			42	65.3	8	7
			63	70.3	9	12
		60	21	26.7	4	4
			42	69.0	9	8
			63	98.3	10	12
Canadian Wonder	<21	0	21	34.0	5	4
			42	58.3	8	6
			63	86.3	9	9
		30	21	35.3	3	3
			42	68.3	7	6
			63	90.0	10	12
		60	21	28.0	5	4
			42	74.0	8	7
			63	112.7	12	12
	21 -50	0	21	39.0	5	4
			42	67.3	8	7
			63	89.3	10	9
		30	21	25.7	4	4
			42	44.0	7	7
			63	89.7	11	12
		60	21	34.3	5	4
			42	75.7	9	8
			63	99.0	11	12
	51 – 60	0	21	30.0	4	4
			42	68.3	8	7
			63	85.0	9	9
		30	21	38.7	4	4
			42	69.0	8	7
			63	88.0	10	9
		60	21	45.3	5	5
			42	85.3	10	9
			63	89.3	11	10
LSD (0.05)						
Variety				NS	0.4	NS
Moisture				3.7	0.4	NS
Phosphorus				3.7	0.4	0.4
Variety ×Moisture				3.7	NS	NS
Variety × Phosphorus				3.7	4.4	4.4
Moisture × Phosphorus				NS	NS	NS
Variety×Moisture×Phosphorus				NS	NS	NS

(Table 6). With 30 kgP/ha SUA 90 had the tallest plants (35 cm) compared with Kablanketi (24.3 cm) and Canadian wonder (25.7 cm), while at 60 kgP/ha

Kablanketi had the tallest plants (44.7 cm) of SUA 90 (35.7 cm) and Canadian wonder (34.3 cm).

When the Moisture tension was between 51 cb and 60 cb, during early growth i.e. 21 DAP, plant height significantly varied in the treatment with 0 kgP/ha among varieties. Canadian wonder had the tallest plants (30 cm) compared with Kablanketi (29 cm) and SUA 90 (26.7 cm) (Table 6). Under 30 kgP/ha, Canadian wonder had the tallest plants (38.7 cm) compared with SUA 90 (24 cm) and Kablanketi (36.3 cm) (Table 6). At 60 kgP/ha, Canadian wonder had the tallest plants (45.3 cm) compared with SUA 90 (33.7 cm) and Kablanketi (26.7 cm).

The effects of P applications among varieties at 21 DAP under moisture tension of between 21 cb and 50 cb, were significant only in Canadian wonder. The tallest Canadian wonder plants were among those that received 60 kgP/ha (45.3 cm), followed by those with 30 kgP/ha (38.7 cm) and 0 kgP/ha (30 cm) (Table 6). SUA 90 had tallest plants in treatments with 60 kgP/ha (33.7 cm) followed by those that received 0 kgP/ha (26.7 cm) or 30 kgP/ha (24 cm). In Kablanketi, plants that received 30 kgP/ha had the tallest plants (36.3 cm) followed by those that received 0 kgP/ha (29 cm) and 60 kgP/ha (26.7 cm).

At 42 DAP, treatments with less than 21 cb of moisture tension and 0 kgP/ha showed significant variations in plant heights across the bean varieties. Canadian wonder had the tallest plants (58.3 cm) followed by SUA 90 (56.3 cm) and Kablanketi (47 cm). In treatments with 30 kgP/ha, SUA 90 had the tallest plants (75 cm) followed by Canadian wonder (68.3 cm) and Kablanketi (36.3 cm) (Table 6). At 60 kgP/ha, Canadian wonder had the tallest plants (74 cm) followed by SUA 90 (71.7 cm) and Kablanketi (59.7 cm) (Table 6). These variations in plant were not statistically significant later in growth.

Varietal responces to P application at 42 DAP in treatments with less than 21 cb of moisture tension were statistically significant but only in Canadian wonder. The tallest plants in this variety were observed from treatments that received 60 kgP/ha (74 cm) followed by those with 30 kgP/ha (68.3 cm) and 0 kgP/ha (Table 6). In SUA 90, tallest plants were obtained from treatments with 30 kgP/ha (75 cm) followed by those with 60 kgP/ha (71 cm) and 0 kgP/ha (56.3 cm). In Kablanketi, however, tallest plant were recorded from treatments with 60 kgP/ha (59.7 cm) followed by those with 0 kgP/ha (47 cm) and lastly 30 kgP/ha (36.3 cm).

Under the slightly stressed treatments i.e. 21 cb and 50 cb, at 42 DAP and 0 kgP/ha there were significant differences in plant height among varieties. Canadian wonder had the tallest plants (67.3 cm) compared with SUA 90 (51 cm) and Kablanketi (66.7 cm) (Table 6). In treatments with 30 kgP/ha, SUA 90 had the tallest plants (76.7 cm) compared with Kablanketi (58.7 cm) and Canadian wonder (44 cm). In treatments with 60 kgP/ha, Kablanketi had the tallest plants (81.7 cm) followed by SUA 90 (78.7 cm) and Canadian wonder (75.7 cm).

The effects of P applications within varieties at 42 DAP under the moisture tension of between 21 and 50 cb were statistically significant but only in SUA 90. In this variety, the tallest plants were recorded from 60 kgP/ha (78.7 cm) followed by 30 kgP/ha (76.7 cm) and 0 kgP/ha (55 cm). In Kablanketi, tallest plants were those that received 60 kgP/ha (81.7 cm) followed by 0 kgP/ha (66.7 cm) and the shortest were those with 30 kgP/ha (58.7 cm) (Table 6). In Canadian wonder, the tallest plants were those that received 60 kgP/ha (75.7 cm) followed by 0 kgP/ha (67.3 cm) and the shortest were those with 30 kgP/ha (44 cm) (Table 6).

Bean grown under the moisture tension of between 51 cb and 60 cb, at 42 DAP and with 0 kgP/ha were significantly different in terms of plant height among varieties. In this response, Canadian wonder had the tallest plants (68.3 cm) compared with SUA 90 (62.7 cm) and Kablanketi (55 cm) (Table 6). With 30 kgP/ha, Canadian wonder gave the tallest plants (69 cm) compared with SUA 90 (58.7 cm) and Kablanketi (65.3 cm). With 60 kgP/ha application, Canadian wonder had the tallest plants (85.3 cm) compared with SUA 90 (78.7 cm) and Kablanketi (69 cm).

The effects of P applications within the varieties at 42 DAP under the moisture tension of between 51 cb and 60 cb were statistically significant in Kablanketi and Canadian wonder. The tallest Kablanketi plants were those that received 60 kgP/ha (69 cm) followed by 30 kgP/ha (65.3 cm) and 0 kgP/ha (55 cm) (Table 6). In Canadian wonder, the tallest plants were those that received 60 kgP/ha (85.3 cm) followed by 30 kgP/ha (69 cm) and 0 kgP/ha (68.3 cm) (Table 6). In SUA 90, the tallest plants were those with 60 kgP/ha (78.7 cm) followed by 0 kgP/ha (62.7 cm) and 30 kgP/ha (58.7 cm) (Table 6).

At 63 DAP, treatments with less than 21 cb of moisture tension and 0 kgP/ha had plant height differing significantly among varieties. Under these conditions, Canadian wonder had tallest plants (86.3 cm) followed by SUA 90 (64.7 cm) and Kablanketi (53 cm) (Table 6). Applications of 30 kgP/ha, Canadian wonder gave the tallest plants (90 cm) compared with SUA 90 (88.3 cm) and Kablanketi (48.3 cm). At 63 DAP, 60 kgP/ha on Canadian wonder had tallest plants (112.7 cm) compared with SUA 90 (94.3 cm) and Kablanketi (89.3 cm) (Table 6).

The effects of P applications on plant height within the varieties at 63 DAP in treaments with less than 21 cb of moisture tension were statistically significant in SUA 90 and Canadian wonder. The tallest in SUA 90 plants were those that received 60 kgP/ha (94.3 cm) followed by those with 30 kgP/ha (88.3 cm) and 0 kgP/ha (64.7 cm) (Table 6). Tallest plants in Canadian wonder were those that received 60 kgP/ha (112.7 cm) followed by those with 30 kgP/ha (90 cm) and 0 kgP/ha (86.3 cm) (Table 6). In Kablanketi tallest plants were those that received 60 kgP/ha (89.3 cm) followed by 0 kgP/ha (53 cm) and 30 kgP/ha (48.3 cm) (Table 6).

At 63 DAP, treatments with moisture tension of between 21 cb and 50 cb, and 0 kgP/ha showed significant differences in plant height among varieties. Canadian wonder had the tallest plants (89.3 cm) compared with Kablanketi (84.7 cm) and SUA 90 (72.3 cm) (Table 6). With 30 kgP/ha, SUA 90 had the tallest plants (90.7 cm) compared with Kablanketi (86 cm) and Canadian wonder (89.7 cm) (Table 6). At 60 kgP/ha, Kablanketi had the tallest plants (111.3 cm) compared with Canadian wonder (99 cm) and SUA 90 (94 cm) (Table 6).

The effects of P applications within varieties at 63 DAP and moisture tension of between 21 cb and 50 cb, were significant in all varieties. The tallest plants in SUA 90 were those that received 60 kgP/ha (94 cm) followed by 30 kgP/ha (90.7 cm) and 0 kgP/ha (72.3 cm) (Table 6). In Kablanketi the tallest plants were those that received 60 kgP/ha (111.3 cm) followed by 30 kgP/ha (86 cm) and 0 kgP/ha (84.7 cm) (Table 6). In Canadian wonder, tallest plants were those that received 60 kgP/ha (99 cm) followed by 30 kgP/ha (89.7 cm) and 0 kgP/ha (89.3 cm) (Table 6).

Under the moisture tension of between 51 cb and 60 cb, at 63 DAP and 0 kgP/ha there were significant differences in plant height among varieties. Canadian wonder had the tallest plants (85 cm) compared with SUA 90 (74 cm) and Kablanketi (64.3 cm) (Table 6). At 30 kgP/ha, Canadian wonder had the tallest plants (88 cm) compared with SUA 90 (75 cm) and Kablanketi (70.3 cm) (Table 6). At 60 kgP/ha, Kablanketi had the tallest plants (98.3 cm) compared with SUA 90 (89.7 cm) and Canadian wonder (89.3 cm) (Table 6).

4.1.2.2 Number of leaves per plant

At 21 DAP, plants growing under less than 21 cb of moisture tension with 0 kgP/ha had no significant difference in number of leaves per plant among varieties. With 30 kgP/ha, SUA 90 and Kablanketi had higher number of leaves per plant (4) compared with Canadian wonder (3) (Table 6). With 60 kgP/ha, Kablanketi gave the highest number of leaves per plant (4) than that of Canadian wonder and SUA 90 (3) (Table 6).

The effects of P applications within the varieties at 21 DAP under less than 21 cb of moisture tension did not have a significant influence on the number of leaves per plant. In SUA 90, applications of 0 and 30 kgP/ha had the same number of leaves per plant (4) while treatments with 60 kgP/ha had fewer (3) number of leaves per plant (Table 6). In Kablanketi, all the three P applications gave similar number of leaves per plant (4) (Table 6). Application of 30 kgP/ha in Canadian wonder gave the lowest number of leaves per plant (3), while 0 and 60 kgP/ha had the largest number of leaves per plant (4) (Table 6).

Under the moisture tension of between 21 cb and 50 cb and 0 kgP/ha at 21 DAP, all the three bean varieties had the same number of leaves per plant (4). In the treatment with 30 kgP/ha, SUA 90 and Kablanketi had the same number of leaves per plant (4), while Canadian wonder had fewer number of leaves per plant (3) (Table 6). With 60 kgP/ha, all the varieties had the same number of leaves per plant (4).

Phosphorous applications did not have any influence on number of leaves per plant among varieties at 21 DAP and moisture tension of between 21 cb and 50 cb. All the three P applications gave the same number of leaves per plant (4) in all the three bean varieties.

Under the Moisture tension of between 51 cb and 60 cb, at 21 DAP and 0 kgP/ha there was no significant difference in number of leaves per plant among varieties. The treatments with 30 kgP/ha behaved the same, all the three varieties had the same number of leaves per plant (4). With application of 60 kgP/ha, SUA 90 and

Kablanketi had the same number of leaves per plant (4), while at Canadian wonder had the highest number of leaves per plant (5) (Table 6).

The effects of P applications within the varieties at 21 DAP and the moisture tension of between 51 cb and 60 cb were significant, but only in Canadian wonder. In SUA 90 all the P applications gave the same number of leaves per plant (4) (Table 6). In Kablanketi, treatments with 0 and 60 kgP/ha had 4 leaves per plant while application of 30 kgP/ha had 5 leaves per plant (Table 6). In Canadian wonder, treatments with 0 kgP/ha and 30 kgP/ha had 4 leaves per plant while treatments with 60 kgP/ha had 5 leaves per plant (Table 6).

At 42 DAP, under less than 21 cb of moisture tension and 0 kgP/ha; there was a significant difference in number of leaves per plant among varieties. SUA 90 had the highest number of leaves per plant (8) than both Kablanketi and Canadian wonder (6) (Table 6). With 30 kgP/ha, SUA 90 had the highest number of leaves per plant (9) than both Kablanketi and Canadian wonder (6) (Table 6). With 60 kgP/ha, SUA 90 had the highest number of leaves per plant (8) than both Kablanketi and Canadian wonder (7) (Table 6).

The effects of P applications within the varieties at 42 DAP under less than 21 cb of moisture tension were significant in Kablanketi and Canadian wonder. In both Kablanketi and Canadian wonder the higher number of leaves per plant (7) were observed in treatments with 60 kgP/ha, compared to 0 kgP/ha and 30 kgP/ha that had 6 leaves each (Table 6). In SUA 90, the highest number of leaves per plant (9) were observed in treatments that with 30 kgP/ha while those with 0 and 60 kgP/ha had 8 leaves per plant (Table 6).

Under the moisture tension of between 21 cb and 50 cb, at 42 DAP and 0 kgP/ha there was significant difference in number of leaves per plant among varieties. Kablanketi and Canadian wonder had the same number of leaves per plant (7) higher than SUA 90 (6) (Table 6). With 30 kgP/ha, SUA 90 had the highest number of leaves per plant (9) compared with Kablanketi and Canadian wonder (6) (Table 6). With 60 kgP/ha, all the three varieties had the same number of leaves per plant (8).

The effects of P applications within the varieties at 42 DAP under the moisture tension of between 21 cb and 50 cb were significant in Kablanketi and Canadian wonder. In Kablanketi, the treatments with 60 kgP/ha had the highest number of leaves per plant (8) while those with 0 and 30 kgP/ha had 6 leaves per plant (Table 6). In Canadian wonder, treatments with 0 and 30 kgP/ha had 7 leaves per plant while those with 60 kgP/ha had 8 leaves per plant (Table 6). In SUA 90, application of 30 kgP/ha had the large number of leaves per plant (9) compared to 60 kgP/ha with 8 and 0 kgP/ha with 7 leaves per plant each (Table 6).

Under the moisture tension of between 51 cb and 60 cb, at 42 DAP and 0 kgP/ha there was a significant difference in number of leaves per plant among varieties. Kablanketi and Canadian wonder had 7 leaves per plant while SUA 90 had 6 leaves per plant (Table 6). With 30 kgP/ha, SUA 90 had the highest number of leaves per plant (9) compared with Kablanketi and Canadian wonder (7) (Table 6). With 60 kgP/ha Canadian wonder gave the highest number of leaves per plant (9) compared with SUA 90 and Kablanketi (8) (Table 6).

The effects of P applications within the varieties at 42 DAP under the moisture tension of between 51 cb and 60 cb were significant in Kablanketi and Canadian wonder. Kablanketi had the highest number of leaves per plant with 60 kgP/ha (8) compared with both 0 and 30 kgP/ha (7) (Table 6). In Canadian wonder, the highest number of leaves per plant were observed in treatments with 60 kgP/ha (9) compared with both 0 kgP/ha and 30 kgP/ha had 7 leaves per plant (Table 6). In SUA 90, the highest number of leaves per plant were observed at 30 kgP/ha (9) followed by 60 kgP/ha (8) and the fewest leaves were those received 0 kgP/ha (6) (Table 6).

At 63 DAP, under less than 21 cb of moisture tension and 0 kgP/ha; there was a significant difference in number of leaves per plant among the bean varieties. SUA 90 had the highest number of leaves per plant (11) followed by Kablanketi (10) while Canadian wonder had few leaves (9) (Table 6). At 30 kgP/ha, SUA 90 had the highest number of leaves per plant (14) followed by Canadian wonder (12) and lastly Kablanketi (9) (Table 6). With 60 kgP/ha all the bean varieties had the same number of leaves per plant (12).

The effects of P applications within the varieties at 63 DAP under less than 21 cb of moisture tension were significant in Canadian wonder. In this variety, 30 kgP/ha and 60 kgP/ha had the highest number of leaves per plant (12) than 0 kgP/ha (9) (Table 6). In Kablanketi, 60 kgP/ha had the highest number of leaves per plant (12) followed by 0 kgP/ha (1) and 30 kgP/ha (Table 6). In SUA 90, the highest number of leaves per plant were those received 30 kgP/ha (14) followed by 60 kgP/ha (12) and 0 kgP/ha (11) (Table 6).

Under the moisture tension of between 21 cb and 50 cb, at 63 DAP, treatments with 0 kgP/ha had significant difference in number of leaves per plant among the bean varieties. Kablanketi had the highest number of leaves per plant (10) compared with Canadian wonder and SUA 90 (9) (Table 6). With 30 kgP/ha, SUA 90 had the highest number of leaves per plant (15) compared with both Canadian wonder and Kablanketi (12) (Table 6). With 60 kgP/ha, Kablanketi had the highest number of leaves per plant (13) compared with both Canadian wonder and SUA 90 (12) (Table 6).

The effects of P applications within the varieties at 63 DAP under the moisture tension of between 21 cb and 50 cb were significant in Kablanketi and Canadian wonder (Table 6). Kablanketi had the highest number of leaves per plant (13) at 60 kgP/ha followed by 30 kgP/ha (12) and 0 kgP/ha (10) (Table 6). Plate 1 show the effect of low P in Kablanketi at the moisture tension of between 21 cb and 50 cb. The plant appeared to have a stunted growth, short internodes and shading leaves. On the other hand plate 2 show the same plant supplied with adequate amount of P at the same supply. In Canadian wonder the highest number of leaves per plant were observed in treatments with 30 kgP/ha and 60 kgP/ha (12) while the fewest were obtained from treatments with 0 kgP/ha (10) (Table 6). In SUA 90 the highest number of leaves per plant were obtained from treatments with 30 kgP/ha (15) followed by 60 kgP/ha (12) and 0 kgP/ha (8) (Table 6).

Plate 1: Kablanketi bean plant under P stress (0 kg P/ha) and adequate moisture supply (21 to 50 cb).

Plate 2: Kablanketi bean plant supplied with adequate P (60 kg P/ha) and moisture supply (21 to 50 cb).

Under the moisture tension of between 51 cb and 60 cb, at 63 DAP and 0 kgP/ha there was significant difference in number of leaves per plant among the bean varieties. Kablanketi had highest number of leaves per plant (11) compared with SUA 90 and Canadian wonder (9) (Table 6). At 30 kgP/ha, SUA 90 had the highest number of leaves per plant (12) compared with Canadian wonder (10) and Kablanketi (9) (Table 6). With 60 kgP/ha, Canadian wonder had the highest number of leaves per plant (11) compared with Kablanketi (10) and SUA 90 (9) (Table 6).

The effects of P applications within the varieties at 63 DAP under the moisture tension of between 51 cb and 60 cb were significant in all the three bean varieties. SUA 90 had the highest number of leaves per plant (12) at 30 kgP/ha and 60 kgP/ha while 0 kgP/ha had few leaves per plant (9) (Table 6). In Kablanketi, the highest number of leaves per plant were observed in treatments with 30 kgP/ha and 60 kgP/ha (12) while 0 kgP/ha had fewest leaves per plant (11) (Table 6). In Canadian wonder, highest number of leaves per plant were obtained in treatments 60 kgP/ha (10) while 0 kgP/ha and 30 kgP/ha had the fewest number of leaves per plant (9) (Table 6).

4.1.2.3 Number of nodes per plant

The number of nodes per plant is an important yield component in common bean. At 21 DAP, treatments with less than 21 cb of moisture tension and 0 kgP/ha showed significant differences in the number of nodes per plant among varieties. While Canadian wonder had 5 nodes, SUA 90 and Kablanketi had 4 nodes each (Table 6). At 30 kgP/ha, however, number of nodes per plant was higher in SUA 90 (6) followed by Kablanketi (4) and Canadian wonder (3) (Table 6). At 60 kgP/ha, Canadian wonder gave the largest number of nodes per plant (5) compared with Kablanketi (4) and SUA 90 (3) (Table 6).

The effects of P applications within the varieties at 21 DAP under less than 21 cb of moisture tension did not have significant influence on the number of nodes per plant. In SUA 90, both 0 kgP/ha and 30 kgP/ha treatments had the same number of nodes per plant (4) while 60 kgP/ha had fewer (3) number of nodes per plant (Table 6). In Kablanketi, all the three P treatments gave similar number of nodes per plant (4) (Table 6). In Canadian wonder, 30 kgP/ha had the lowest number of nodes per plant (3), while 0 kgP/ha and 60 kgP/ha had the largest number of nodes per plant (5) (Table 6).

Under the moisture tension of between 21 cb and 50 cb and 0 kgP/ha at 21 DAP, Canadian wonder had more number of nodes per plant (5) than both SUA 90 and Kablanketi (4) (Table 6). The treatment with 30 kgP/ha did not have any significant influence on the number of nodes per plant across varieties (4), but at 60 kgP/ha, Canadian wonder had the largest number of nodes per plant (5) followed by SUA 90 and Kablanketi (4) (Table 6).

The effects of P applications within the varieties at 21 DAP under moisture tension of between 21 cb and 50 cb were not significant in all the varieties. In SUA 90 and Kablanketi, all the three P treatments had the same number of nodes per plant (4). In

Canadian wonder, 0 kgP/ha and 60 kgP/ha had 5 nodes per plant, while with 30 kgP/ha it had 4 nodes per plant (Table 6).

Under the Moisture tension of between 51 cb and 60 cb, and 0 kgP/ha at 21 DAP there was no significant difference in the number of nodes per plant among varieties. However, the treatment with 30 kgP/ha Kablanketi had significantly higher number of nodes per plant (5) than SUA 90 and Canadian wonder (4) (Table 6). At 60 kgP/ha, all the three varieties had the same number of nodes per plant (4).

The effects of P applications within the varieties at 21 DAP under moisture tension of between 51 cb and 60 cb were significant only in Canadian wonder. In SUA 90 all plants in the three P treatments had same number of nodes (4) (Table 6). In Kablanketi, 0 and 60 kgP/ha gave 4 nodes per plant while application of 30 kgP/ha gave 5 nodes per plant (Table 6). In Canadian wonder, 0 and 30 kgP/ha plants gave 4 nodes while treatments with 60 kgP/ha had 5 nodes per plant (Table 6).

At 42 DAP, plants growing under less than 21 cb of moisture tension with 0 kgP/ha had significant differences in the number of nodes per plant among varieties. Overall, Canadian wonder had the largest number of nodes per plant (8) followed closely by SUA 90 (7) and Kablanketi (6) (Table 6). However at 30 kgP/ha, SUA 90 had the largest number of nodes per plant (10) compared with Canadian wonder and Kablanketi (7) (Table 6). At higher levels of P, i.e. 60 kgP/ha, Canadian wonder gave the highest number of nodes per plant (8) compared with SUA 90 and Kablanketi (7) (Table 6).

The effects of P applications on number of nodes per plant within the varieties at 42 DAP under less than 21 cb of moisture tension were significant in Kablanketi alone. This indeterminate variety had the largest number of nodes per plant at 30 kgP/ha and 60 kgP/ha compared to the aspplication of 0 kgP/ha (Table 6). In SUA 90, the largest number of nodes per plant were observed in those plants that received 30 kgP/ha while those that received 0 or 60 kgP/ha had fewer nodes per plant (Table 6). In Canadian wonder, the largest number of nodes per plant (8) were observed from plants that received 0 kgP/ha or 60 kgP/ha, while those that received 30 kgP/ha had 7 nodes per plant (Table 6).

Under the moisture tension between 21 cb and 50 cb at 42 DAP, 0 kgP/ha had a significant infuence in the number of nodes per plant among the bean varieties. The largest number of nodes per plant were observed in Canadian wonder compared with SUA 90 and Kablanketi (Table 6). Application of 30 kgP/ha resulted into largest number of nodes per plant in SUA 90 compared with Kablanketi and Canadian wonder (Table 6), whrere as 60 kgP/ha gave the largest number of nodes per plant in SUA 90 and Canadian wonder (Table 6).

P applications within the varieties at 42 DAP under the moisture tension between 21 cb and 50 cb were significant, but only in Kablanketi. The plants that received 60 kgP/ha had the largest number of nodes, while those that received 30 kgP/ha and 0 kgP/ha had fewer nodes per plant (Table 6). In SUA 90, 30 kgP/ha had the largest number of nodes per plant (10) followed by those received 60 kgP/ha (9) and 0 kgP/ha (7) (Table 6). In Canadian wonder, treatments with 60 kgP/ha had the highest number of nodes per plant (9) followed those that received 0 kgP/ha (8) or 30 kgP/ha (7) (Table 6).

The moisture tension between 51 cb and 60 cb, at 42 DAP and 0 kgP/ha had a significant influence in the number of nodes per plant among varieties. Canadian wonder and Kablanketi had 8 nodes per plant compared with SUA 90 (7) (Table 6). At 30 kgP/ha, SUA 90 had the largest number of nodes per plant compared with Kablanketi and Canadian wonder (Table 6). At 60 kgP/ha Canadian wonder had the highest number of nodes per plant compared with SUA 90 and Kablanketi (Table 6).

The effects of P applications within the varieties at 42 DAP under the moisture tension of between 51 cb and 60 cb were significant in Kablanketi and Canadian wonder. The two had the largest number of nodes per plant with 60 kgP/ha followed by 0 kgP/ha and 30 kgP/ha (Table 6). In SUA 90, although not statisticaly significant, the largest number of nodes per plant were observed in treatments with 30 kgP/ha (11) followed by those with 60 or 0 kgP/ha (7) (Table 6).

At 63 DAP under less than 21 cb of moisture tension; there was a significant difference in number of nodes per plant among varieties. SUA 90 and Canadian wonder had the largest number of nodes per plant while Kablanketi had fewer nodes per plant when subjected to no P application (0 kgP/ha) at all (Table 6). With 30 kgP/ha, SUA 90 had the highest number of nodes per plant compared with Kablanketi and Canadian wonder (Table 6). At 60 kgP/ha Canadian wonder had the largest number of nodes per plant than SUA 90 and Kablanketi (Table 6).

The effects of P applications within the varieties at 63 DAP under less than 21 cb of moisture tension were statistically significant in all the three bean varieties. SUA 90 plants had the highest number of nodes per plant at 60 kgP/ha followed by those with 30 kgP/ha or 0 kgP/ha (Table 6). Kablanketi plants had the highest number of nodes per plant with 60 kgP/ha compared with 0 kgP/ha or 30 kgP/ha (Table 6). In Canadian wonder the highest number of nodes per plant were those that received 60 kgP/ha followed by those with 30 kgP/ha and 0 kgP/ha (Table 6).

Likewise, under the moisture tension of between 21 cb and 50 cb, at 63 DAP there was a significant difference in the number of nodes per plant among the bean varieties. With the application of 0 kgP/ha, Canadian wonder had the highest number of nodes per plant compared with Kablanketi and SUA 90 (Table 6). SUA 90 plants subjected to 30 kgP/ha had the highest number of nodes per plant compared with both Canadian wonder and Kablanketi (Table 6). With 60 kgP/ha, Kablanketi had the highest number of nodes per plant compared with Canadian wonder and SUA 90 (Table 6).

The effects of P applications within the varieties at 63 DAP under the moisture tension of between 21 cb and 50 cb were statistically significant in Kablanketi and Canadian wonder. Kablanketi had the highest number of nodes per plant with 60 kgP/ha followed by those that received 30 kgP/ha and 0 kgP/ha (Table 6). In Canadian wonder, the highest number of nodes per plant were observed in treatments with 30 kgP/ha and 60 kgP/ha (Table 6). In SUA 90, although it was not statisti8cally significant, the highest number of nodes per plant were observed in treatments with 30 kgP/ha followed by 60 kgP/ha and 0 kgP/ha (Table 6).

Under the moisture tension of between 51 cb and 60 cb, at 63 DAP and 0 kgP/ha there was no significant difference in number of nodes per plant among varieties although there were several observations. With 30 kgP/ha, SUA 90 appeared to have the largest number of nodes per plant compared with Canadian wonder and Kablanketi (Table 6). With 60 kgP/ha, Canadian wonder had the highest number of nodes per plant compared with Kablanketi and SUA 90 (Table 6).

Applications of P within the varieties at 63 DAP under the moisture tension of between 51 cb and 60 cb were significant in Kablanketi and Canadian wonder. Kablanketi had the highest number of nodes per plant with 60 kgP/ha than treatments with 0 and 30 kgP/ha (Table 6). In Canadian wonder the highest number of nodes per plant were observed in treatments with 60 kgP/ha followed by those with 30 kgP/ha and ending with 0 kgP/ha (Table 6). In SUA 90 the highest number of nodes per plant were observed in treatments with 30 kgP/ha where as treatments with 0 and 60 kgP/ha had the same number of nodes per plant (Table 6).

4.1.2.4 Yield and yield components

The yield characteristics studied were pods per plant, seeds per pod and seed yield per plant. All the yield parameters analysed were not significantly influenced by the varietal differences (Table 7). However, the plants that were subjected to less than 21centibars (cb) of available soil moisture had the largest number of seeds per pod followed by those subjected to between 21 and 50 centibars (cb) of available soil moisture while those subjected to between 51 and 60 centibars (cb) of available soil moisture had the lowest number of seeds per pod (Table 7). Pods per plant and Seed yield per plant were not influenced by the varietal differences (Table 7).

Phosphorus rates had a non significant influence on increased number of pods per plant, although plants with 60 kg P/ha had the largest number of pods per plant compared with those with 30 kg P/ha and 0 kg P/ha (Table 7). Phosphorus rates also had a non significant influence on the increased in the number of seeds per pod, although those plants that received 60 kg P/ha had the largest number of seeds per pod compared with those received 30 kg P/ha and 0 kg P/ha (Table 7). Phosphorus rates did not have any significant influence on seed yield and neither the yield components. The interaction effects among variety and moisture did not have any significant influence on all the yield parameters analysed.

The interaction effects among variety and phosphorus had apparently greater influence on the number of seeds per pod in Canadian wonder followed by SUA 90 and Kablanketi. All the parameters analysed were not affected by varieties and phosphorus interaction effects (Table 7).

Table 7: Effect of Moisture and Phosphorus on Yield of Common Bean Varieties

Bean Variety	Moisture Levels (cb)	Phosphorus rate (kgP/ha)	Yield Characteristics		
			Pods/Plant	Seeds/Pod	Yield (g/plant)
SUA 90	<21	0	3	2	1.8
		30	6	2	5.3
		60	6	2	5.4
	21 -50	0	6	2	16.6
		30	4	3	5.2
		60	6	3	5.6
	51 – 60	0	4	2	2.7
		30	5	2	5.1
		60	8	4	11.0
Kablanketi	<21	0	2	1	1.7
		30	3	2	3.9
		60	5	2	5.5
	21 -50	0	3	2	2.9
		30	3	2	3.2
		60	7	2	7.7
	51 – 60	0	3	1	2.3
		30	5	2	5.1
		60	9	3	11.7
Canadian Wonder	<21	0	4	3	3.8
		30	3	2	3.2
		60	5	3	8.8
	21 -50	0	5	3	7.9
		30	5	2	5.3
		60	5	2	6.6
	51 – 60	0	4	3	4.2
		30	4	3	7.5
		60	6	2	9.2
LSD (0.05)					
Variety			NS	NS	NS
Moisture			NS	NS	NS
Phosphorus			NS	NS	NS
Variety ×Moisture			NS	NS	NS
Variety × Phosphorus			NS	NS	NS
Moisture × Phosphorus			NS	NS	NS
Variety×Moisture× Phosphorus			NS	NS	NS

Similarly all the yield parameters analysed were neither affected by moisture by phosphorus interaction effects nor varieties by moisture by phosphorus interaction.

4.2 Discussion

This study was conducted to asses responses related to moisture stress and low P tolerance in three common bean varieties. These responces were based on differences in morphological growh characteristics i.e. whether determinate, semi determinate or indeterminate.

In Canadian wonder total plant biomass significantly increased with increasing P levels in the field at 21 DAP. SUA 90 had the largest total plant biomass at 42 DAP and at 63 DAP. This was contributed by shoot biomass at 42 DAP and root biomass at 63 DAP. At 63 DAP LAI of SUA 90 incresed and reached 2. SUA 90 is the determinate common bean variety. The result suggests that the determinate growth types respond better to P application rates. Further more, with regard to phosphorus, plants under 60 kgP/ha produced greater number of seeds per pod than either 30 or 0 kg P/ha. Similar observations were reported by Mourice (2006). This suggests that P application had a positive influence on crop yield as reported earlier by Herna´ndez (2007).

Shoot biomass accumulation is considered an important trait to attain high seed yield in grain legumes. Significant differences have been observed for shoot biomass accumulation among dry bean cultivars grown under severe water stress (Rosales-Serna *et al.*, 2004). Differences in biomass accumulation and allocation have been detected among bean cultivars with different growth habits (Rosales-Serna *et al.*, 2004). The shoot biomass, however was not influenced by varietal differences, phosphorus levels or variety by phosphorus interaction effects in the field experiment, this being contrary to the findings of Nwoke *et al.*, (2007) in which shoot biomass of soybean was significantly higher with P addition than without. This suggests that the crops were not responding to the added P in the field because the amount P in the soil in the field was not deficient (Table 2). The root growth response of the three common beans varieties in the field experiments had significant differences at 42 DAP and at 63 DAP. Root biomass increased with increasing P application in SUA 90. This response suggests that SUA 90 responded to P application through increased root biomass compared to Canadian wonder or Kablanketi. Similar results were reported by Santos (2006). Canadian wonder had the largest root dry mass, followed by Kablanketi and SUA 90 at 21 DAP. These differences suggest the varieties differed genetically (Singh, 2003). SUA 90 was the shortest of the three varieties. This variety is determinate in growth habit while Kablanketi is semi determinate (semi climbing) and Canadian wonder is indeterminate climbing type (Mhile, 2002).

The growth response of the common beans at 21 DAP were not influenced by varietal differences, phosphorus levels or variety and phosphorus interaction effects, compared with later growth stages 42 and 63 DAP, although some linear root biomass increment was observed in Canadian wonder. This suggests that the crop responded to treatment during later stages in physiological development (Bates, 2000).

Those plants that were subjected to less than 21 centibars of moisture tensions had the largest number of nodes and leaves per plant compared with those growing under moisture tensions of between 21 and 50 cb and between 51 and 60 cb. This shows that those plants that received enough moisture grew efficiently than those that were subjected to moisture stress conditions in this experiment. Moisture stress retards growth and reduces both biological and economical yield (Nielsen, 1998).

Moisture availability also affected number of seeds per pod in bean varieties. The plants differed in number of seeds per pod whereby those plants that grew under 21 cb of moisture availability had the highest number of seeds per pod followed by 21 – 50 cb and the least under 51 – 60 cb. Seed yield did not differ among the moisture regimes, similar findings were reported by Nillsen (1998).

Althoug there was no significant response among common bean varieties to P, there were slight differences in yield under field conditions. SUA 90 had the largest number of seeds per pod than Kablanketi and Canadian wonder under higher P levels. The varieties did not differ significantly in number of pods per plant, seeds per pod or seed yield in the pot experiment. Also the varieties did not differ significantly in number of pods per plant. The plants, however, differed in number of seeds per pod in which those plants growing under 21 cb of moisture tension had the largest number of seeds per pods followed by those under 21 – 50 cb and 51 – 60 cb. These seed yield responses were similar to those reported by Nillsen (1998).

Phosphorus levels influenced productivity of the common bean varieties. Plants that received 60 kgP/ha. These had the highest number of seeds per pod and pods per plant compared with those receiving 30 kgP/ha as earlier reported by Mourice (2006). This suggests that phosphorus application increases crop yield in common beans (Herna'ndez, 2007).

Number of nodes per plant was not significantly influenced by P application under field conditions at all the three growth stages although, there were some slight differences in responces in Canadian Wonder. This variety had the highest number of nodes per plant in the field experiment. Under the pot experiment in the screen house, the number of nodes per plant were significantly different at all growth stages except at 21 DAP. Kablanketi and Canadian wonder showed a positive linear response to P applications with regard to number of nodes per plant. The number of nodes per plant varied with the growth habit of the variety. Large plants with many nodes on both the main-stem and branches have greater potential sites available for pod formation. Floral nodes are potential sites for pod production in common bean varieties (Bildirici, 2005, Kisman 2003). This suggests that it might be possible that Canadian wonder and Kablanketi responded well to P applications by producing more potential sites for pod formation.

The number of branches per plant was not influenced by P apllication although this morphological characteristic has been reported to determine seed yield in common beans. Leaf area index increased with P application in all the three varieties, especially at 63 DAP. Increase in LAI indicates increase in above ground biomass, which is the biological yield. This observation suggests that P application significantly increased vegetative growth in the three varieties. This observation must have influenced shoot biomass response to P as well as subsequent potential yield of the varieties.

Plant height was significantly increased by P application such that treatments with 60 kgP/ha had the tallest plants, followed by 30 and 0 kgP/ha. Among varieties, Canadian wonder had the tallest plants of all the three moisture regimes and P levels. This suggests that Canadian wonder responded linearly to phosphorus application as earlier reported by Bates (2000). Plant heights have been observed to differ among bean cultivars of different growth habits (morphological characteristics) (Mhile, 2002).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main objective of this study was to assess responses of three common bean varieties, SUA 90, Kablanketi and Canadian wonder to moisture stress and different levels of phosphorus fertilizer. From the results, it is concluded that varietal differences exist with regard to morphological characteristics and tolerance of low P and moisture stress. Morphological characteristics relevant to tolerance to low P and moisture stress were manifested in plant height, (LAI), (N_L), (N_d), (WShoot) and (WRoot), and (TDM). Canadian wonder had the tallest plants, (LAI), (N_L), (N_d), (WShoot) and (WRoot), and (TDM), followed by Kablanketi and SUA 90. Therefore Canadian wonder is the most vigorous and tolerant variety among the three.

Common beans varietal response to moisture stress showed Canadian wonder was the most tolerant due to relatively more vigorous growth under moisture stress. It had tallest plants and largest number of leaves and nodes per plant compared with Kablanketi and SUA 90 under moisture stress conditions.

Common beans varietal response to different phosphorus fertilizer levels showed that Canadian wonder was more tolerant to low P applications due to its stable growth in treatments with low P compared with Kablanketi and SUA 90. Canadian wonder is an indeterminate variety, it has a vigorous growth which enabled it to tolerate low P and moisture stress. Kablanketi is semi indeterminate variety and SUA 90 is determinate.

Regarding the relationship between moisture availability and phosphorus use efficiency in common bean production, it was concluded that moisture availability is important for phosphorus acquisition in the common bean crop. When Canadian wonder plants were subjected to moisture stress with adequate P did not show any significant superriority over those subjected to moisture stress under low P. Those subjected to adequate moisture and P perfomed well.

Overall grain yield and yield components were not significantly influenced by moisture stress and phosphorus fertilizer application in the bean crop.

5.2 Recommendations

From the results of this study, although interesting information has been found regarding response of the three common bean varieties SUA 90, Kablanketi and Canadian wonder to the interaction of moisture stress and phosphorus applications, it is recommended that this study to be conducted under field condition with facilities like rain outshelters or tunnels in order to confirm the current findings.

Canadian wonder has been observed in this study to be superior in perfomance, under moisture stress and P deficiency. Hence this variety has the morphological characteristics that could be useful to bean breeders breeding for tolerance to moisture stress under low P soils.

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