COMPARISON OF SELECTION INDICES FOR TOLERANCE TO WATER STRESS IN COMMON BEANS (*Phaseolus vulgaris L*) FOR THE DRY ENVIRONMENTS OF TANZANIA.

BY

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A THESIS

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DECLARATION

I, **Newton Lwiyiso Kilasi**; do hereby declare to the Senate of University of Zambia that this dissertation is my own original work, and has not been submitted for a degree award in any University.

27/07/2010

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APPROVAL

The University of Zambia approves this dissertation of **Newton Lwiyiso Kilasi** as fulfilling the requirements for the award of the degree of Masters of Science in Plant Breeding and Seed Systems.

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ABSTRACT

Beans are an important crop in Tanzania grown by a wide range of farming communities. Its production, however, is very low due to various factors of which drought is becoming very important due to its frequency in the recent past. Provision of bean varieties that would withstand drought is important to contribute to food security in the farming communities. This study was conducted with the overall aim of selecting a simple selection index for drought tolerance. Performance of the bean genotypes under water stress conditions was assessed and drought tolerant varieties were identified. Fourteen genotypes, MN 14059-4-4P, RWR 109, MR 14000-2-1P, MR 14144, MMS 243, MN 14059-4-4P, MR14000-2-10P, MR 14140-45-4P, MR 14215-9-8P, MR13944-14-9P, MR 14153-3-2P, MR 14198-13-1P, CNF5547 (Control), MR 13095-6-1P and DOR 390 were planted in a Split-Plot design with water stress period as main plot and bean genotypes as subplots at Sokoine University of Agriculture horticulture unit in Tanzania. Grain yield, seeds/pod; pods/plant, 100-seed weight, root length, root weight, days to physiological maturity, days to 50% flowering and dry matter content were determined. Drought Susceptibility Index (DSI), Sensitivity Index (SI) and Drought Intensity Index (DII) were derived from the grain yield data under the three water stress treatments. The water stress imposed at different periods of plant growth and development significantly influenced the phenotypic expression of the bean line in morphological traits and grain yield and its components. Days to 50% flowering dropped from 43 in the no water stress treatment to 41 days when water stress was imposed from flowering to mid-pod filling. The early maturing lines however showed less sensitivity to water stress with regards to days to 50% flowering. Root weight and dry matter weight were reduced under water stress while root elongation was enhanced from 27 cm to 29 cm when stress was early. Water stress imposed during any period of growth and development negatively affected grain yield. In this study yields dropped from 1188 kg/ha (stress O) to 720 kg/ha (stress I) and 432 kg/ha (stress II). Yields of early maturing genotypes were relatively less affected by water stress at any of the periods due to the earlier flowering, thereby escaped the full effects of the stress. Medium maturing lines, gave the lowest yield reduction from stress 0 to stress I and this was associated with relatively high retention of root weight, dry matter accumulation and enhanced root elongation under water stress. DSI was found to be the most reliable index to identify the drought tolerant genotypes because it identified specific drought tolerant genotypes while DII and SI related intensity of drought at a location and grouping of drought tolerant genotypes, respectively. In this regards the current study recommends DSI to be used further in breeding programme. Based on DSI MR 14154-4-6P, MR 14153-4-2P, MR 14000-2-10P and MR 14144-11-5 were the most tolerant genotype.

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DEDICATION

I would like to dedicate this piece of work to my lovely Mum Anzanukie Mnegelwa and to my caring sisters Lida Kilasi, Ashira Kilasi, Helena Kilasi, and Lanesi Kilasi as well as to my brothers Amasha Kilasi, Piusi Kilasi and Chedy Kilasi for their support and encouragement throughout my study. God bless you all.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

%	percent
&	and
/	per
±	plus or minus
≤	less or equal to
a.s.l	above sea level
ANOVA	Analysis of Variance
C.V	Coefficient of Variation
cm	centimetre
cm^2	centimetre squares
Ds	Drought Stress
g	gram
GM	Geometric mean
i.e.	That is
m	meter
Ns	No significant difference
P	Probability
DSI	Drought susceptibility index
SI	Sensitivity index
DII	Drought intensity index
Kg	Kilogram
Ha	Hectare
KJ	Kilo Jules
Mg	Milligrams
USD	United State Dollar

LSD	Least significance difference
SP	Stress Periods
DAP	Days after Planting
SUA	Sokoine University of Agriculture
Fc	Field Capacity
Yd	Yield.

CHAPTER 1

1.0 INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is the world's most important food legume for direct human consumption, especially in Latin America and in East and southern Africa. Some 12 million metric tons are produced annually worldwide, of which about 8 million tons are from Latin America and Africa (FAO, 2005). In the developing world bean is a small farmer's crop, and in Africa it is cultivated largely by women. Beans are important source of dietary protein and starch in Africa and a primary staple in parts of the Great Lakes Region (Hillocks et al., 2006). Tanzania remains one of the world's major bean producing countries although according to official statistics, production per capita has almost halved in the last 20 years (Hillocks et al., 2006).

In Tanzania common bean is an important source of protein in the diet of rural and urban populations and serves as an alternative to animal protein in these communities where it is estimated that over 75% of rural households in Tanzania depend on beans for daily subsistence. Beans are also good source of Vitamin A and C (Hillocks et al., 2006).

Besides supplementation of protein and vitamins beans are also rich in essential micronutrients that are found only in low amounts in cereals or root crops (Wang et al., 2003). The average composition of micronutrients in common bean per 100 g edible portion is as presented in Table1 below.

Table 1: The average composition of micronutrients in common bean per 100 g edible portion

Micro nutrient	Composition
Fe	6.7 mg
Zn	2.8 mg
Carotene	trace
Thiamine	0.45 mg
Water	11.3 g
Energy	1218 kJ
Protein	21.4 g
Fat	1.6 g,
Carbohydrates	49.7 g
Dietary fibre	22.9 g
P	310 mg
Ca	180 mg
Mg	180 mg
Riboflavin	0.13 mg
Niacin	2.5 mg
Vitamin	B6 0.56 mg

Source: Holland, Unwin and Buss, 1991

On the other hand the essential amino acid composition per 100 g edible portion being lysine 1540 mg, methionine 240 mg, phynylanine 1130 mg, threonine 860 mg tryptophan 210 mg, valine 990 mg, leucine 1640 mg and isolucine 890 mg (Paul, Southgate and Russell, 1990).

Beans are mainly utilized as side dish, eaten along with rice or thick porridge (ugali) 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 also a principle cash crop in the tropics. About 40% of the total production from Africa is marketed, at an average annual value of USD 452 million (Wortmann et al., 1998).

A symbiotic relationship between a bacterium called Rhizobium and common beans provide small amounts of nitrogen to the soils where they are grown. The fixed nitrogen is an important source of nitrogen nutrient for plant growth and development. Despite the importance of beans as a leader of all grain legumes in supplying dietary protein to human beings in Tanzania and as a source of soil nitrogen, the yields are still very low due to several factors such as poor seed quality, use of unimproved varieties that are susceptible to pests and diseases, low soil fertility, poor crop management and recurrent droughts.

In Tanzania continuous drought years have been occurring in some areas mainly the Central, Estern and Northen zones, leading to total crops failure or reduced yields. In additional to reduced yield, quality of the grains produced under drought conditions has always been poor and in the recent year's drought has become a great problem in common bean production. The average bean yields in Tanzania are around 500 kg/ha while the potential yield under rain fed condition is 1500-3000 kg/ha (Hillocks et al., 2006).

To mitigate the effects of drought several strategies can be employed including irrigation and use of drought tolerant varieties. Irrigation is not a viable option for most small scale farmers due to the cost factor; while the use of drought tolerant varieties is a preferred option.

However, drought tolerance is a complex trait that cannot be selected directly as it is influenced by many traits. Because of this the current study was aimed at developing a simple selection strategy for drought tolerance that will be used to identify the drought tolerant bean lines.

Current bean varieties in Tanzania are not adapted to the emerging environmental challenges of droughts. The continued use of such varieties when droughts are becoming frequent has led to reduced bean productivity and production among smallholder farmers. Hence there is need for introduction of drought tolerant bean varieties. However development of drought tolerant bean varieties has not yet yielded appropriate varieties.

To enhance development of drought tolerant varieties it is important that simple selection method(s) are employed, given the complexity of drought tolerance. Several selection criteria including morphological, phenological, yield and yield related traits have been used with varying success.

The overall objective of this study was to compare the simple selection indices for drought tolerance as a tool in identifying drought tolerant bean lines. The specific objectives were to assess bean lines performance under water stress applied at different periods of plant growth and development and to identify the bean lines tolerant to water stress based on selection indices. The main hypotheses were that bean lines tested under water stress at different periods of growth and development exhibited the same performance and that the bean lines tested were not drought tolerant.

CHAPTER 2

2. 0 LITERATURE REVIEW.

2.1 Botanical description and origin

Common bean (*Phaseolus vulgaris* L.) refers to the food legumes of genus *Phaseolus*, family Fabaceae, subfamily Papilionoideae, tribe phaseoleae and the subtribe phaseolinae and is a major legume crop, third in importance after soybean and peanut, but first in direct human consumption (Broughton et al,. 2003).

It originated in Latin America and has two primary centres of origin in the Mesoamerican and Andean regions that are easily distinguished by molecular means (Blair, 2006). All species of the genus are diploid and most have 22 chromosomes (2n = 22, x=11). The genome of common bean is one of the smallest in the legume family at 625 Mbp per haploid genome.

2.2 World Production of Beans

The major producing countries for national consumption are Brazil and Mexico; while the United States, Canada, Argentina and China are all exporting countries. The crop is also important in a number of developing countries of Central America, of the Andean region of South America and of Eastern and Southern Africa (Singh, 1999). In these regions beans are grown for both subsistence agriculture and for regional markets where they play an important role in food security and income generations.

2.3 Production Requirements.

In Tanzania beans are grown in well-drained soils with high organic matter content, having rainfall ranging from 500-2000 mm, and at temperature ranging from 21-30°C with 50% relative humidity and the PH ranging from 6-7. Temperatures below 10 °C will kill the plant by freezing and above 30 °C will cause flower abortion. Moreover for good performance of beans, Nitrogenious fertilizer of about 40 kg/ha should be added which goes together with weeding and pests and diseases control. Beans do poorly in very wet or humid tropical climates because of their susceptibility to bacterial and fungal diseases. Bean production is mostly found in the medium altitude areas from 800-2000 m above sea level (a.s.l), although some is grown at an attitude higher than 2700 m a.s.l. The crop is grown in many parts of Tanzania, where semi arid conditions are experienced. The major bean growing areas within the country are upland areas of Tanga, Arusha, Mbeya, Mbinga, Morogoro and Mara (Misangu, 1982).

2.3 Common Beans Production Constraints in Tanzania.

The average bean yields in Tanzania are around 500 kg/ha although the potential yield under rainfed condition is 1500-3000 kg/ha using improved varieties and proper crop husbandry

(Hillocks et al., 2006). The rate of annual production increase is low while the area under production is more or less stable (Table 2). The main reasons for the low yield obtained by most small holders are poor seed quality, use of unimproved varieties that are susceptible to pests and diseases, low soil fertility, poor crop management and recurrent droughts. Drought, however, is considered one of limiting factors to agricultural production (Kramer and Beyer, 1995).

Table 2: Dry beans Production statistics in Tanzania 1991-2004

Year	Area harvested x 1 (tons/ ha)	Yield (kg/ha)	Production x 1000
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 (2005)

2.4. Drought and its Effect on Bean Production

Drought denotes a prolonged period without considerable precipitation that may result in reduction in soil water content and thus, cause plant water deficit. It can be defined in terms of either the external water status at the boundaries of the plant (soil, air) or the internal plant water status within the tissue (Tardieu, 1996). The first approach defines water stress as an imbalance between supply and demand, linked to the atmospheric saturation deficit following the water potential gradient and leaf area. The second definition associates water stress with the control mechanisms of the plant, where plant water status is regulated within the plant accompanied by changes in water flux with or without change in plant water potential under low soil water potential conditions (Amede, 1998).

Drought is a worldwide constraint to dry bean production. It is one of the most important problems affecting bean production because about 60% is obtained from the regions subjected to water shortage. Intermittent and terminal droughts are the two distinct kinds of drought associated with limited rainfall. The intermittent drought is 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). In contrast terminal drought occurs when plants suffer lack of water during later stages of growth or experienced when the crops are planted at the beginning of dry season. In tropical and subtropical regions bean growing environments, drought is often intermittent (Acosta et al., 1999; Schneider et al., 1997). Munoz-Perea *et al.*, 2006 pointed out that intermittent or terminal drought affects more than 60% of dry bean production worldwide.

Drought is ranked only next to diseases as most important constraint to common bean production (Kristin *et al* 1997). According to Singh (1995) 60% of common bean production worldwide is grown under water stress. In Tanzania bean yields are low ranging from 200 to 670 kg/ha and according to Mduruma et al., (1998) this is mainly due to unreliability of rainfall during the growing seasons.

The effects of drought stress vary depending on the frequencies, duration and intensity of stress and growth stages affected. The nature of the effects depends on type of drought stress; intermittent drought affects more than 60% of dry bean production worldwide (White and Singh, 1991). For example drought is endemic in more than 1.5 million ha of dry bean planted each in northern Brazil, central and northern highlands of Mexico. In general the lack of water interferes with the normal metabolism of the plant during flowering and grains filling as these are stages when drought causes the greatest yield reduction (White and Singh, 1991). In dry beans excessive abortion of flowers, young pods and seeds occurs when there is drought stress during pre-flowering, 10 to 12 days before anthesis, and when it occurs during reproductive phase (Munoz-Perea etal, 2006). Moderate to high drought stress can reduce biomass of seeds and pods, days to maturity, harvest index, seed yield and seed weight in common beans (Ramirez-Vallejo and Kelly 1998; Acosta- Gallegos and Adams, 1991; Nunez –Barrios et al., 2005; Teran and Singh, 2002; Nielsen and Nelson, 1998; Ramirez-Vallejo and Kelly 1998). A moderate drought stress can reduce yield by 41% (Foster et al., 1995). However, severe drought stress can reduced yields by 92 % (Castellanos et al, 1996).

Drought stress also showed the tendency of causing root shrinkage that consequently affects nutrients transport to the root surface due to reduced contact between root and soil (North and Norbel, 1997). Among Phaseolus species the tepary bean, P.*acutifolius* and A.*gray*, has the highest level of drought resistance (Lazcano-ferrat and Lovatt, 1999). However the resistance genes from tepary bean have not yet been introduced into dry bean. In dry bean, drought tolerance was reported in the race Durango, Meso-american and Jalisco (Teran and Singh 2002).

2.5 Drought Tolerance

Drought tolerance in common beans encompasses all mechanism that allows greater yield under soil moisture deficit (Maghembe, 1999), like thick cuticle with hairs, narrow leaves and deep roots. When a crop plant is able to grow satisfactorily in areas subjected to water deficit it is said to be drought resistant or tolerant. Drought is classified into three categories, which are drought escape, drought tolerance and drought resistance.

Drought escape is the ability of plant to complete its life cycle before a serious plant water deficit develops. It is accomplished by rapid phenological development or by developmental plasticity. However, drought escape also plays a significant role in crop species both through yield and their early maturity and development plasticity. Invariably, earliness, which is otherwise a highly heritable character, was negatively correlated with yield (Chopra and Paroda, 1986). White and Singh, 1991 explained this phenomenon as being due to reduced period of photo assimilations and shortened remobilization/ translocation times. Subbarao et al., 1995 suggested that bean genotypes with drought escape mechanism may be associated with a potential for development of plasticity which gives the genotypes the ability to adjust the duration of different growth phases and patterns of canopy development to suit the moisture availability during growing seasons. Drought escape mechanism was pointed to explain the performance of chickpea as pod setting and filling at lower nodes during early growth ensured that at least some seed setting occurred when there was receding soil moisture (Saxena et al., 1993). Early seed establishment, early vigour, rapid canopy development in order to minimize evaporation as well as leaf area have been suggested as a potential mechanism for drought resistance in grain legumes (Subbaro et al., 1995).

On the other hand drought tolerance mechanism is the ability of the plant to endure environmental drought conditions as they prevail, and this may be at higher tissue water potentials, which is the ability of the plant to endure periods without significant water while maintaining a higher water potentials and at the lower tissue water potentials, which is the ability of the plant to recover satisfactory from water stress conditions. The mechanism includes the rapid recovery of plant growth and the accompanying compensatory development and may closely results into normal production levels despite the intermittent drought conditions.

Mode of inheritance of some mechanisms of drought tolerance that is highly heritable like early flowering varies from monogenic, digenic to polygenic. In addition, resistance to flower abscission and ability to support pod formation in common beans seem to be determined by oligogenes (Singh 2003). However, the remaining traits associated with drought resistance are polygenically controlled and generally, both additive and dominance gene action are involved (Singh 2003). Evaluation of plant types capable of tolerant or escaping moisture stress is therefore the major consideration in crop improvement programmes.

2.6 Traits Associated with Drought Tolerance

Studies on drought resistance in common beans have shown that no single attribute can alone be responsible for resistance (Kristin et al 1997). 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 (Ehleringer et al 1991; 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 (Acosta and white 1995), which allows shortening of the growth cycle.

Because seed yield is the most important economic traits in common beans, the most practical method to screening for drought tolerance has been found to be through the direct measurements of yield related characteristics (Acosta and Adams, 1991). Yield means and drought indices have, therefore, been used more often than not as the direct ways of measuring drought tolerance (Blum, 1988; Kristin et al., 1997). Among drought indices includes drought susceptibility index (Fischer and Maurer, 1978), harvest index and biomass (Kristin et al., 1997).

Genotypic variation for drought resistance had been reported for common bean (Abebe et al., 1998; Acosta et al 1999). The most effective selection among various morphological, physiological, phonological, yield and yield related traits for identifying drought resistant genotype was mean seed yield (Abebe et al., 1998).

2.7 Selection for Drought Tolerance in Common Beans

The effect of drought can vary depending on when it occurs during different stages of development of the plant. 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. For example the bean cultivar ‘Pinto Villa’ has broad adaptation and yield stability in the semi arid highlands of Mexico (intermittent drought) partially due to phenotypic plasticity and the ability to continue to fill seed at low night temperatures (Acosta-Gallegos et al., 1995). Beaver and Rosas (1998) found that selection for earlier flowering, a greater rate of partitioning and a shorter reproductive period permitted the selection of small red bean breeding lines having one week earlier maturity without sacrificing yield potential. Lines with earlier maturity would be less vulnerable to terminal drought, but caution needs to be exercised, as an association between early maturity and lower yields exists.

Kelly (1998) suggested using differences in growth habit to indirectly select for root architecture as superficial root systems are better suited to intermittent drought where as the deep tap root of systems sustains plants through short periods of drought by mining the lower soil profiles for moisture. Also adequate root density throughout the soil profile may increase the diffusion area, thereby improving water availability and uptake. Maintenance of water status under conditions of limited water can be partially attributed to root depth and root length density (Turner, 1986; Subbaro et al., 1995). Slim and Saxena (1993) showed that root depth could be considered as an alternative trait to screen drought-resistant lines.

Their results showed that differences in drought resistance among genotypes were associated with root depth, but not root length density, as roots of drought-tolerant genotypes reached a depth of 1.3 m, while roots of drought-sensitive ones only reached 0.8 m. Similarly, in chickpeas, genotypes with deeper root systems exhibited higher leaf water potential than shallow-rooted genotypes under drought-stress conditions (Slim and Saxena, 1993).

Several indices have been utilized to assess genotypes for drought tolerance based on grain yields and these include geometric mean productivity, mean productivity, standard superiority measure, drought susceptibility index (DSI), drought intensity index (DII), sensitivity index and stress tolerance index (Saba et al, 2001). Teran and Singh (2002) used geometric mean, percent reduction and drought susceptibility index (DSI) in identifying drought resistant line. Similarly, Ramirez-Vallejo and Kelly (1998) used geometric mean and DSI to evaluate the association of physiological and phenological traits with resistance to drought in common beans where seed yield components such as pods number/plant, seeds number/pod, grain yield and 100 seed weight (g) have been used. Drought susceptibility index (DSI) which was formulated by Fischer and Maurer, 1978 measures the susceptibility of a genotype to drought stress and it is given by the following formular:-

$$DSI = (1 - Ys/Yi) / DII$$

Where Ys= mean yield across all genotypes under water stress

Yi= mean yield across all genotypes under non stress conditions

DII= drought intensity index.

DSI above 1 indicate lower levels of drought tolerance and DSI less than 1 shows below-average susceptibility to drought. According to White and Singh, (1991) caution needs to be taken when using DSI as certain genotypes with the lowest DSI rankings had the lowest overall yield potential.

The drought sensitivity index was used to give an extendable opportunity to compare the drought stress and non stress treatments (Fischer and Maurer 1978). The SI is used to group the genotype under the study into two groups; it groups it as drought sensitive with the SI value greater than 1which is associated with lower grain yield and another group of genotype which is tolerant to drought with the SI value lower than 1 which is associated with higher grain Yield and it is given by:-

$$SI = 1-(D/C)/1-(Dm/Cm)$$

Where,

D = Drought yield

C = Control yield

Dm = Mean yield across all lines under drought

Cm = Mean yield across all lines under control

On the other hand DII is used to quantify drought severity of a particular dry environments, it indicates how severe was the drought condition and hence identifying the varieties which are suited to such environments. DII is given by DII = 1 – Xd/Xp, Where Xd is the mean yield averaged across lines under stress, and Xp is the mean yield averaged across lines under non-stress conditions. DII values exceeding 0.7 indicate severe drought conditions, 0.4 to 0.6 moderate drought conditions while below 0.4 is signifying lower level of drought. Environments with higher DII values are required for identification of the highest levels of drought resistance for unpredictable fluctuating drought conditions in non irrigation assisted and dry land production regions Frahm et al.(2004), Schneider et al. (1997), and Tera´n and Singh (2002) also reported a wide range (from 0.02 to 0.90) in DII values. However, growing environments with DII values lower than 0.50, hence a milder drought stress may identify different cultivars as drought resistant from those environments with higher DII values.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Location

This research was conducted in 2009 at Sokoine University of Agriculture (SUA) Horticulture Unit, Morogoro, Tanzania (latitude 6°5` South and 37°37`East at an elevation of 525 m above the sea level in the leeward side of Augurs mountain). The climate of the area is between sub-humid and semi- arid with predominantly alfisols and entisols. The temperature of this area is ranging from 24°C-34°C with the relative humidity of 70-90%.

3.2 Materials

Fourteen bean lines from a drought nursery namely MN 14059-4-4P, RWR 109, MR 14000-2-1P, MR 14144, MMS 243, MN 14059-4-4P, MR14000-2-10P, MR 14140 -45-4P, MR 14215-9-8P, MR13944-14-9P, MR 14153-3-2P, MR 14198-13-1P, CNF5547 (CONTROL), MR 13095-6-1P and DOR 390 were tested. Lines MMS 243 and CNF5547 were included as checks.

3.3 Stress Periods

Four stress periods were used and included (1) no water stress applied (the control treatment), SP_1, (2) stress from flowering to mid pod filling (SP_2); (3) stress from mid pod filling to harvesting (SP_3) and (4) stress throughout the period of stress testing (SP_4).

3.5 Experimental Design

The experimental design was a Split plot laid out in a randomized completely block design with 3 replications. With the water stress periods were the main plots and the bean lines were sub-plots. The main plot size was 40 m^2 and consisted of 14 rows corresponding to the varieties as sub-plots. Each row was 5 m long and the spaces between rows were 0.5 m apart. Twenty seeds were planted per row. The drought stress plots as well as non stress plots were arranged adjacent to each other with the distance of 2 m apart to avoid water seepage effects.

Figure 1: Field Layout

3.6 Introduction of Drought Stress

The furrow irrigation was used to irrigate the field after planting. All plots were irrigated immediately after sowing, but subsequent irrigation was carried out according to the treatments described above using furrow irrigation in uniformity to ensure a good plant

3.6 Introduction of Drought Stress

The furrow irrigation was used to irrigate the field after planting. All plots were irrigated immediately after sowing, but subsequent irrigation was carried out according to the treatments described above using furrow irrigation in uniformity to ensure a good plant emergence. The irrigation interval was aided by tensiometer. This is a tool which is used to determine the moisture content of the soil. SP_O followed the normal irrigation; it was irrigated to 95 ± 5% field capacity (fc) which was determined by a tensiometer reading while in the stressed plots the tensiometer used were in place to give an indication as to when an additional irrigation was required so as to prevent the permanent wilting point. The three stress treatments were at different growth stages. For SP_3 irrigation was applied only once to after emergence. For SP_1 and SP_2 irrigation was withheld during the period from flowering to mid-pod filling and from mid-pod filling to harvesting, respectively. SP_1 allowed flowering and pod formation to take place under moisture stress, while SP_2 applied to simulate rainfall pattern in most of Tanzania environment where rains tend to stop earlier leaving many crops immature.

3.7 Data Collection.

Data collection included; grain yield, Seeds/pod; pods/plant, seed weight per plant, root length, root weight, Days to maturity, days to 50% flowering and dry matter content.

3.7.1 Grain Yields

The plots were harvested when 95% of pods were dry and brown. The area harvested were identified and determined before harvest where by the border rows and plants within the harvest plots were clearly marked. The harvest area was determined as, harvest area = total length of harvested rows x space between rows. After harvesting the seed from each plot was measured using electronic balance that has an accuracy of at least 0.1g and recorded.

The grain yield was determined as:-

Grain yield=Seed weight/harvested area

3.7.2 Days to 50% Flowering

This parameter was measured as the difference in number of days from date of planting to date when 50% of plants in each plot had one or more first flower. This stage coincides with the initiation of development stage (CIAT, 1987).

3.7.3 Days to Maturity.

The number of days from date of planting to date when 95% of plants in each plot attained physiological maturity will be recorded. This was taken only when the pods were dry and brown. The planting dates coincided with the availability of sufficient soil moisture to allow germination of seeds.

3.7.5 100 - Seed Weight

The seed weight of all 14 bean lines was measured in the Department of Crop Science Plant Breeding laboratory using the electronic balance. This was done by randomly weighing 100 seeds.

3.7.6 Number of Seeds per Pod

The number of seeds per pod was obtained from10 randomly selected pods from each plot. The average number of seeds per pod were then determined.

3.7.7 Root Weight.

Three plants were randomly excavated from each plot carefully without damage during mid-pod filling, oven dried until the weight remained constant. The root weight was measured using a sensitive balance and its weight was recorded.

3.7.8 Number of Pods per Plant

The number of pods per plant determined as the average number from harvesting randomly 5 plants in a plot, counting the number of physiological maturity and divide by five.

3.7.9 Root Length.

The root length was determined by randomly selecting three plants, carefully excavating and measuring their root length and dividing their total length by 3 to get its average number.

3.7.10 Dry Matter Weight.

The plants used to determine root length and root weight during mid-pod filling were also used to determine the dry matter weight. This was done by oven drying the plants samples from each plot until when the weight remained constant and the total weight was divided it by 3 to get the average weight per plant which was recorded.

3.8 Derived variables

3.8.1 Sensitivity Index (SI)

From the above collected data a sensitivity index developed by Fischer and Maur (1978) was used to give an extendable opportunity to compare the drought stress and non stress treatments.

This is given by

SI= 1-(D/C)/1-(Dm/Cm)

Where,

D = Drought yield

C = Control yield

Dm = Mean yield across all lines under drought

Cm = Mean yield across all lines under control

3.8.2 Drought Intensity Index (DII)

To quantify drought severity the DII was calculated a drought intensity index (DII = 1 – Xd/Xp, Where Xd is the mean yield averaged across lines under stress, and Xp is the mean yield averaged across lines under non-stress conditions). DII values exceeding 0.7 indicate severe drought conditions.

3.8.3 Drought Susceptibility Index (DSI)

To predict the performance of a line under stressed and non-stressed conditions, the drought susceptibility index (S = (1 - Yd/Yp)/DII) was calculated. Where, Yd is mean yield of a line under stress and Yp is mean yield for the same line under non-stress conditions).

3.8.4 Data Analysis

Analysis of variance (ANOVA) was done using GENSTAT computer program. Total variation as represented by the statistical linear model:-

$$Y_{ijk} = \mu + p_k + \alpha_i + \delta_{ik} + \beta_j + + E_{ijk}$$

Where: **Yijk** is the observed value of k^{th} replicate of the i^{th} level of factor A and the j^{th} level of factor B (where i=1 to a, j=1 to b and k=1 to r)

μ is the general mean

α_i is the effect of i^{th} level of factor A,

Bj is the effect for the j^{th} level of factor B

p_k is the block effect for the k^{th} block

δ_{ik} is the whole plot random error effect, for the i^{th}, k^{th} combination of block and factor A

$(A\beta)_{ij}$ is the e interaction of effect of the i^{th} level of factor A with the j^{th} level of factor B

E_{ijk} is the subplot random error effect associated with the Y_{ijk} subplot unit.

This variation was decomposed as per format in Table 3

Table 3: Analysis of Variance Format for Split-Plot Design used in the Study.

Source of variation	Degrees of Freedom	Means of Squares	Expected Means Square
Replication	r-1	SSR/DF(r)	$\delta_E^2 + b\delta_\delta^2 + ab\delta_{Blk}^2$
StressPeriods	n-1	SSSP/DF(sp)	$\delta_E^2 + b\delta_\delta^2 + rb\theta_A^2$
Error(a)	(r-1)(n-1)	SSE(a)/DF (Ea)	$\delta_E^2 + b\delta_\delta^2$
Varieties (V)	(g-1)	SSV/DF(v)	$\delta_E^2 + ra\theta_B^2$
V x SP	(n-1)(g-1)	SSV*S P/DF(v*sp)	$\delta_E^2 + r\theta_{AB}^2$
Error (b)	(r-1)(g-1)+(n-1)(g-1)	SSE(b)/DF(Eb)	δ_E^2
Total	rab-1		

CHAPTER 4

4.0 RESULTS

4.1 Days to 50% Flowering.

Highly significant differences ($P \leq 0.001$) were observed for number of days to 50% flowering (Table 5). On the other hand stress levels and the interactions were significant different ($P \leq 0.05$) for the number of days to flowering. Plants flowered earliest (41 days after planting) in stress I and later (43 DAP) in the other stress levels.

CFN 5547, MR 13944-14-9P and MMS 243 flowered latest, 49, 48 and 48 DAP, respectively, while. MR14153-3-2P was the earliest (29 DAP) along with MR 14000-2-10P at 33 DAP. The differential responses of the bean lines tested over different stress levels varied significantly for the number of days to flowering (Table 5). Under stress O, MR 13944-14-9P, CFN 5547, MR 14144-11-5P and MMS 243 were the latest at 52, 49, 48, and 48 DAP, respectively. The earliest were MR 14153-3-2P at 28 days and MR 14000-2-10P at 33 days from planting. Under stress I the latest was in MR 13944-14-9P at 50 DAP and at 49 DAP for CFN 5547 while the earliest was at 28 DAP and 32 DAP for MR 14153-3-2P/ MR 14000-2-10P and MR 14154-4-6P . On the other hand under stress II the latest was MMS 243 at 49 DAP while the earliest were MR 14153-3-2P and MR 14000-2-10P at 32 and 33 DAP respectively (Table 4).

Table 4. Means of the number of days to flowering in non-water stress treatment and two stress treatments in common bean lines.

	STRESS LEVELS			
Lines	SP_0	SP_I	SP_{II}	Mean
MR 13944-14-9P	52.00	50.00	41.33	47.67
CFN 5547	49.00	49.00	49.33	49.22
MR 14144-11-5P	48.00	46.33	43.33	45.89
MMS 243	48.00	44.00	49.00	47.00
RWR 109	47.00	45.00	46.67	46.33
MR 14000-2-1P	47.00	45.67	46.00	46.11
DOR 390	47.00	44.67	46.67	46.11
MR 14215-9-8P	45.00	43.33	45.00	44.44
MR 14140-45-4P	42.00	40.67	42.33	41.78
MR 14198-13-1P	39.00	35.33	43.00	39.00
MR 13095-6-1P	38.00	37.00	34.33	36.56
MR 14154-4-6P	35.00	32.33	44.00	37.22
MR 14000-2-10P	33.00	32.33	33.00	32.78
MR 14153-3-2P	28.00	28.00	32.00	29.44
MEAN	42.79	40.98	42.57	42.6
L.S.D	5.8	0.9556	4.134	3.32
CV%	4.134	1.4	5.8	4.7
STRESS PERIODS				
LSD	1.43			
CV	1.5			
For Interaction				
LS.D	5.793			
CV%	8.6			

Table 5 presents mean squares of the variables measured and derived in this study.

source	DF	Dayst o 50% flowering	Days to maturity	Grain yield kg/ha	Number of pods/plant	Number of seeds/pod	100 seed weight g	Dry matter weight	Root weight (g)	Root length (cm)
Replication	2	15.48	7.389	27068	179.76	0.5206	18.867	15.2	0.05	3.882
Stress level	2	41.06*	450.865***	6106110***	706.65**	3.6720 NS	269.657***	3787.79***	1.957*	169.64***
Line	13	337.15***	237.549***	166749***	40.29*	2.5722***	45.737***	577.2***	4.8458***	97.002***
Stress level x line	26	22.06*	45.472***	185045***	12.19NS	0.3163 NS	3.601 NS	396.65***	0.0771**	53.831***
Error	78	13.26	3.461	9013	18.7	0.4071	5.615	15.82	0.037	3.585
Cv%		8.6	2.3	12.2	26.9	11.6	10.2	7.1	11.5	7

*Significant at $P \leq 0.05$

**Siginficant at $P \leq 0.01$

*** Significant at $P\leq 0.001$

NS: non stress

4.2 Days to Maturity

Stress levels, lines and their interactions were significant (P<0.001) for days to maturity (Table 5). Means for the days to maturity are presented in Table 6. The earliest maturity was at 77 DAP in the Stress I, while the latest was at 84 DAP in the Stress 0. The earliest lines were MR 14153-3-2P and MR 14000-2-10P maturing at 71 and 72 DAP, respectively (Table 6). The latest line was CFN 5547 at 90 DAP.

There was differential response in days to maturity for the lines tested over the stress levels as evidenced by the significant interactions. Under Stress 0 CFN 5547, RWR 109, MMS 243, and MR 14000-2-1P were the latest at 92, 92, 90, and 90 DAP respectively, however under Stress I the latest were MR 13944-14-8P, CFN 5547 and MR 14144-11-5P at 88, 86 and 83 days after planting and under stress II it was CFN 5547 with 91 days after planting, MMS 243 86 days and MR 14154-4-6P at 84 days after planting.. The earliest lines on the other hand were MR 14153-3-2P, MR 14000-2-10P, and MR 14144-11-5P at 70, 74 and 78 days after planting respectively under Stress 0, MR 14153-3-2P and MR 14000-2-10P under stress I at 66 and 67 days after planting and MR 14153-3-2P at 70 days after planting under stress II. The ranking of the lines in terms of DAP changed. CFN 5547 which was the latest in stress 0 was the second under stress I and was the latest under stress II.

Table 6: Means for the days to physiological maturity for the non stress treatment and two stress treatments in common bean lines.

	STRESS LEVELS			
LINES	SP_0	SP_I	SP_{II}	MEAN
MR 13944-14-9P	81	88	77	82.22
CFN 5547	92	86	91	89.56
MR 14144-11-5P	78	83	77	79.44
MMS 243	90	80	86	85.33
RWR 109	92	78	82	83.89
MR 14000-2-1P	90	79	80	82.67
DOR 390	86	77	84	82.11
MR 14215-9-8P	88	79	82	83.33
MR 14140-45-4P	84	79	80	81
MR 14198-13-1P	84	74	82	80.22
MR 13095-6-1P	82	77	75	78.22
MR 14154-4-6P	79	69	84	77.22
MR 14000-2-10P	74	67	74	71.67
MR 14153-3-2P	73	66	70	69.89
MEAN	84	77	80	80
LSD	2	3	4	2
CV%	1.4	2	3.2	1.5
STRESS PERIOD				
LSD	1.15			
CV%	0.6			
For interactions				
LSD	3			
CV%	2.3			

4.3 Grain Yield (kg/ha)

Stress levels, lines and their interactions were very highly significant different ($P \leq 0.001$) for grain yield (Table 5). The highest yielding bean lines were MR 13095-6-1P, DOR 390 and MR 13944-14-9P with grain yield values of 1049 kg/ha, 998.9 kg/ha and 972.4 kg/ha respectively. MR 14153-3-2P and MR 14000-2-10P were the lowest yielding with yield values of 657.7 kg/ha and 564.6 kg/ha respectively.

Significant interactions ($P<0.05$) between stress levels and varieties were detected for grain yield signifying differential varietal response to stress levels (Table 5). Table 7 presents the means for the interactions. It was observed that the average yield reduction from Stress 0 to Stress I was lower (34%) compared to the reduction from Stress I to Stress II (58%). Varietal performance under Stress 0 showed MR 13095-6-1P having the highest yield of 1732.8 kg/ha, while the lowest yields were observed for MR 14153-3-2P, MR 14144-11-5P, MR 14000-2-10P, 962 kg/ha, 732 kg/ha and 638.5 kg/ha, respectively, Under Stress I the highest yielding lines were DOR 390, MR 14000-2-10P and CFN 5547 with the grain yield values of 1058.9 kg/ha, 897.6 kg/ha and 887.9 kg/ha respectively and under Stress II MR 13944-14-9P had the highest yield value of 962.9 kg/ha. The performance of MR 14000-2-10P fluctuated from being the lowest under Stress 0 and Stress II, 638.50 kg/ha and 157.60 kg/ha, respectively to being one of the highest under Stress I (897.60 kg/ha). Similar differential responses by other varieties tested were observed from the results.

Table 7: Means for the grain yield (kg/ha) for non- water stress treatment and two stress treatments in common bean lines

Line	STRESS LEVELS					Mean
	SP_0	SP_I	%Yield reduction	SP_{II}	%yield reduction	
MR 13944-14-9P	1227.9	726.4	44.9	962.9	21	972.4
CFN 5547	1088.9	887.9	18.4	228.1	79.1	735
MR 14144-11-5P	962.8	850.7	11.6	485.3	49.6	766.3
MMS 243	1382.7	486.7	64.8	340.9	75.3	736.7
RWR 109	1248.3	623.5	50	242.7	80.6	704.8
MR 14000-2-1P	1403.7	443.9	68.4	380.3	72.9	742.6
DOR 390	1333.2	1058.9	20.5	604.6	54.7	998.9
MR 14215-9-8P	1196	610.4	49	361.5	69.8	722.6
MR 14140-45-4P	1316.3	557.5	57.6	255	80.6	709.6
MR 14198-13-1P	1355.8	519.5	61.6	354.4	73.8	743.2
MR 13095-6-1P	1732.8	778.5	55	636	63.3	1049.1
MR 14154-4-6P	1010.5	1120.2	-10	322.5	68.1	817.7
MR 14000-2-10P	638.5	897.6	-40	157.6	75.3	564.6
MR 14153-3-2P	732.8	518.3	29.3	722.1	1.5	657.7
MEAN	1187.9	720	34.36	432.4	58.29	780.1
LSD	234.5	56.57		134		86.22
STRESS PERIOD						
L.S.D	69.2					
CV%	3.9					
For interaction						
L.S.D	156.21					
CV%	12.2					

4.4. Number of pods/plant

Stress levels and lines were significant ($P \leq 0.05$) for the number of pods per plant (Table 5). The highest number of pods per plant was 21 in stress 0 and the lowest at 14 in stress periods I and II. The line with the highest number of pods was DOR 390 with 19 pods while the lowest was 11 pods for MR 14140-45-4P (Table 8).

Table 8: Means for the number of Pods/plant in non water stress treatment and two stress treatments in common bean lines

	STRESS LEVELS			
LINE	SP_0	SP_I	SP_{II}	MEAN
MR 13944-14-9P	23.83	15.10	17.62	18.85
CFN 5547	22.53	13.60	16.17	17.43
MR 14144-11-5P	19.28	11.13	11.33	13.92
MMS 243	21.70	12.53	10.27	14.83
RWR 109	22.10	19.33	12.68	18.04
MR 14000-2-1P	18.07	13.33	12.47	14.62
DOR 390	21.88	17.47	17.67	19.01
MR 14215-9-8P	20.40	12.10	11.93	14.81
MR 14140-45-4P	13.58	9.67	10.52	11.25
MR 14198-13-1P	19.77	12.77	14.43	15.66
MR 13095-6-1P	18.88	13.63	16.53	16.35
MR 14154-4-6P	22.80	16.37	13.43	17.53
MR 14000-2-10P	21.53	14.83	11.30	15.89
MR 14153-3-2P	25.00	11.22	14.40	16.87
MEAN	20.81	13.79	13.62	16.08
L.S.D	8.14	6.123	7.165	4.114
CV%	23.8	26.5	31.3	4.114
STRESS PERIODS				
LSD	3.16			
CV %	9.9			
For interactions				
L.S.D	7.26			
CV%	26.9			

No significant interactions between stress periods and lines for pods per plant.

4.5. Number of Seeds/Pod

The lines were very highly significant differences ($P \leq 0.001$) for the number of seeds per pod (Table 5), while stress levels were not significant. The lines with the highest number of seeds per pod were CFN 5547 and DOR 390 with 7 seeds per pod (Table 9). There were no interactions for the number of seeds per pod

Table 9: Means of number of seeds/pod for the non stress and two stress treatments.

	STRESS LEVELS			
LINE	SP_0	SP_I	SP_{II}	MEAN
MR 13944-14-9P	5.6	4.97	5.3	5.289
CFN 5547	6.93	5.93	6.87	6.578
MR 14144-11-5P	6.03	5.4	5.53	5.656
MMS 243	6.17	5.57	5.87	5.867
RWR 109	5.77	5.23	5.13	5.378
MR 14000-2-1P	5.07	5.3	4.97	5.111
DOR 390	6.43	6.33	6.9	6.556
MR 14215-9-8P	5.43	5.57	6.23	5.744
MR 14140-45-4P	5.47	4.87	5.13	5.156
MR 14198-13-1P	5.7	4.37	5.57	5.211
MR 13095-6-1P	5.3	4.73	4.7	4.911
MR 14154-4-6P	5.97	4.9	5.2	5.356
MR 14000-2-10P	5.07	4.9	4.97	4.978
MR 14153-3-2P	5.5	4.27	5.5	5.089
MEAN	5.75	5.17	5.56	5.22
L.S.D	0.9237	1.337	0.894	0.9618
CV%	9.6	15.4	9.6	10.3
STRESS PERIODS				
LSD	0.578			
CV%	4.6			
For interactions				
L.S.D	1.0844			
CV%	11.6			

4.6 100- seed weight

Stress levels and lines were highly significant for 100 seed weight (P≤ 0.001). The heaviest seeds (26.16 g) across lines were under stress 0 (no water stress treatment) while the smallest (21.5 g) were under stress II. The lines with largest 100 seed weight were MR 14000-2-1P, MR 14000-2-10P and MR 14140-45-4P having weight of 27.14 g, 26.37 g and 25.84 g, respectively (Table 10). The lines with the smallest seeds across stress periods were DOR 390 (19.3 g) and RWR and CFN 5547 at 20.8 g each. There were no interactions for 100 seed weight (Table 5).

Table 10: Means of 100 seed weight for non- water stress treatment and two stress treatments in common bean lines

	STRESS LEVELS					
Line	SP_0	SP_I	% Reduction in100 seed weight	SP_{II}	% Reduction 100 seed weight	Mean
MR 13944-14-9P	27.73	21.33	23	21.4	6.3	23.49
CFN 5547	23.9	19.4	18.8	19.03	20.5	20.78
MR 14144-11-5P	28.33	23.4	17.4	21.43	29.6	24.39
MMS 243	24	20.77	13.4	21.47	10.5	22.08
RWR 109	24	19.6	18.3	18.93	21.1	20.84
MR 14000-2-1P	28	27.27	2.6	26.17	6.5	27.14
DOR 390	23.33	17.23	26	17.27	26	19.28
MR 14215-9-8P	25.67	21.9	14.7	20.57	18.9	22.71
MR 14140-45-4P	29.67	24.63	17	23.23	21.7	25.84
MR 14198-13-1P	27.67	22.13	20	23.47	15.2	24.42
MR 13095-6-1P	26.67	22.47	15.7	22.73	14.8	23.96
MR 14154-4-6P	23	22.57	1.8	20.5	10.9	22.02
MR 14000-2-10P	30	24.6	18	24.33	18.9	26.31
MR 14153-3-2P	24.33	22.53	7.4	20.33	16.4	22.4
MEAN	26.16	22.13		21.49		23.26
LSD	4.111	4.273		3.506		2.1
CV%	9.4	11.5		9.7		5.4
For interactions						
L.S.D	3.762					
CV%	10.2					

4.7 Dry matter weight

Stress levels, lines and their interactions were significant different ($P \leq 0.001$) for the dry matter weight (Table 5). The highest average weight was 66.5 g from Stress 0 across lines while the lowest was 48.87 g from stress I. Dry matter weight across lines was highest for MR 14144-11-5P at 69.14 g with CFN 5547 having the lowest at 39.32 g (Table 11).

Table 11: Means for the dry matter weight in non water stress treatment and two stress treatments in common bean lines.

	STRESS LEVELS			
Line	SP_0	SP_I	SP_{II}	Mean
MR 13944-14-9P	53.9	43.7	66.2	54.61
CFN 5547	34.6	36.1	47.2	39.32
MR 14144-11-5P	77.3	54.8	75.3	69.14
MMS 243	56.9	44.0	42.8	47.9
RWR 109	80.9	58.2	41.3	60.13
MR 14000-2-1P	64.8	55.8	60.8	60.46
DOR 390	74.6	69.0	44.7	62.77
MR 14215-9-8P	70.0	49.5	68.3	62.62
MR 14140-45-4P	67.8	35.1	58.2	53.71
MR 14198-13-1P	73.3	41.2	29.9	48.14
MR 13095-6-1P	50.7	53.4	59.4	54.49
MR 14154-4-6P	65.6	45.0	36.8	49.16
MR 14000-2-10P	70.1	45.1	42.7	52.64
MR 14153-3-2P	90.6	53.0	48.2	63.94
MEAN	66.5	48.9	51.6	55.63
LSD	4.1	5.8	9.1	3.86
CV%	3.7	7.1	10.5	4.1
STRESS PERIOD				
L.S.D	1.9			
CV%	1.5			
For interactions				
L.S.D	6.4			
CV%	7.1			

The interactions between lines and stress levels were significantly different for dry matter weight (Table 5). Under Stress 0 MR 14153-3-2P had the highest dry matter weight of 90.6 g; In Stress I DOR had the highest weight of 69.0 g while under stress II MR 14144-11-5P gave the highest weight of 75.5 g. The lowest dry matter weight of 34.6 g was for CFN 5547 under stress 0, 35.1 g for MR 14140-45-4P under stress I and 29.93 g for MR 14198-13-1P under stress II (Table 11).

4.8 Root weight (g)

Stress periods, lines and their interactions were significantly different ($P \leq 0.05$) for root weight, (Table 5). The highest root weight across the stress periods was 1.92 g in stress 0 while the lowest was 1.53 g in stress II. Mean of root weight was highest for DOR 390 with 3.25 g across the stress periods. The lowest root weight was 0.74 g for MR 14144-11-5P along with, MR 14154-4-6P (0.83 g) and for MR 14140-45-4P (0.94 g).

Significant interactions ($P<0.05$) between stress levels and varieties were detected for root weight yield signifying differential varietal response to stress levels (Table 5). Table 11 presents the means for the interactions. Under all three stresses the heaviest root weight was observed in DOR 390, under stress 0 had 3.5 g, while under stress periods I and II had 3.1 g. The lightest weight observed was 0.67 g, for MR 14144-11-5P and under stress I and II the lightest was MR 14154-4-6P having 0.73 g and 0.6 g respectively. While the root weight reduced with stress imposition, the rates of reduction varied greatly among the lines. Line DOR 390 showed no reduction in the root weight from stresses 0 to stress I, while MR 13095-6-1P and

MMS 243 had least reduction (9%). MR 14154-4-6P and MR 14154-4-6P had the highest reductions in excess of 30%.

Table 12: Means of root weight (g) for non water stress treatment and two stress treatments in common bean lines.

	STRESS LEVELS			
Line	SP_0	SP_I	SP_{II}	Mean
MR 13944-14-9P	1.60	1.23	1.23	1.356
CFN 5547	2.20	1.80	1.67	1.889
MR 14144-11-5P	0.67	0.83	0.73	0.744
MMS 243	1.17	1.07	1.13	1.122
RWR 109	2.13	2.13	2.10	2.122
MR 14000-2-1P	1.37	1.07	1.07	1.167
DOR 390	3.53	3.10	3.13	3.256
MR 14215-9-8P	3.00	2.40	2.20	2.533
MR 14140-45-4P	1.30	0.83	0.70	0.944
MR 14198-13-1P	2.83	2.00	2.10	2.311
MR 13095-6-1P	2.13	1.93	1.87	1.978
MR 14154-4-6P	1.10	0.73	0.67	0.833
MR 14000-2-10P	1.47	1.13	1.17	1.256
MR 14153-3-2P	2.43	1.70	1.70	1.944
MEAN	1.92	1.57	1.533	1.675
L.S.D	0.343	0.1970	0.3984	0.23
CV%	10.6	7.5	15.5	8.2
STRESS PERIOD				
L.S.D	0.1084			
CV%	2.8			
For interactions				
L.S.D	0.3169			
CV%	11.5			

4.9 Root Length (cm)

Stress level, lines and their interaction were very highly significant ($P \leq 0.001$) for root length (Table 5). The longest roots across stress periods were 29.07 cm long under stress I while the shortest were 25.07cm in stress II. MR 14215-9-8P had the longest roots (37.08 cm) while MR 14000-2-10P had the shortest roots. The interactions were highly significant different ($P \leq 0.01$) for the root length (Table 5) which showed that there exist a relationship between stress levels and varietal performance under drought stress.

Table 13: Means of root length (cm) non stress treatment and two stress treatments in common bean lines

LINES	STRESS LEVELS SP0	SPI	SPII	MEAN
MR 13944-14-9P	27.80	31.43	23.5	27.58
CFN 5547	29.47	22.77	26.07	26.1
MR 14144-11-5P	32.87	29.1	19.97	27.31
MMS 243	30.03	29.0	29.67	29.57
RWR 109	25.1	28.93	23.63	25.89
MR 14000-2-1P	20.0	33.0	23.37	25.46
DOR 390	25.63	28.6	26.00	26.74
MR 14215-9-8P	42.63	33.17	35.43	37.08
MR 14140-45-4P	31.17	27.17	24.63	27.66
MR 14198-13-1P	25.67	32.4	22.87	26.98
MR 13095-6-1P	28.9	20.7	24.43	24.68
MR 14154-4-6P	22.07	25.67	26.4	24.71
MR 14000-2-10P	27.73	31.23	20.03	23.00
MR 14153-3-2P	24.07	33.83	24.93	27.61
MEAN	27.37	29.07	25.07	27.12
LSD	4.2	0.6586	5.107	2.09
CV%	0.99	1.3	12.1	4.6
Stress Period				
L.S.D	0.99			
CV%	1.6			
For interactions				
L.S.D	3.049			
CV%	7			

4.10. Drought Susceptibility Index (DSI)

Drought Susceptibility Index (DSI) measures the performance of a line under stressed and non stressed condition. The DSI for the grain yield for the water stress I (from flowering to mid-pod filling) was lowest (-1.04) for MR 14000-2-10P and (-0.3) for MR 14154-4-6P. The DSI for CFN 5547 (check) was also low with the value of (0.47). (Table 14A). The highest DSI value was for MR 13905-6-1P with the value of 1.75. For stress II (from midpod filling to maturity) the lowest DSI value was 0.02 for MR 14153-3-2P and the highest value was 1.26 for MR 14140-45-4P a and RWR 109.

Table 14 (a): Means for grain yield for non stress and water stress from flowering to midpod filling, DSI, SI and DII.

Line	STRESS LEVELS				
	SP_0	SP_I	$DSI^{(A)}$	$SI^{(A)}$	DII
MR 13944-14-9P	1227.90	726.40	1.08	1.0	0.34
CFN 5547	1088.90	887.90	0.47	0.47	
MR 14144-11-5P	962.80	850.70	0.30	0.3	
MMS 243	1382.70	486.70	1.62	1.66	
RWR 109	1248.30	623.50	1.28	1.3	
MR 14000-2-1P	1403.70	443.90	1.75	1.75	
DOR 390	1333.20	1058.90	0.53	0.52	
MR 14215-9-8P	1196.0	610.40	1.26	1.25	
MR 14140-45-4P	1316.30	557.50	1.48	1.48	
MR 14198-13-1P	1355.80	519.50	1.63	1.58	
MR 13095-6-1P	732.80	778.50	1.41	1.28	
MR 14154-4-6P	1010.50	1120.20	-0.28	-0.3	
MR 14000-2-10P	638.50	897.60	-1.04	-10	
MR 14153-3-2P	732.80	518.30	0.75	0.7	
MEAN	1187.90	720.00	0.96	0.96	
L.S.D	234.5	56.57	0.49	0.68	
CV%	11.8	4.7	69.7	111.9	
For interactions					
L.S.D	156.21				
CV%	12.2				

4.11 Sensitivity Index (SI)

Sensitivity Index (SI) gives an extendable opportunity to compare the different treatments. The SI values for the 14 bean lines tested are presented in table 14 (a) and (b). Under stress I the lowest SI values were -0.3 and 0.3 for both MR 14154-4-6P and MR 14144-11-5P while the largest SI value was 1.75 for MR 14000-2-1P (Table 14a). For stress II the SI ranged from 0.02 to 1.26 for MR 14153-3-2P as the lowest with the highest being MR 14140-45-4P at 1.26 and RWR 109 (Table 14 (b)).

4.12. Drought Intensity Index (DII)

Drought Intensity Index (DII) measures the magnitude of stress for the two stress treatments is represented in the DII values for each treatment in Table 14 (a) for the stress level I and Table 14 (b) for stress level II. The drought impact, as represented by DII, for the water stress from mid-pod filling to maturity, was 0.64, while for the water stress from flowering to mid-pod filling the DII value was 0.34. This value was almost 50% of the one from stress I.

Table 14 (b): Means of grain yield for non stress and water stress from midpod filling to maturity, DSI, SI and DII.

	STRESS LEVELS				
Line	SP_0	SP_{II}	$DSI^{(B)}$	$SI^{(B)}$	DII
MR 13944-14-9P	1227.90	962.90	1.23	1.14	0.64
CFN 5547	1088.90	228.10	1.24	1.2	
MR 14144-11-5P	962.80	485.30	0.77	0.7	
MMS 243	1382.70	340.90	1.18	1.18	
RWR 109	1248.30	242.70	1.26	1.26	
MR 14000-2-1P	1403.7	800.30	1.14	1.1	
DOR 390	1333.20	604.60	0.85	0.85	
MR 14215-9-8P	1196.0	361.50	1.09	1.1	
MR 14140-45-4P	1316.30	255.00	1.26	1.26	
MR 14198-13-1P	1355.80	354.40	1.15	1.15	
MR 13095-6-1P	1732.80	636.00	0.99	1.0	
MR 14154-4-6P	1010.50	322.50	1.06	1.0	
MR 14000-2-10P	638.50	157.60	1.30	1.2	
MR 14153-3-2P	732.80	722.10	0.02	0.02	
MEAN	1187.90	432.40	0.96	0.96	
L.S.D	234.5	134.0	0.29	0.28	
CV%	11.8	18.5	38.9	39.1	
For interactions					
L.S.D	156.21				
CV%	12.2				

CHAPTER 5

5.0 DISCUSSION

5.1 Performance of bean lines under varying water stress periods.

Differences were observed among the 14 bean genotypes grown under various water stress periods with respect to the several variables measured/derived, namely days to 50% flowering root length, root weight, dry matter weight, days to physiological maturity and grain yield.

The differential response of the bean lines tested over different stress levels with regards to the number of days to 50% flowering confirmed varietal response to water stress at different periods of plant growth and development. The lines MR 14000-2-10P and MR 14153-3-2P flowered earlier at 32 DAP and 33 DAP, respectively, in stress 0 (no water stress treatment) compared to 29 DAP and 32 DAP, respectively, in stress I (stress from flowering to mid-pod filling), which was 3 and 1 days earlier confirming early phenology under stress (Table 4). Flowering of these lines was not affected by stress II as they had already passed flowering, though the indeterminate tendency in MR 14153-3-2P could be have led to the prolonged days to flowering.

Lines MR 13944-14-9P, CFN 5547 and MR 13944-14-9P, which flowered at, 52, 48 and 48 DAP, respectively, presented late maturing types. Days to flowering averaged 50 DAP under stress 0 and 48 DAP under stress I, again confirming the accelerated phenology as a response to water stress. When water stress was imposed during the period of flowering for these lines, stress II, the effect of water stress in accelerating flowering was further observed with a reduction in days to flowering from 48 DAP under stress I to 44 DAP under stress II; a reduction of 11 days to flowering was observed for MR 13944-14-9P and 5 days for MR 13944-14-9P. The response of CFN 5547, which did not show any effect of the water stress, depicted a different drought tolerance mechanism.

This type of adjustment mechanism to water stress conditions was reported by Sabaghpour et al, (2003), who 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. Gaur et al (2008) associated the rapid adoption of early maturing chickpea in the drought areas of India to their drought escape mechanism. The lines with early maturity would be less vulnerable to terminal drought and hence suited as drought escaping genotypes. Similar results was found by Beaver and Rosas (1998) in their study for drought tolerance in common beans, where selection for earlier flowering in red beans permitted the identification of the bean genotypes with a shorter reproductive period maturing a week earlier without sacrifying yield potential and with a greater rate of partitioning of assimilates.

There was a differential response by lines tested with regard to root length (Table 13). Root length, which could represent the capacity to extract water from the soil mass, was enhanced under stress conditions imposed early (stress I) in the growth and development of the plants, from 27 cm under no stress to 29 cm when stress was early (Table 13). Late maturing lines had higher root elongation than the early ones (averaging 30 cm for the top four late lines compared to 27 cm for the four early ones), but under water stress root elongation was enhanced more in the early ones from 27 cm to 29 cm (8%) compared to an apparent reduction from 30 cm to 28 cm (7%) in the late ones.

The reduction in root length under stress II could be associated with root decay, which affected the recovery of roots; no other plausible reason can be advanced for this reduction.

The elongation in root length in the early maturing lines due to stress imposed during flowering indicates that these bean lines reacted to water stress by diverting assimilates to root development hence the root elongation; a drought avoidance mechanism. Sponchiado et al, (1988) pointed out that drought avoidance through greater root growth can be an important drought tolerance mechanism in common beans, though its usefulness could be limited where soil conditions restricted root growth. The same authors reported that roots of drought tolerant bean lines reached a depth of 1.3 m, while drought sensitive lines only reached 0.8 m.

Similar studies by Kashiwagi et al., (2006), reported that root length especially at the soil depth of 15-30 cm, contributed positively to seed yield under moderate terminal drought intensity and deeper root systems was shown to contribute to improved yield under severe terminal drought conditions. There was no direct relationship that could be established between root length and seed yield in the current study, as lines that had longer roots did not necessarily have high seed yield.

Mean root weights for the lines subjected to water stress at different phenological periods were comparably lower than the root weights under condition where no water stress was imposed (Table 12). Indeed the reduction was different for the different lines.

The differential reduction in root weights by lines signified that while some lines reduced assimilates to root growth, others maintained accumulation of assimilates to the roots when stress was imposed. The root dry weight was decreased due to water stress in sugar beet ((Mohammadian et al., 2005). Similar results were reported in *Populus species* (Wullschleger et al., 2005). The possible reason for the reduction in dry root weight due to severe drought may be due to root shrinkage that consequently affects its growth as well as nutrient transport to the root surface due to reduced contact between root and soil (Munoz-Perea et al., 2006: In North and Norble, 1997).

The highest dry matter was obtained from stress 0 (no water stress treatment), 26% and 22% higher than in stress I and stress II, respectively. The differential response of the lines with regards to dry matter showed virtual no reduction in dry matter for CFN 5547, DOR 390, and MR 13095-6-1P while MR 14140-45-4P, MR 14198-13-1P and MR 14153-3-2P had the highest reductions of 48%, 44% and 36%, respectively.

Dry matter accumulation is directly affected by water stress (Nunez-Barrious, 1991). (Hamid et al, 1990) reported similar results to the current study when water stress was imposed during phenological stage in crop development. Specht *et al.*, (2001) found that there was a reduction in biomass when soya bean was subjected to water stress. The ability to maintain dry matter accumulation under water stress has been associated with drought tolerance in sunflower (Tahir & Mehid, 2001). The responses of CFN 5547, DOR 390, and MR 13095-6-1P in this regard are significant.

5.2 Yield and Yield Components Response to Water Stress

The water stress imposed at different period of the plant growth and development significantly influenced the phenotypic expression of grain yield and its components for the 14 common bean lines tested in the current study (Table 5). These results agree with those reported by Manjarrez-Sandoval et al (1997), who noted that water stress can reduce grain weight by much as 50%.

From stress 0 to stress I pods per plant reduced from 21 to 14 and 100 seed weight dropped from 26 g to 22 g. There was no change in these two yield components from stress I to stress II. Seeds per pod on the other hand remained the same at 6 under all stress periods. The reduction in pods per plant and seed weight was associated with grain yield reduction from 1.2 ton/ha under stress I to 0.7 ton/ha under stress I and 0.4 ton/ha under stress II.

Differential response observed for grain yield suggests that lines responded differently to periods of water stress. The failure of the same lines to respond differently for the yield components suggests that the employed different water stress adjustment mechanisms were not manifested through yield components.

Line DOR 390, a high yield, medium maturing variety, gave the lowest yield reduction from stress 0 to stress I and this is associated with relatively high retention of root weight and dry matter accumulation and enhanced root elongation under water stress. A similar mechanism to responding to water stress was seen with MR 13095-6-1P, a high yielding medium late maturing variety, which retained dry matter and root weight accumulation and enhanced root elongation.

The late maturing line MR 13944-14-9P, similarly a high yielding line, had enhanced root elongation under stress I and dry matter accumulation under stress II, resulting in a low 22% drop in yield from stress 0 to stress II compared to other late lines.

The early maturing lines on the other hand simply had enhanced root elongation under stress I, and the fact that flowering was early thus avoided the full effects of water stress under stress I, with virtually no reduction in yield (Table 7). Together with retention of root elongation under stress I for the early maturing lines, this mechanism enabled the lines to have lower reduction in yields. The phenomenon represented by the performance of MR 14154-4-6P and MR 14000-2-10P, which had 10% and 40% increase in grain yield under stress I compared to stress 0 (no water stress treatment) has been explained by Gaur et al. (2008) whose noted that early maturing varieties under normal irrigation produced low yield due to the excessive vegetative growth.

According to Ramirez-Vallejo and Kelly (1998) a moderate to high drought can reduce biomass of seed, pods, and days to maturity, harvest index, seed yield and seed weight in common beans. Studies by Foster et al, (1995) showed that when beans are grown under moderate stress reduces yield by 41% and as higher as 50-92% yield reduction for the high to severe drought stress condition. This supports the study where in the two water stress periods; the drought effect was more severe in stress II than in stress I where their mean yield reduction was 58% and 34% respectively.

In general lack of water interferes with the normal metabolism of the plant during flowering and grain filling. White and Singh (1991) yield reduction in common beans depends on the type of drought stress. Intermittent drought affects more than 60% of dry bean grown under drought. The reduction in grain yield in dry beans grown under stress is due to excessive abortion of flowers, young pods and seed which occurs during pre-flowering 10-12 days before anthesis and reproductive periods (Munoz-Perea 2006). Also North and Norbel (1997) found that the reduction in yields was due to root shrinkage that consequently affects the nutrients transport to the root surface due to reduced contact between root and soil as a result of drought stress.

Under this study lines MR 14000-2-10P and MR 14153-3-2P flowered earlier than others in such a way they were not affected by drought stress, these lines showed to have a reduced reproductive mechanism and hence can be used in areas experiencing early drought conditions. While the lines CFN 5549 and MR 14144-11-5P which represents the late maturing variety showed to have a lower percentage in yield reduction (18.4% and 11.6% respectively) regardless of the water stress imposed and qualifying as drought tolerant lines. This result conforms to the research findings by Teran and Singh (2002), who found that the genotype 'San Cristobal 83' lengthened its growth cycle under drought with better recovery of yield and identified it as a drought tolerant bean line. Comparing the two stress periods, the yields were reduced more in stress II than that in stress I. The yield reduction in stress I was 34% while in stress II it was 58%, with the mean grain yield of 720 kg/ha for stress I and 432.4 kg/ha in stress II. These results do not conform to the research findings of Munoz-Perea et al. (2006), Singh, (1995), and Teran and Singh (2002) that, a plant water requirements is high during flowering and mid-pod filling.

5.3 Drought tolerance of the lines tested

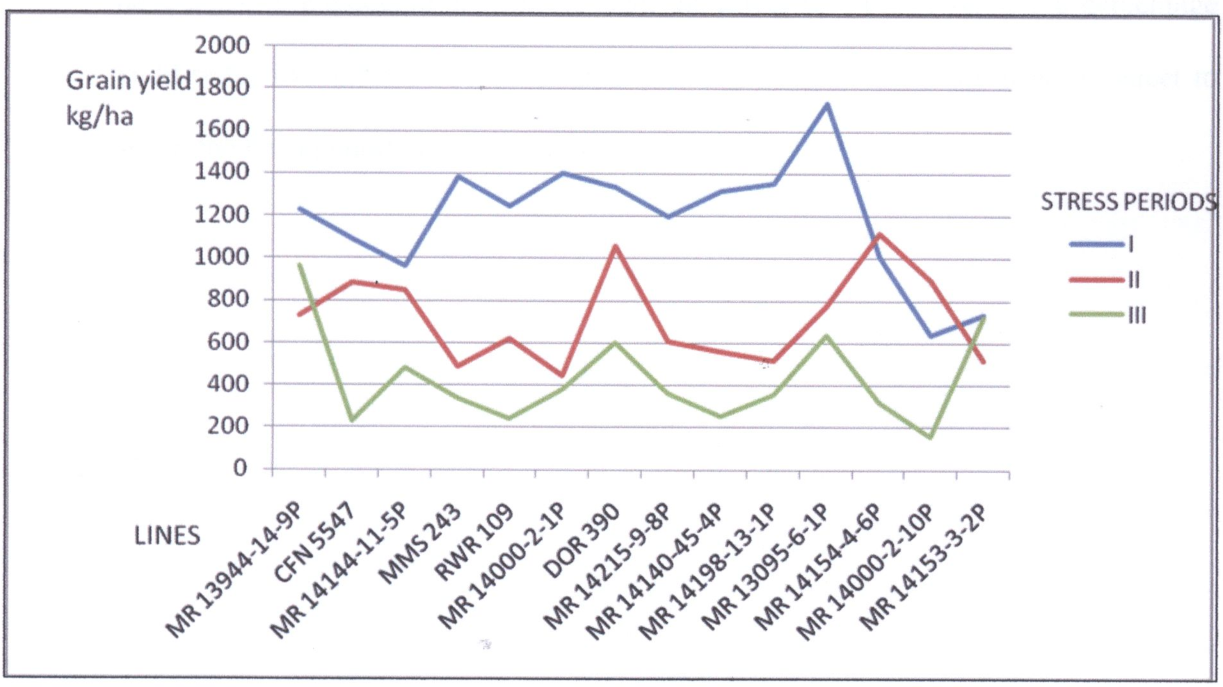
The observed significant interactions between variety and stress period for the grain yield suggest that, varieties responded differently to period of stress for yield. Such differential response is a phenomenon that relates to individual homeostasis in inbreeding populations as explained by Allard and Bradshaw (1964). There is specific buffering arising from different genotypes, which manifests itself as genotype by environment interactions. Under this study the bean genotype MR 14154-4-6P and MR 14000-2-10P yielded higher in stress I while the same line in stress II they yielded lower.

5.3 Drought tolerance of the lines tested

5.3.1 Drought Susceptibility Index

The observed significant interactions between variety and stress period for the grain yield suggest that, varieties responded differently to period of stress for yield. Such differential response is a phenomenon that relates to individual homeostasis in inbreeding populations as explained by Allard and Bradshaw (1964). There is specific buffering arising from different genotypes, which manifests itself as genotype by environment interactions. Under this study the bean genotype MR 14154-4-6P and MR 14000-2-10P yielded higher in stress II while the same line in stress III they yielded lower.

Figure 2: Grain yields of 14 bean genotypes at various stress periods

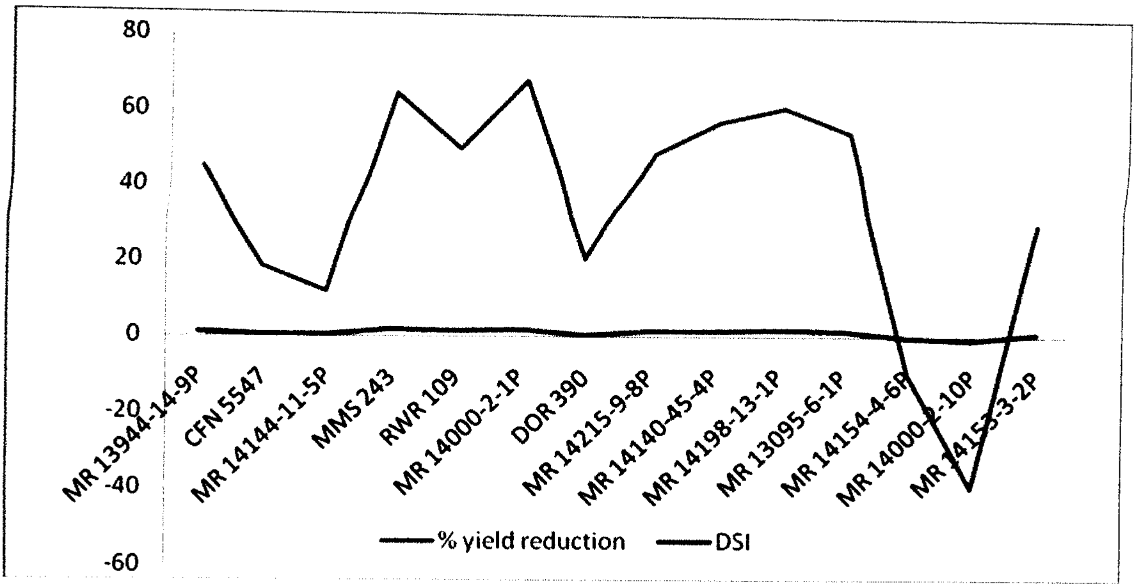


Grain yield is the best indicator for response to varying levels of stress as such lines response to water stress period in this study could be summarized through DSI. DSI measures the

722kg/ha and 485kg/ha respectively and this 'confirms' the above DSI rating and the drought characterization thereof.

The above rating is as to Fischer and Maurer (1978), Positive correlation between seed yield in drought stress and stress environments supported similar findings by Ramirez-Vallejo and Kelly (1998). The similarity in Yielding capacity of the bean lines under drought water stress were taken into consideration in selecting the bean lines into both treatments. According to Teran and Singh (2002) the negative relationship between seed yield in DS would be expected because a higher yield in drought stress result into lower DSI and Percentage yield reduction. Percentage Yield reduction also is used to select the bean lines which are higher yielding as they have a positive association with the DSI, the lower DSI the lower is the percentage yield reduction and vice versa. Due to that any of these traits are used to select to select the bean genotype tolerant to drought.

Figure 3: The relationship between DSI and % yield reduction.



5.3.2 Sensitivity Index

The drought sensitivity index was used to give an extendable opportunity to compare the drought stress and non stress treatments (Fischer and Maurer 1978). As a tool to select the drought tolerant bean line sensitivity index were also used to compare the 14 bean lines grown under drought water stress and non waters stress condition. The lower value of SI means higher tolerance to drought and it has been has been found that sensitivity index has a negative relationship with grain yield. Under this result the SI groups the 14 genotypes into two groups, those with SI value lower than one as a drought tolerant and those with SI value greater than one as a drought sensitive bean lines. The tolerant bean lines in that case were DOR 390 (0.52), CFN 5547 (0.47), MR 14154-4-6P (-0.3), MR 14144-11-5P (0.3), MR 14153-3-2P (0.7), and MR 14000-2-10P (-10) in stress II while the rest were grouped as drought sensitive bean lines (table 14 A). Also two bean lines were grouped as drought tolerant in stress III, these lines were DOR 390 with SI value of 0.85 and MR 14144-11-5P with the SI value of 0.7. The remaining 12 bean lines were grouped as drought sensitive as sensitive as their SI value were greater than 1. This fact is supported also from the results of other studies (Shakhatreh et al., 2001).

The Magnitude of stress for the two stress periods is represented by DII values; Stress period I experienced a severe terminal drought stress with the DII value of 0.64. This stress was more severe than that in Stress III (DII=0.34). This result conforms to other experiments conducted with beans under rain-fed conditions in the Mexican highlands (DII=0.49; Schneider et al., 1997) and under a rain-shelter controlled drought treatment in Michigan (DII=0.63; Ramirezi-Vallejo and Kelly, 1998). Also values for DII between 0.02 and 0.9 have been reported from other production regions (Munoz-Perea, 2006). In general the grain yield was comparatively higher for the non stress treatments than from the two water stress treatments.

DII values obtained in this study for the two water stress will be useful in identifying the bean lines which are suited to specific dry environment. The DII values less than 0.5 hence a milder drought stress may identify different lines as drought resistant for the areas with moderate drought conditions. Among the 14 bean lines used in this study, the means for the 5 bean lines were far higher than the checks (CFN 5547 with 228.1 kg/ha) as twice as much, their means were 962.9 kg/ha, 722.1 kg/ha, 636.0 kg/ha, 604.6 kg/ha and 485.30 kg/ha for MR 13944-14-6P, MR 14153-3-2P, MR 13095-6-1P DOR 390 and MR 14144-11-5P respectively. The means for the rest of bean lines yielded more or less same as checks. Considering the DII value of 0.34 being moderate drought stress condition the five bean lines are suited to the environments.

The DII value in stress I of 0.64 indicates a severe stress condition. Under this Stress period three bean lines were identified to perform very well in a severe drought conditions. Their means for grain yields were higher than their check (CFN 5547) with 887.90 kg/ha). Their means were 1058.9 kg/ha, 1120.2 kg/ha and 897.6 kg/ha for DOR 390, MR 14154-4-6P and MR 14000-2-10P respectively.

CHAPTER 6

6.0 CONCLUSIONS

Bean genotypes showed varied responses to water stress imposed at the two different periods of growth and development. Water stress influenced the expression of the various morphological traits measured and adversely affected root weight, dry matter and grain yield of all genotypes assessed. Water stress enhanced flowering of lines and tended to enhance root elongation. Yields of bean lines declined under water stress but this was at different rates for different lines. This differential response could be related to some morphological traits responses.

Yields of early maturing genotypes were relatively less affected by water stress at any of the periods due to the earlier flowering, thereby escaped the full effects of the stress. This effect was not reflected in the changes in the yield components. MR 14000-2-10P and MR 14153-3-2P showed this particular mechanism of responding to water stress. Medium maturing lines, DOR 390 and MR 13095-6-1P, gave the lowest yield reduction from stress 0 to stress I and this is associated with relatively high retention of root weight, dry matter accumulation and enhanced root elongation under water stress. On the other hand late maturing genotypes, MR 13944-14-9P, and MR 14144-11-5P, responded to water stress in stress II by hastening its phenology (the maturing days) where they matured relatively earlier than in no water stress situation.

Despite the fact that DSI, DII and SI all gave some measure of drought toleranceDSI and SI permitted relating the indices to a particular genotypes or group of genotypes.

DSI was found to be the most reliable index to identify the drought tolerant genotypes as it was able to indicate the genotypes which were highly tolerant, moderate and susceptible to waters stress imposed. Based on the drought indices MR 14154-4-6P, MR 14153-4-2P, MR 14000-2-10P and MR 14144-11-5 were the most drought tolerant genotype(s). These identified bean lines can be recommended to be used in a breeding program.

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