# A STUDY OF THE PHYSIOLOGICAL AND ECOLOGICAL ADAPTATION OF COMMON BEANS (*Phaseolus vulgaris* L.) TO DROUGHT STRESS

BY

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## DECLARATION

I hereby declare that this thesis is my original work and has not been presented for a degree in any other University.

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This thesis has been submitted for examination with our approval as University Supervisors.

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**Second Supervisor**

# DEDICATION

This thesis dedicated to my dearest father ERNEST and mother AMELIA, whose care and love brought me into existence, and my lovely wife EDDY and our two children, whose comfort motivated me to successfully complete this work.

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## ABSTRACT

Two experiments were conducted in the field and one in the greenhouse to study differences in drought response in ten varieties of common beans, collected from different ecological zones. The bean varieties were treated to two watering levels between late vegetative and mid-podding stages. Leaf water and solute potentials were determined using thermocouple psychrometer, while stomatal conductances, transpiration rate and net photosynthetic rates were determined using the infra-red-gas analyzer system. Relative water content, total plant biomass and downward root penetration were also determined.

Varietal differences were observed in leaf water and solute potentials, relative water content, stomatal conductance, transpiration rates, net photosynthetic rates and rates of downward root growth. Ulonzo and White Haricot (both landraces from low rainfall areas) and variety GLP-1004 (developed for low rainfall areas), maintained lower leaf water and solute potentials. However, they had higher stomatal conductances, transpiration rates, net photosynthetic rates, relative water content and rates of downward root penetration than varieties from high rainfall areas.

The study indicated that adaptation to drought stress in common beans is associated with ability to adjust osmotically and rapid downward root growth. The parameters may therefore be used as indicators of drought resistance in beans. Relationship between agroecology and drought resistance was also suggested.

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# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Economic importance of Agriculture in Kenya:

Agriculture is the backbone of Kenya's economy. More than 90% of population live in the rural areas and wholly depend on agriculture for living (Mukunya, et al. 1982). Agriculture contributes about 35% of the total gross domestic product per year and agricultural products constitute 70% of the country's total export (Anonymous, 1985).

National agricultural production in Kenya largely depends on about 21% of the land classified as having high to medium rainfall and to a lesser extent on the vast expanses of land falling in the category of semi-arid comprising more than 78% of Kenya(Mukunya, et al.1982). In the latter areas, total amount, distribution, duration and reliability of rainfall during cropping season are the major limiting factors.

Due to increasing population pressure and subsequent shortage of exploitable land in the high and medium potential areas of the country, the government has been left with two alternatives. One alternative is to increase the productivity of the high potential areas through intensified application of improved technology. The second alternative is to expand and strengthen production currently under small scale agriculture in the medium and marginal potential areas. To achieve increased food production in dryland areas, research is required to identify suitable crop varieties which will maximize

productivity, and thus promote self-sufficiency.
For crops grown in semi-arid regions without irrigation, drought resistant crop varieties should be identified and improved, if sufficiency in food production is to be realized in these areas. Equally important is the development of appropriate technology for crop production in these areas.

## 1.2 Origin, distribution and economic importance of common beans in Kenya

Common beans (*Phaselous vulgaris* L.) is the most widely grown of the four cultivated species of Phaselous from the South America tropics. It is believed to have originated from Mexico and spread to other parts of Europe and Africa (Purseglove, 1968). It is the important grain legume for human consumption in the world. Of the world production of 8.3 million tons (1976-78), 16% is produced in Africa (CIAT, 1968). Bean production is widely distributed in East Africa, being important in all agricultural areas, except at the coast.

In Kenya, common beans are by far the most important pulse crop (Acland,1971) and one of the most important crops grown in the semi-arid areas, although it is also grown in high rainfall areas (Mukunya, et al. 1982). They require moderate rainfall and free draining soils, with reasonably high nutrient content. Beans do not grow well below 600 m above sea level in Kenya as high temperatures cause poor fruit set (Ackland,1971). Furthermore, a combination of high temperatures and excessive moisture predisposes the plants to disease attack. Beans are best suited to the medium altitude areas, from 900-2100 m above sea level,

although they are often found growing at altitude as high as 2700 m above sea level in some parts of Kenya. It is estimated that between 500,000 and 700,000 hectares are covered by common beans annually in Kenya (Anonymous,1989). The 1989 distribution of bean production in Kenya from the major production provinces is presented in Table 1.

Table 1: Areas of bean production in Kenya.

| | Bean Growing Province | |
|---|---|---|
| Item | Central | Eastern |
| Farmed land(ha) | 89600 | 205700 |
| Production(tons | 43820 | 110020 |
| Yield(tons/ha) | 0.49 | 0.53 |

Source: Anonymous, 1989.

The bean growing areas of the Eastern province largely fall in the marginal rainfall areas and thus the low yield per hectare.

As a food crop, beans rank second to maize in Kenya and are grown mainly in intercropping system, by small scale farmers (Anonymous 1985). The per capita consumption of beans has been estimated at 20 Kg. (Mukunya, 1984), so beans have a substantial contribution to the nutritional balance of the diets of millions of Kenyans, whose purchasing power does not allow sufficient consumption of animal proteins.

Common beans, like other members of *Leguminosae*, have Rhizobia in the root nodules, which contribute to the nitrogen nutrition of the bean crop. Thus in intercropping systems involving beans, the other crops in the system benefit from the nitrogen fixed by beans. This is of special importance to small scale farmers, who are often unable to meet the high costs of artificial nitrogen fertilizers.

Recent research work on beans in Kenya has concentrated on improvement for drought resistance, stability of agronomic characters under various agro-ecological zones and disease and pest resistance (Itulya, 1982). Results of primary observation trials with beans in arid and semi-arid areas of Kenya indicate a wide generic variability in drought resistance among unimproved and improved bean cultivars (Mukunya, et al, 1982; Itulya,1982). Selection of plants for yield in various agro-ecological zones, has led to identification of a number of suitable varieties. Varieties Resecoco (GLP-2), Canadian Wonder (GLP-24) and Mwezi Moja (GLP-1004) have been released for high, medium and low rainfall areas respectively. However, the fundamental mechanism

underlying performance of these varieties under drought conditions are poorly understood and therefore, progress in the development of drought resistance bean cultivars has been considerably slow.

## 1.3 Physiological markers for adaptation of plants to drought stress

Adaptation refers to the heritable modifications in the structure or functions that increase the probability of an organism surviving and reproducing in a particular environment (Kramer, 1980). In agronomic terms, drought resistance is the ability of crop plants to give satisfactory yields when subjected to water deficits (Tesha, 1987). Three broad drought resistance mechanisms have been identified namely: dehydration avoidance, dehydration tolerance and drought escape (Turner, 1979). Dehydration avoidance refers to the ability of the plant to endure drought period while maintaining a high water status. Dehydration tolerance is the ability of a plant to endure low rainfall periods at low tissue water potential, while drought escape is the ability of a plant to complete its life cycle before serious soil and plant water deficits develop.

Differences in adaptation to water stress among and within crop species have long been observed and suggested by several researchers. Exploitation of available diversity in plants to select and breed for desirable traits is a method of proven effectiveness and in principle, this method could be used to develop environmentally tolerant crops. However, it is essential to know the traits for which selection is desirable if quick and

accurate results are to be achieved. A common procedure for evaluating drought resistance is to relate yield to a standard cultivar over several years at locations where drought is likely to occur. This process is dependent on year to year changes in weather and is extremely time consuming (Matin, et al. 1989). At the same time, the multitude of factors potentially involved in drought resistance makes it unlikely that any single measurement can provide an all-encompassing test of drought resistance. For example, the variety Mwezi Moja (GLP-1004) was selected for drought escape traits. But recently it has shown to have deep rooting habits, a character which may allow exploitation of more moisture from deeper soil horizons (Tabu, 1988). There are also some indications that the variety GLP-1004 may effect osmotic adjustment in drought conditions (Ouma, 1989). Hence, even though the drought escape characteristics of this variety have been emphasized, the role of other traits cannot be underrated. Deep rooting habit and osmotic adjustment may be the primary factors underlying its good performance under low rainfall conditions, thus drought avoidance playing a major role in the survival of the variety.

There is a need to include eco-physiological studies in bean research so as to identify easily monitored physiological indices that can be used in bean improvement for dry areas. The literature on this topic which has been reviewed by Boyer (1982) indicates that selection based on physiological parameters should lead to quick results. While the ability of a plant to acquire water and continue to operate physiologically under drought conditions is important, the ability of the plant to regulate its

water losses through physiological processes such as transpiration is equally desirable, as long as productivity is not seriously affected. Therefore, parameters related to plant water status should receive priority in an attempt to identify physiological markers for drought resistance. Boyer, et al. (1980) observed that high evaporative demands around midday caused water stress in soybeans and the newly developed high yielding soybean hybrids generally had a higher midday water potential compared to the older lower yielding hybrids. They concluded that development of high yielding soybean hybrids generally had higher midday water potential compared to the older lower yield hybrids. They concluded that development of high yielding soybeans could have been rapid, had plant breeders of the earlier days bred selectively against low midday water potential. That selection based on plant water status can be effective and rapid, has been demonstrated in field experiments by Meyer and Boyer (1972) and Greasen and Oh (1972). They independently showed that plants can compensate osmotically for the onset of dryness in soils to maintain growth. Similar results were also reported by Boyer (1982). Morgan (1977) found that wheat cultivars selected for osmotic adjustment outyielded conventionally grown cultivars by 100% under dry conditions.

Whereas total water potentials of plant tissues may differentiate between drought resistant and susceptible cultivars (Cortes and Sinclair, 1986; Novero, et al. 1985), leaf relative water content (RWC) has been suggested as a better indicator of water status than leaf water potential because RWC is less sensitive to water stress than leaf water potential (Sinclair and

Ludlow, 1985 and Bennett, et al. 1987). Other techniques suggested for drought screening include, root length and rooting depth (Sullivan and Ross, 1979; Bennett, et al. 1981; Robertson, et al. 1985 and Cortes and Sinclair 1986) and leaf conductance (Sojka, et al. 1979; Clarke and McCraig, 1982). This suggests that physiological knowledge has a tremendous impact on crop improvement in arid areas and many physiological characters may be involved in drought resistance.

In this study an experiment was conducted to study the differences in plant water status in different cultivars of common beans. The starting hypothesis was that through natural and farmers' selection, beans have adapted to the rainfall ecozones in which they are traditionally grown, so that differences in plant water status would be indicative of adaptive trends.

The Objectives of the study were:

(i) to investigate the difference in drought resistance among the selected common bean cultivars.

(ii) to explore the relationship between the drought resistance of these cultivars and the rainfall pattern in the area of cultivation.

(iii) to study the fundamental mechanism and basis of adaption of common beans to drought stress.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Effect of water stress on plant growth and development

Most aspects of plant growth and development are sensitive to water stress (Hsiao, 1973) and the worldwide losses in yield from water stress probably exceeds the losses from all the other causes combined (Kramer, 1980; Schonfeld, et al. 1988). Drought causes water deficits, which characteristically reduce cell turgor causing closure of stomata and reduction in cell enlargement, thereby reducing both the leaf surface area and the rate of photosynthesis per unit of leaf area. In cases of severe plant water deficits, photosynthetic machinery is damaged leading to further reduction of the rate of photosynthesis per unit area hence the final yield (Kramer, 1980; Makhart, 1985).

Limited literature is available to explain the effect of water stress on plant development. Lawn (1982) reported rapid maturity with *Vigna* species whereby crop duration was reduced by 12 and 28%. The effect was small in soybeans and blackgrams, only reducing the duration of flowering. In beans, pod formation was reported to commence one week earlier in variety GLP-1004 under low irrigation regime (Ouma, 1988). In ecological terms, such developmental plasticity facilitates the matching of crop growth and development to the constraints of the environment, especially in terms of minimizing the occurance of the critical reproductive phase during drought periods (Lawn, 1982). Fast development may

allow the successful completion of the plants' life cycle before the existing soil water supply is exhausted, although the ultimate yield potential of the crop may be reduced.

Leaf area, the main photosynthetic surface of the plant has been reported to be affected most by water stress (Coulson, 1982; D'Souza, 1985; Cruz, et al. 1986). The effects generally take the form of reduced leaf expansion and accelerated leaf senescence (Muchow, et al.1986). Drought adapted bean cultivars, however, have been reported to maintain higher leaf area than drought susceptible cultivars under drought conditions (Makhart, 1985).

Water stress depresses dry matter production in most crop plants (Coulson, 1982; D'Souza, 1985; Garrity, et al.1984; Muchow, et al. 1986; Cruz, et al. 1986; Nyabundi and Hsiao, 1989). However less effect on shoot biomass have been reported in drought resistant cultivars (Makhart, 1985; Lorens, et al. 19870. Ouma (1988) observed that besides the drought adapted bean variety GLP-1004 maintaining a higher leaf area index (LAI) and more effective leaves than the drought susceptible variety GLP-2 during the senescence phase, it also had higher total dry matter and pod formation. Although both leaf stem and pod dry weight declined under water stress in both varieties, the drought adapted GLP-1004 performed better than the drought susceptible variety GLP-2.

This literature suggests that leaf area development, dry matter accumulation rate and possibly phenology of the plant may be used as morphological indices for adaption to drought stress.

## 2.2 Effect of water stress on leaf water potential

The flow of water from the soil to the atmosphere via the plant is driven by a water potential gradient between the leaf and the soil. The magnitude of the water potential gradients depend on the relative rates of water absorption from the soil and water loss from the leaf. Evaporation from the leaf lowers leaf water potential and this change is transmitted via the xylem to the root and hence to the soil. Water deficit leads to fall in leaf water potential. This has been reported in blackgram, greengram, cowpeas and soybeans (Lawn, 1982), common beans (Flores-Lui 1984; Masumba, 1984; Ouma, 1988), cowpeas and sugar beet (McCree and Richardson, 1987).

Research has indicated that differences exist within and between species with respect to reduction in leaf water potential due to drought stress, such that leaf potential is now commonly used as a measure of plant water status. A study by Lawn (1982) indicated that soybean had the lowest leaf water potential value compared to cowpeas, backgram and greengrams, tested under the same stress treatments. Vignes, et al.(1986) also reported that the soybean cultivar which yielded high under drought conditions was also able to tolerate low water potential. With common beans, a drought resistant variety maintained higher leaf area index (LAI) and biomass accumulation, although such a variety had lower leaf water potential under water stress conditions (Ouma, 1988). Other studies with peanuts (*Arachis hypogeae L.*) also demonstrated similar findings (Bennett, et al. 1981). In winter wheat, low leaf water potential was noted to be strongly associated with high yield (Winter, et al. 1988). Since no

differences were observed in total water extraction, it was concluded that the superior variety was drought tolerant and tolerated lower leaf water potential in order to retain green leaves (Winter, et al. 1988). The more drought resistant hybrid maize varieties maintained higher leaf water potentials than the drought susceptible varieties. This was due to the ability of drought resistant maize varieties to utilize water from deeper rooting zones (Ackerson, Makhart, 1985). Parjon, et al.(1979), Laing, et al.(1983) and Lorens, et al.(1987) also associated the maintenance of higher leaf water potentials with the ability of roots to penetrate deeper soil horizons to tap available moisture under limited moisture conditions. More drought resistant lines of barley (Hanson, et al.1977), rice (Novero, et al. 1985) and soybeans (Cortes and Sinclair,1986), have been shown to maintain higher leaf water potentials under water stress conditions. Matin, et al.(1989) confirmed similar results in barley and suggested that one time measurement of pre-dawn water potential was not adequate to separate cultivars within resistant and susceptible groups or even clearly between groups due to inconsistencies.

The general consensus among researchers is that water stress reduces leaf water potential, but whether drought resistant cultivars maintain higher or lower leaf water potentials than susceptible ones, is still debatable. This may be due to the fact that leaf water potential is also determined by the efficiency of the plant roots to absorb water from the soil and sensitivity of the stomata to plant water stress. The latter may continue to open, increasing water loss, thus lowering water potentials but

the plant adjust osmotically, so that physiological activity is maintained. Alternatively the stomates may close as a response to moisture stress in the soil and thus maintain a high leaf water potential at the expense of carbon gain. The response to stress that includes keeping stomates open and adjusting osmotically will not necessarily result in a greater carbon gain than the alternative response of closing stomates and maintaining high leaf water potential (McCree and Richardson, 1987). Furthermore, plants that keep their stomates open at low water potentials must exhaust any available soil water quicker than plants that do not. This may tend to nullify any advantage conferred by osmotic adjustments, If it is combined with lack of stomatal closure. Irrigation cycle on the other hand contributes to the nature of responses of particular plant material: plants often develop adaptive mechanisms when water stress is gradually introduced, such that large differences in irrigation levels in the field or longer irrigation cycles in the greenhouses may not detect any difference in adaptation mechanisms among the tested materials (Nyabundi, 1985).

These factors contribute greatly to the complex nature of responses to drought stress and hence the continued debate on the nature of drought resistance in different crops.

## 2.3 Effect of water stress on transpiration rate and stomatal conductance.

When the water is not limiting and prior to the establishment of a complete crop canopy, transpiration rates

relative to the evaporation potential have been observed to be approximately proportional to the square root of the LAI for cotton and sorghum (Ritchie and Burnett,1971). After an effective cover is completely developed and the stomata are fully open, transpiration rate is determined by the available energy. However, as soil water potential decreases and water becomes limiting, actual evapotranspiration rates eventually fall below potential rates. This increased resistance to transpiration is probably caused by a reduction in stomatal aperture due to changes in internal plant water balance (Kanemasu and Turner, 1969; Jarvis and Slatyer 1970). Although other mechanisms have been proposed, concrete relationship between the degree of stomatal opening, transpiration rates and plant water status have not been well defined, especially under water stress conditions.

Millar and Gardener (1972) reported a rapid decline in transpiration rate in snap beans, with decreasing leaf water potentials beyond -8 bars. Similar reductions in transpiration rates with reduction in water status have been reported by other workers in cowpeas, soybeans, greengrams and backgrams (Lawn, 1982), common beans (Masumba, 1984), cowpeas and sugarbeet (McCree and Richardson,1987). However, Coulson (1982) and Ouma (1988) reported lack of significant reductions in transpiration rates to water stress.

Information on varietal differences in transpiration rate under conditions of water stress have been variable, probably due to the complexities in the mechanisms which different plants use to maintain tissue water status when moisture stress increases. Masumba(1984) working with *Phaseolus vulgaris* and *Phaseolus*

*acutifolius* Gray under field conditions found that the most drought resistant P. acutifolius had the lowest transpiration rate at all irrigation levels. Similar findings were also reported by Makhart(1985) who concluded that the lowest transpiration rate of *P. acutifolius* was due to its stomatal responsiveness to environmental conditions compared to *P. vulgaris*. However no significant differences in transpiration rates were observed among the two *P. vulgaris* cultivars tested under field conditions by Coulson (1982) and Ouma (1988).

Stomatal closure, which reduces fluxes of both $CO_2$ and water vapor, is a common response to water stress. Alternatively, the stomates may maintain turgor through osmotic adjustment and remain open (McCree and Richardson, 1987). Previous research has clearly established that severe plant water deficits lead to decreased stomatal conductance. However, little data exist to describe stomatal response during relatively mild water deficits, especially under field conditions (Bennett, et al. 1987). Reduction in stomatal conductance as result of water stress has been reported by Turk and Hall (1980), Ackerson (1981), Sionit, et al.(1984), Makhart (1985) and Bennett, et al. 1987).

Interspecific differences have been observed among the legumes tested under drought stress, with stomatal conductance being consistently higher in soybeans, lower in cowpeas and intermediate in blackgrams and greengrams (Lawn, 1982). McCree and Richardson (1987) reported minimal stomatal closure in sugarbeet plants compared to cowpeas which closed stomata earlier as soil water deficits developed under field conditions.

Varietal differences in stomatal conductance have been

reported in a number of crops. For example, drought resistant sorghum varieties were noted to have medium to low leaf diffusion resistance by Blum (1974) under conditions of water stress. High stomatal conductance in drought susceptible cultivars of field beans has been observed throughout the warmer period of the day (Laing, et al.(1987) attributed the high grain yield of drought resistant hybrid of maize to the ability of that variety to maintain lower leaf diffusive resistant under severe water stress. In barley, measurements of leaf diffusive resistance separated the cultivars between resistant and susceptible groups for both low and high stressed plants (Matin, et al. 1989). Jones (1977) also observed some differences between spring wheat cultivars but the relationship changed with plant age. Similar observations were reported in wheat (Sojka et al. 1981, Clarke and Mc Craig,1982). Lack of significant differences in terms of stomatal conductance have been observed in beans under field conditions (Coulson, 1984 and Ouma, 1988) and in wheat (Winter, et al. 1988).

Plants of the same genotypes have been observed to behave differently depending on the environments where they are being tested. Whereas stomatal resistance increased sharply in cotton plants tested in the greenhouse when leaf potential was decreased to -16 bars, the stomatal resistance remained low for the field grown plants even at a leaf water potential of -27 bars (Jordan and Ritchie,1971). Greenhouse grown plants wilted at leaf water potentials near - 15 bars, while no wilting was observed in the field grown plants of cotton (Jordan and Ritchie, 1971; Ackerson, 1981). This suggests the possibility for modifications

of stomatal response to water stress caused by slow and prolonged exposure to drought conditions in the field (Ackerson, 1981; Nyabundi, 1985). Higher sensitivity in the greenhouse compared to the field conditions were also observed in legumes by Lawn (1982).

The literature suggests that stomatal responses may undergo modifications under water stress conditions to play a major role in the regulations of plant water status. These modifications may be important in certain species or varieties only but not as important as in others. It may also be assumed that, depending on how the drought stress was imposed, stomates can adjust themselves to play a major role in the regulation of plant water status. Otherwise, it is still not clear whether or not stomatal conductance and transpiration rate can be employed accurately and efficiently to screen all plant materials for drought resistance, both under field and greenhouse conditions.

## 2.4 Effect of water stress on relative water content (RWC)

The importance of water for the maintenance of turgidity for plant growth and/or survival is widely recognized. It has been observed that drought resistant plants have smaller water deficit per unit decrease in leaf water potential than drought susceptible plants (Winter, et al. 1988). It would be expected that under non-stressed conditions, relative water content (RWC) of the plant would be near 100% (Fully turgid) and thus water potential values approach zero. As water stress in a plant increases, both RWC and leaf water potential would be expected to decrease. Literature indicates that stressed plants usually

show lower RWC compared to non-stressed plants (Bennet, et al. 1987; Schonfeld, et al. 1988; Matin, 1989).

Relative water content has been used in several studies to distinguish between drought tolerant and drought susceptible plants. Drought tolerant wheat cultivars have been reported to maintain higher RWC under water stress conditions (Clark and McCraig, 1982; Schonfeld, et al. 1988). Similar results have also been reported in barley by Matin, et al.(1989). Drought resistant cultivars would conserve higher water status by either closing their stomates after enough stress have developed and opening stomata as stress ceases for photosynthetic activity or by adjusting osmotically (Bennett,et al. Schonfeld, et al. 1988). Alternatively, the ability of the drought adapted variety to root deeper in the soil horizon and extract more water may help maintain high RWC of the plant and thus photosynthetic activity without a significant reduction in stomatal conductance and transpiration rates (McCree and Richardson, 1987).

Leaf relative water content was proposed as a better indication of water status than waterpotential because RWC, through its relationship to cell volume could more closely reflect the balance between water supply to the leaf and transpiration rate. It has also shown to be inherently a more stable value than the thermodynamic components, namely, water potential, solute potential and turgor potential (Sinclair and Ludlow, 1985). However, Bennett, et al. 1987) found that, although the variability in RWC as compared to its means was much less than the thermodynamic measure of leaf water status, RWC was not found to have a clear association with changes in stomatal

conductance. The lower coefficients of variation (Cvs), however, agreed with the suggestion that RWC might be more stable than the thermodynamic components of leaf water.

Recently, Schonfeld, et al.(1988) reported that the slope of the decline in relative water content was substantially greater for drought susceptible cultivars than for the drought resistant cultivars of winter wheat. The phenotypic distribution in the $F_2$ and the backcrosses indicated that RWC was quantitatively inherited and not under the control of one or a few major genes. This was supported by the high $h^2$ for RWC, which was higher for RWC than that for yield indicating the higher stability of RWC as compared to yield. Further observations suggest that RWC was usually significantly higher in resistant cultivars after the development of enough plant stress, to result in plant diffusive resistance of about 1000 sm-1. Thus, although RWC may be a dependable indicator of drought resistance, decision on when the measurements should be taken is critical if reliable results are to be achieved (Matin, et al.1989).

## 2.5 Importance of rooting depth on water stress development

Preferential development of roots over shoots under drought stress is an adaptive mechanism that enables the crop to explore a greater soil volume of water. If soil water is available at low depths, the development of a deep root system would be a useful adaptive feature to drought conditions (Jordan and Miller, 1980; Passioura, 1982).

Soybean root growth shows a significant response to drought stress, and under drought conditions soybean roots grow slowly

in the surface layer and more rapidly in the deeper, wetter soil layers (Mayaki, et al.1976; Garay and Wilhelm, 1983). Robertson, et al.(1980) observed that total soybean root growth was not affected by various drought stress and irrigation treatments, although root length distribution was different. Non-irrigated treatments, produced more roots in the deeper parts of the soil profile. In cotton, it has been demonstrated that the maximum root absorption rate occurred below the main rooting zone. This allowed the crop to continue extracting water from the deeper soils and thus transpire continuously during periods of prolonged drought (Jordan and Ritchie, 1971). Such continued extraction of water from the soil by the cotton plants may be associated with the failure of stomates to close completely in response to low leaf water potentials.

Varietal differences in root densities at all depths in soybeans has been observed by several researchers who associated it with more water extraction (Boyer, et al.1980; Kasper, et al. 1984; Huck, et al. 1983). Cortes and Sinclair (1986) reported differences in the rooting depth of irrigated and non-irrigated soybeans. In this study, the deepest rooting non-irrigated plants had higher root dry matter than the shallow-rooting non-irrigated plants. Significant genotypic differences in rooting depth have also been reported in cowpeas (Robertson, et al.1985).

Drought resistance of certain bean genotypes has been associated with their deep rooting ability (Laing, et al. 1983 Makhart, 1985; Ouma, 1988; Tabu, 1988). Sponchiado, et al. (I989) reported that in fertile Mollisols the roots of the drought tolerant lines reached a depth of 1.3m, while those of drought

sensitive lines only reached 0.8m. These differences were associated with differences in the seed yield, crop growth and soil moisture extraction. Drought avoidance through greater root growth and extraction of soil moisture appeared to be an important drought tolerance mechanism in this study. Winter wheat cultivars differed in root length but not in rooting depth. Therefore, rooting depth was ruled out as a selection technique for drought resistance in wheat (winter, et al. 1988). Rooting characteristics have also been shown to be an important drought avoidance mechanism in peanuts (*Arachis hypogeae L.*) (Bennett, et al. 1981).

It is believed that more extensive rooting habit is likely to be superior as long as the soil is deep enough, the soil profile is adequately replenished with water from each cropping season and advantage gained from the increased root growth more than offsets the expenses of its growth. If in contrast, the depth of soil profile is limited, then slow early water use characteristics may be preferred over the rooting depth characteristics (Robertson, et al. 1985).

## 2.6 Drought resistance as related to leaf water potential, stomatal conductance, transpiration rate, relative water content and rooting depth

It has been reported that although specific and varietal differences exists in terms of drought resistance, no single vegetative or physiological variable can alone be reliably utilized to assess cultivar performance under drought conditions. A combination of physiological indicators must be employed

(Sammons, et al. 1979; Ekanayake, et al. 1985).

A qualitative model of plant water status was outlined as a simple mass budget equation:

W = (G + E) + H; where W is water status of the plant, G is water gained by absorption, primarily through the roots, E is water lost (transpired through the leaves) and H is water stored within the plant (Gary, et al. 1975). During daylight hours, E normally exceeds G, resulting in progressive decrease in W, a situation termed "water deficit", until deficit induced stomatal closure retards transpiration. At night, stomatal closure and reduced atmospheric demand for water retards E and thereby allowing residual energy gradients within the plant to equilibrate (Gary, et al. 1975).

To quantify the response of stomata with changes in plant water status, researchers have attempted to relate stomatal conductance (or resistance) to the thermodynamic state of leaf water. Yet, to-date, there is no consensus on the utility of these water relation parameters as drought resistance selection criteria (Schonfeld, et al. 1988). Bates and Hall (1981) reported a substantial decrease in leaf conductance in droughted cowpea (*Vigna unguiculata* L.) plants without changes in bulk leaf water potential. That the decline is stomatal conductance was independent of leaf water potential in cowpeas was also reported by Osunubi (1985). Mild soil dehydration, which resulted in decreases in stomatal conductance for maize and cowpeas, could neither be statistically associated with measures of bulk leaf water status. Only when including data collected from plots subjected to severe soil dehydration were significant

correlations obtained among stomatal conductance, leaf water potential, solute potential, turgor potential and RWC. The changes in stomatal conductance without significant reductions in water status parameters in mild dehydration treatments was associated with significant reduction in leaf areas of individual plants and crop growth (Bennett, et al. 1987). In peanuts (*Arachis hypogeae* L.). neither bulk leaf water potential nor turgor potential were initially changed when stomatal conductance began decreasing in response to soil water deficits (Black, et al. 1985).

Generally, a linear relationship is reported, which only appears when data from severely dehydrated plants with low stomatal conductance and water potential values are combined with data from more adequately watered plants (Bennett, et al. 1987). The general conclusions thus suggest that stomatal conductance reduces only after a threshold leaf water or turgor potential is attained (Baldochi, et al. 1985; Makhart, 1985). However, leaf water potential continued to fall in sugarbeet throughout the dry cycle without fall in stomatal conductance, indicating a minimal amount of stomatal closure in some species even under severe drought conditions (McCree and Richardson, 1987). Carters and Sinclair (1986) associated maintenance of turgor and drought tolerance in soybeans with the preservation of high leaf water potential and not the ability to decrease osmotic potential. They thus associated high leaf water potential with aspects of roots to grow into wetter portions of the soil as well as the resistance to water flow between the bulk soil and the vascular system of the roots.

A consequence of osmotic adjustment, is the tendency for greater leaf dehydration or RWC and increase in cell water volume and solute concentration, which combine to determine solute potential (Morgan, 1984). Therefore, if leaves from two geneotypes have the same solute potential, but differ in RWC, it may be inferred that greater solute accumulation and osmotic adjustment occurred in the genotype with higher RWC (Schonfeld, et al. 1988). It was reported that a drought resistant variety of wheat maintained higher RWC, retained chlorophyll for longer duration and recorded higher grain yield under water stress. However, the test varieties did not differ significantly in terms of stomatal conductance, suggesting that higher RWC was due to osmotic adjustment (Schonfeld, et al. 1988).

Ouma (1988), reported the lowest leaf water potential with the drought adapted variety of bean under water stress condition, although the same variety had higher final seed yield than the drought susceptible variety under all irrigation regimes. No significant differences were observed in stomatal conductance and transpiration rates. The better performance of the drought adapted variety was attributed to its ability to maintain guard cell turgidity through solute accumulation or ability to tap water from deeper soil layers.

Evidence exists which suggests that varietal differences in drought tolerance do occur in common beans among other crops. Although common beans are not indigenous to Kenya, they have been cultivated in Kenya for many years, resulting in development of local cultivars, through natural and deliberate selection by farmers. It is conceived that such selection has favoured the

accumulation of adaptive characters and genetic resistance to physical stress, including drought. Since rainfall is a major limiting factor in the arid and semi arid areas of Kenya, common bean genotypes that have adapted to such areas must have specific mechanisms of sustaining productivity under such low rainfall conditions. Environmentally determined physiological adaptation has been reported among plant species. For example, Bjorkman (1980) showed that plants from high temperature regions exhibited higher optimal temperature for photosynthesis. This may also occur in common beans with respect to drought stress and knowledge of the mechanisms involved is of paramount importance.

# CHAPTER THREE

## 3.0 MATERIALS AND METHODS

Three experiments two in the field and one in the greenhouse were carried out at the University of Nairobi's Faculty of Agriculture farm, Kabete. The farm is located on latitude $1^0$ 15' south and longitude $36^0$ 44' east. The altitude of Kabete is 1800 metres above seal level. The soils are humid nitosols, well drained, very deep, dark reddish brown to dark red, friable clay with acid humic top soils, developed from Limuru Trachyte (Michieka, 1977). The average annual rainfall about 1000 mm with a mean monthly maximum temperature of $23^0$C and a minimum of $12^0$C.

### 3.1 Field Experiments

Ten common bean genotypes (Table 2), collected from low (Ulonzo, Pinto, GLP-1004, White Haricot and Zebra bean) and high (Rosecoco, Pocho, Local II, Okuodo and GLP-2) rainfall areas of Kenya were used. Of the ten genotypes, GLP-2 and GLP-1004 have been developed for high and low rainfall areas respectively and the rest are unimproved landraces. One experiment (Experiment 1) was conducted to study varietal differences in leaf and solute potentials, stomatal conductances, transpiration rates, net photosynthetic rates and total plant biomass. The other experiment (Experiment 2) was aimed at studying varietal differences in downward root growth.

#### 3.1.1 Field Experiment - 1

This was conducted between early January, 1990 and mid-

e 2: Summary of information on the ten bean varieities indicating the source of the materials and the characteristics of the agrocological zones in which they are traditionally grown

| ety | Source | Agroeco-logical zone | Days to 50% Flowe-ring | 60% Rel. Rainfal | | 60% Rel. of Growing Period | | Annual Mean Tempe-rature (°C) |
|---|---|---|---|---|---|---|---|---|
| | | | | 1st Rains (mm) | 2nd Rains (mm) | 1st Rains (mm) | 2nd Rains (mm) | |
| 1004 (M/ | Recommended LP | - | 30 | 150-200 | 280-350 | 45-55 | 75-85 | 21.4-18.2 |
| ızo | Kitui | LM4 | 34 | 150-200 | 280-350 | 45-55 | 75-85 | 21.4-18.2 |
| o | Thika | UM4 | 30 | 300-350 | 180-200 | 105-115 | 75-85 | 20.7-19.9 |
| a bean | Taitta-Taveta | LM5 | 30 | 200-250 | 160-200 | 55-75 | 45-55 | 23.5-22.4 |
| e Haricot | Taitta-Taveta | LM5 | 35 | 200-250 | 140-200 | 55-75 | 45-55 | 23.5-22.4 |
| coco(Meru) | Meru | UM3 | 31 | 250-400 | 250-450 | 75-115 | 75-115 | 19.3-18.0 |
| 2 ccoco) | Recomme-nded (H-P) | - | 33 | 480-650 | 300-500 | 155-165 | 80-90 | 22.7-22.0 |
| ıo | Siaya | LM3 | 29 | 480-650 | 300-500 | 155-165 | 80-90 | 22.7-22.0 |
| l II | Siaya | LM3 | 34 | 480-650 | 300-550 | 155-165 | 80-90 | 22.7-22.0 |
| ıdo | Kisumu | LM3 | 37 | 450-650 | 350-500 | 155-175 | 75-106 | 22.7-21.0 |

ce: Jaetzold, R. and H. Schmidt (1982)

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LM = Low Midland Zone

UM = Upper Midland Zone

LP = Low Potential

HP = High Potential

April, 1990. The mean maximum and minimum temperatures during the course of the experiment were 23.5$^0$ C and 13.7$^0$ C respectively. The total rainfall was 319 mm, while total evaporation (measured using Class 'A' pan) was 302 mm. Weekly rainfall and evaporation are attached (Appendix 1). The experimental site was previously planted with *Zea mays*.

The bean varieties were subjected to two watering levels (High and Low) in a split plot design with three replications. The two irrigation level constituted the main treatments (main plots) and the bean collections formed the sub-treatments (sub-plots). Each subplot measured 3 x 4 m$^2$. Irrigation water was applied using a line-source sprinkler irrigation system, which provided a moisture gradient,. decreasing with increase in distance from the sprinkler line (Hanks, et al. 1976). The sprinkler line was laid at the edge of the plots so that only one side of the sprinkler throw was used. In this way, differences in wind drift effect were avoided and uniform water distribution ensured. The irrigation interval was initially seven days. However, it was observed that there was not enough water stress in the low water treatments and thus irrigation interval was extended to 10 days. Irrigation was carried out early in the morning when wind speed was minimal and amount of water applied in each irrigation was determined by evaporation in the preceeding week as determined from the class 'A' pan. The latter was located in an agro-meteorological station, about 300 m from the experimental site. High irrigation treatment received an amount of water equivalent to the weekly evaporation while the low irrigation treatment was controlled by the distance from the

sprinkler line. Thus, high irrigation treatments receive a total of 544 mm of water while the low irrigation treatment received a total of 322 mm of water for the whole experimental period.

Cultivation was done to attain appropriate tilths and planting furrows marked at a spacing of 50 cm. Diammonium phosphate (DAP) fertilizer, 18:46:0, N, $P_2O_5$ and $K_2O$ respectively was applied pre-planting along the furrows, at the rate of 200 kg DAP per hectare. Bean seeds were dusted with Malathion 5% at the rate of 10 g per kg of seed to control cutworms and beanfly (*Melanogromyza spp.*) and planted at an intra-row spacing of 10 cm. Two seeds were sown per hill but the crop was later thinned to one plant per hill seven days after emergence. Starting from one week after emergence, the young seedlings were sprayed with Dimethoate (dimethyl-S-(N-Methylcarbomethyl)-phosphorothiol-thionate), 40% EC at the rate of 1 litre in 500 litres of water per hectare to control beanfly (*Melanogromyza spp.*) on the aerial parts of the plants. This was done at weekly intervals up to flowering stage. After flowering Cypermethrin, a synthetic pyrethroid, was sprayed at weekly interval, at the rate of 100 ml per 20 litres of water to control flower eating insects. One day after every spray of insecticides, Benomyl (Methyl-N)-(1-butylcarbomoyl-2-benzimidazole)-carbomate) was sprayed at the rate of 20 g per 20 litres of water to control bean rust (*Uromyces phaseoli*) and other fungal diseases. Weeding was done manually to keep the field clean. No weeding was done after prodding.

The leaf parameters measured include leaf water potential, leaf solute potential, leaf stomatal conductance and leaf

transpiration rate. These parameters were determined at 35 and 40 days after emergence (DAE) of beans. Net photosynthetic rate and total plant biomass were also determined at flowering.

3.1.1.1 Leaf water potential

Measurements of leaf water potential were done on the centre leaflet of the youngest, well exposed and fully expanded trifoliate, on clear sunny days. Measurements started 21 days after emergence and due to frequent weather variations at Kabete, measurements were done only when the weather was favourable. Three plants were randomly selected per subplot and small discs were obtained from three centre leaflets of each plant using a 12 mm cork borer. Immediately, the leaf discs were placed in the sample chamber of the thermocouple psychrometer (Wescor, C-52, Crump Scientific Products, U.K.) connected to the HR-33T dew point Microvoltmeter (Wescor Inc. London). The discs were left in the sample chamber for 15 minutes to equilibrate, before the readings were obtained. Each reading was calibrated to standard temperature ($25^0$ C) and then calibrated for chamber differences. The final readings were recorded as leaf water potential in bars at $25^0$ C.

3.1.1.2 Leaf solute potential

Readings for leaf solute potential were also obtained from the centre leaflets of the youngest, well exposed and fully expanded trifoliate on the clear sunny days starting from 48 days after emergence. However, rains started unexpectedly early and thus measurements were recorded only from the high water subplots. Three centre leaflets were detached from the three

plants and then squeezed to obtain the sap enough to fully wet three standard 12 mm paper discs. Immediately, the paper discs were placed in the sample chamber of the thermocouple psychrometer (Wescor, C-52, Crump Scientific Products Ltd., UK) connected to the HR-33T dew point Microvoltmeter (Wescor Inc.) for 15 minutes equilibration, after which the readings were taken. Each reading was then calibrated to standard temperature ($25^0$ C) and for sample chamber differences before recording the final reading in bars at $25^0$ C.

3.1.1.3 Stomatal conductance, transpiration rate and photosynthetic rate

These measurements were obtained from the $3m^2$ area on either side of the central 4 $m^2$ left for final yield determination. The measurements were taken on the middle leaflet of the youngest, fully expanded and well exposed leaf using a closed system infra-red-gas-analyzer (Analytical Development Co. Ltd. Herts). This measured the percent relative humidity, reference $CO_2$ concentration, photon flux density, chamber air temperature and differential $CO_2$ concentration. From the above measurements, net photosynthetic rate, stomatal conductance and transpiration rates were calculated. Care was taken to avoid those plants earlier sampled for leaf water and solute potentials. Plants used for measurements were earlier tagged to eliminate the leaf age effect. Three readings were taken from each subplot on clear sunny days.

3.1.1.4 Total Shoot biomass

Biomass was determined at flowering stage. Three plants per subplot were randomly sampled from the 3 $m^2$ area on either side of the central 4 $m^2$ left for yield determination. The plants were cut at ground level, washed under tap water and dried in an oven at 70$^0$ C for 24 hours to constant weight. After this, the dry weight was recorded.

3.1.2 Field Experiment - 2

The beans were planted towards the end of the long rains, in late May, 1990 and terminated in early August, 1990. Mean maximum and minimum temperatures were 21.8$^0$ C and 18.9$^0$ C respectively. Total rainfall during the course of the experiment was 123 mm. No recordings were available for evaporation as the class 'A' evaporation pan was out of order. The experimental site was previously planted with Amaranthus. The experiment was designed as completely randomized Block Design (CRBD) replicated three times and the ten bean varieties formed the only treatments. Each plot consisted of 6 rows, 50 cm apart with an intrarow placing of 10 cm. The field was cultivated to appropriate tilth and then two trenches one 30 cm deep and the other 40 cm deep were manually opened in each plot using a hand hoe. The trenches were located along the second row from either side of each plot. This left two unaffected rows between the two trenches. At the bottom of each trench, a herbicide Metribuzin (4-amino-6-(1-dimethylethyl)-3-(Methylthio)-1, 2,4-triazin-5(4h)-one), was dusted uniformly to cover the whole width of the trench. The trenches were then covered with soil which had been dug out. Gentle compaction was done until all the soil was

returned and the trench filled to surface level. Beans were then planted at a depth of approximately 3 cm in the herbicide bearing rows and the other four rows in each plot.

The herbicide was chosen basing upon the greenhouse experiments, which indicated that, Metribuzin consistently produced distinctive symptoms in leaves at low concentration and was not expected to persist in the field beyond one growing season. Leaf symptoms expression have been observed to be consistently the same over different plant materials and time. Bioassays of soil samples showed persistence of herbicide activity throughout the season and lack of vertical movement of the herbicide during the growing season (Robertson, et al. 1985). No irrigation was done. Fertilization, weeding and insect and disease control was carried out as in field experiment 1.

The plant leaves were observed and the time of appearance of herbicide sysmpotms noted in each plot. Differences among plants in time of development of symptoms were assumed to indicated differences in either the rate of root extension or density of roots at a given depth. The variable used for analysis was the mean time (n), in number of days from planting, at which 50% of the plants in the plot developed the herbicide symptoms. Number of plants developing herbicide symptoms each day were recorded and plants tagged to eliminate ambiguity due to other sources of kill, particularly insect attack. Average root growth rate (cm/day) was then estimated.

### 3.2 Greenhouse Experiment

This was conducted to study leaf water potential, leaf

solute potential, leaf stomatal conductance, transpiration rate, net photosynthetic rate and leaf relative water content in seven of the ten bean varieties listed in Table 2 namely GLP-1004, Pinto, White Haricot, GLP-2, Local II and Okuodo. The experiment was conducted between mid-February, 1990 and mid-May, 1990. Mean maximum and minimum temperatures in the greenhouse were 32.0$^{0}$ C and 21.8$^{0}$ C respectively. Plants were grown in pots filled with soil.

A split plot design with three replications was adopted. Two watering levels (High and low) formed the main treatments while the seven bean cultivars formed the sub-treatments.

Each pot was filled with 12 kg of field soil. Four bean plants belonging to one variety were grown in each pot. In each replication there were two pots for each bean variety; one for high and the other for low water level. Pots for high water level were packed in one main plot and for low water level in the other. Application of water was done such that the high water level treatment was kept well watered throughout the growing season. The low water level treatment was not watered until some varieties (usually GLP-2 and Okuodo) started showing wilting symptoms. The total amount of water applied was 532 and 182 mm for high and low water treatments respectively. The irrigation cycle varied overtime. It was longer early in the growing season, and became shorter as the plants because larger. Fertilization and pesticide applications were done as in field experiment I.

The parameters measured include leaf relative water content, leaf water potential, leaf solute potential, leaf stomatal conductances and leaf transpiration rate. Net photosynthetic

rates were also determined at flowering. No plant biomass sampling was done in the greenhouse due to limited plant sample.

Relative water content values were determined as described by Bennet, et al. (1987). The readings were obtained from young, fully expanded trifoliate. Three plants were selected in a pot. leaf discs were collected, one from each of the three plants, avoiding major veins. The discs were excised using 12 mm diameter cork borers. Immediately the discs were placed in a vial and taken to the laboratory where their fresh weights were determined. The discs were then returned into the vial, the vial filled with distilled water and covered tightly with a parafilm. The samples were then placed in a dark refrigerator maintained at approximately $5^0$ C. After 16 hours, the discs were removed, blotted gently between filter papers and then weighed to determine the turgid weight. The discs were then oven dried (at $70^0$ C) and dry weight obtained. Relative water content (%RWC) was then determined as:

$$\%RWC = \frac{\text{Fresh weight - Dry Weight}}{\text{Turgid weight - Dry weight}} \times 100\%$$

RWC for each variety was computed as a mean of three replications.

Other parameters namely leaf water and solute potentials, stomatal conductances, transpiration rates and photosynthetic rates were determined as in field experiment 1.

3. Data Analysis

The data collected in all the experiments were analyzed using 'INSTAT', a statistical package of the BBC microcomputer (Statistical Service Centre, University of Reading, 1985) to obtain treatment means, analysis of variance and correlations between the measured parameters.

# CHAPTER FOUR

## 4.0 RESULTS

### 4.1 Varietal differences in leaf water potential

The performance of the ten bean cultivars tested under the field conditions in shown in Table 3. Ulonzo and White Haricot (from dry areas) maintained the lowest leaf water potential values under low irrigation treatment followed by GLP-1004 (Mwezi Moja). Ulonzo and White Haricot did not differ significantly from each other, but both differed significantly from GLP-1004 (Mwezi Moja). Rosecoco (Meru) from wet areas and GLP-2 (Rosecoco), maintained significantly higher leaf water potential values under low irrigation treatment. The other cultivars were in between. Under high irrigation treatment, White Haricot had significantly lower leaf water potential values, followed by GLP-1004 (Mwezi Moja). Varieties GLP-2 (Rosecoco) and Local II (from wet areas) had significantly higher leaf water potential values than others.

In the greenhouse trial, the mean leaf water potential for the beans from the dry areas given low water level treatment was in the order GLP-1004 > Pinto > White Haricot (Table 4). Variety GLP-2 (Resecoco) and Okuodo (from wet areas) maintained significantly higher leaf water potential values under low water level treatment. Under high water level treatment, White Haricot had significantly lower water potential, followed by Ulonzo, although the two were not significantly different from each other. Varieties GLP-1004 (Mwezi Moja) and Pinto (from dry areas) followed and were not significantly different from each other. Okuodo maintained significantly higher leaf water potential,

followed by Local II and GLP-2 (Rosecoco). In both the field and greenhouse experiments, water level treatments were significant.

e 3: Varietal differences in leaf water potential for ten bean varieties, as tested in the field 35 and 40 days after emergence (DAE)

| ety | Leaf Water Potentia * (Bars) | | | |
|---|---|---|---|---|
| | High water level | | Low water level | |
| | 35DAE | 40DAE | 35DAE | 40DAE |
| dry areas: | | | | |
| 100 (M/Mo,ja) | -8.33b | -10.89b | -9.41bc | -11.54b |
| ızo | -6.84cd | -9.22c | -10.53a | -13.47a |
| o | -7.13cd | -10.57c | -9.63b | -11.47b |
| ·a bean | -6.99cd | -8.76f | -10.01ab | -11.54b |
| e Haricot | -9.33a | -11.15a | -10.33a | -13.55a |
| wet areas: | | | | |
| ·coco (Meru) | -6.45de | -8.76f | -8.43d | -9.29d |
| -2 (Rosecoco) | -5.76e | -7.27g | -7.42e | -9.23d |
| ıo | -7.22c | -9.08e | -10.00b | -11.11bc |
| ıl II | -4.82f | -7.10g | -9.09c | -10.52c |
| ›do | -7.97b | -10.24d | -9.53b | -11.43b |
| (%) | 5.88 | 1.35 | 3.30 | 1.39 |

erage of three replications. Mean separation by DMRT at 5% level each column, means followed by the same letter are not significantly ferent (DMRT 5% level).

able 4: Varietal differences in leaf water potential of seven bean varieties as tested in the greenhouse 35 and 40 days after emergence (DAE)

| Variety | Leaf water potential * (Bars) | | | |
|---|---|---|---|---|
| | High Water Level | | Low Water Level | |
| | 35DAE | 40DAE | 35DAE | 40DAE |
| From dry areas: | | | | |
| GLP-1004 | -8.53bc | -9.75 | -9.04bc | -9.06c |
| Alonzo | -9.01ab | -8.64b | -11.38a | -11.32a |
| Pinto | -8.42bc | -8.94ab | -9.49b | -10.72b |
| White Haricot | -9.33a | -9.56ab | -9.62b | -10.75b |
| From wet areas: | | | | |
| GLP-2 (Rosecoco) | -9.01ab | -8.16c | -8.21d | -8.07d |
| Local II | -7.92c | -8.84abc | -8.54c | -9.22c |
| Okuodo | -8.31c | -6.88c | -8.04c | -8.52d |
| CV(%) | 4.09 | 5.63 | 4.48 | 3.07 |

*Average of three replications.

Mean separation by DMRT at 5% level

In each column, means followed by the same letter are not significantly different (DMRT 5% level)

## 4.2 Varietal differences in solute potential

Table 5 indicates that Ulonzo maintained consistently and significantly lower solute potential under high water treatment in the field. This was followed by White Haricot and then GLP-1004 (Mwezi Moja) and Pinto (all from dry areas). However, Ulonzo and White Haricot were not significantly different from each other. Variety GLP-2 (Rosecoco) had significantly higher solute potential followed by Local II (from wet areas) under similar irrigation treatment. Varietal differences were also observed in the greenhouse (Table 6). Under low water treatment, Ulonzo and White Haricot had the lowest solute potential values which were not significantly different from each other. They were followed by GLP-1004. Variety GLP-2 (Rosecoco) had significantly higher values of solute potential, followed by Okuodo. A similar trend was also observed under high water treatment.

Table 5: Varietal differences in leaf solute potential of ten bean varieties as tested in the field 52 and 58 days after emergence (DAE)

| Variety | Leaf Solute Potential * (Bars) | |
|---|---|---|
| | High Water Level | |
| | 52 DAE | 56 DAE |
| From dry areas: | | |
| GLP-1004 (M/Moja) | -14.74ab | -13.83b |
| Ulonzo | -15.11a | -14.81a |
| Pinto | -13.71bc | -13.31c |
| Zebra Beans | -12.70cd | -13.91b |
| White Haricot | -15.09a | -14.45a |
| From wet areas: | | |
| Rosecoco (Meru) | -12.77cd | -10.96c |
| GLP-2 (Rosecoco) | -9.75f | -11.16d |
| Pocho | -12.46d | -13.14c |
| Local II | -11.57e | -10.95d |
| Okuodo | -10.89e | -10.93d |
| CV(%) | 5.06 | 2.30 |

*Average of three replications.

Mean separation by DMRT at 5% level

In each column, means followed by the same letter are not significantly different at % level.

Table 6: Varietal differences in leaf solute potential in the greenhouse 35 and 40 days after emergence

| Variety | Leaf Solute Potential * (Bars) | | | |
|---|---|---|---|---|
| | High Water Level | | Low Water Level | |
| | 35 DAE | 40 DAE | 35 DAE | 40 DAE |
| From dry areas: | | | | |
| GLP-1004 (M/Moja) | -9.42ab | -9.06bc | -11.02b | -10.01b |
| Ulonzo | -9.61a | -9.73a | -11.80a | -11.05a |
| Pinto | -8.85c | -8.77c | -10.17d | -10.31b |
| White Haricot | -9.23b | -9.29b | -11.68a | -11.21a |
| From wet areas: | | | | |
| GLP-2 (Rosecoco) | -8.23b | -9.30d | -8.22f | 8.82c |
| Local II | -8.88c | -8.90bc | -10.64c | -10.04b |
| Okuodo | -8.49d | -9.04bc | -9.07e | -9.27c |
| CV(%) | 1.17 | 2.6 | 1.30 | 3.10 |

*Average of three replications.

Mean separation by DMRT at 5% level.

Various means followed by the same letters in a column are not significantly different (DMRT 5% level).

## 4.3 Varietal differences in Stomatal conductance

Varietal differences in stomatal conductances were observed in the field experiment. White Haricot and Ulonzo had consistently and significantly higher mean stomatal conductance values and the two were not significantly different from each other both under low and high water treatments. Varieties GLP-2 (Rosecoco), Okuodo and Pinto has significantly lower values under low water treatment and the two cultivars did not differ significantly from each other. Under high water treatment, GLP-2 (Rosecoco), Rosecoco (Meru) and Okuodo had significantly lower values (Table 7).

Table 8 suggests that Ulonzo and White Haricot had the highest stomatal conductance values followd by Pinto. Variety GLP-1004 (Mwezi Moja) had significantly lower values followed by GLP-2 (Rosecoco) and Okuodo both under low and higher water treatments.

7: Varietal differences in stomatal conductance of ten bean varieties as tested in the field 30 and 42 days after emergence (DAE)

| ty | Stomatal Conductance * ($mMoIm^{-2}S^{-1}$) | | | |
|---|---|---|---|---|
| | High Water Level | | Low Water Level | |
| | 30 DAE | 42 DAE$^{ns}$ | 30 DAE | 42 DAE |
| dry areas: | | | | |
| 004 (M/Moja) | 298.0a | 571.0 | 173.7b | 604.1c |
| o | 313.7a | 613.7 | 394.7a | 759.7b |
| ) | 167.0c | 563.0 | 250.0ab | 775.0b |
| Bean | 245.0ab | 395.7 | 203.0b | 395.7d |
| Haricot | 319.0a | 581.7 | 256.7ab | 682.0a |
| wet areas: | | | | |
| coco (Meru) | 266.0ab | 318.3 | 266.7ab | 336.7e |
| (Rosecoco) | 154.0c | 334.0 | 292.7ab | 400.7d |
| ) | 260.0ab | 354.7 | 177.7b | 707.0bc |
| II | 188.0bc | 361.7 | 165.0b | 551.3cd |
| do | 122.0c | 329.3 | 199.7b | 391.7d |
| ) | 18.3 | 33.1 | 32.4 | 16.4 |

rage of three replications.

separation by DMRT at 5% level.

not significant.

es followed by the same letter in a given column are not significantly

erent (DMRT ad 5% level)

8: Varietal differences in stomatal conductance of ten bean varieties as tested in the greenhouse 30 and 40 days after emergence (DAE)

| ty | Stomatal Conductance *($mMolm^{-2}S^{-2}$) | | | |
|---|---|---|---|---|
| | High Water Level | | Low Water Level | |
| | 30 DAE | 40 DAE$^{ns}$ | 30 DAE | 40 DAE |
| dry areas: | | | | |
| 1004 (M/Moja) | 95.0c | 114.0 | 128.7c | 380.7bc |
| to | 415.7a | 121.3 | 592.0b | 801.0a |
| o | 211.3b | 120.3 | 866.0a | 482.0bc |
| e Haricot | 343.3a | 146.3 | 657.3ab | 862.0a |
| wet areas: | | | | |
| 2 (Rosecoco) | 107.0c | 118.3 | 510.0b | 566.7b |
| . II | 157.3bc | 120.7 | 450.7b | 509.3bc |
| do | 165.7bc | 116.7 | 527.3b | 283.0c |
| | 20.8 | 18.2 | 22.5 | 21.8 |

rage of three replications.

separation by DMRT at 5% level

not significant

e column means followed by the same letters are not significant

erent (DMRT at 5% level)

### Varietal differences in transpiration rates

In the field experiment, White Haricot and Ulonzo had the highes
anspiration rate values under low water treatment, followed by GLP-100
ich was not significantly different from either White Haricot or Ulonzo
uodo had the lowest transpiration rate values followed by GLP-
osecoco) under the same water treatment. Under high water treatment, th
an transpiration rates were in the order White Haricot > Ulonzo > GLP
01 > Zebra bean > Pocho > Local II > Pinto > GLP-2 > Okuodo (Table 9)

In the greenhouse, White Haricot and Ulonzo had the highes
anspiration rate values under low water level treatment, although the tw
ultivars did not differ significantly. Variety GLP-2 had the lowe
anspiration rate values and it was not significantly different from GL
04 (Mwezi Moja) under similar treatment of water. Under high water lev
eatment, Ulonzo and White Haricot had the highest transpiration ra
lues and the two were not significantly different from each other. Loc
l, Okuodo and GLP-2 had the lowest values and were not significant
fferent from each other. However, 40 days after emergence, there were
gnificant differences among the bean cultivars both for the high and l
ter treatments (Table 10).

Table 9: Varietal differences in Transpiration rate of ten bean varieties as tested in the field 30 and 42 days after emergence (DAE)

| | Transpiration Rate * ($mMolm^{-2}S^{-1}$) | | | |
|---|---|---|---|---|
| | High Water Level | | Low Water Level | |
| | 30 DAE | 42 DAE | 30 DAE | 42 DAE |
| From dry areas: | | | | |
| GLP-1004 (M/Moja) | 6.37ab | 4.93ab | 5.03e | 4.10de |
| Ulonzo | 6.47ab | 5.00a | 7.57a | 5.87ab |
| Pinto | 5.47de | 4.07abc | 5.67abc | 5.67abc |
| Zebra Bean | 5.67bcd | 4.17def | 6.13bcd | 3.17e |
| White Haricot | 7.10a | 4.60bc | 6.50bc | 6.17a |
| From wet areas: | | | | |
| Rosecoco (Meru) | 6.03bcd | 4.03ef | 6.90ab | 4.67cd |
| GLP-2 (Rosecoco) | 4.70ef | 4.40bc | 6.37bc | 5.00bcd |
| Pocho | 5.67cd | 3.50g | 6.20bcd | 5.80ab |
| Local II | 5.57cd | 4.37cdc | 5.73cde | 5.23abc |
| Okuodo | 4.20f | 3.97f | 5.33de | 4.60cd |
| CV (%) | 7.8 | 11.4 | 9.5 | 11.6 |

*Average of three replications.

Mean separation by DMRT at 5% level.

In a column, means followed by the same letter are not significantly different (DMRT 5% level).

e 10: Varietal differences in transpiration rate of seven bean varieties as tested in the greenhouse 30 and 40 days after emergence

| iety | Transpiration Rate *(mMolm$^{-2}$ S$^{-1}$) | | | |
|---|---|---|---|---|
| | High Water Level | | Low Water Level | |
| | 30 DAE | 40 DAE$^{ns}$ | 30 DAE | 40 DAE$^{ns}$ |
| m dry areas: | | | | |
| -1004 (M/Moja) | 3.47c | 4.03 | 3.67d | 5.27 |
| nzo | 5.97a | 4.57 | 6.37ab | 6.23 |
| to | 4.63b | 4.23 | 5.97b | 5.00 |
| te Haricot | 5.53a | 4.63 | 6.60a | 6.40 |
| m wet areas: | | | | |
| -2 (Rosecoco) | 3.27c | 4.10 | 5.30c | 6.17 |
| al II | 4.27b | 4.10 | 5.20c | 5.90 |
| odo | 4.50b | 3.87 | 5.30c | 5.67 |
| (%) | 7.4 | 9.1 | 5.5 | 17.2 |

erage of three replications.

an separation by DMRT at 5% level.

= not significant

a column, means followed by the same letter are not significantly fferent

## 4.5 Varietal differences in leaf relative water content

Varietal differences were observed among the tested bean cultivars in terms of RWC in the greenhouse. In general, the RWC values for both treatments decreased with increasing days after emergence (DAE). The RWC for bean given low water treatment was in the order Ulonzo > GLP-1004 > White Haricot > Pinto > Local II > Okuodo > GLP-2 (Rosecoco). (Table 11). Under high water treatment, Ulonzo had significantly hinger RWC followed by White Haricot and GLP-1004 (Mwezi Moja) which did not differ significantly. Okuodo had significantly lower RWC values followed by GLP-2 (Rosecoco). However, 56 days after emergence, the varieties did not differ significantly in the high water level treatment (Table 11).

e 11: Varietal differences in leaf relative water content (RWC) of seven bean varieties as tested in the greenhouse 52, 54 and 56 days after emergence (DAE).

| iety | Relative Water Content (RWC) (%) | | | | | |
|---|---|---|---|---|---|---|
| | High Water Level | | | Low Water Level | | |
| | 52 DAE | 54 DAE | 56 DAE$^{ns}$ | 52 DAE | 54 DAE | 56 DAE$^{ns}$ |
| **m dry areas:** | | | | | | |
| -1004 (M/Moja) | 85.63b | 88.10ab | 76.53 | 79.47b | 76.13b | 72.30b |
| nzo | 92.10a | 91.70a | 80.33 | 83.53a | 84.10a | 77.00a |
| to | 79.37c | 85.23bc | 76.27 | 77.67bc | 74.83b | 73.83ab |
| ite Haricot | 85.60b | 88.53ab | 79.60 | 78.87bc | 75.77b | 72.40b |
| **m wet areas:** | | | | | | |
| P-2 (Rosecoco) | 77.97c | 83.30c | 73.63 | 70.23d | 71.13b | 70.20bc |
| cal II | 83.93b | 82.00cd | 79.07 | 76.80c | 74.33b | 70.43bc |
| uodo | 79.27c | 78.40d | 73.07 | 71.17d | 70.17b | 67.27c |
| (%) | 2.83 | 2.59 | 9.16 | 1.71 | 4.30 | 3.24 |

verage of three replications

ean separation by DMRT at 5% Level.

s - not significant

n a column, means followed by the same letter, are not significantly ifferent (DMRT 5% level)

## .6 Varietal rooting characteristics

The tested varieties differed in terms of the mean number f plants which showed herbicide symptoms at different depths of erbicide placement (Table 12). Plants in 30 cm herbicide lacement plots developed symptoms and died sooner than those in he 40 cm herbicide placement plots (Table 12).

In the 30 cm herbicide placement plots, Pocho had consistently higher mean number of plants showing herbicide symptoms, followed by Ulonzo, GLP-1004 (Mwezi Moja) and then hite Haricot. Pinto had consistently lower mean number of plants showing herbicide symptoms then Zebra bean, Okuodo and Local II Table 12). In the 40 cm herbicide placement plots, Ulonzo had consistently higher mean number of plants showing herbicide symptoms followed by GLP-1004 (mwezi Moja) and then Pocho. Pinto ad consistently the lowest mean numbers followed by Okuodo and hen Zebra Bean (Table 12).

As in the case of plants showing herbicide symptoms, the ean varieties differed in terms of mortality and root growth ates (Table 13). In 30 cm depth of herbicide placement, Pocho ad the lowest mean number of days to 50% mortality followed by lonzo and then White Haricot, GLP-1004 (Mwezi Moja) and Rosecoco Meru). Pinto had the highest mean number of days to 50% rtality then Zebra bean and Okuodo. At 40 cm depth, Ulonzo and LP-1004 (Mwezi Moja) had the lowest mean number of days to 50% rtality followed by White Haricot and Rosecoco (Meru). Pinto ad the highest number of days then Okuodo, Local II and GLP-2 osecoco).

However, GLP-1004 (Mwezi Moja) indicated the highest average
t growth rate followed by Ulonzo and then Pocho. Varieties
-2 (Rosecoco) and Local II indicated the lowest average root
wth rate and next was Okuodo. The rest were intermediate.

12: Genotypic means of the number of plants (n)* which showed herbicide symptoms from the 5th to 10th week after emergence (WAE) at different depths of herbicide placement, under field conditions

| y | 30 cm DEPTH | | | | 40 cm DEPTH | | | |
|---|---|---|---|---|---|---|---|---|
| | Weeks After Emergence | | | | | | | |
| | 5 | 6 | 8 | 10 | 5 | 6 | 8 | 10 |
| dry areas: | | | | | | | | |
| 004 (M/Moja) | 54c | 89b | 95b | 99a | 27b | 56a | 71ab | 77c |
| o | 66b | 89b | 93c | 98ab | 29a | 57a | 72a | 85a |
| | 21h | 40h | 46j | 67g | 4h | 11g | 34h | 47g |
| Bean | 38f | 53g | 67i | 79f | 8g | 25e | 59d | 66d |
| Haricot | 51d | 88b | 89d | 97b | 11f | 39c | 59d | 66d |
| wet areas: | | | | | | | | |
| coco (Meru) | 52d | 77c | 87e | 94c | 11d | 39c | 70b | 82b |
| 2(Rosecoco) | 34g | 63d | 75f | 83d | 13e | 28d | 48e | 54e |
| o | 70a | 92a | 97a | 100a | 15c | 46b | 68c | 74c |
| l II | 38f | 59e | 69h | 81e | 16d | 29d | 46f | 54e |
| do | 40e | 56f | 72g | 82de | 5h | 18f | 44g | 52f |
| ) | 5.8 | 5.5 | 3.3 | 2.1 | 19.2 | 7.6 | 4.1 | 4.7 |

rage of three replications. Mean separation by DMRT at % level.

column, means followed by the same letter are not significantly erent (DMRT 5% level)

3: Mean number of days to 50% mortality+ and estimated average root growth rates for the ten bean varieties as tested in the field

| y | Days to 50% mortality | | Difference (days) | Average Root growth rate (cm/day) |
|---|---|---|---|---|
| | 30 cm Depth | 40 cm Depth | | |
| dry areas: | | | | |
| 004 (M/Moja) | 35 | 42 | 7 | 1.43a |
| o | 34 | 42 | 8 | 1.25b |
| | 58 | 66 | 12 | 0.83d |
| Bean | 42 | 54 | 12 | 0.83de |
| Haricot | 35 | 49 | 14 | 0.71e |
| were areas: | | | | |
| coco (Meru) | 35 | 49 | 14 | 0.71e |
| 2 (Rosecoco) | 37 | 58 | 10 | 0.48f |
| o | 32 | 42 | 10 | 1.00c |
| l II | 37 | 58 | 21 | 0.48f |
| do | 40 | 58 | 18 | 0.56f |
| l) | | | | 12.0 |
| | 38.5 | 51.8 | 13.7 | 0.83 |

tality refers to plants dying or showing herbicide symptoms.

separation by DMRT at 5% level.
a column, means followed by the same letter are not significantly
ferent (DMRT 5% level).

## 4.7 Net photosynthetic rate and total plant biomass at flowering stage

Mean total biomass per plant recorded when all the varieties were flowering was highest for Ulonzo followed by Pinto and then White Haricot. Local II had the lowest total biomass per plant followed by Okuodo and then GLP-2. However, there was no significant difference among the tested varieties (Table 14). Ulonzo also recorded the highest net photosynthetic rate under field conditions. Next was GLP-1004 (Mwezi Moja) and White Haricot, which were not significantly different. Variety GLP-2 (Rosecoco) had the lowest net photosynthetic rate and then Rosecoco (Meru), Local II and Okuodo, which were not significantly different from each other (Table 14). Under greenhouse conditions, Ulonzo had significantly higher net photosynthetic rate, followed by Pinto and then White Haricot. Okuodo had the lowest net photosynthetic rate followed by GLP-1004 (Mwezi Moja) and Local II, which did not differ significantly (Table 14).

Table 14: Relationship between total plant biomass, leaf water potential and net photosynthetic rates at flowering stage, under low water level*

| Variety | FIELD EXPERIMENT | | | GREENHOUSE EXPERIMENT | |
|---|---|---|---|---|---|
| | Biomass$^{ns}$ (g/plant) | Water Potential (Bars) | Photosynthetic Rate ($Umolm^{-2}S^{-1}$) | Water Potential (Bars) | Photosynthetic rate, ($Umolm^{-2}S^{-1}$) |
| From dry areas: | | | | | |
| GLP-1004 | 10.03 | -9.41bc | 22.26ab | -9.04bc | 16.3d |
| Ulonzo | 11.06 | -10.53a | 23.26a | -11.38a | 19.43a |
| Pinto | 11.02 | -9.63b | 19.60de | -9.49b | 18.12b |
| Zebra Bean | 9.42 | -10.01ab | 19.68de | - | - |
| White Haricot | 10.62 | -10.33a | 21.18bc | -9.62b | 17.15c |
| From wet areas: | | | | | |
| Rosecoco (Meru) | 9.46 | -8.43d | 18.39e | - | - |
| GLP-2 | 9.37 | -7.42e | 18.17e | -8.21d | 16.59cd |
| Pocho | 10.09 | -10.00ab | 20.82c | - | - |
| Local II | 6.85 | -9.09c | 18.66c | -8.54c | 16.95cd |
| Okuodo | 9.59 | -9.53b | 19.26e | -8.40c | 16.29d |
| CV(%) | | 3.3 | 4.0 | 4.5 | 2.3 |

* - Mean of three replications. Mean separation by DMRT at 5% level.
ns = not significant
In a column, means followed by the same letter are not significantly different (DMRT 5% level)
- No observation

Regression and correlation analysis revealed a non-significant linear correction between total plant biomass per plant and leaf water potential at flowering (r = 0.386). However, when total plant biomass values were transformed logarithmically, a significant linear correlation was obtained (r = 0.679*) (Figure 1)., indicating a logarithmic relationship between total plant biomass per plant and leaf water potential under field conditions. A significant linear correlation was observed when leaf water potentials were related to net photosynthetic rate (r = 0.724*) (Figure 2). Under greenhouse conditions, a highly significant linear correlation was observed between leaf water potentials and net photosynthetic rate (r = 0.89**), (Figure 3).

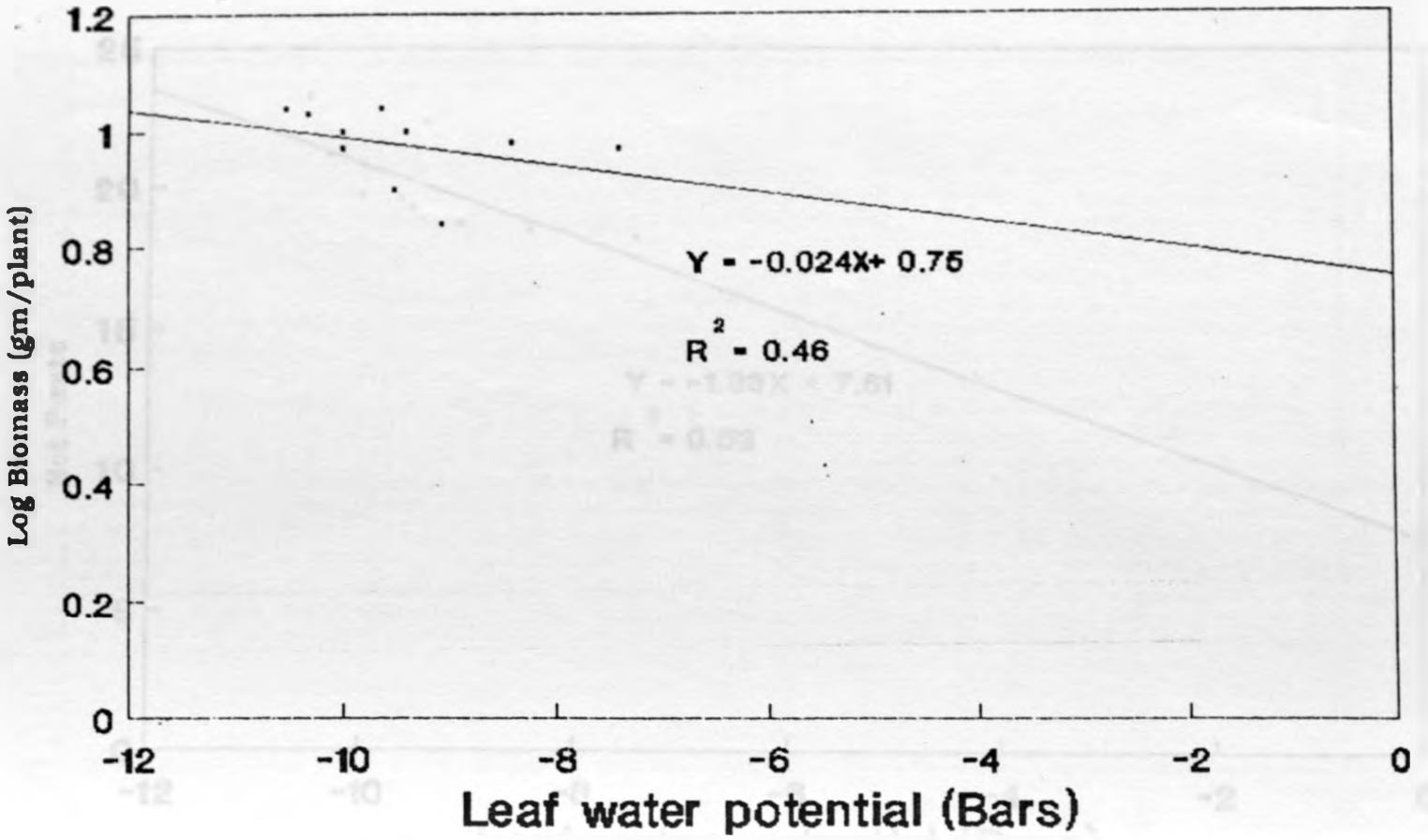


Figure 1: **Relationship between total biomass and leaf water potentional at flowerin stage under low warer level in the field**

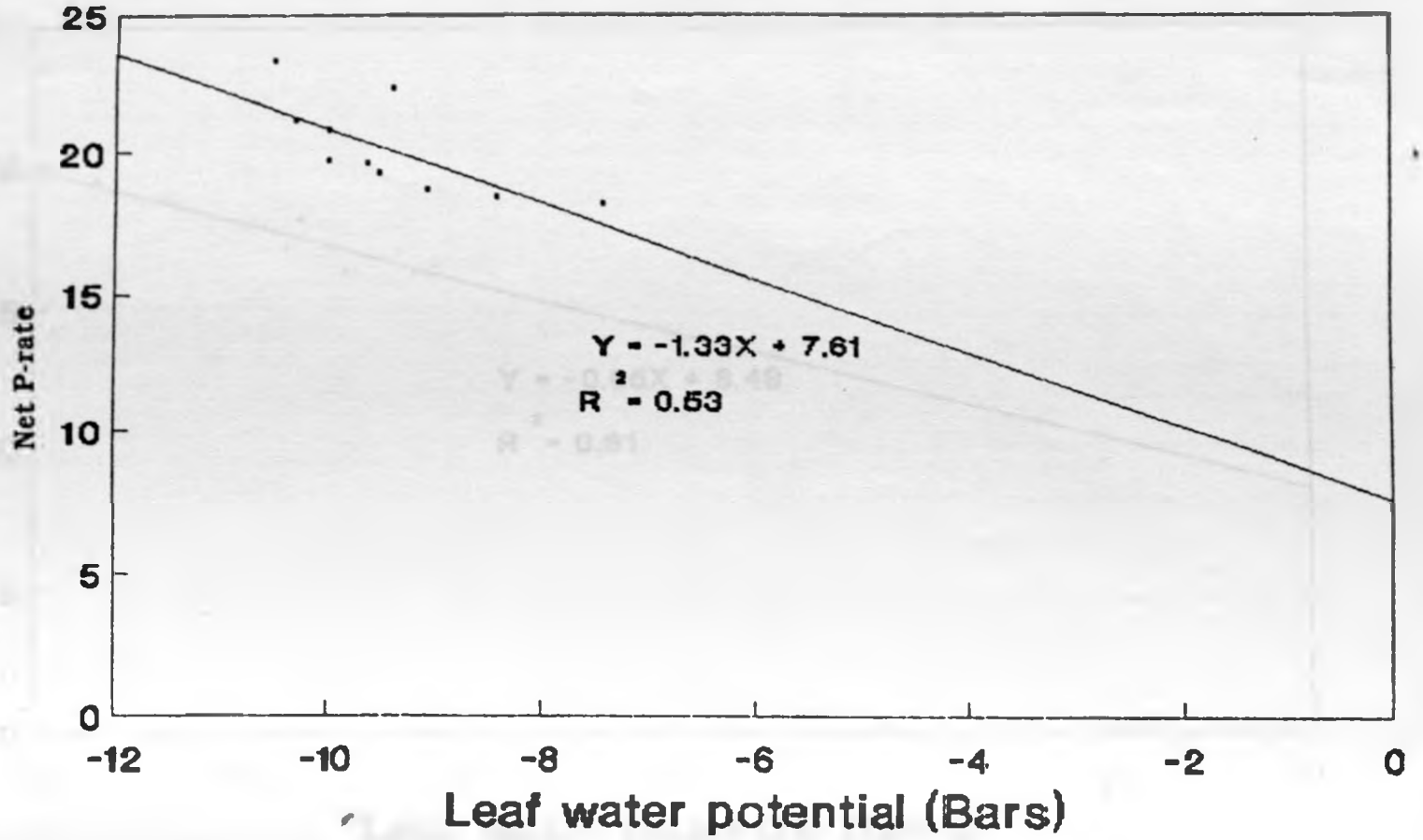


Figure 2: **Relationship between net photosynthetic rate and leaf water potential at flowering stage under low water level in the field**

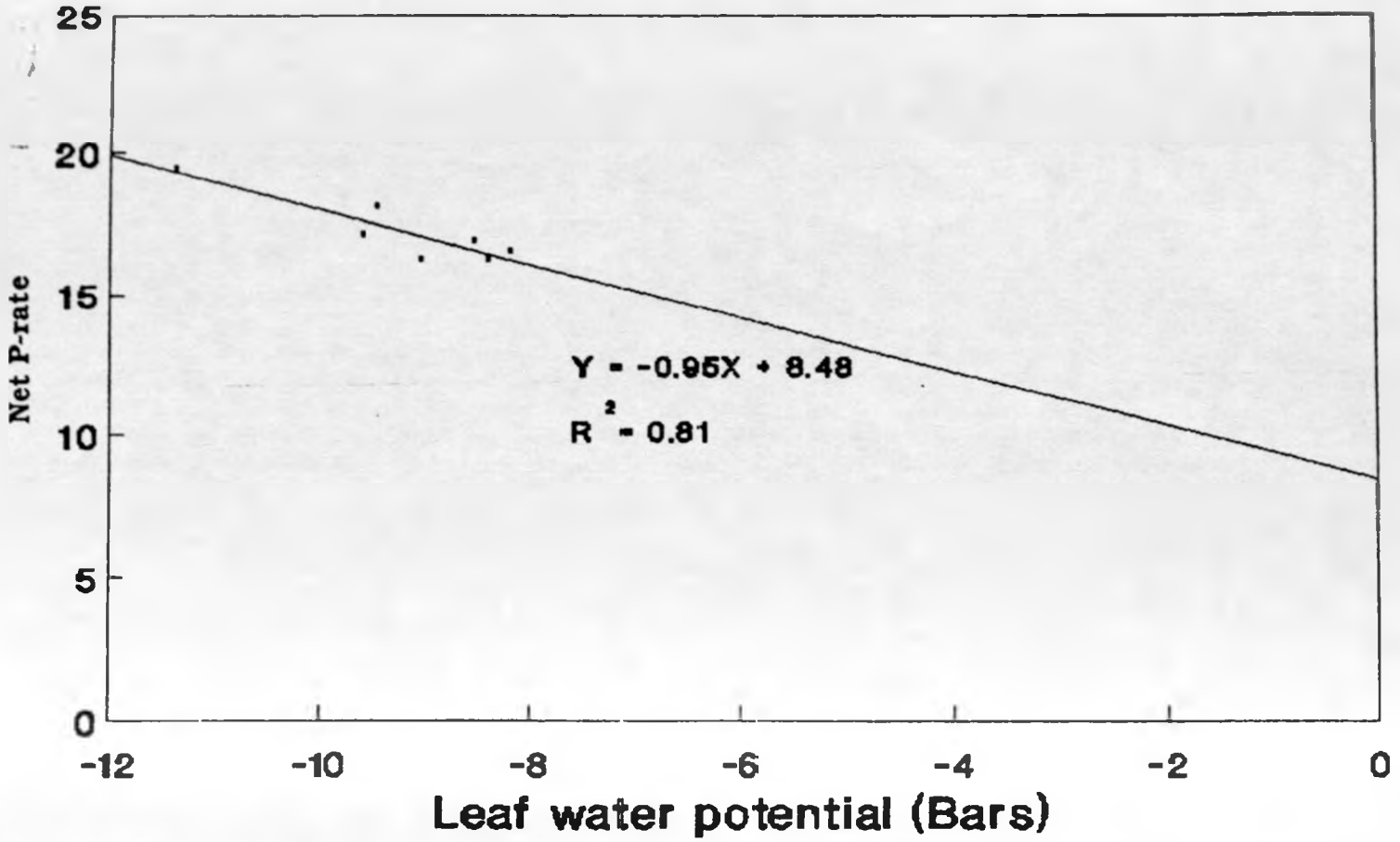


**Figure 3. Relationship between net photosynthetic rate and leaf water potential at flowering stage under low water level in the greenhouse**

# CHAPTER FIVE

## 5.0 DISCUSSION

Water stress decreased leaf water potential, leaf solut potential, leaf relative water content, transpiration rate ar stomatal conductance. Fall in leaf water potential may b associated with reduction in bulk soil water when irrigatio water becomes limiting, while transpiration demand remaine constant. Similar reductions in leaf water potential with wate stress have been reported in blackgram, greengram, cowpeas ar soybeans (Lawn, 1982; Vignes, et al. 1986) in common bean (Flores-Lui, 1984; Masumba, 1984; Ouma, 1988), in cowpeas ar sugar beet (McCree and Richardson, 1987).

The relatively lower leaf water potentials in Ulonzo ar White Haricot may be due to higher solute accumulation in thes varieties, which led to higher stomatal conductances ar transpiration rates observed for two varieties (Table 7 to 10) The higher values in stomatal conductance and transpiration rate suggest that stomates remained open both under high and low eate levels, allowing continued water loss to the atmospher (transpiration). This suggests adaptive osmotic adjustment i these cultivars from the dry areas. Similar varietal difference in leaf water potential have also been observed in common bean (Ouma, 1988), in cotton (Ackerson, 1981), soybeans (Virgnes, e al. 1986; Cortes and Sinclair, 1986), French beans (Parjorn, e al 1979), winter wheat (Winger, et al. 1988) and barley (Martin et al 1989).

Lower leaf solute potential may be associated with reduction in the cell water volume (Schonfeld, et al. 1988) or increase in solute concentration (Morgan, 1980) or both, as a result of water stress. Varietal differences in solute potentials were observed among the tested bean varieties whereby Ulonzo, White haricot and GLP-1004 (Mwezi Moja) maintained relatively low solute potentials compared to GLP-2 and Okuodo which maintained higher solute potentials under water stress conditions. The ability of Ulonzo, White Haricot and GLP-1004 to maintain higher RWC (Table 11), suggests that these varieties accumulated more solutes in their cells than GLP-2 and Okuodo, rather than their cell water volume being reduced. Low solute potentials observed in Ulonzo even under higher water level, suggests that this variety may have inherently higher solutes in their cells than the other bean varieties. In studies with wheat, Schonfeld, et al. (1988) reported a decline in solute potential with water stress in different varieties, but no varietal differences were observed. However, interspecific differences in solute potentials have been reported in cowpeas and sugarbeet (McCree and Richardson, 1987), in wheat (Morgan, 1980) and in rice (Steponkus, et al. 1980).

Water stress reduced leaf RWC in the greenhouse and the extent varied among the varieties. This variation may be attributed to differences in the ability of the varieties to absorb more water from the soil and/or the ability to control water loss (transpiration) through the stomates (Sinclair and Ludlow, 1985). It may also be due to differences in the ability of the tested varieties to accumulate solutes and adjust osmotically differentially (Schonfeld, et al. 1988). However,

varieties with higher RWC also maintained higher stomatal conductance and transpiration rate, suggesting a major role of osmotic adjustment. Similar varietal differences in RWC have also been reported by other workers (Bennett, et al. 1987; Schonfeld, et al. 1988; Matin, et al. 1989).

Transpiration rate and stomatal conductance were both reduced by water stress. Significant differences among the tested bean varieties suggest that stomates of different bean varieties responded differently to environmental conditions both under water stress and non-stress conditions. Since plants lose water through stomata, varietal differences in transpiration rates may be associated with varietal differences in stomatal conductances.

Higher stomatal conductances for Ulonzo, White Haricot and GLP-1004 in the field suggest that these varieties maintained open stomates both under low and high water level than others, which may be due to inherently higher ability of these varieties to maintain open stomates than others. Osmotic adjustment would also have contributed in maintaining turgor under water stressed conditions. However, lack of data on the relative reductions in stomatal conductances with increasing water stress, limited the discussion on the relative sensitivity of the stomates among the tested bean varieties.

Variety GLP-1004 performed differently in the greenhouse compared to the field (Table 7 and 8). This may be due to the differences in the way water stress was introduced between the greenhouse and the field conditions. Since water stress develops quickly in the greenhouse due to limited soil volume (in pots), plants may not have enough time to adjust their stomata. The

effect may differ according to the variety. Modifications in stomatal response to water stress also depends to a greater extent on the length of exposure to water stress and may differ with the length of irrigation cycle and temperatures in the growing conditions (Ackerson, 1981). All these factors could have contributed to differential performance of variety GLP-1004. Sharp decrease in stomatal conductance and transpiration rate with water stress has been reported in common bean (Miller and Gardener, 1972; Masumba, 1984 and Laing, et al. 1983); in cowpeas, soybeans, greengram and blackgram (Lawn, 1982; McCree and Richardson, 1987) and other crops (Lorens, et al. 1987).

To be able to maintain tissue turgor, and thus maintain physiological activity, the plant may maximize the soil water reserve by fully extracting water in the existing rooting zone and/or extending the rooting depth, so that the amount of water reserve is increased (Cortes and Sinclair, 1986). Differences among the tested bean varieties in their ability to show herbicide symptoms suggest genotypic differences in rooting characteristics (Table 12 and 13). The varieties which recorded higher mean number of plants showing herbicide symptoms are likely to have extended most of their roots faster into the herbicide zone than the others. Results suggest that Pocho, Ulonzo, GLP-1004 and White Haricot extended most of their roots faster into the 30 cm zone than other varieties, while Pinto was the least. However, Ulonzo indicated faster extension of its roots into the 40 cm zone, followed by GLP-1004 and Pocho with Pinto being the slowest. Similar indications were revealed by the number of days to 50% mortality (Table 13). Differences in

responses between 30 and 40 cm depths may be attributed to differences among the tested varieties in maturity as revealed by days to 50% maturity (Table 2). It has been observed that when the number of days to herbicide symptoms is recorded between one and two months after sowing the data should be inversely correlated with the final extensiveness and depth of the root system in short-cycle crops (Robertson, et al. 1985). In wheat, cultivars indicated genotypic differences in root length whereby a tall wheat variety had the longest individual root and the greatest total root length than semi-dwarf (Winter, et al. 1988).

The differential root growth rate observed among the tested genotypes may result in differential capacity to tap water in deeper soil layers and thus account for the differences in ability to meet transpirational demand as observed by Hoogenboom, et al . (1987). Similar observations were also reported by Huck, et al. (1983) who found that large root system in non-irrigated plants absorbed sufficient water to meet diurnal evaporative demand for several days following a rain. Conversely, if a plant had developed a large root system during early season vegetative development, it would be in a excellent strategy for maintaining turgor during the critical seed filling stages of reproductive development (Hoogenboom, et al. 1987).

The data on varietal differences in net photosynthetic rate under water stress also indicated that Ulonzo, GLP-1004 and White Haricot performed better than GLP-2, Local II and Okuodo (Table 14). This could be attributed partly to differences in stomatal conductance (Table 7 and 8) which might have restricted the $CO_2$ diffusion into the cells differentially (Kanemasu and Turner,

1969), although non-stomatal factors could have contributed also (Sharkey, 1985). Similar differential reduction in net photosynthetic rate with water stress have also been reported in common beans (Millar and Gardener, 1972; Ouma, 1988), in soybeans (Sionit, et al. 1984) and in cotton (Ackerson, 1981).

Ulonzo and White Haricot maintained consistently higher stomatal conductance, transpiration rates, leaf relative water content and net photosynthetic rate, but lower leaf water and solute potentials. They also had relatively lower mean number of days to mortality and relatively higher root growth rate than the other varieties. This may suggest that the varieties acquired enough water either through their ability to lower leaf water and solute potentials through solute accumulation or by extending their roots deeper into the lower soil horizons faster than others even under low soil water potential. This helped the varieties to maintain higher RWC and thus the stomata remained open for a longer period of time, maintaining higher transpiration rates, more $CO_2$ intake and thus higher photosynthetic rates, although Sharkey (1983) has suggested that other factors besides stomata could be involved. Ability to maintain higher net photosynthetic rate even with low water potentials may also suggest that their photosynthetic machinery was less sensitive to low water potential. Variety GLP-2, Okuodo and Local II maintained relatively lower stomatal conductance, transpiration rates, RWC, net photosynthetic rates, although they maintained higher leaf water and solute potentials. This may be partly associated with slower root growth (Table 13). Low stomatal conductance even under high water level suggests

inherently low conductances which may reduce water loss at the expense of $CO_2$ intake.

Correlation analysis indicated that under water stress, net photosynthetic rate increased linearly with a decrease in leaf water potentials whereas plant biomass correlated logarithmically with leaf water potential within the range of the measured values. Adopting Levitt's (1972) definition, we may classify drought resistance into drought avoiding and drought tolerating. Drought avoiding plants can further be classified into water savers and spenders, while drought tolerating can be dehydration (elastic strain) avoiding or dehydration (elastic strain) tolerating. Whereas drought avoiders maintain higher water potentials and maintain open stomata, drought tolerance due to avoidance ensures survival of the plant at low leaf water potentials. Several drought response patterns however, may occur at a time in crops (Blum, 1974). Water spenders are able to maintain higher water contents than unadapted plants, maintaining higher stomatal conductance and transpiration rates by extracting larger quantities of water from the soil per unit time and leaf surface. As a result of open stomata, they maintain larger accumulation of photosynthetic products per day.

Low leaf water potentials for Ulonzo and White Haricot, concurrently with comparatively high stomatal conductance, suggests that relatively large soil to leaf water potential gradient is developed and thus an extensive exploration of soil moisture made feasible than in GLP-2, Okuodo and Local II. Under water stress, turgor is maintained at lower water potential because of decrease in osmotic potential (Cuttler, et al. 1980).

In this case Ulonzo, White Haricot and GLP-1004 may be considered the most adapted bean varieties to drought stress as compared to Okuodo, GLP-2 and Local II. Differences in the ability of the tested bean varieties to adjust osmotically and the ability of their roots to grow faster and deeper may be the most important mechanisms and basis of adaptation of common beans to drought stress.

The inherited ability to adjust to drought or unfavorable stresses is clearly an adaptation, but phenotypic modifications produced by variation in environmental factors in termed acclimation. Changes in various plant characteristics caused by exposure to water stress are examples of acclimation and includes reduced leaf area, less responsive stomata, decrease in osmotic potential and increase in the ratio of roots to shoots (Kramer, 1983). The fact that Ulonzo, GLP-1004 and White Haricot maintained low solute potential both at low and high water level suggests adaptative osmoregulation rather than acclimation. Ulonzo and White Haricot originated from the low rainfall areas, while GLP-1004 is recommended for low rainfall areas. Okuodo and Local II originated from high rainfall areas whereas variety GLP-2 (Rosecoco) is recommended for similar areas (Table 2). Although the sample size for the tested bean varieties was limited, the results suggest that differences in adaptability to drought stress may be associated with the origin of material and thus there is a bigger chance of obtaining drought adapted bean varieties from low rather than high rainfall areas. Similar observations were also reported by Ashenden, et al. (1975).

Although no attempt was made to determine the heritability

of these adaptability attributes observed in the tested bean varieties, the results suggest that leaf water potential, solute potential, RWC and root growth can be used successfully in drought resistance studies rather than stomatal conductance and transpiration rate which proved unreliable due to high coefficients of variation (CVs) (Table 7 and 8).

# CHAPTER SIX

## 6.0 CONCLUSIONS

Although common beans (*P. vulgaris* L.) are susceptible to short water stress periods, varietal differences in drought tolerance has been observed in this study. Water stress reduced leaf water potential, leaf solute potential, relative water content, stomatal conductance and transpiration rate in all the tested common bean varieties, but, the extent differed with the variety. There was evidence that Ulonzo, White Haricot and GLP-1004 accumulated more solutes in their cells, and their roots grew faster, thus extracting more water from the soil and maintaining higher physiological activities than others. When related to the agroecological zones, it was observed that Ulonzo and White Haricot originated from marginal rainfall areas and GLP-1004 is recommended for similar areas while Okuodo and Local II originated from high rainfall areas and GLP-2 is recommended for these areas.

The experiments were conducted to investigate the differences in plant water status among the selected varieties of common beans to study other fundamental mechanism involved in adaptation of common beans to drought stress and explore the relationship between drought resistance and rainfall pattern in areas of origin of the tested bean varieties.

From this study, the following conclusions can be made:

1. The varieties tested differed in leaf water potentials and RWC. More drought adapted varieties maintained higher RWC, transpiration rates and stomatal conductance at relatively lower leaf water and solute potentials than the non-adapted varieties.

2. Ability of Ulonzo, White Haricot and GLP-1004 to tolerate drought was associated with their ability to adjust osmotically and the ability of their roots to grow faster downwards. This allows more water extraction from the soil even under low soil water potentials to maintain higher physiological activities than GLP-2, Local II and Okuodo.

3. Leaf water potential, solute potential, RWC and root growth rate can be employed reliably in drought resistance studies than transpiration rate and stomatal conductance.

4. Ulonzo and White Haricot are traditionally grown in low rainfall areas, whereas Okuodo and Local II are grown in high rainfall areas. This suggests that there is a greater chance of obtaining drought adapted varieties in dry areas than in wetter areas.

## 6.2 RECOMMENDATIONS FOR FURTHER RESEARCH

1. There is need to further test the varieties showing adaptation to drought stress in arid and semi-arid areas so as to study the extent of adaptation, other specific mechanisms involved and relate the physiological markers to drought resistance with biomass accumulation and crop yield under rainfall marginal areas.

2. Common beans have been observed to root up to beyond 1 m. There is a need to study the maximum rooting depth of drought adapted bean varieties as compared to the non adapted varieties.

3. A detailed study needs to be conducted to investigate the relationship between leaf water potential and stomatal conductance and to differentiate between osmotic adjustment and mere accumulation of solutes in common beans.

# CHAPTER EIGHT

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