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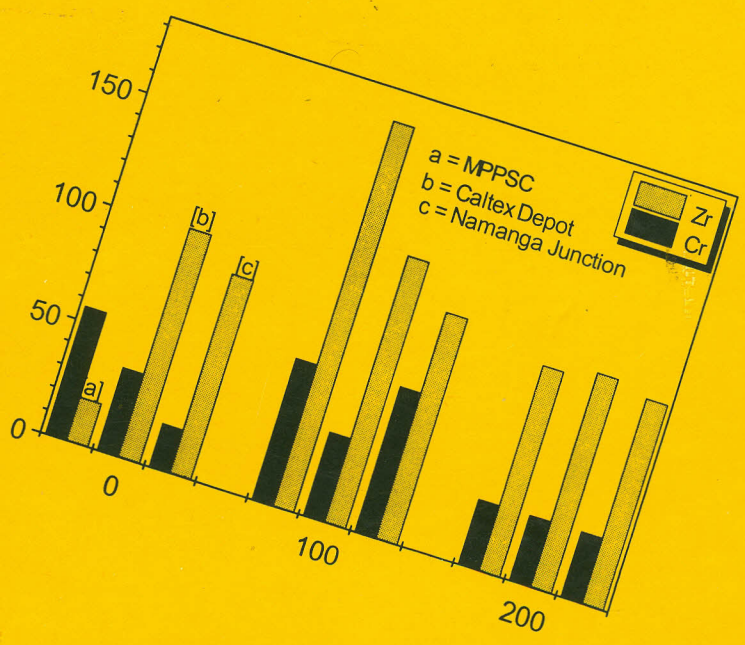

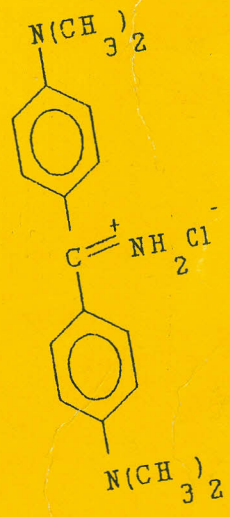

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Phenology and diurnal course of leaf water potential of three bean varieties under a semi-arid environment in south-east Kenya

C. A. Shisanya
Department of Geography, Kenyatta University, P. O. Box 43844, Nairobi, Kenya

The objectives of this study were to observe the phenology and to investigate the diurnal behaviour of leaf water potential (LWP) in three bean varieties under irrigated and unirrigated treatments with a view to making recommendations on their suitability for the semi-arid environments of Kenya. The field experiments were conducted during the short rainy season of 1993/94 in a typical semi-arid environment at KARI/NRRC/ICRISAT Kiboko experimental field station, southeast Kenya. The selected beans were: high-yielding kenyan bean varieties Mwezi moja (MM) and Rose coco (RC) (*Phaseolus vulgaris*, var. GLP-1004 and var. GLP-2, respectively) and "minor pulse" Tepary beans (TB) (*Phaseolus acutifolius* A. Gray var. *latifolius*), possessing a high nutritional value.
Under irrigated conditions, the bean varieties took 60 (TB), 65 (MM) and 70 days (RC), after emergence to reach full maturity respectively; water deficit induced false starting of phenological phases of the less adapted *Phaseolus vulgaris*. Differences in leaf water potential between the treatments were apparent. TB appeared to maintain higher leaf water potential values and showed more pronounced diurnal responses than MM and RC beans in both treatments. This also resulted in less yield reductions during water deficit for *Phaseolus acutifolius*. The susceptibility of *Phaseolus vulgaris* to water deficit is also documented by the fact that their LWP decreases more rapidly much earlier in the morning than TB. The short growth cycle of TB together with the maintenance of high leaf water potentials (and good yield performance) even under water deficit could be interpreted to mean that they are more adaptable to the semi-arid environments of Kenya compared to MM and RC beans.

Key words: beans; leaf water potential; minor pulse; phenological phases; semi-arid; southeast Kenya; water deficit, *Phaseolus acutifolius; vulgaris*

INTRODUCTION

In Kenya, the most commonly grown legumes are field beans (*Phaseolus vulgaris* L.), pigeon peas (*Cajanus cajan* L.), cowpeas (*Vigna unguiculata* L. Walp.), green grams (*Phaseolus aureus* L.) and field peas (*Pisum sativum* L.). Of these, field beans are the most widely cultivated. The importance of beans mainly lies in their actual and potential value as a source of plant protein rich in lysine, tryptophane and methionine (Agwanda, 1988). They are second only to maize as a major food crop and they have been grown in Kenya for nearly 300 years; the crop is grown in all agricultural areas of Kenya except the lowlands (Shisanya, 1996). In developing countries like Kenya, where animal protein is in short supply and therefore expensive for the majority of low income groups, beans and other pulses containing considerable amount of protein of high nutritional value assume an eminent role as a potential source of low cost readily obtainable protein.

Increasing population pressure, particularly in the so called "high potential areas" has forced cropping into more marginal rainfall areas, where productivity of such cropping systems is uncertain (Frenken *et al.*, 1993; Pilbeam *et al.*, 1995). It should be pointed out here that these marginal rainfall areas have only short to very short wet periods of about 40/45 to 85/105 days (Jaetzold & Schmidt, 1983), with low intensity water supply during the main part of the rainy season < 80 % of the potential evapotranspiration and frequent dry spells (Hornetz, 1988).

The search for crop cultivars that are well adapted to the semi-arid environments of Kenya will continue to be at the forefront of the research agendas of Kenyan agricultural researchers (Odhiambo, 1989). As Hornetz (1988) observed, one of the things that needs to be considered in such research agendas is to test eco-physiological properties of the plants such as crop water

requirements or response to high temperature and water deficit. The response of annual crops to water deficit depends upon the developmental stage of the plants at the time water becomes limiting (Levitt, 1972). Some ontogenetic stages, like those corresponding to the early growth of the reproductive organs, are particularly sensitive to plant-water balance which if unfavourable, may result in an important reduction in grain yield (Soriano & Ginzo, 1975). Leaf water potential (LWP) has proved to be one of the valid indicators of crop water deficit (Idso, 1982; Olufayo *et al.*, 1993). LWP is a suitable index for screening suitable crops for given climatic environments (Hornetz, 1990; Olufayo *et al.*, 1993). Using three bean varieties, i.e. "high yielding varieties" like MM and RC (*Phaseolus vulgaris*)[1] and the "minor crop" TB (*Phaseolus acutifolius*) as examples, the objectives of this study were to observe the phenology and to investigate the diurnal behaviour of LWP in the three bean varieties under different watering treatments, with a view to making recommendations on their suitability for the semi-arid environments of Kenya.

MATERIALS AND METHODS

The soil on the experimental field site at the National Range Research Centre (KARI/NRRC/ICRISAT) Kiboko, Kenya (2° 10' S, 37° 40' E) is classified as an acri-orthic Ferralsol (Touber, 1983). The soil is a well drained sandy clay loam overlying a sandy clay (Pilbeam *et al.*, 1995). The soil chemistry indicates in particular a deficiency in nitrogenous plant nutrients (N_{min}) such as ammonium and nitrate (0.07 and 0.04 mg/100g of soil, respectively; soil profile depth = 60 cm) (C. Antoine, unpublished data). Rainfall is bimodally distributed, with mean monthly maximum in April (113 mm) and November (145 mm); mean annual rainfall is about 562 mm year^{-1}. The short rains (October to January) generally have more rainfall and are more reliable than the long rains (March to June) (Musembi & Griffiths, 1986). The lengths of wet periods for drought adapted crops as calculated by WATBAL.Module 1 computer program (Kutsch & Schuh, 1983) are 50 - 55 days (long rains) and 65 days (short rains). Average monthly temperatures are highest in February (24.3°C) and October (23.4°C) (KMD 1984), prior to the onset of the rains in March and November, respectively.

Seeds of bean varieties were obtained from the seed production unit at the station. Land preparation was carried out by disc ploughing followed by disc harrowing. The bean seeds were sown in the field at Kiboko experimental field site before the onset of the short rains in October 1993. The experimental design was a randomised block with plots replicated four times for both treatments. Before planting, the bean seeds were dressed with Aldrin at the rate of 5g per kg of seeds, to control soil pests especially bean fly (*Melanargromyza phaseoli*). Furadan (5% carbofuran) was applied at a rate of 2g m^{-1} in the bean rows at sowing to control cutworms (*Agrotis ipsilon*). Bean plant population density was 8.3 plants m^{-2} (75 cm between row spacing and an intra-row spacing of 15 cm). Plot sizes were 6 × 4 m, and each treatment (irrigation and unirrigated) was replicated four times. All the plots were irrigated at the time of emergence in order to ensure good germination. The irrigated plots were thereafter supplied with water whenever the soil moisture levels fell below 60 % of field capacity. The plots received farm-yard manure at sowing to give minimal nutrient supplement to the plants after preliminary soil analysis data of the plots indicated nutrient deficiencies. All plots were top-dressed with calcium ammonium nitrate fertilizer (CAN: 26% N) at an equivalent rate of 20 kg ha^{-1} 3 weeks after germination. The fertilizer was top-dressed between the plant rows.

The irrigation water requirements were estimated using the water balance method (Lenga & Stewart, 1983). Irrigation was done on the following dates: 10.11., 17.11., 8.12., 14.12. and 23.12.93, respectively (see Fig. 1). Each irrigation amounted to approximately 43.2 mm of rainfall. Soil moisture monitoring was done using gypsum block electrodes (Soil moisture, Sta. Barbara, California/USA, see Hartmann, 1993). The gypsum blocks had earlier been calibrated for the soils at the experimental site. The soil moisture monitoring was done in 15 and 40 cm soil depth based on the assumption that the bean rooting depth is 60 cm (Agwanda, 1988). For illustrative purposes of monitoring soil moisture, plots of the short duration TB variety were used in this respect (see Figs. 1 and 2). Potential evapotranspiration

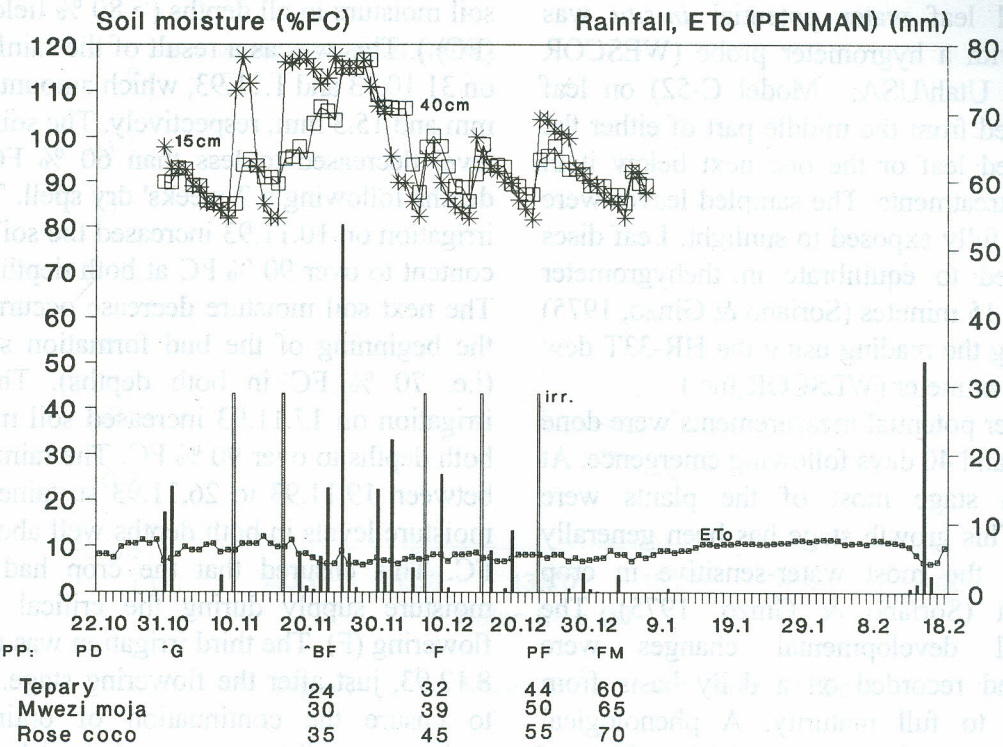

Figure 1. Rainfall, soil moisture, ETo and phenological phases of the bean varieties during 1993/94 short rains.

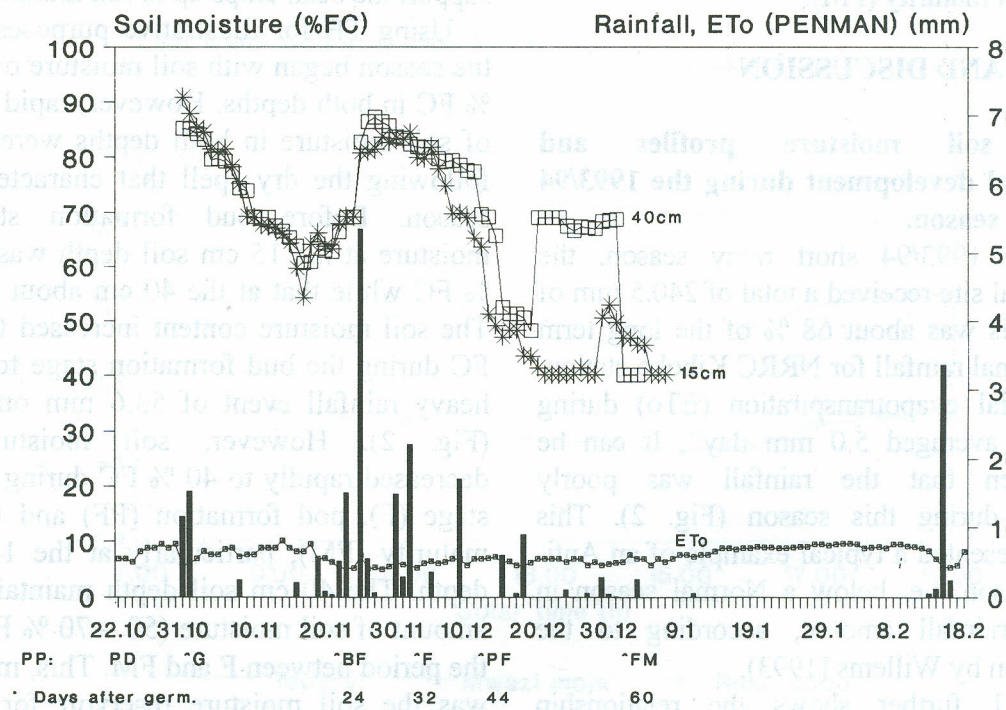

Figure 2. Rainfall, soil moisture, ETo and phenological phases of Tepary beans during 1993/94 short rains.

(ETo) was estimated using the modified Penman formula (McCulloch, 1965).

The diurnal leaf water potential *in-situ* was measured with a hygrometer probe (WESCOR Inc. Logan, Utah/USA; Model C-52) on leaf discs punched from the middle part of either the last expanded leaf or the one next below it in each of the treatments. The sampled leaves were healthy and fully exposed to sunlight. Leaf discs were allowed to equilibrate in thehygrometer chamber for 15 minutes (Soriano & Ginzo, 1975) before taking the reading using the HR-33T dew point microvoltmeter (WESCOR Inc.).

Leaf water potential measurements were done between 30 and 40 days following emergence. At this growth stage most of the plants were flowering. This growth stage has been generally accepted as the most water-sensitive in crop development (Soriano & Ginzo, 1975). The phenological developmental changes were observed and recorded on a daily basis from germination to full maturity. A phenological phase was taken to have occurred when 75 % of the crops had attained the characteristics of the respective phase (Masumba, 1984). The following phenological phases (PP) of the bean varieties were distinguished: germination (G), bud formation (BF), flowering (F), pod formation (PF) and full maturity (FM).

RESULTS AND DISCUSSION

Rainfall, soil moisture profiles and phenological development during the 1993/94 short rainy season.

During the 1993/94 short rainy season, the experimental site received a total of 240.5 mm of rainfall. This was about 68 % of the long term mean seasonal rainfall for NRRC Kiboko station. The potential evapotranspiration (ETo) during the season averaged 5.0 mm day^{-1}. It can be clearly seen that the rainfall was poorly distributed during this season (Fig. 2). This season represented a typical example of an Anti-ENSO[2] season, i.e. below a Normal season in terms of rainfall amount, according to the classification by Willems (1993).

Figure 1 further shows the relationship between rainfall, soil moisture, ETo, irrigation and the respective phenological phases of Tepary, MM and RC bean varieties (Figure 2 shows this relationship in the unirrigated treatment, for TB). From Figure 1, it can be clearly seen that the season began with adequate soil moisture in all depths (> 80 % field capacity (FC)). This was as a result of the rainfall events on 31.10.93 and 1.11.93, which amounted to 11.5 mm and 15.3 mm, respectively. The soil moisture level decreased to less than 60 % FC at both depths following a 2 weeks' dry spell. The initial irrigation on 10.11.93 increased the soil moisture content to over 90 % FC at both depths (Fig. 1). The next soil moisture decrease occurred before the beginning of the bud formation stage (BF) (i.e. 70 % FC in both depths). The second irrigation on 17.11.93 increased soil moisture at both depths to over 90 % FC. The rainfall events between 19.11.93 to 26.11.93 sustained the soil moisture levels in both depths well above 100 % FC. This ensured that the crop had adequate moisture supply during the critical period of flowering (F). The third irrigation was applied on 8.12.93, just after the flowering stage. This was to ensure the continuation of optimum soil moisture conditions to support pod formation. The fourth and fifth irrigations were on 14.12.93 and 23.12.93, respectively. These applications together with the rainfall events between 27.12.93 and 3.1.94 ensured that the soil moisture levels remained well above 80 % FC to support the bean crops up to full maturity (FM).

Using TB for illustrative purposes (Fig. 2), the season began with soil moisture of about 90 % FC in both depths. However, rapid decreases of soil moisture in both depths were observed following the dry spell that characterized this season. Before bud formation stage, soil moisture at the 15 cm soil depth was about 55 % FC while that at the 40 cm about 60 % FC. The soil moisture content increased to > 80 % FC during the bud formation stage following a heavy rainfall event of 53.6 mm on 25.11.94 (Fig. 2). However, soil moisture levels decreased rapidly to 40 % FC during flowering stage (F), pod formation (PF) and up to full maturity (FM), particularly at the 15 cm soil depth. The 40 cm soil depth maintained some amount of soil moisture (50 – 70 % FC) during the period between F and FM. This, most likely, was the soil moisture reservoir for the bean crops until FM. This amount of soil moisture, however, was far below that required to support the crop, especially at the critical time of flowering when water use is at its maximum

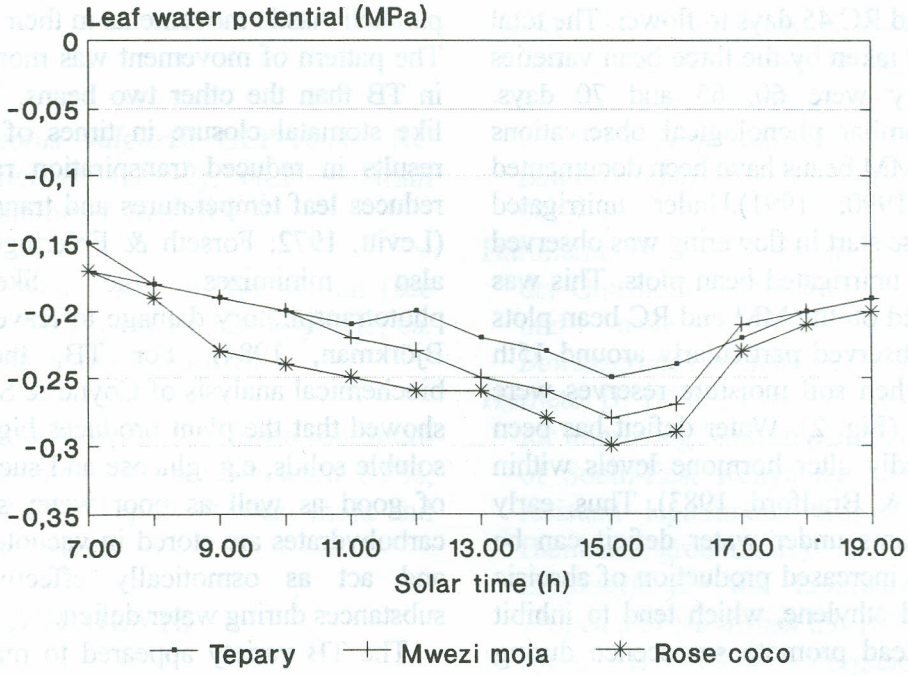

Figure 3 (a). Leaf water potential measurements of three bean varieties under irrigated conditions, 1993/94 short rains.

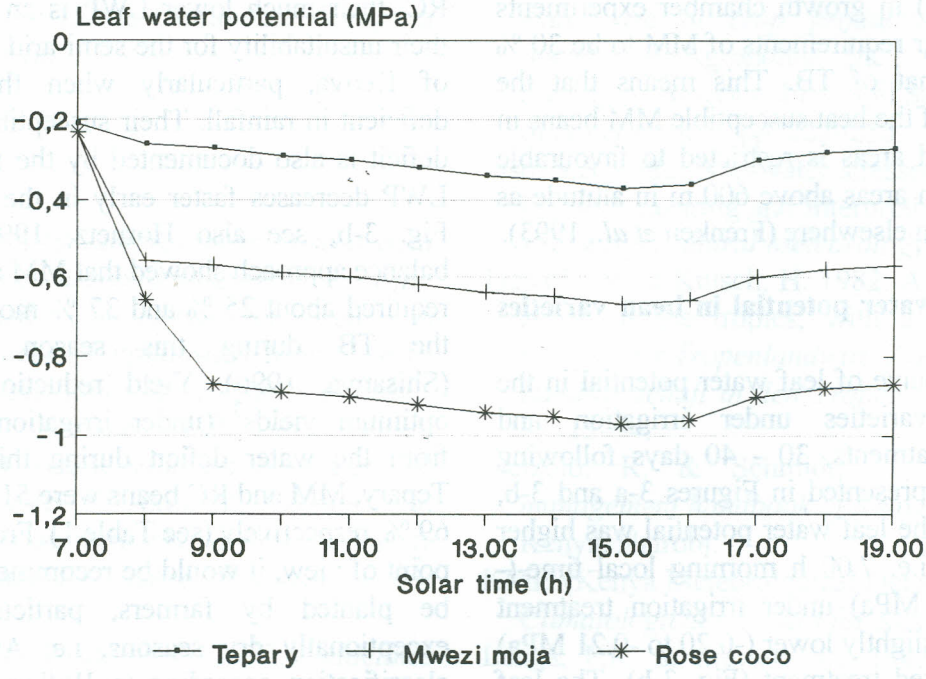

Figure 3 (b). Leaf water potential measurements of three bean varieties under unirrigated conditions, 1993/94 short rains.

(Doorenbos & Pruitt, 1977).

From Fig. 1, it can be seen that under optimum conditions, TB took about 32 days, MM 39 days and RC 45 days to flower. The total number of days taken by the three bean varieties to full maturity were 60, 65 and 70 days, respectively. Similar phenological observations on Tepary and MM beans have been documented by Hornetz (1990; 1991).Under unirrigated conditions a false start in flowering was observed on some of the unirrigated bean plots. This was more pronounced on the MM and RC bean plots and could be observed particularly around 15th of December when soil moisture reserves were almost depleted (Fig. 2). Water deficit has been found to markedly alter hormone levels within theplant (Hsiao & Bradford, 1983). Thus, early flowering in plants under water deficit can be attributed to the increased production of abscisic acid (ABA) and ethylene, which tend to inhibit growth but instead promote senescence during water deficit (Hsiao & Bradford, 1983).

RC beans are not well suited for these semi-arid areas because of their long vegetative cycle (70 days), which occurs in these semi-arid areas with a relatively low probability (Jaetzold & Schmidt, 1983). In any case, RC is well adapted to the high rainfall areas of Kenya (Ministry of Agriculture & Livestock Development, 1984). Hornetz (1990) in growth chamber experiments found the water requirements of MM to be 30 % higher than that of TB. This means that the performance of the heat susceptible MM beans in these semi-arid areas is restricted to favourable seasons only in areas above 600 m in altitude as has been shown elsewhere (Frenken *et al.*, 1993).

Diurnal leaf water potential in bean varieties and yield.

The diurnal course of leaf water potential in the three bean varieties under irrigation and unirrigated treatments, 30 - 40 days following emergence, is presented in Figures 3-a and 3-b, respectively. The leaf water potential was higher at day break, i.e. 7.00 h morning local time-(-0.15 to -0.17 MPa) under irrigation treatment (Fig. 3-a) and slightly lower (-0.20 to -0.21 MPa) under unirrigated treatment (Fig. 3-b). The leaf water potential decreased during the course of the day, reaching a minimum of about -0.25 to -0.30 MPa under irrigation treatment and about -0.38 MPa (TB), -0.68 MPa (MM) and -0.98 MPa (RC) under unirrigated treatment, between 15.00 h and 17.00 h local time. Most of the bean plants under unirrigated treatment exhibited parahelionastic movements in their leaf canopies. The pattern of movement was more pronounced in TB than the other two beans. This response like stomatal closure in times of water deficit results in reduced transpiration rates and also reduces leaf temperatures and transpiration rates (Levitt, 1972; Forseth & Ehleringer, 1983) and also minimizes the likelihood of phototranspiratory damage to leaves (Ludlow & Björkman, 1984). For TB, the results of biochemical analysis of Coyne & Serrano (1963) showed that the plant produces high amounts of soluble solids, e.g. glucose and sucrose, in times of good as well as poor water supply. These carbohydrates are stored in vacuoles of the cells and act as osmotically effective protective substances during water deficit.

The TB variety appeared to maintain higher leaf water potentials compared to MM and RC bean varieties. For example, under the unirrigated treatment the TB attained a minimum leaf water potential of about -0.38 MPa compared to -0.68/-0.98 MPa attained by MM and RC, respectively (Fig. 3-b). This gives evidence that TB possesses drought tolerance mechanisms as described by Hornetz (1988; 1990). With regard to MM and RC, their much lower LWP is an indication of their unsuitability for the semi-arid environments of Kenya, particularly when the season is deficient in rainfall. Their susceptibility to water deficit is also documented by the fact that their LWP decreases faster early in the morning (cf. Fig. 3-b; see also Hornetz, 1990). A water balance approach showed that MM and RC beans required about 25 % and 37 % more water than the TB during this season, respectively (Shisanya, 1996). Yield reductions from the optimum yields[3] (under irrigation) , resulting from the water deficit during this season for Tepary, MM and RC beans were 51 %, 65 % and 69 %, respectively (see Table 1). From a practical point of view, it would be recommended that TB be planted by farmers, particularly during exceptionally dry seasons, i.e. Anti-ENSO (= classification according to Willems, 1993). All the three bean varieties can be planted during good seasons. An actual atmosphere-ocean-teleconnection has already been described by

Frenken *et al.*, (1993), particularly for South-East Kenya.

NOTES

[1] MM (*Phaseolus vulgaris*, GLP-1004), RC (*Phaseolus vulgaris*, GLP-2); GLP = Grain Legume Programme of the FAO.

[2] ENSO = El Niño Southern Oscillation (see Frenken *et al.*, 1993; Anti-ENSO: opposite; ca. 30-35 % of all short rainy seasons).

[3] Yield reductions from the mean optimum yields over two short rainy seasons were: 62 %, 73 % and 76 % for Tepary, Mwezi moja and Rose Coco, respectively.

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Table 1: Comparison of block and treatment effects on three bean varieties grown at KARI/NRRC Kiboko experimental field station during the short rainy season of 1993/94

Treatments	Mean grain yield (kg ha^{-1})
Plot 1.4 (IRR-TB)	1357.2^{c}
Plot 1.7 (IRR-TB)	1328.4^{c}
Plot 2.4 (RF-TB)	634.3^{d}
Plot 2.6 (RF-TB)	691.6^{d}
F-Ratio (T)	0.7009**
F-Ratio (B)	NS
CV (%)	39.2
Plot 1.6 (IRR-MM)	1822.3^{b}
Plot 1.9 (IRR-MM)	1554.1^{b}
Plot 2.3 (RF-MM)	578.9^{e}
Plot 2.11 (RF-MM)	603.3^{e}
F-Ratio (T)	3.0840**
F-Ratio (B)	NS
CV (%)	56.4
Plot 1.10 (IRR-RC)	1741.3^{a}
Plot 1.12 (IRR-RC	2041.3^{a}
Plot 2.1 (RF-RC)	489.9^{e}
Plot 2.12 (RF-RC)	679.0^{e}
F-Ratio (T)	3.2581**
F-Ratio (B)	NS
CV (%)	62.1

Notes on Table 1:
a, b, c, d, e: Yields with the same column followed by the same letter are not significantly different at 0.95 & 0.99 levels of significance according to the Duncan's Newman Multiple Range test
** = significant at both 0.95 and 0.99 levels of significance.

NS = Not significant at both levels
CV = Coefficient of variation
IRR = Irrigation treatment
T = Treatment
RC = Rose coco
B = Block
RF = Rainfed treatment
TB = Tepary beans
MM = Mwezi moja