THE EFFECT OF SOIL WATER DEFICITS ON GROWTH AND DEVELOPMENT OF SELECTED COMMON BEAN CULTIVARS (*Phaseolus vulgaris L.)*

BY

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ABSTRACT

Research was conducted to study the performance of three common bean (*Phaseolus vulgaris* L.) cultivars grown under stressed and non-stressed water conditions. Two experiments were conducted at Sokoine University of Agriculture (SUA) located at 6°.5' latitude South, 37°.3' longitude East; and 525m a.s.l The first experiment was conducted under screen-house conditions between March and May, 1998; while the second experiment was conducted under field conditions in May through August, 1998.

The experimental design used was a split plot with four replicates. The main treatments were irrigated and non-irrigated. The subtreatments were three common bean cultivars. In the screen-house experiment, ten litre plastic pots filled with sandy clay loam soil were used for planting. Under the field experiment, the size of each subtreatment was 10.8m^2 and the crop was spaced at 60 by 20cm. Sulphate of ammonia and triple supper phosphate were applied at 30kg N and 25kg P per hectare, respectively. Data were collected from underground and above ground plant parts at first flowering (R1), 50% flowering (R4), physiological maturity (R8) and harvest maturity (R9).

Highly significant effects of irrigation treatments, cultivars and their interactions were obtained at all sampling times except at R1 when the main treatments had just been applied. Non-irrigated plants completed their life cycle earlier than irrigated plants. Stressed cultivars had severe leaf curling, wilting and drooping between R4 and R8. Non-stressed cultivars had significantly higher plants heights, leaf area, root length, total biomass and seed yield than drought-stressed plants. It was also noted that stress levels differ from one cultivar to another. Cultivar SUA 90 gave the highest total biomass and seed yield in both experiments under both maintreatments. This was followed by "Rojo" and finally Canadian Wonder. The BEANGRO crop simulation model indicated that root length, root weight, leaf weight, and specific leaf area were very important parameters to consider when evaluating bean genotypes for drought tolerance.

DECLARATION

I, Neema Abdallah Maghembe, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work and that, to the best of my knowledge, has never been submitted for a higher degree in any other University.

Signature: ....

Date: 12-10-1999

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DEDICATION

This dissertation is dedicated to my family, particularly my children Magodi and Mwanamkuu, for their patience during the time I was not with them because of this study.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABREVIATIONS AND SYMBOLS

ANOVA	Analysis of variance
a.s.l	above sea level.
BMD	Biomass duration
Ca	Calcium.
CEC	Cation exchange capacity
CIAT	Central International de Agricultural Tropical.
cm	centimeter.
CORR	Correlation
CV	Coefficient of variation
D	Rooting depth.
DAP	Days after planting.
DMRT	Duncan,s multiple range test.
e.g	for- example.
Eta	Actual evapotranspiration.
ETc	Crop evapotranspiration or crop water requirement.
ETo	Reference evapotranspiration.
ETm	Maximum evapotranspiration.

FAO	Food and Agriculture Organization of the United Nations.
H_20	Water.
HI	Harvest index.
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer.
IR1	Irrigation throughout the growing period.
IR2	Moisture stress from first flowering to harvest maturity.
In	Natural log.
Kc	Crop coefficient or crop factor.
K	Constant.
Ky	Yield response factor.
L	Length of leaflet or lamina length.
LA	Leaf area.
LAD	Leaf area duration.
LA1	Leaf area one.
LA2	Leaf area two.
Mg	Magnesium.
MALDC	Ministry of Agriculture Livestock Development and Cooperatives.
MSU	Michigan State University.

mm	millimeter.
m	metres
me	milliequivalent.
Mol $_c$\kg	mole per kilogramme.
NAR	Net assimilation rate.
N	Nitrogen.
Na	Sodium.
P	Phosphorus.
P	Fraction of available soil water.
R1	Reproductive growth stage one or first flowering.
R4	Reproductive growth stage four or 50% flowering
R8	Reproductive growth stage eight or physiological maturity.
R9	Reproductive growth stage nine or harvest maturity.
SALB	Albedo, fraction
SCOM	Colour, moist, munsell
SLUI	Evaporation limit, cm
SLDR	Drainage rate, fraction per day
SLRO	Run-off curve number

SLNF	Mineralization factor, 0 to 1 scale
SLPF	Photosynthesis factor, 0 to 1 scale
SMHB	Ph in buffer determination method
SMPX	Phosphorus, extractable, determination
SMKE	Potassium determination method
SGRP	Root growth factor
SLB	Soil layer depth
SLMH	Master horizon
SLLL	Lower limit water content
SDUL	Drained upper limit water content
SLSA	Saturated water content
SLRF	Root growth factor
SLKS	Saturated hydraulic conductivity
SLDM	Bulky density, moist
SLOM	Organic carbon
SLFC	Sand
SLSI	Silt
SLCY	Clay

SLNI	Total nitrogen
SLHW	PH (water)
SCEC	Cation extraction capacity
r	Correlation coefficient.
RGR	Relative growth rate.
SA	Sulphate of ammonia.
SE	Standard error.
SUA	Sokoine University of Agriculture.
SLA	Specific leaf area.
Sw	Seed weight
SLW	Specific leaf weight.
T1	Time one
T2	Time two.
V0	Vegitative growth stage zero or planting.
V1	Vegitative growth stage one or germination.
V3	Vegitative growth stage three or when the crop attain three nodes.
W1	Weight one.
W2	Weight two.

W	Width.
Ya	Actual harvested yield.
Ym	Maximum harvested yield.

CHAPTER ONE

1.0 INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is believed to have originated from Central and Southern America where, together with maize, they are the most ancient of cultivated crops (Kaplan, 1965). The common bean is grown all over Eastern, Central and Southern Africa (Edje *et al.*, 1973; Wortmann, 1998). In Tanzania the crop is usually grown in small fields intercropped mainly with maize, sorghum, bananas, cassava, coffee, etc. Common bean is grown in every region of Tanzania. However, it is mainly grown in Kilimanjaro, Arusha, Tanga, Kigoma, Kagera, Mbeya, and Morogoro (Tesha, 1987). Morogoro region is estimated to have 33,425 hectares that are under bean production. This area is equivalent to 8.3% of the total area under bean production in Tanzania mainland (MALDC,1990).

In Tanzania, common bean is the most important grain legume. The crop forms an integral part of the diet of the people in many African and Latin American countries (Karel *et al.*,1981). It is widely used as a source of protein for families with low income and limited access to animal protein.

The dry bean contains about 20-26 crude protein with high content of essential amino acids such as threonine, isoleusine, methionine and lysine (Edje *et al.*, 1973). Bean protein is high in lysine which is relatively deficient in maize, rice, and cassava, so when consumed with these staples, as is customary in Tanzania, the mixture does provide a more balanced diet (Edje *et al.*, 1973). The immature pods are also widely eaten as green vegetables and they are a good source of vitamins A and C. Apart from providing the subsistence needs for growers, beans are also sold for cash especially in urban areas where animal protein is becoming less affordable.

Common bean yield, especially under small farmer production in Tanzania is low, ranging from 450 to 500 kg/ha (MALDC, 1990). The poor yields are mainly due to lack of suitable cultivars for the different production areas, inappropriate agronomic practices, pests and drought (Karel *et al.*, 1981 ; Teri *et al.*, 1990). Among these constraints, water stress/drought is probably the most important problem in bean producing areas (CIAT, 1993). Approximately 60% of bean producing regions suffer serious drought conditions
(CIAT, 1980).

Common bean is grown during the short and the long rainy seasons in those parts of Tanzania where there is bimodal rainfall (Karel et al., 1981). However, the crop is not suited to the humid wet tropics (FAO, 1986). Optimum mean daily temperatures range between 15 and 20°C. The minimum mean daily temperature for growth is 10°C, while the maximum is 27°C (FAO, 1986). The crop does not have specific soil requirements but friable, deep soils with pH 5.5 to 6.0 are preferred. Most beans are grown in medium to high altitude of 1000 to 2400 metre a.s.l. under diverse climatic conditions and cropping systems (Mushi,1991).

Water is very vital to any stage of bean development. Establishment failures in dry land cropping are often caused by a small shower that is sufficient to initiate germination, but which will not sustain the seedlings. Water deficits at this stage may severely reduce crop development and thus crop yield (CIAT,1980).

Drought is considered one of the most limiting factors to agricultural production (Kramer and Boyer,1995). Throughout the tropics, periodic droughts caused by irregular rainfall distribution, and accentuated by soils with low water holding capacity, cause sizeable reduction in bean yields. During the vegetative stage of development severe water deficits cause leaf area reduction and stomata closure. As a result both the leaf surface area and the rate of photosynthesis per unit of leaf area is reduced. This is because carbon dioxide uptake for photosynthesis is reduced.

Water stress in common bean causes abscission of many blossoms, thus resulting in poor fruit set. Water stress may also cause reduction in several yield components of common bean, including the number of pods plant^{-1}, seeds pod^{-1} and an individual seed mass. Under water stress, common bean is seriously affected from flowering to early pod set (Stoker, 1974). In general, water requirements in common bean depend on soils and climatical factors. Overall, the crop is considered to be poorly tolerant to water stress (Fageria *et al.*, 1997) Although irrigation is used to reduce water stress in a few regions, water shortages and high irrigation costs often prevent irrigation at rates required to eliminate drought stress in bean production. Therefore, drought tolerant varieties or cultivars of bean are important in the bean producing areas with erratic rainfall as in many parts of tropical Africa. Only few farmers in most of the semiarid tropics where common bean is grown apply irrigation. This is because irrigation facilities are not within economic reach of most farmers. In such areas drought is the one of the major constraints limiting production. In such areas, drought is one of the major constraints limiting bean production. Tanzania is equally affected by this environmental problem (Tesha, 1987). This is the reason why drought tolerant varieties or cultivars of beans are important.

The overall objective of the present study was to assess the performance of three common bean cultivars grown under stressed and non-stressed water conditions. The specific objectives were:

1. To assess the effect of water deficit imposed to common bean at flowering under screen house and field conditions.
2. To identify possible drought tolerance mechanisms in selected common bean (*Phaseolus vulgaris*) cultivars commonly grown in Tanzania.
3. Use of BEANGRO crop simulation model to identify important bean traits that will make the crop more resistant to drought stress, thus resulting into higher yields.

CHAPTER TWO

2.0 LITERATURE REVIEW.

2.1. Functions of Water and Water Requirements for Common Bean.

Functions of water in plants have been reviewed by a number of researchers (Kramer,1983; Gardner *et al.,*1985; Kramer and Boyer 1995). In general water acts as a medium that gives turgor to plant cells, which in turn promotes cell enlargement, plant structure and foliar display. Water is useful for hydration and neutralization of charges of colloidal molecule. It is a raw material for photosynthesis, hydrolytic processes and other chemical reactions. Water evaporation during transpiration acts as a coolant in plant surfaces.

Crop water requirements are defined as the depth of water needed to meet the water loss through crop evapotranspiration (ETc) of a disease free crop (FAO,1984). Water requirenments in common bean depends on soil and climatic factors, but the bean crop is generally considered to be poorly tolerant to water stress (Fageria *et al.*,1997). Generally water stress at flowering and at early pod determination phase is essentially harmful (Stoker,1974). Studies have shown that common bean yields depends on adequate soil moisture of 70% to 80% of available water storage capacity in the soil volume from flowering to near maturity. Various reports show that water stress does affect common bean if it occurs at preflowering time (Thung,1991), but yield is sometimes not reduced if adequate soil water was maintained during flowering. In general terms, however, water stress occuring during preflowering, flowering and pod formation periods reduce yield by 53%, 71% and 35%, respectively (Dubetz and Mahale, 1969; Stoker, 1974).

Calculation of ETc involves three stages as described by FAO (1984). The first stage is the consideration of the effect of climate on crop water requirements which is given by the reference crop evapotranspiration (ETo). The second stage is determination of the effect of crop characteristics on crop water requirements, which is given by crop coefficient (kc). Crop coefficient for common bean is estimated to be 0.69, 1.28 and 1.04 for growth period up to 35 days, from 30 to 60 days, and 60 to 80 days after germination, respectively. The average kc for common bean is estimated to be 1.8 depending on environmental, cultivars and agronomic factors (Thung, 1991). The third stage is the effect of local conditions and agricultural practices on crop water requirements which include: the local effects in variation of climate over time, distance and altitude, size of fields, soil water availability, salinity, methods of irrigation, cultural methods and practices for which local field data are acquired.

Common bean and other plants require a consistent source of water for growth and development. Water requirements for maximum production of bean crop vary between 300 and 500 mm depending on climate (FAO,1986). The water requirements during the ripening period depend very much on whether the pod is harvested green or dry. When common bean is grown for its fresh product, the total growing period of the crop is relatively short. However, during the ripening of the crop, the crop evapotranspiration is relatively small because of the drying of the leaves.

The use of water conserving systems for common bean offers the possibility of increasing yield when water is limited. Mulching does affect soil evaporation, water storage and yield of the crops. Mulched plots have usually shown a higher water use efficiency, that is, mass of dry matter produced/mass of water used than bare plots (Kramer and Boyer,1995). Similar results have bean reported on bean crop where dry matter and seed yields have been found to be significantly greater for mulched plots than bare plots (Barros and Hamus,1993). Common bean is susceptible to excess water. At seedling stage, excess water may induce seed rot attack, while at advanced growth stage sclerotinia rot may be encouraged. With excess water bean seed may germinate within the pod (Thung,1991). Common bean does not do well in wet areas, but does well in areas with medium rainfall. Excessive rainfall also causes flower drop, increases disease incidences and results into poor soil aeration (Fageria at al.,1997).

2.2 Growth and Development of Common Bean.

Growth and development of common bean from germination to maturity involve a number of changes in morphology and components of the whole plant. Common bean has an epigeal type of germination. Its life cycle usually depends on growth habit, that is, determinate or indeterminate, together with climatic conditions such as temperature and soil moisture (White *et al.*, 1994). Common bean has a taproot system which may grow up to 100 cm, but the lateral root system is mainly found in the upper 20 to 25 cm of the soil profile depending on the soil type (White and Singh 1991). Common bean growth and development have been categorised based on the growth habit. Growth and development of common bean is divided into vegetative and reproductive stages. The vegetative stages are defined on the basis of number of nodes and leaves on the main stems. The reproductive stages are defined on the basis of pod and seed characteristics (Nuland and Schwartz,1989; Fageria *et al,*.1997).

Accumulation of dry weight in common bean is a direct result of the balance among photosynthesis, respiration, and losses caused by senescence and abscission (White and Singh ,1991). Partitioning establishes equilibrium between vegetative and reproductive growth integrated during the development of bean, resulting in an end product of yield (Fischer and Turner, 1978). Common bean is a C3 plant and maximum values of net photosynthetic rate range from 25 to 40 mg $C0_2 dm^{-2}h^{-1}$ depending on the leaf area index (LAI) and the irradiation on the crop. Maximum dry matter accumulation of common bean is usually attained between 30 to 60 days after planting (DAP). Total dry matter has been found to be significantly correlated to grain yield and pod yield (Fageria *et al.*, 1997). Many factors are known to influence the growth and production of field crops in general. Some of these factors are soil moisture, crop cultivars, nutrients, pests and crop management practices (White and Singh, 1994).

2.3 Soil Water Deficit or Drought Stress

Mkandawire (1987) defined drought as " a period of moisture deficits that adversely affects a specific crop growth and development or any of its related physiological processes". In general terms, drought is a period of water stress, which may affect crop growth, development and eventually yield.

Internal plant water deficits occur, when water potential of the cell, tissue or organ under study has dropped below the reference value of zero potential (Turner, 1981). The water potential gradient is induced by the transpirational water loss, thereby inducing a coupled water deficit in leaves, shoots, roots and soil (Narang *et al.*, 1989; Bishnoi *et al.*, 1994). Thus, water deficit reduces both cell division and cell elongation of leaves, shoots and roots. As a result plant growth and development is adversely affected.

Common bean production in many regions occurs under rainfed conditions where water deficit limits yield and causes instability of production (White *et al.*, 1994). Although agronomic practices are important under water deficits, cultivar improvement is usually seen as the most promising approach to increase yields. Various studies have indicated that direct selection of seed yield in common bean can be effective for both well-watered (Nienhuis and Singh, 1988; Singh et al.,1990) and moisture stressed conditions (White *et al.*,1994).

Water stress in common bean causes abscission of many blossoms, thus resulting in poor fruit set. Water stress may also cause reductions in several yield components of bean (Tesha, 1987). Among these yield components are: pods/plant, number of seeds/pod, and seed size. Drought stress in bean is usually associated with accelerated maturity, although late season release from stress may trigger recuperative growth resulting in delayed maturity (Sponchiado *et al.,* 1985). Drought during flowering reduced the number of days to physiological maturity, leaf area index and canopy height of common bean (Mkandawire and Gundo, 1990).

2.4 Drought Tolerance in Common Bean

/ Drought tolerance in agronomic terms means the ability of the crop plant to produce satisfactory yield when subjected to water deficit. Drought tolerance, as defined by White and Singh (1991) in common bean encompasses all mechanisms that allow greater yields under soil moisture deficits. This includes traits such as a deep root system, early and late maturity, etc. A cultivar is tolerant if it yields well compared to the others under conditions involving water deficits. Drought effects vary greately depending on specific drought conditions, and plant genetic variability (White and Izquierdo, 1994). Since many bean researchers feel that genetic variability for drought tolerance in common bean in common bean is very low, related species such as tepary bean (*P. acutifolius*) and the related species (*P. filiformis)* are usually considered as sources of genes for drought tolerance in various breeding programs (White and Singh, 1991).

Common bean genotypes that are able to postpone dehydration due to water deficits through greater rooting systems are usually drought tolerant (CIAT, 1985). This is because those genotypes are able to extract moisture deep into the soil, while other genotypes are unable to absorb at such depth. Water stress generally decrease as the extent of root system increases. That is, as the width, depth and branching of the rooting system increase the plant/common bean water stress decreases (Mgema *et al.*,1987; White and Castillo 1989; Richner *et al.*,1996). An increase in root weight may indicate a greater density of roots or a greater depth of roots which are both important morphologically adaptation to water deficits in that they can extract soil water and maintain a high plant water potential (Turner, 1981). Variation in root growth among species determines the differences in drought tolerance within and among species (Turner, 1981). As in many other crops, drought tolerance in common bean have been associated with greater root growth. Increasing efficiency of roots in extracting soil moisture must also result in greater water uptake. Another alternative is for roots to have greater hydraulic conductance, either axially/for transport along the xylem or radially/for uptake from soil to the xylem (Turner,1981).

Early and late maturity may also provide a crop with means of escaping drought (White and Izquierdo,1991). Earliness is advantageous for crops where soil moisture is adequately early in the season but declines rapidly (White and Izquierdo,1991). Late maturing is of advantageous when drought occurs early or mid in the season and then followed by a period of abundant moisture throughout the cropping season. Fischer and

Turner (1978) concluded that for arid and semiarid zones, breeding for early flowering was the most promising approach.

Unfortunately there are few, if any, bean lines with good agronomic characteristics that have proven drought resistant or tolerant in Tanzania (Tesha, 1984) . Tepary bean has been suggested as a good source for drought tolerance genes for inclusion into bean breeding programmes but the bean is uncommon to Tanzanian farmers (Tesha,1987). It is possible to select for genes which confer drought tolerance in some locally grown cultivars (Tesha,1987). In order to increase efficiency of selection for drought tolerance among local cultivars, plant characters, which relate to drought tolerance those which can easily be observed have to be identified.

The ability to withstand water stress may result from one or all of the following characteristics: reduction of leaf size in order to reduce evapotranspiration surface (Parsons and Davis,1978); change of leaf orientation (paraheliotropy) to dissipate less energy as latent heat while optimizing photosynthesis, long extensive roots confer advantage under field conditions by exploring stored moisture in the lower soil horizons; low water potential at high relative water content i.e. osmoregulation (Parsons and Howe, 1984) and the ability to reduce water loss and optimize photosynthesis through regulation of stomatal conductance.

2.5 Breeding for Drought Tolerance in Common Bean.

Most common bean production occurs under some stress (White and Singh, 1991). Although drought, disease, and poor soil fertility might be among the most widely distributed production constraints, stress factors and their relative importance vary greatly from region to region (CIAT,1993).Thus, any effort to breed for drought tolerance in common bean; as a first goal, crosses should assure maximum recombination of different traits, mechanisms, sources, and genes associated with drought tolerance (Sponchiado *et al*,.1989; White and Singh, 1991). Genes for large root volume and deeper root growth, early or late maturity, tolerance to heat, or low temperature, poor soil fertility, small foliage, low canopy temperature and other traits directly or indirectly associated with drought, should also be intercrossed with tolerance parents (White and Singh,1991). When differences among parents are extremely great, such as seed size, maturity, growth habit and adaptation strategies such as recurrent selection, backcrosses, three way crosses or modified double crosses should be used to increase the frequency of desirable genes (White and Castillo,1989).

Given a wide range of morphological and physiological characters in common bean, it is possible that they will differ in their response to drought during growth and development. As such, there is a wide scope of selection for drought tolerance in common bean (Wallace,1985). Selection for drought tolerance should be carried out from already proven high yielding genotypes to avoid selection for low yielders (Tarimo *et al.*, 1994). Moreover, cultivars recommended for dry areas should have proven capacity to yield high under optimum moisture conditions. Mgema *et al.*(1987)

identified drought tolerant lines using the physiological parameters like stomatal resistance, electrical conductivity and relative water content. TMO 101 was found to be tolerant/resistant to drought and is being used as a parent in the development of drought tolerant cultivars.

Another important factor is agronomic management of common bean cultivars. Essentially all aspects of agronomy may affect the level of drought stress. For example, pests like pathogenic root fungi, nematodes may increase water loss or may reduce the efficiency of root system in extracting soil moisture.

In general, successful crop production in regions of frequent drought requires methods and practices for providing or maintaining sufficient available water for crop growth. Among these methods and practices are selection of crops that evade or endure a long periods of insufficient moisture, utilization of cultural and soil management techniques that increase soil water storage or decrease the rate of use of the limited water supply, and developments of methods that reduce evapotranspiration (Viets, 1971).

2.6 Use of Common Bean Crop Model in Drought Studies.

Agricultural and environmental research ultilise knowledge of specific processes within a complex system of interacting the independent phenomena to attempt a comprehensive understanding of the operation of the system as a whole. Crop models and simulation techniques have been developed to provide comprehensive and quantitative description of the behaviour of dynamic crop growth patterns (Singh *et al.*,1985). A model is defined by Ritchie (1991) as a small representation of a real thing or a system of postulates, data and inferences presented as mathematical description of an entity or state of affairs. Crop models integrate component submodels of various processes in the soil - plant-atmosphere system to provide predictions of growth and yield of crops (Ritchie, 1991).

The BEANGRO is a crop simulation model that operates at a daily time steps, and simulates crop growth and development from the date of sowing until harvest maturity (Hoogenboom *et al.*,1994). The BEANGRO is a versatile, user-friendly simulation model for common bean (Boote, 1994). This crop model responds to environmental variables including air temperature, solar radiation, precipitation, and soil moisture retention characteristics as well as to crop management conditions.

According to (Whisler *et al.*,1986) crop simulation is defined as a process by which a model acts like a real crop by gradually growing leaves, stems and roots during the season, and finally predicts the biomass and seed yield. Due to the magnitude of possible management x genotype x environmental interactions, traditional field experimentation has proved to be limited in its ability to identify improved crop production practices. This is especially true in the tropics where each farmer and each farm is unique, and its results are site, cultivar, and management specific (Rwe-yemamu,1995). Thus the approach of matching the crop requirements to land characteristics through systems analysis and crop simulation is important (IBSNAT,1990).

Low funding for agricultural research and extension, makes the use of simulation model even more of a necessity as a tool for assisting decision making in sustainable agricultural systems. There are very few documented studies from Southern Africa (Rweyemamu, 1995; Lourens and de Jager,1997) showing the use of crop models in identifying specific growth stages sensitive to drought, which is a serious disaster in Sub-Saharan Africa. In addition to this, no field studies on common bean production under irrigation have been reported whereby the total dry matter, plant part dry matter, leaf area index, and other related growth parameters were determined under Tanzanian conditions (Rweyemamu, 1995). Crop growth models are receiving an increasing attention as tools for crop research in different displines such as water deficit (drought), temperature effects on phenology and yield; and cultivar differences in phenology (White *et al.*,1995 and Lourens and de Jager,1997).

According to Kaswamila (1997) Geographical Information System (GIS), which is an essential tool for management and decision making process, is becoming popular in some goverment departments, universities and non-govermental organizations (NGOs) for use.Therefore, the use of both crop simulation models and GIS may provide a better decision support system for resource managers (agriculturalists) working on drought studies in various parts of Tanzania.

CHAPTER THREE

3.0 MATERIALS AND METHODS

Two experiments were conducted during the study period. The first experiment was conducted under screen house conditions while the second experiment was conducted under field conditions. Both experiments were conducted at Sokoine University of Agriculture (SUA) in the Morogoro region. The University is located at 6°.5' latitude South, 37°.3' longitude East; and 525m above sea level (asl). Initially both experiments were to be conducted under field conditions. But because of very heavy rains (EL NINO) during the first growing season, a screen-house experiment had to be planned.

3.1 Screen-house Experiment

Seeds of three bean cultivars which included Canadian Wonder, "Rojo" and SUA 90 were sown on 5 March, 1998 in sandy clay loam soils. The soil physical and chemical characteristics were determined before planting. Sowing was done in 10 litre plastic pots. The soils used were collected from the SUA horticulture unit where the field experiment was conducted during the dry period (May to August, 1998). Eight seeds were sown in each pot. Ten 10 days after emergence seedlings were thinned and six plants per pot were left. Fertilizers, 21% N sulphate of ammonia (SA) and 45% P triple supper phosphate (TSP) were applied at 30kg N and 25kg P per hectare at planting, respectively. However, SA was split applied i.e, half of the rate at planting time and the other half was applied 25 days after planting to reduce N leaching losses due to percolating water. Weeds were controlled by hand pulling.

3.1.1 Experimental design

The experiment was arranged as a split plot with two main plots (main treatments) and three subplots (subtreatments). The main plots were: Irrigated throughout the growing period (IR1) and moisture stressed or drought- stressed (IR2) induced by complete cessation of irrigation at first flowering (R1). The subplots were three common bean cultivars i.e. Canadian wonder which is a local variety, large seeded and commercially available to farmers; " Rojo" which is a medium seeded, fairly early maturity and newly released variety ; and SUA 90 which is small seeded and early maturity. The experiment was replicated four times. The whole experiment had a total of 24 subplots; and the combination of treatments in each replication were:

IR_1 + Canadian wonder

IR_1 + "Rojo"

IR_1 + SUA 90

IR_2 + Canadian wonder

IR_2 + "Rojo"

IR_2 + SUA 90

3.1.2 Water management

3.1.2.1 Water requirement for common bean.

Water requirement for common bean was calculated using the procedure recommended by FAO (1984; 1986). The effect of climate on bean crop water requirements i.e., reference crop evapotranspiration (ETo) in mm/day; and the effect of crop characteristics on bean crop i.e., crop coefficient (kc) were used as follows:-

$$\text{ETc} = \text{ETo} \times \text{kc}$$

Where ETc = Crop evapotranspiration/crop water requirement

ETo = Reference crop evapotranspiration

kc = Crop coefficient

Details are shown in appendices 1a.

3.1.2.2 Irrigation intervals

Irrigation interval was calculated as follows:-

$$I = \frac{P \times Sa \times D}{ETc}$$

Where I = Irrigation interval

P = Fractional of available soil water

Sa = Total available soil water in mm/m

D = Rooting depth

ETc = Crop evapotranspiration in mm/day.

Details on this are shown in appendices 2a.

3.1.3 Quantification of drought stress

The effect of drought on yield loss was determined using the following relationship as given by FAO (1986).

$$\frac{1 - Y_a}{Y_m} = ky \cdot \frac{(1 - Eta)}{ET_m}$$

where Y_a = actual harvested yield

Y_m = maximum harvested yield

ky = yield response factor which is equal to 1.15 for total growing season of common bean.

ET_a = actual evapotranspiration

ET_m = maximum evapotranspiration

Details are shown in Appendix 3a.

3.1.4 Data collection

3.1.4.1 Soil data

The soil physical and chemical characteristics were determined using the procedure found in the Soil Science Department at Sokoine University of Agriculture (SUA).

3.1.4.2 Weather data

A thermometer was placed in the screen house to collect an average daily temperature and be compared with values collected at the SUA meteorological station. The remaining weather data including rainfall (mm), evaporation (mm), radiation (MJm^{-2}), maximum and minimum temperatures (${}^{0}C$), minimum and maximum relative humidity (%), sunshine hours (hr/day),and wind run(mls/day) were obtained from SUA Meteorological Station. The data were used to estimate potential evapotranspiration (ETo), which later were used to calculate the crop water requirement (ETc). The same weather data were used to run the bean simulation model. Appendix 4 and 5

3.1.4.3 Plant height and Phenological data

Plant height was determined by the use of a ruler measuring the plants starting from the ground level to the tip of the main branch. Measurements were taken at first flowering (R1), 50% flowering (R4) and physiological maturity (R8) growth stages. Phenological data were determined by recording different developmental stages of the three common bean cultivars starting from days of emergence (V1) up to harvest maturity (R9).

3.1.4.4 Leaf area

To determine the leaf area, lamina length (L) and maximum width (W) of each leaf let was measured with a ruler to the nearest millimetre. Leaf area was then calculated as the product of the length, width and a constant (k) determined for each type of leaflet. To obtain k several leaflets (trifoliate) were measured using graph papers as described by IBSNAT (1990). Finally, leaf area per plant was calculated by multiplying the average number of leaves (n), length (l) and width (w) of a leaflet by an area constant (k). That is: LA = l x w x k x n. The value k is an empirically derived constant which was obtained by comparing leaflet area measured directly with graph papers vs leaf let area obtained from length and maximum width measurements.

3.1.4.5 Leaf number

Number of leaves per plant on the main stem was determined from V1 to R4 growth stages by counting the number of nodes.

3.1.4.6 Total biomass

Total biomass was determined at R1, R4, and R8 by uprooting one plant in each harvest from every pot. Care was taken so as to recover most of the roots from the soil. The plants were oven dried at 70°C for 48 hours. The total of whole plants were taken and then separated into roots, stems, leaves, pods and their respective dry weight determined.

3.1.4.6.1 Root length

The root length was recorded by measuring the length of the taproot using a ruler.

3.1.4.7 Yield and yield components

Yield was determined by harvesting three plants per pot (subplot) at harvest maturity. Yield components data were taken by counting the number of pods per plant and number of seeds per pod from harvested plants. Hundred seeds were counted from each subplot and weighed to obtain seed size. Seeds from each subplot were oven dried at 70°C for 48 hours to obtain constant weight. Finally, number of pods per plant, seed per pod, and seed size (mg), were multiplied to obtain yield per plant in (g) as described by (Fagaria *et al.*,1997).

3.1.4.8 Physiological traits

Data for physiological traits were calculated from plants sampled within each replication for each cultivar between R_1 and R_4; and between R_4 and R_8 growth stages. Computations were done as given by Gardner *et al.*(1985) as follows:

(a) Relative growth rate; RGR $gg^{-1}day^{-1}$

$$= \frac{\text{In } W_2 - \text{In } W_1}{T_2 - T_1}$$

(b) Specific leaf area; SLA ($cm^2\ g^{-1}$)

$$= \frac{\dfrac{LA_2}{W_2} + \dfrac{LA_1}{W_1}}{2}$$

(c) Specific leaf weight; SLW (g cm^{-2})

$$= \frac{\frac{LW_2}{LA_2} + \frac{LW_1}{LA_1}}{2}$$

(d) Net assimilation rate; NAR (g cm^{-2} day^{-1})

$$= \frac{W_2 + W_1}{T_2 - T_1} \text{ X } \frac{(\ln LA_2 - \ln LA_1)}{LA_2 - LA_1}$$

(e) Leaf area Duration; LAD (cm^2 day^{1-})

$$= \frac{\frac{LA_1 + LA_2}{T_2 - T_1}}{2}$$

(f) Biomass duration; BMD (g day^{1-})

$$= \frac{(W_2 + W_1) \text{ x } T_2 - T_1}{2}$$

Where :

W1 and W2 = dry plant weights in two consecutive harvest

TI and T2 = time intervals (days)

In = natural log value

LA = leaf area (cm^2)

LW = leaf weight (g)

3.1.5 Data analysis

Statistical treatment effects ($P \leq 0.05$) of data collected were identified by analysis of variance (ANOVA) procedures using MSTAT-C programme (MSU,1993) as a randomized complete block design - split plot. When significant treatment effects occurred, means were separated and ranked using Duncan's Multiple Range Test (DM-RT) at $P \leq 0.05$. Simple linear correlations and regressions were also analysed using the same statistical programme, subroutine CORR.

The statistical model was:-

$$Yijk = U + Bi + aj + Uij + k + ajk + Eijk$$

Where Yijk = Response
U = General effect
Bi = Replication effect
aj = Main factor effect
Uij = Main plot random error effect
k = Subplot factor effect
ajk = Interaction effect due to jth block and kth factor B
Eijk = Subplot random error effect

Data obtained from screen house experiment were also used to calibrate the BEANGRO crop model.

3.2 Field Experiment

The field experiment was conducted at SUA horticultural unit during the dry season. It was between 28 May and 20 August, 1998. This period allowed an application of drought stress and irrigation treatments as planned.

3.2.1 Land preparation and experimental design.

The experimental area was prepared by using hand hoes. Ridges of about 15cm in height were prepared so as to avoid water running from one sub plot to another without control. Each subplot had five rows/ridges. The spacing between ridges was 0.6m, while the spacing from one plant to another was 0.2m, which resulted in a $10.8m^2$ for each subplot.

Similar common bean cultivars of Canadian wonder,"Rojo" and SUA 90 were used in this experiment. Gap filling was done 12 days after emergence. Weeds were controlled by use of hand hoes. Insect pests were controlled by spraying Karate (Landecyhalothrin) at a rate of 30ml/20lts of water at two weeks interval. Fertilizer application rates and experimental design were as outlined under screen-house experiment in section 3.1.1.

3.2.2. Water management

Estimation of soil moisture contents was done by placing four tensiometers in each replication at the depth of 30cm. The procedure recommended by (FAO,1984;1986) was used to calculate irrigation inteval and water requirements for common bean. Details are as shown in Appendices 2a, 2b and 3b. Furrow irrigation was applied.

3.2.3. Quantification of drought stress

Quantification of drought stress were done as described under section 3.1.3 in the previous experiment and details are shown in Appendices 3c and d.

3.2.4. Collection of other data

Leaf area index (LAI) was determined by taking an average leaf area from plants harvested from central area of 1m^2 for each plot. Then leaf area was divided by ground area to obtain LAI. Total biomass were determined from plants harvested from the 1.0m^2 central area per plot. The procedure described under section 3.1.4.6 was followed. Plants from 1.0m^2 was harvested and their seeds weighed to obtain actual seed weight per meter square. This was then multiplied by plot area (10.8m$^{2)}$ to obtain seed yield per plot. Later, seed yield obtained per plot was used to extrapolate seed yield per hactare. Seed yield components were determined as described in section 3.1.4.7. The seed yield per plant (g/plant) obtained by use of yield components was multiplied by plant population (m^{-2}) at harvest, and value of seed yield compared to that obtained from direct weighing.

3.2.5. Physiological traits

Physiological traits were calculated as described under section 3.1.4.8.

3.2.6. Bean crop simulations

3.2.6.1. Data entry

Since the BEANGRO model requires a data set on daily weather, the data were collected from SUA meteorological station during the cropping season as shown in Appendix 5. The collected weather data were entered in file FILEW designated as SUAMO9801.WTH in this study.

The soil characteristics as obtained from horticulture unit are shown in Table 1. However, the value of field measured soil water availability were determined for DUL, SSAT and SLLL using the computer program SWLIM, where the sand clay percentage and bulky density values determined in the laboratory were used for the three top most horizons. In addition, all the management activities for the experiment were entered in FILEX also known as SUMO9801.BNX.

The estimated genetic coefficients of the three common bean cultivars were used for the evaluation of the bean crop and were entered in FILEC refered to as BNGRO980.-CUL. The genetic coefficients in BNGRO980.CUL for Canadian Wonder variety used in this study were calbrated using the methods described by Hoogenboom *et al.*(1991) and Boote (1994). In the BEANGRO crop simulation model, Canadian Wonder cultivar coefficients were estimated as defaults, followed trial and error approach to get the real values. Cultivars "Rojo" and SUA 90 were first assumed to have similar genetic coefficients as Canadian Wonder, although SUA 90 differs phenotypically because of its smaller seed size. From this point of view, various simulations were run based on data collected from screen house and field to estimate various coefficients.

3.2.6.2. Procedure for calibrating genetic coefficient.

1. The crop life cycle was estimated by adjusting the EM-FL (minimum time between emergence and first flower in photothermal days), until the correct date of flowering was approximately attained. The SD-PM ie; minimum time between R5 and R8 growth stage was then adjusted until simulated and field measured dates of physiological maturity were almost the same.

2. Estimation of dry matter accumulation at flowering, pod yield (kg/ha), seed yield (kg/ha), seed number m^{-2} and maximum leaf area index (LAI): involved the adjustiments of EM-FL, FL-SH (time between first flower and first pod, FL-SD (time between first flower and first seed). The SFDUR (time for seed filling period in a pod) and PODUR (time required for a cultivar to reach final pod load under optimum conditions).

3. The LAI was calibrated by using the SLA (specific leaf area) measured during the study, and the SIZLF (maximum size of three leaflets in cm^2). Seed size and seeds per pod were adjusted by using WTPSD (maximum weight in gram per seed and maximum

number of seed per pod counted under irrigated treatments for each cultivar).

4. Some parameters such as maximum (SLAMAX) and minimum (SLAMIN) specific leaf area (SLA); biomass accumulated during the vegitative and reproductive growth phases were adjusted by using CMOBMX (proportion in carbohydrate reserves that can be mobilized in a day) and CADSTF (carbohydrate added to stem reserve at the end of the day after growth). Simulated seed yield, pod yield and seed number were matched to those measured under field conditions by setting the maximum threshing (THRSH) to 80% in the ecotype (BNGRO980.ECO) file.

5. The above steps were repeated until reasonable agreements between simulated and field measured values of anthesis, physiological maturity dates, maximum leaf area index, pod yield, seed yield, and seed size were obtained under irrigated conditions for the three cultivars. The genetic coefficients obtained from irrigated treatments were used to simulate the treatments under droughted conditions.

6. After model calibration, the model was tested by comparing simulated values with field collected data in all treatments. Performance data (average field values) for comparisons with simulated values were entered in files FILEA (SUMO9801.BNA) and FILET (SUMO901.BNT). All treatments were simulated as one experiment. Since applied N and P to the experiment were non-experimental variables in both experiments, they were not used for model evaluation.

CHAPTER FOUR

4.0 RESULTS

4.1 Environmental Conditions

The average physical and chemical soil characteristics from the experiment site used are shown in Table 1. The soil characteristics used in the BEANGRO model are presented in Table 9. Average weather values collected during the experimental period are shown in Table 2. However, the daily weather data used to run the simulations are as indicated in Appendix 4 and 5. The average temperature values (^{0}C) inside the screen-house between 12:00 and 3:00 pm in March, April and May, 1998 were 38, 37 and 33, respectively. The maximum temperature in the field experiment were 29.3, 28.8, 28.4, and 29.9; while the minimum temperature were 16.7, 17.7, 16.9 and 18.1.

4.2 Developmental Stages of Three Common Bean Cultivars.

Germination percentage of all three bean cultivars ranged between 90% and 95%. Canadian Wonder took 6 days to emerge, while " Rojo" and SUA 90 took 7 days under screen-house conditions. Under field conditions, the same cultivars took 8, 9 and 10 days, respectively (Table 3). All cultivars did show similar growth habits. They were short, erect with determinate bush type.

There were slight variations within cultivars in terms of days to first flowering (R1) under both irrigated and droughted conditions. Canadian wonder took longer time to reach 50% flowering, physiological maturity and harvest maturity under irrigated treatment (Table 3). But under drought-stressed treatment, the same variety took relatively short time to reach the same stages of growth under both screen house and field conditions.

Cultivar "Rojo" took almost the same number of days to reach 50% flowering, physiological maturity and harvest maturity under both treatments i.e. irrigated and droughted. Cultivar SUA 90 also showed variations between days to physiological maturity under both treatments. Like the other two cultivars, it took relatively shorter days to reach the same stages of growth under droughted conditions. All three cultivars took relatively longer days to reach different stages of growth when planted under field conditions.

Generally, the growth cycle for the three bean cultivars under moisture stressed conditions was shorter than when the cultivars were grown under irrigation. All varieties grown under drought-stressed treatment wilted and dropped almost all the leaves between R4 and R8 growth stages. This was more severe with Canadian Wonder than with other two cultivars.

Table 1. Physical and chemical characteristics of the soil used in experiments at SUA, 1998[1]

Soil properties	Results	Method used	Comments
pH (H_20)	6.6	pH	Slightly acids
Bulky density (g/cm3)	1.4	Core	Low
Moisture content (%)	70	Volumetric	High
Textural classes (%)			Sandy clay loam
Sand	70	Hydrometer	High
Silt	10	"	Low
Clay	20	"	Low
Organic carbon (%)	0.8	Walkley and Black (1965)	Very Low
Total nitrogen (%)	0.2	Micro Kjeldahl	Low
Phosphorus (ppm)	14.7	Bray and Kurtz (1945)	Low
Exchangeable cations(cmol$_c$/kg)			
Calcium	4.6	Ammonium acetate Extraction	Medium
Magnesium	3.0	Ammonium acetate Extraction	Medium
Potasium	0.1	Ammonium acetate Extraction	Medium
CEC (cmol$_c$/kg)	10	Ammonium acetate extraction	Low

[1] The analysis was done in the Soil Science Department at SUA

Table 2. Summarized weather data during the study period, 1998

Month	Week	Temperature (°C) Maximum	Min	Rainfall (mm)	Evapo-Ration (mm)	Radiation MJm^{-2}
February	1	32.7	25.6	72.71	43.9	21.2
	2	31.2	22.4	121.4	23.5	13.7
	3	31.7	21.4	68.5	25.1	16.2
	4	39.6	25.9	0.0	34.0	20.8
				(262.0)	(126.5)	(17.9)
March	1	32.8	23.4	0.0	51.0	21.8
	2	30.7	22.9	44.1	37.6	17.0
	3	32.7	21.9	0.0	35.7	20.5
	4	31.0	21.9	70.7	35.0	16.6
				(114.8)	(159.3)	(75.9)
April	1	31.9	22.1	43.1	32.9	17.8
	2	26.1	19.3	78.9	28.2	12.9
	3	29.1	21.6	23.2	21.3	13.7
	4	29.1	19.2	71.9	24.9	11.5
				(217.1)	(109.3)	(55.9)
May	1	29.6	20.9	32.9	35.2	15.8
	2	30.7	21.3	10.1	26.6	17.6
	3	25.8	14.4	0.0	27.0	16.9
	4	29.3	16.7	1.7	25.1	16.9
				(44.7)	(113.9)	(67.3)
June	1	29.7	19.9	11.1	23.9	14.88
	2	28.5	16.2	0.0	24.0	15.82
	3	28.0	14.9	0.0	28.0	14.60
	4	28.8	17.7	19.9	29.4	15.09
				(31.0)	(105.3)	(60.39)
July	1	27.4	15.4	0.0	24.0	11.9
	2	28.4	15.4	0.0	22.5	18.3
	3	26.6	16.3	0.0	23.5	12.6
	4	28.4	16.9	4.4	39.4	14.5
				(4.4)	(109.4)	(57.3)
August	1	28.8	16.6	0.0	3.8	15.0
	2	29.2	17.8	0.3	4.7	15.8
	3	29.6	17.2	0.5	4.7	15.2
	4	29.9	18.1	0.4	5.0	16.1
				(1.2)	(18.2)	(62.1)

Source: Meteorological Station, Sokoine University of Agriculture (SUA), Morogoro, Tanzania.

Values in parentheses refer to total values at weekly intervals for respective variable measured.

Table 3. Mean number of days taken for developmental stages of three bean cultivars grown under screen-house and field conditions to be initiated

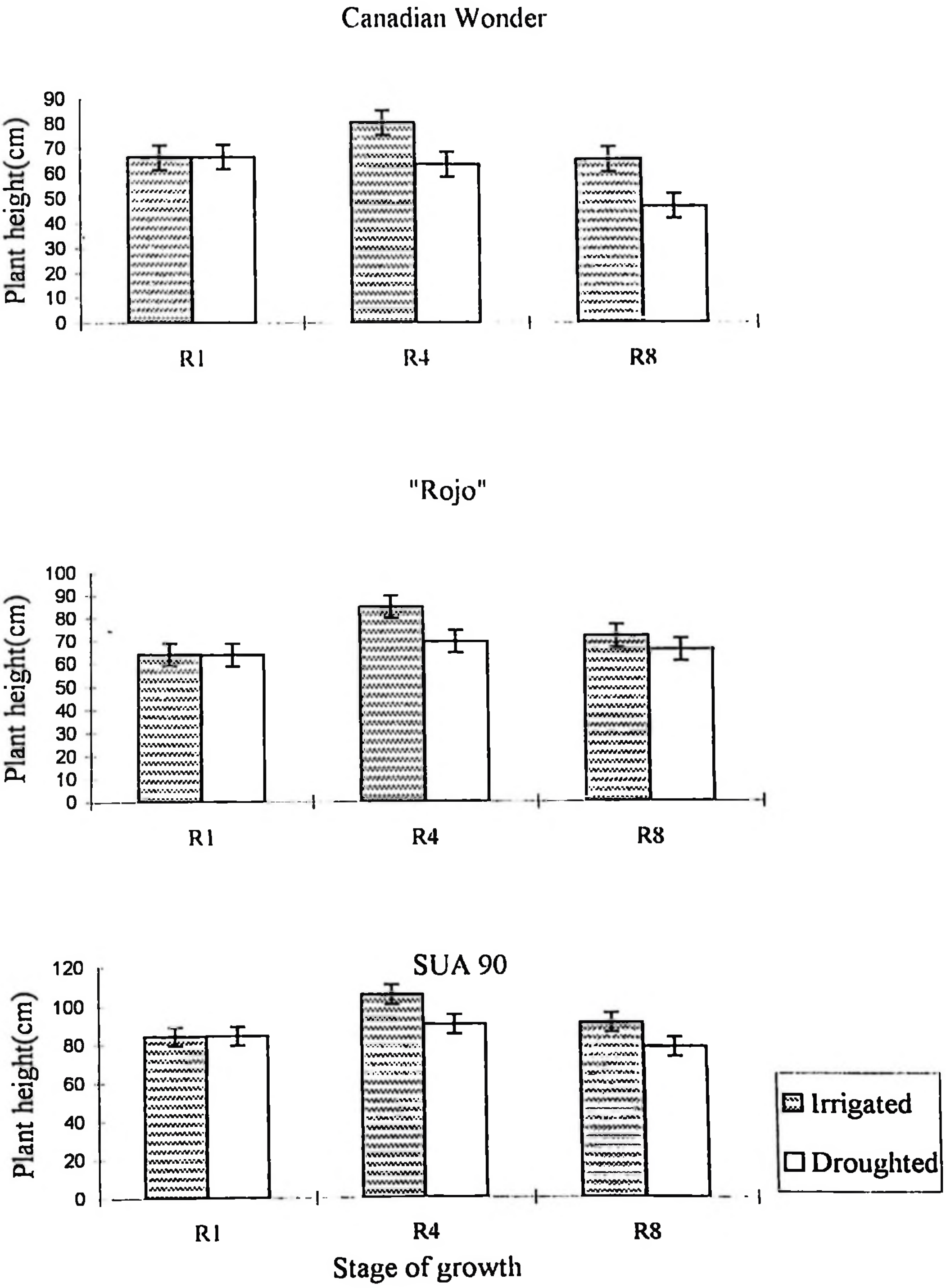
Experiments	Screen house			Field		
	Cultivars					
	CW	"Rojo"	SUA 90	CW	"Rojo"	SUA 90
Growth stage						
Days of emergence (V1)						
Irrigated	6	7	7	8	9	10
Droughted	6	7	7	8	9	10
Days to crop establishment (V3)						
Irrigated	14	16	16	18	22	23
Droughted	14	16	16	18	22	23
Days to first flowering (R1)						
Irrigated	27	30	29	31	30	32
Droughted	27	30	29	31	30	32
Days to 50% Flowering (R4)						
Irrigated	44	41	41	48	43	46
Droughted	39	40	40	45	43	46
Duration of flowering						
Irrigated	17	11	12	17	13	14
Droughted	12	10	10	14	13	14
Days to physiological maturity (R8)						
Irrigated	65	53	55	67	61	64
Droughted	59	51	49	60	59	61
Days to harvest maturity (R9)						
Irrigated	70	69	62	77	70	66
Droughted	61	62	58	67	65	65

4.3 Plant Height.

Plant heights in all cultivars measured under both screen house and field conditions are shown in Figures 1a and 1b. Plant heights ranged between 80.3 and 105.4 cm in all cultivars. Cultivar SUA 90 was the tallest averaging 84.1, 105.4, and 90.7 cm at R1, R4, and R8, respectively. This behaviour was consistent for both screen-house and field conditions.

4.4 Growth Analysis.

The analysis of variance revealed some highly significant differences ($P \leq 0.05$) between water regimes (factor A), among cultivars (factor B) and interaction effects (A x B) in some physiological traits under both screen-house and field conditions (Table 4). However, these significant effects were higher for data collected from screen-house than that collected from field conditions. Further, interaction effect were more significant than effects due to factor A and factor B. This was followed by cultivar effects and lastly water regime effects. Some traits such as average mean specific leaf area (SLA), leaf area duration (LAD) and biomass duration (BMD), were constantly significantly influenced by both factors A and B and the interaction effects between A and B. However, values of some physiological traits determined in defferent harvest intervals are shown in Tables 5a and b.


Canadian Wonder

"Rojo"

SUA 90

Fig.1a Changes in plant height of three bean cultivars grown under two moisture regimes in the screen house

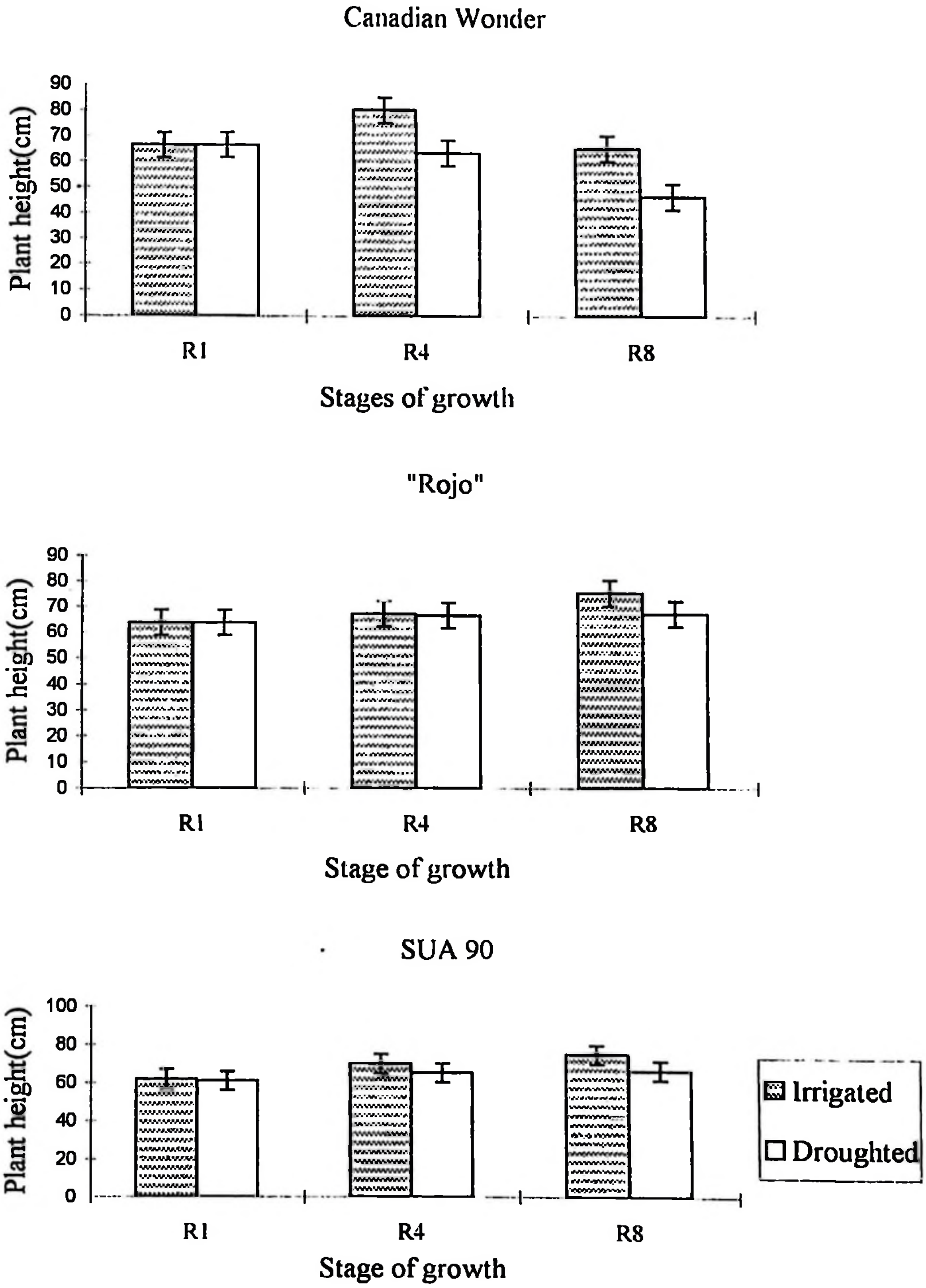


Fig.1b Changes in plant height of three bean cultivars grown under two moisture regimes in the field

Table 4. Randomized complete block design (RCBD) - Split plot analysis of variance summary.

Physiological Trait	Significant levels					
	Water regimes(A)		Cultivar effect (B)		Interaction effect (AB)	
	Under screen-house conditions					
	a	b				
$\overline{\text{RGR}}$	NS	(NS)	**	(**)	**	(*)
$\overline{\text{SLA}}$	**	(NS)	**	(**)	**	(**)
$\overline{\text{SLW}}$	NS	(*)	NS	(NS)	NS	(NS)
$\overline{\text{NAR}}$	NS	(NS)	NS	(*)	NS	(NS)
$\overline{\text{LAD}}$	*	(**)	**	(**)	**	(**)
$\overline{\text{BMD}}$	**	(**)	**	(**)	**	(**)

Table 4 continued under field conditions

$\overline{RGR}$	NS	(NS)	NS	(NS)	*	(NS)
$\overline{SLA}$	**	(*)	**	(**)	**	(*)
$\overline{SLW}$	NS	(NS)	NS	(NS)	NS	(NS)
$\overline{NAR}$	*	(**)	NS	(NS)	NS	(NS)
$\overline{LAD}$	*	(NS)	*	(**)	*	(**)
$\overline{BMD}$	*	(*)	*	(**)	*	(**)

a = Values not in parentheses represent physilogical traits calculated between R1 and R4.
b = Value in parentheses represent physiological traits calculated between R4 and R8.

Table 5a. Value of some physiological traits of three bean cultivars grown under two water levels in the screen-house determined in different harvest intervals.

	Canadian Wonder		"Rojo"		SUA 90	
Water level	IR1	IR2	IR1	IR2	IR1	IR2
Traits[1]						
$\overline{RGR}$	0.05 (0.06)[2]	0.05 (0.03)	0.05 (0.11)	0.04 (0.01)	0.09 (0.06)	0.05 (0.11)
$\overline{SLA}$	180.8 (166.5)	157.2 (152.0)	170.4 (129.0)	174.7 (160.4)	179.5 (153.9)	170.7 (159.3)
$\overline{SLW}$	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
$\overline{NAR}$	0.01 (0.01)	0.00[3] (0.00)	0.01 (0.03)	0.00 (0.01)	0.01 (0.01)	0.01 (0.02)
$\overline{LAD}$	15.57 (15.23)	18.27 (8.94)	16.09 (15.38)	16.60 (13.64)	18.68 (22.27)	17.95 (20.89)
$\overline{BMD}$	237.1 (710.9)	124.2 (345.0)	188.7 (542.4)	153.9 (334.6)	195.0 (748.9)	177.0 (275.8)

1 Physiological traits determined between four consecutive harvests over growth stage R1 and R4; and R4 and R8.

2 Values in parentheses represent traits determined between R4 and R8 growth stages.

3 Zero values are only due to rounding.

Table 5b. Values of some physiological traits of three bean cultivars grown under two water levels in the field detemined in different harvest intervals.

	Canadian Wonder		"Rojo"		SUA 90	
Water levels	IR1	IR2	IR1	IR2	IR1	IR2
Traits[1]						
$\overline{\text{RGR}}$	0.07 (0.01)	0.07 (0.03)	0.07 (0.01)	0.07 (0.02)	0.06 (0.01)	0.05 (0.01)
$\overline{\text{SLA}}$	157.48 (195.49)	151.71 (194.12)	149.27 (165.25)	142.29 (156.56)	165.43 (201.69)	163.8 (185.3)
$\overline{\text{SLW}}$	0.01 (0.2)	0.01 (0.02)	0.0.1 (0.02)	0.01 (0.02)	0.01 (0.02)	0.01 (0.02)
$\overline{\text{NAR}}$	0.05 (0.05)	0.05 (0.02)	0.06 (0.07)	0.05 (0.04)	0.05 (0.08)	0.03 (0.06)
$\overline{\text{LAD}}$	13.13 (14.61)	13.48 (12.84)	15.23 (12.39)	14.28 (12.62)	15.92 (15.69)	15.31 (16.25)
$\overline{\text{BMD}}$	2634.2 (6992.9)	1745.5 (3211.5)	1924.7 (7154.1)	1589.2 (3998.4)	2043.3 (7549.2)	1713.9 (4152)

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[1] Physiological traits determined between four consecutive harvests over growth stages R1 and R4; and R4, and R8.

[2] Value in parentheses represent traits determined between R4 and R8 growth stages.

4.5 Leaf Number, Leaf Area and Leaf Area Index.

Results show that leaf number, leaf area and leaf area index under droughted condition were low as compared to that of irrigated treatment both at R_1 and R4 growth stages. The results were true for both screen house and field experiments (Table 6). But leaf area index for Rojo at R4 was higher under droughted condition than irrigated condition. There were significant differences among cultivars under both treatments ($P \leq 0.05$). There were no significant differences between water levels and among cultivars on leaf number per plant and leaf area at R_1 (Table 6). The leaf number per plant of Canadian wonder and "Rojo" was the same at R1. The SUA 90 maintained the same leaf number from R1 to R4 growth stages under both treatments. In adition to this, leaf area index of all three common bean cultivars were statistically the same at R1 growth stages.

4.6 Biomass Production.

Biomass determined at R1, R4, and R8 growth stages, for bean crop grown under screen house and field conditions are presented in (Figures 2a and b). Highly significant differences ($P \leq 0.05$) among water levels, cultivars and their interactions were obtained in all stages of growth except for R1 where treatments were still the same for all plots. Changes of biomass components of the three bean cultivars after application of treatments at R4, and R8 growth stages were significantly different as shown in Figures 3a to 4b.

Table 6. Effect of drought stress on leaf number per stem and leaf area (cm^2) of three bean cultivars at two growth stages.

	variables			
	Leaf number		Leaf area	
Growth stages	R1	R4	R1	R4
	Screen house experiment			
Treatments				
IR1 + CW	7.5a	7.8a	177.4a	260.8a
IR1 + "Rojo"	7.3ab	7.8a	171.4b	181.6d
IR1+ SUA 90	6.3b	7.5a	169.4c	242.2b
IR2 + CW	6.8ab	4.5c	178.3a	151.8f
IR2 + "Rojo"	7.0ab	5.8b	172.1b	160.4e
IR2 + SUA 90	6.8ab	7.3a	169.4c	190.9c
Mean	7.95	6.78	173.00	197.95
SE±	0.30	0.24	1.17	0.67
CV%	8.69	6.98	0.20	0.68
	Field experiment			
	Leaf number		Leaf area index	
IR1 + CW	7.3ab	8.0a	1.8a	2.7a
IR1 + "Rojo"	6.8ab	7.0b	1.8a	2.0d
IR1 + SUA 90	8.0a	8.0a	1.8a	2.7a
IR2 + CW	7.3ab	5.8d	1.8a	2.0d
IR2 +"Rojo"	6.8ab	6.5c	1.8a	2.2c
IR2 + SUA 90	8.0a	7.8a	1.8a	2.5b
Mean	7.37	7.18	1.80	2.30
SE±	0.12	0.13	0.02	0.10
CV(%)	12.60	14.70	2.00	5.50

Means in the same column followed by the same letter are not statistically different ($P \leq 0.05$) following mean separation test by Duncan's Multiple Range Test (DMRT).

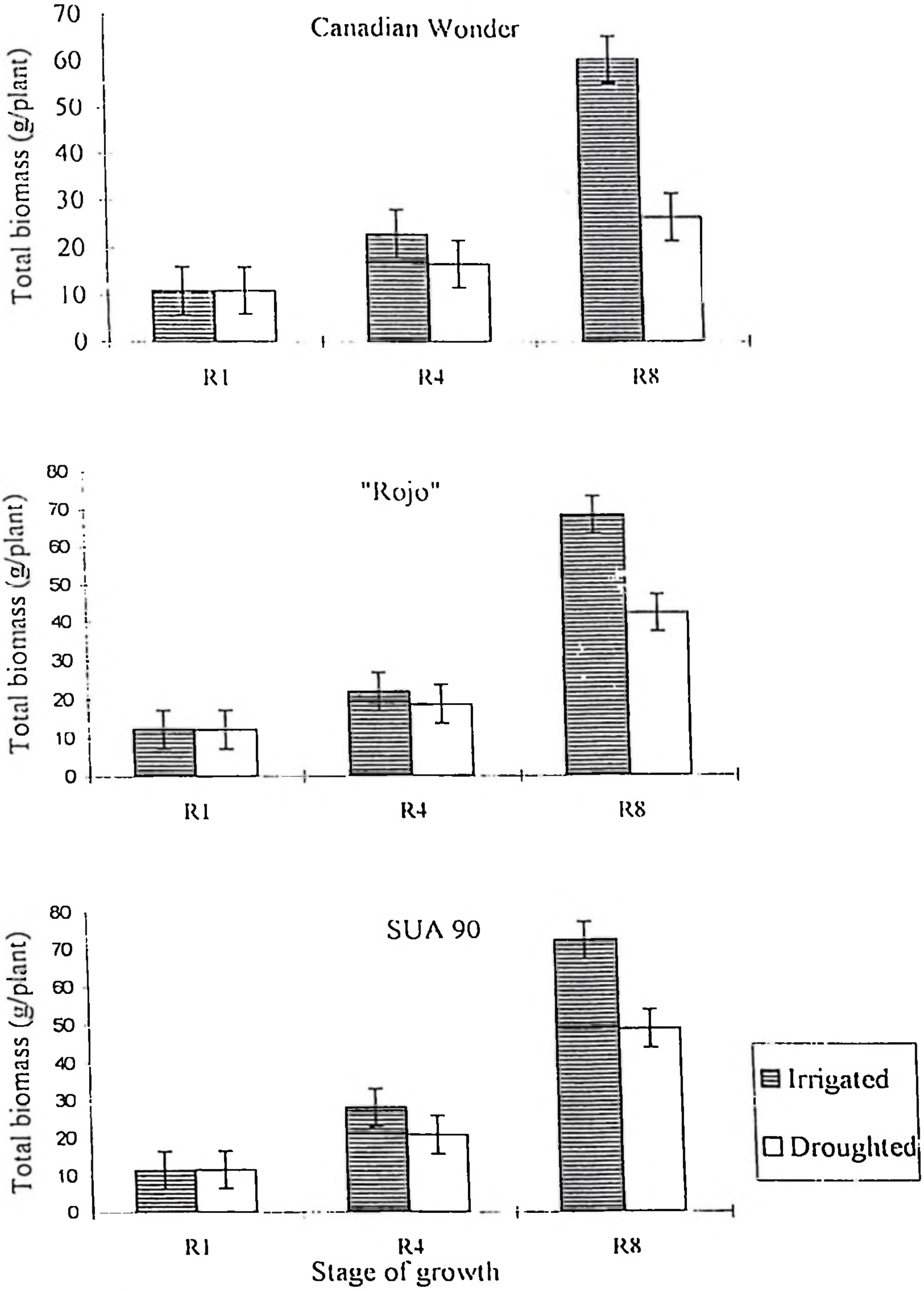

Fig. 2a Total biomass of three bean cultivars as influenced by irrigation regimes in the screen house

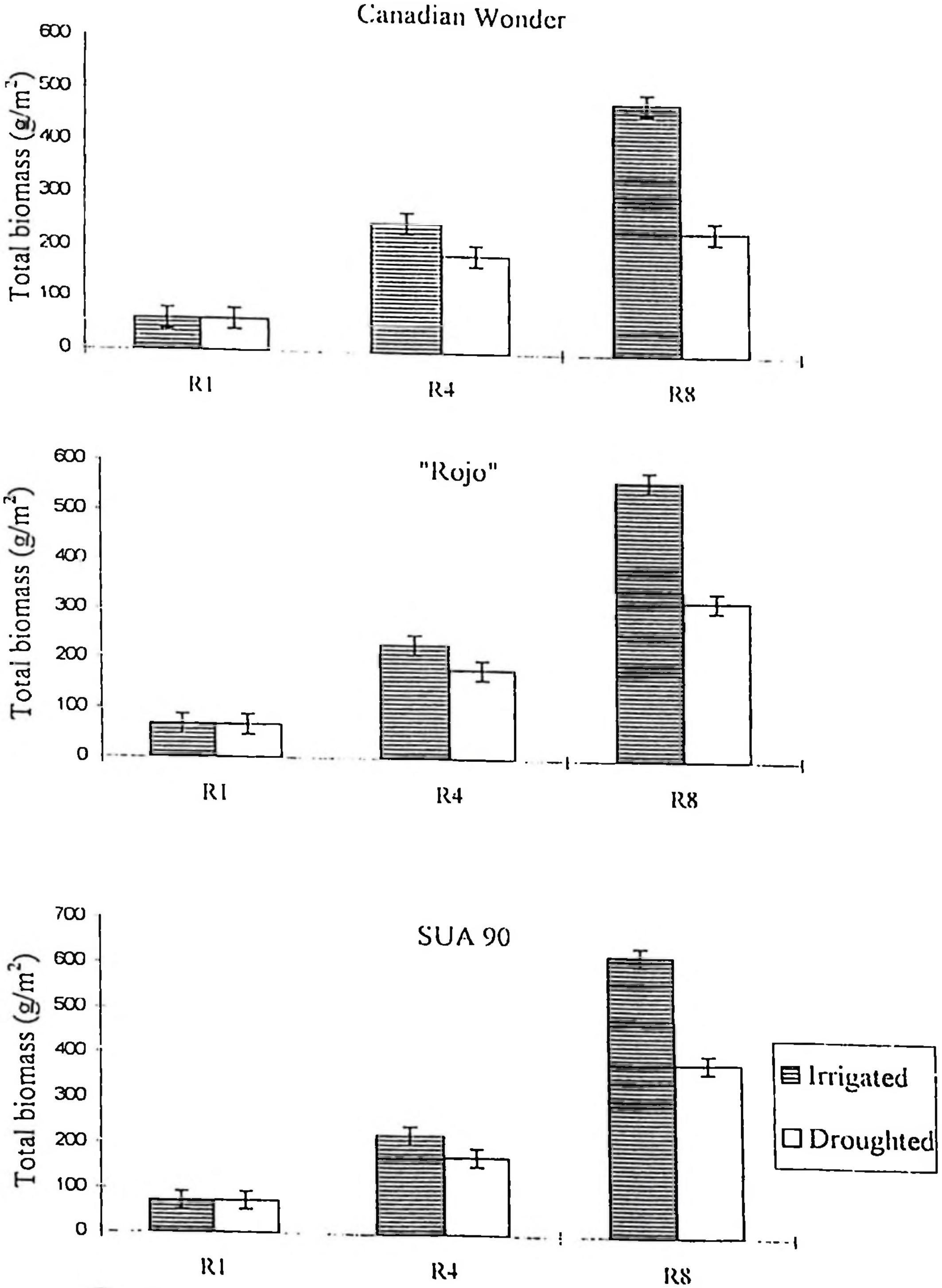

Fig. 2b. Changes in total biomass of three bean cultivars planted under two irrigation regimes in the field

Root biomass was similar for all cultivars at R1 growth stage. Highest stem biomass of 54.7g $m^{-2}$was shown by "Rojo", while SUA 90 had the highest leaf biomass of 93.9g m^{-2} at R4 growth stage under field conditions. There were significant differences ($P \leq 0.05$) among cultivars on root, stem, and leaf biomass due to the applied treatments.

After 50% flowering (R4) growth stage, the same trends of results were observed. "Rojo" had the highest root biomass (43.3g $m^{-2)}$ and stem biomass (84.8g m^{-2}) as shown in Figures 3a, 3d, 5a and 5b. SUA 90 had the highest leaf biomass and pod biomass under both treatments (Figures 3b, 3c, 3e and 3f). Canadian Wonder had the lowest stem, leaf, pod and root biomass under drought treatment (Figures 3a, 3b, 3c, 3d, 3e, 3f, 5a, and 5b). Thus, there were significant differences among cultivars on total biomass, within water levels, and their interactions at ($P \leq 0.05$). SUA 90 showed no significant differences between water levels on root and stem biomass in the screen house conditions at R4 (Figures 3a and 5a). Canadian Wonder had the highest leaf biomass, followed by "Rojo". That is 14.7g $plant^{-1}$ and 13.4g $plant^{-1}$ respectively (Figure 3a).

At physiological maturity, that is, at R8 growth stage, water levels were significant ."Rojo" was still maintaining the highest stem and root biomass (Figures 3a, 3d, 5a, and 5b). Cultivar The SUA 90 had also maintained the highest leaf biomass (107.6g m^{-2} followed by Canadian Wonder (103.9g m^{-2}) under irrigated treatment in the field (Figure 3e). Under drought treatment, the highest leaf biomass was obtained from SUA 90, followed by "Rojo"(Figures 3b and 3e). Cultivar SUA 90 also had the highest pod biomass under both treatments and experiments (Figures 3c and 3f). Canadian Wonder had the highest leaf biomass 14.7g per plant in the screen house, followed by "Rojo" 13.4g per plant respectively (Figure 3b).

4.7 Root length

The highest root length in the screen house experiment, was obtained from SUA 90 (48.3 cm), followed by "Rojo" (47.3 cm) under both treatments. The lowest root length was shown by Canadian wonder (35.5 cm) as shown in (Figure 4a). In the field conditions, the highest root length at 50% flowering (R4) was obtained from "Rojo"(47.3 cm). At physiological maturity (R8) growth stage, SUA 90 had the highest root length under both treatments. That is, 54.5 cm under irrigated treatment and 49.3 cm under droughted treatment (Figure 4b).

4.8 Yield and Yield Components.

The yields and yield components are shown in Table 7. The results show significant differences ($P \leq 0.05$) among cultivars and treatments/water levels. Cultivar SUA 90 gave the highest yields under both experiments and both treatments. These were 20.8 vs 10.4g plant^{-1} under screen house experiment and 1943.3 vs 1208.0 kg ha^{-1} under field experiment for irrigated and water stressed treatments, respectively. Cultivar SUA 90 was followed by "Rojo" which yielded 18.6 vs 3.4 g plant^{-1} and 1814.6 vs 901.9 kg ha^{-1} under screen house and field experiments for irrigated and water stressed conditions, respectively.

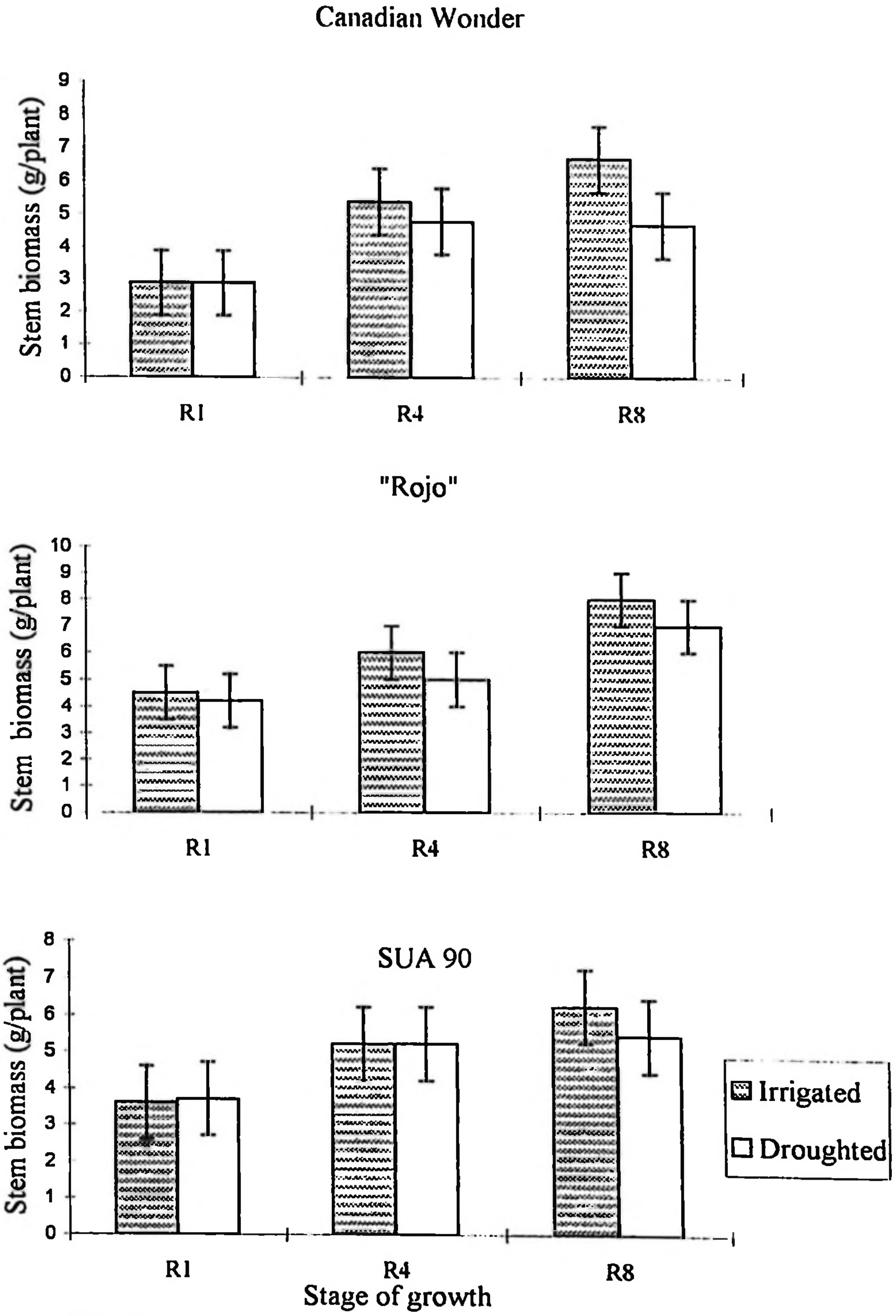

Fig. 3a Changes of stem biomass of the three bean cultivars as influenced by irrigation regimes in the screen house

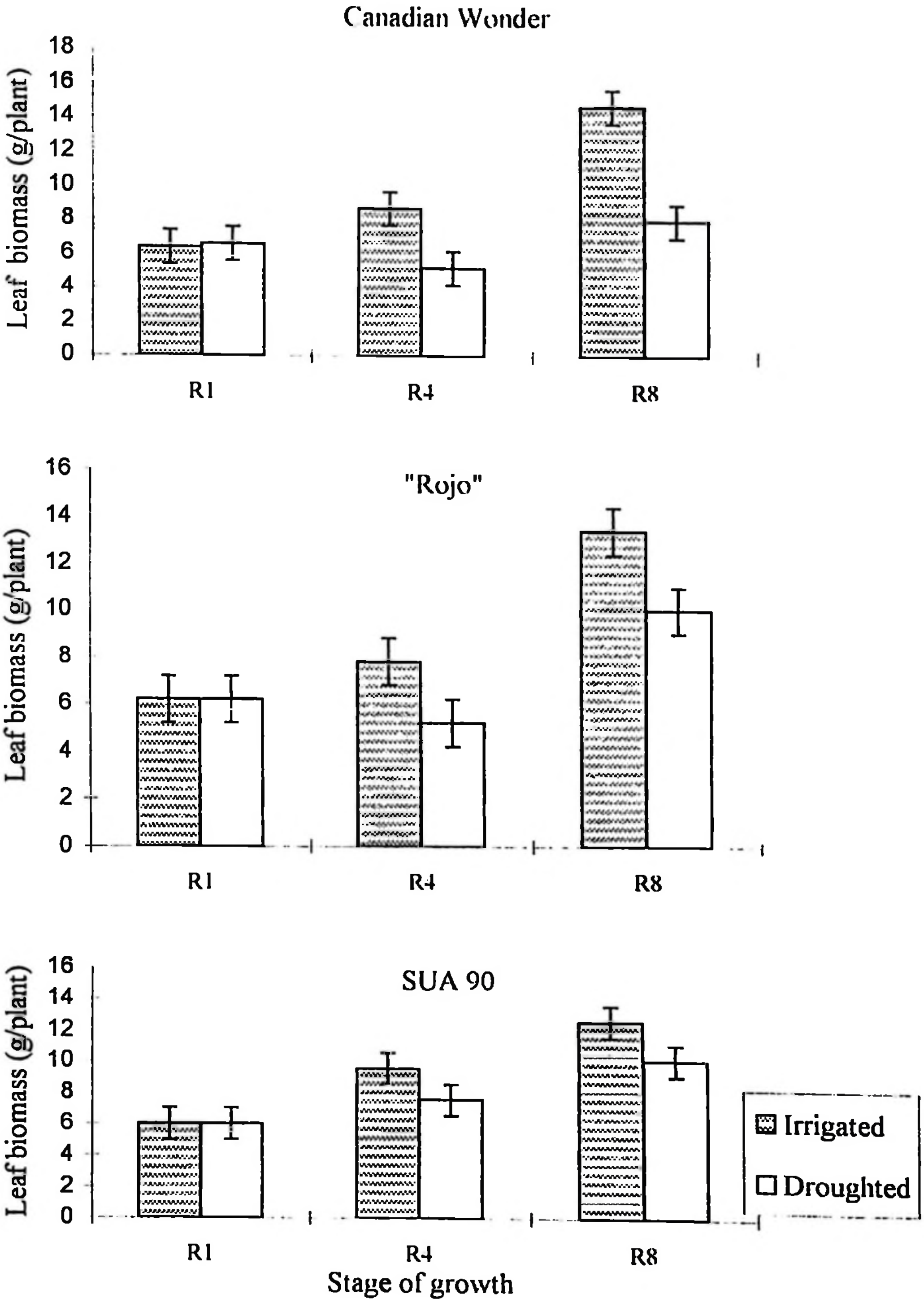

Fig. 3b Changes in leaf biomass of three bean cultivars as influenced by irrigation regimes in the screen house

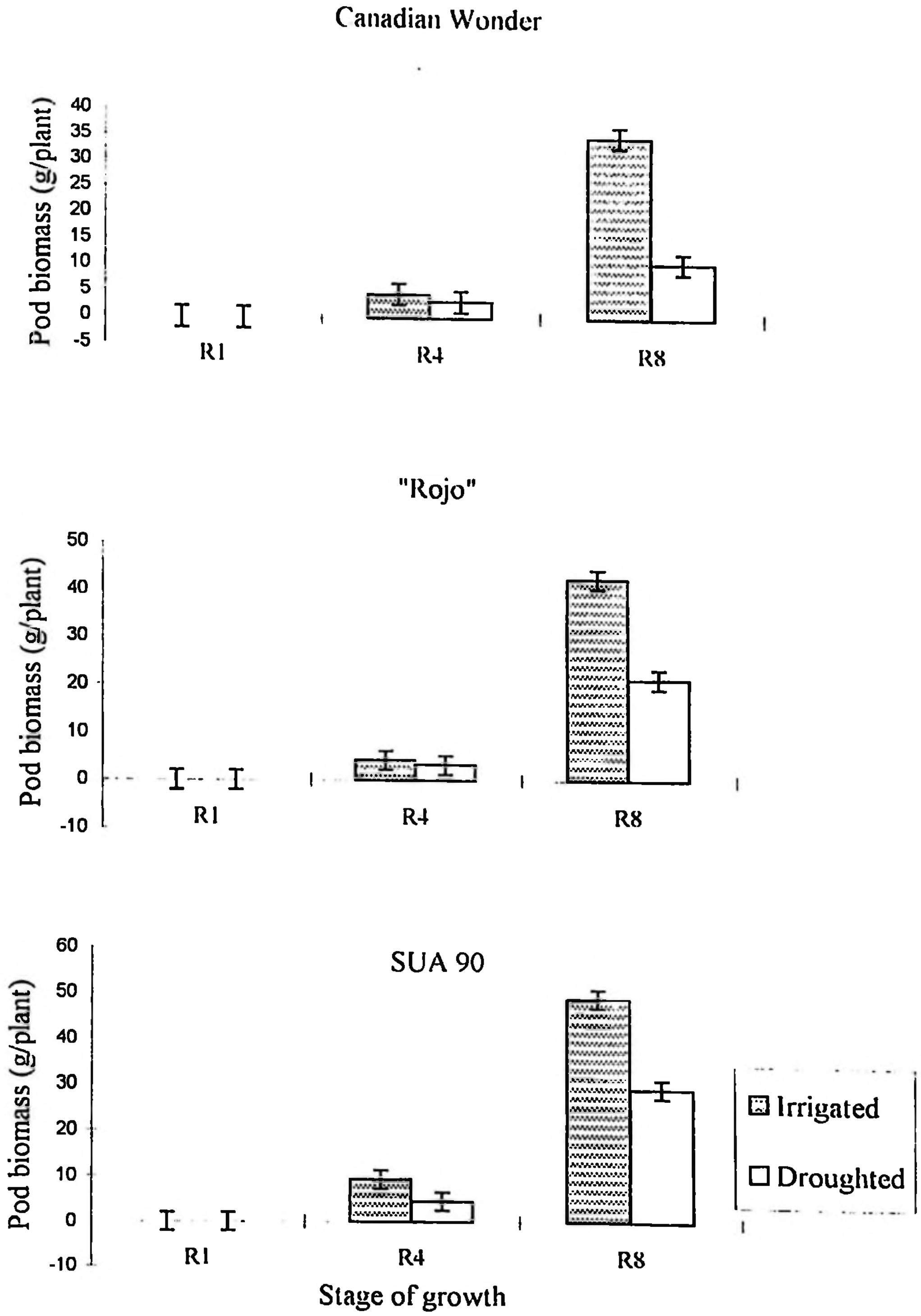

Fig.3c Changes in pod biomass of three bean cultivars as affected by irrigation regimes in the screen house

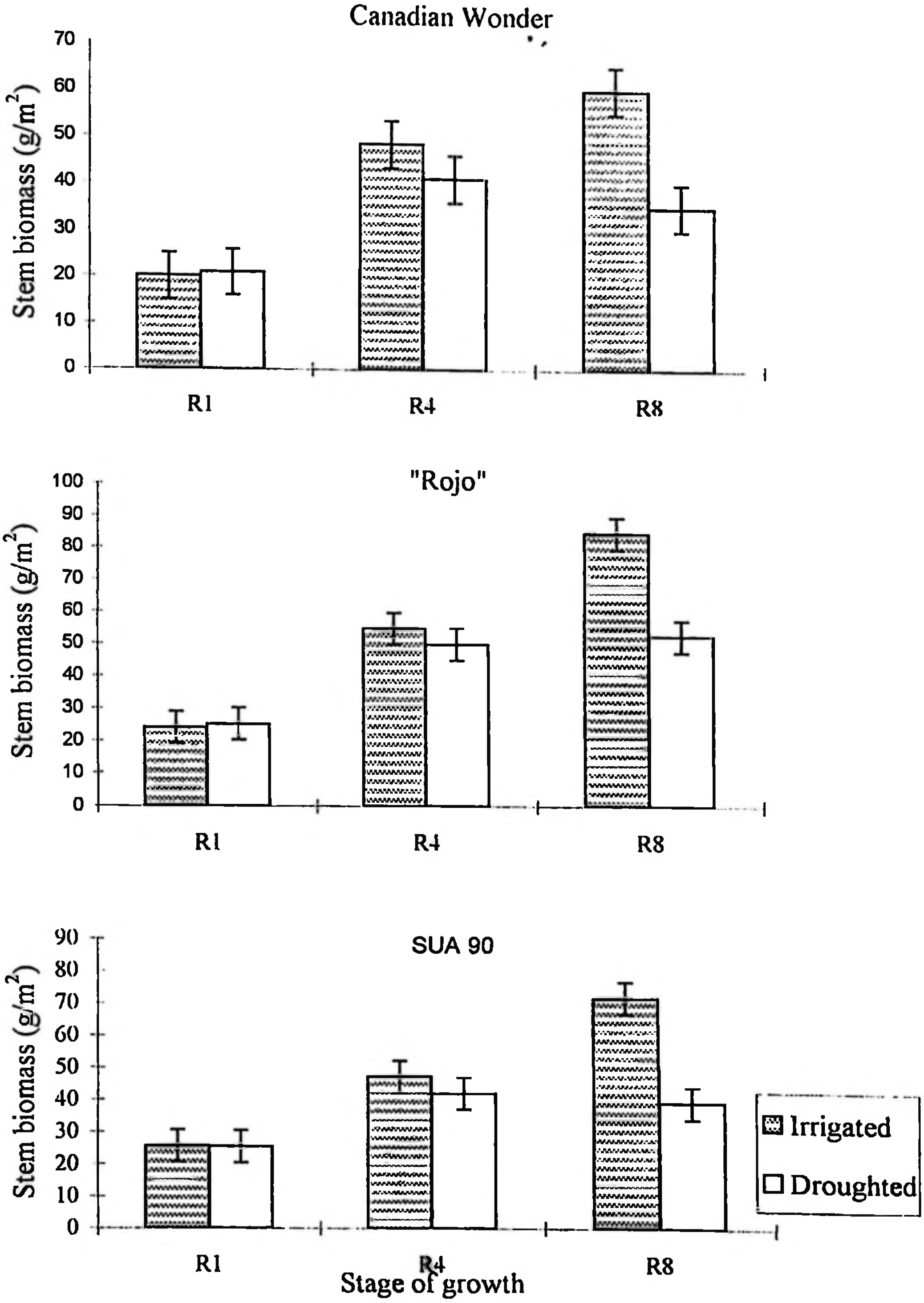

Fig. 3d Changes in stem biomass of three bean cultivars as influenced by irrigation regimes in the field

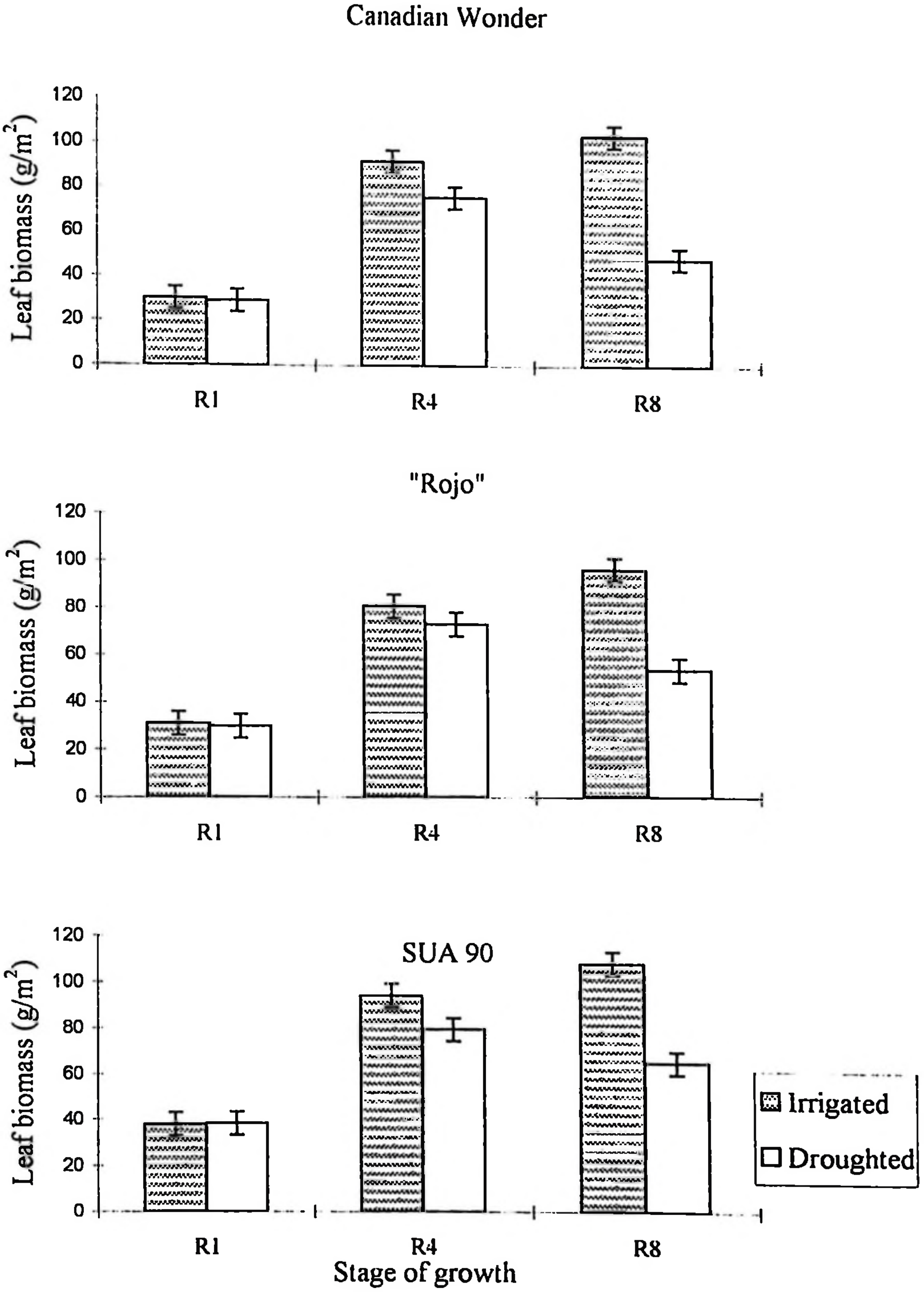

Fig. 3e Changes in leaf biomass of three bean cultivars as affected by water stress in the field

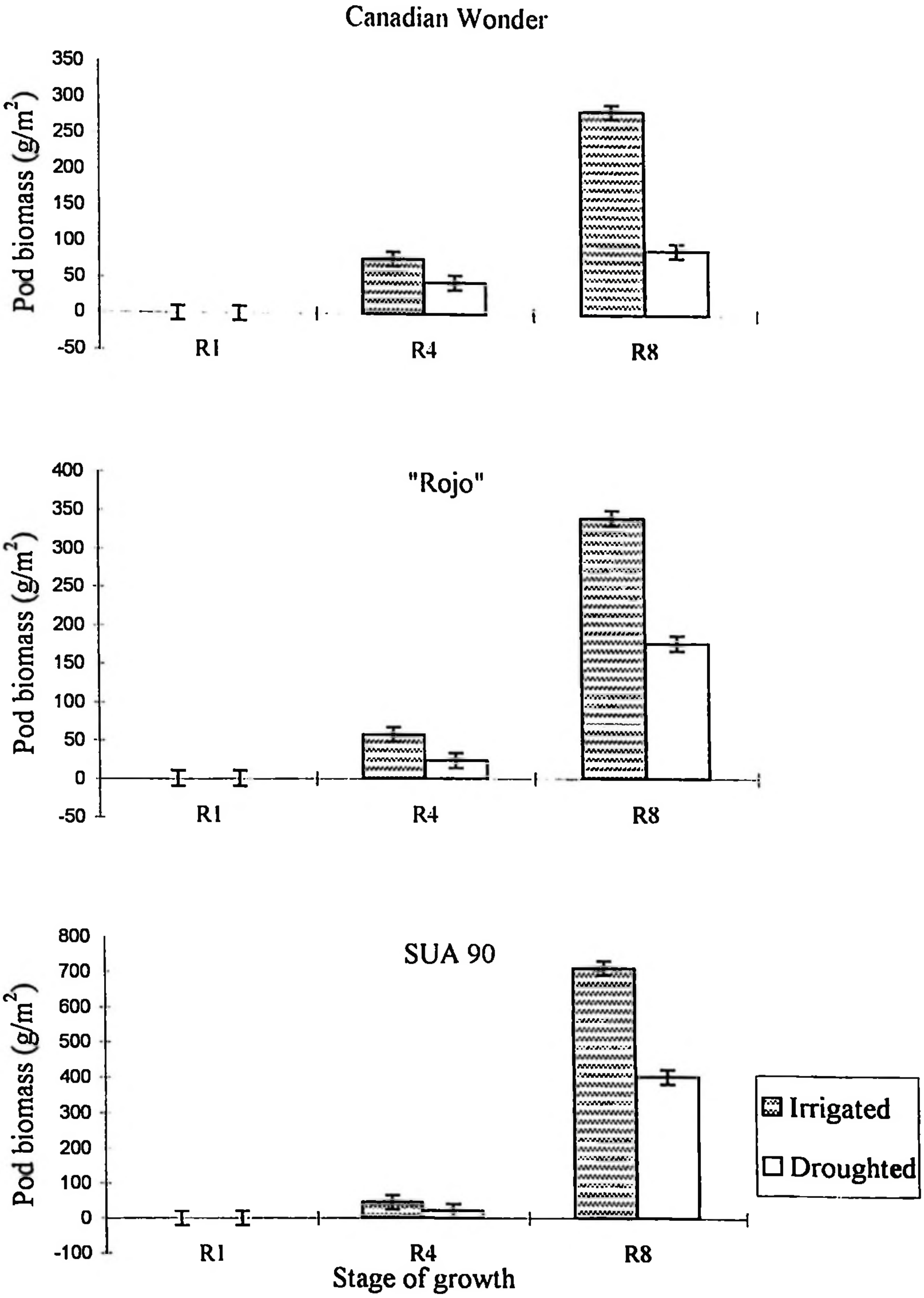

Fig. 3f Changes of pod biomass of three bean cultivars as affected by water stress in the field

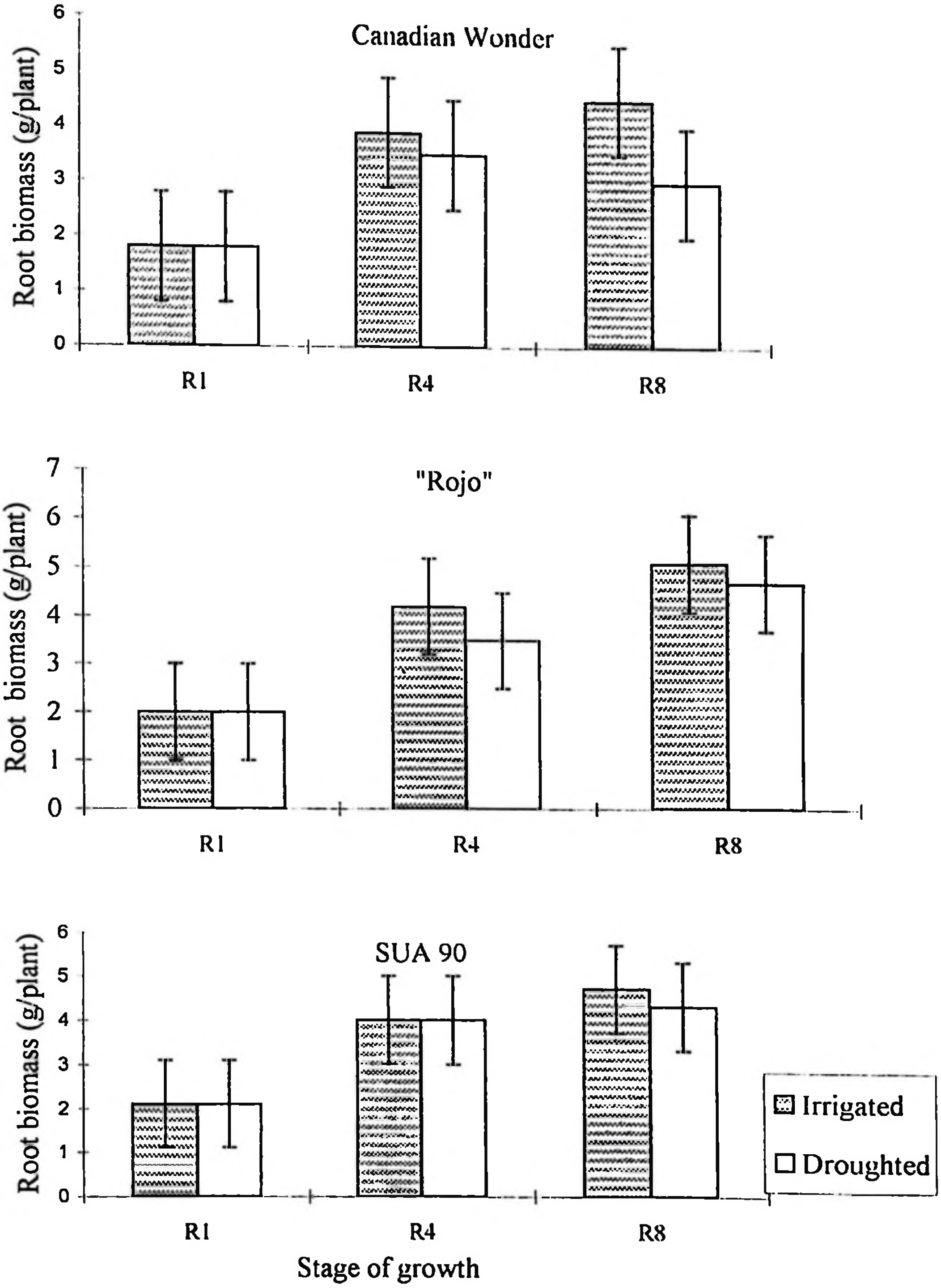

Fig.5a Changes of root biomass of three bean cultivars as influenced by irrigation regimes in the screen house.

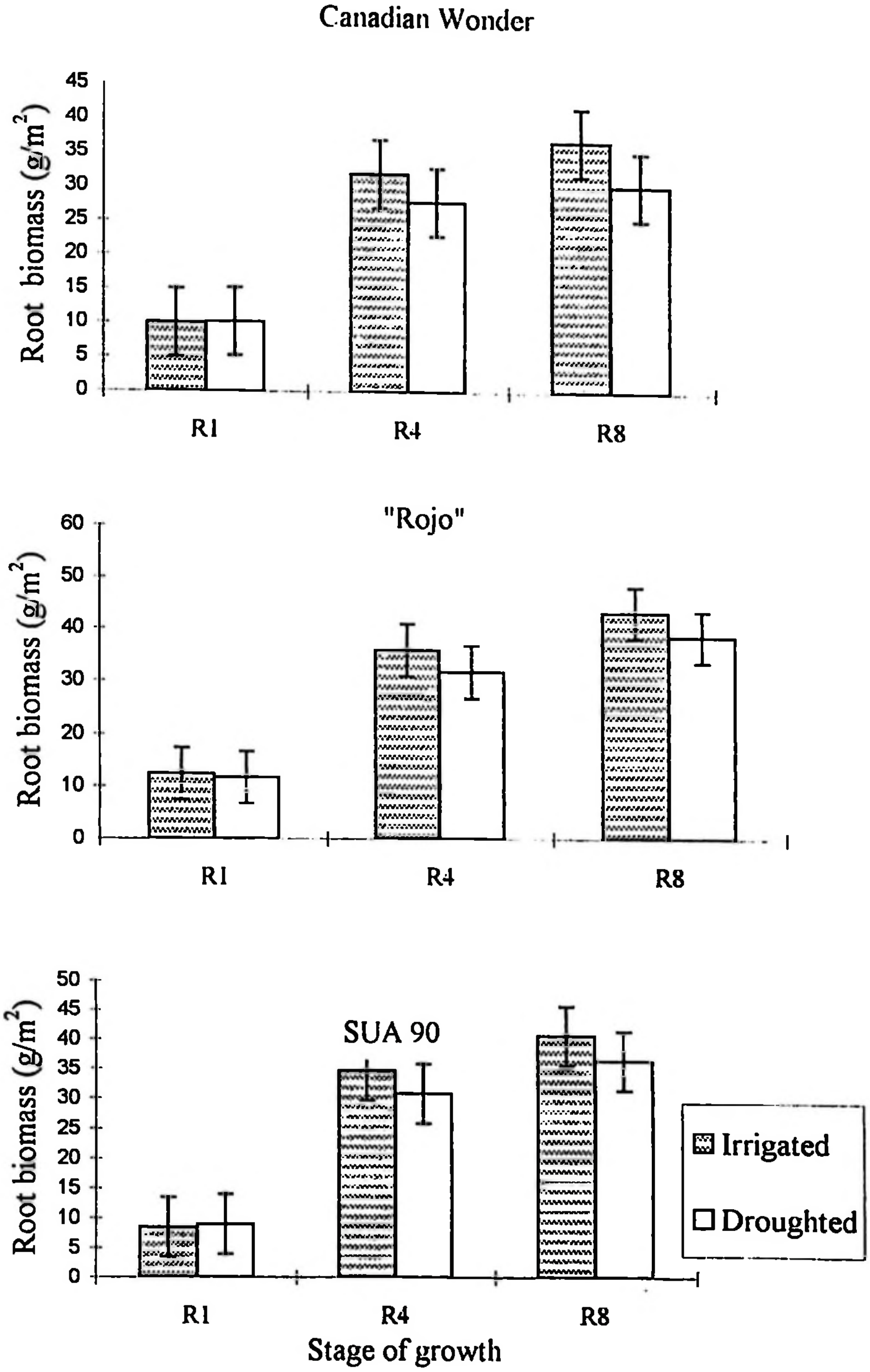

Fig. 5b Changes of root biomass of three bean cultivars as affected by water stress in the field.

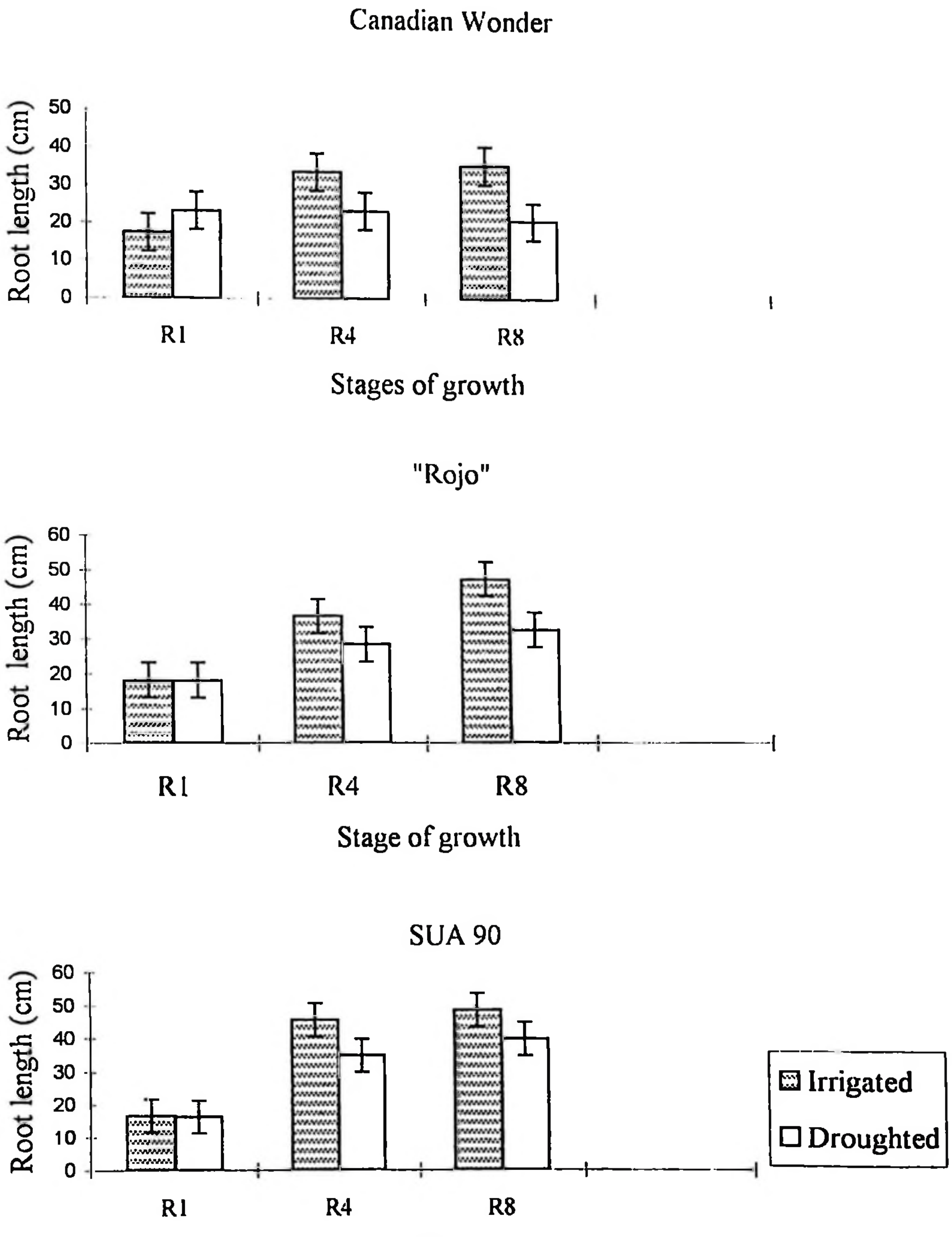

Fig. 4a Changes in root length of three bean cultivars as influenced by irrigation regimes in the screen house

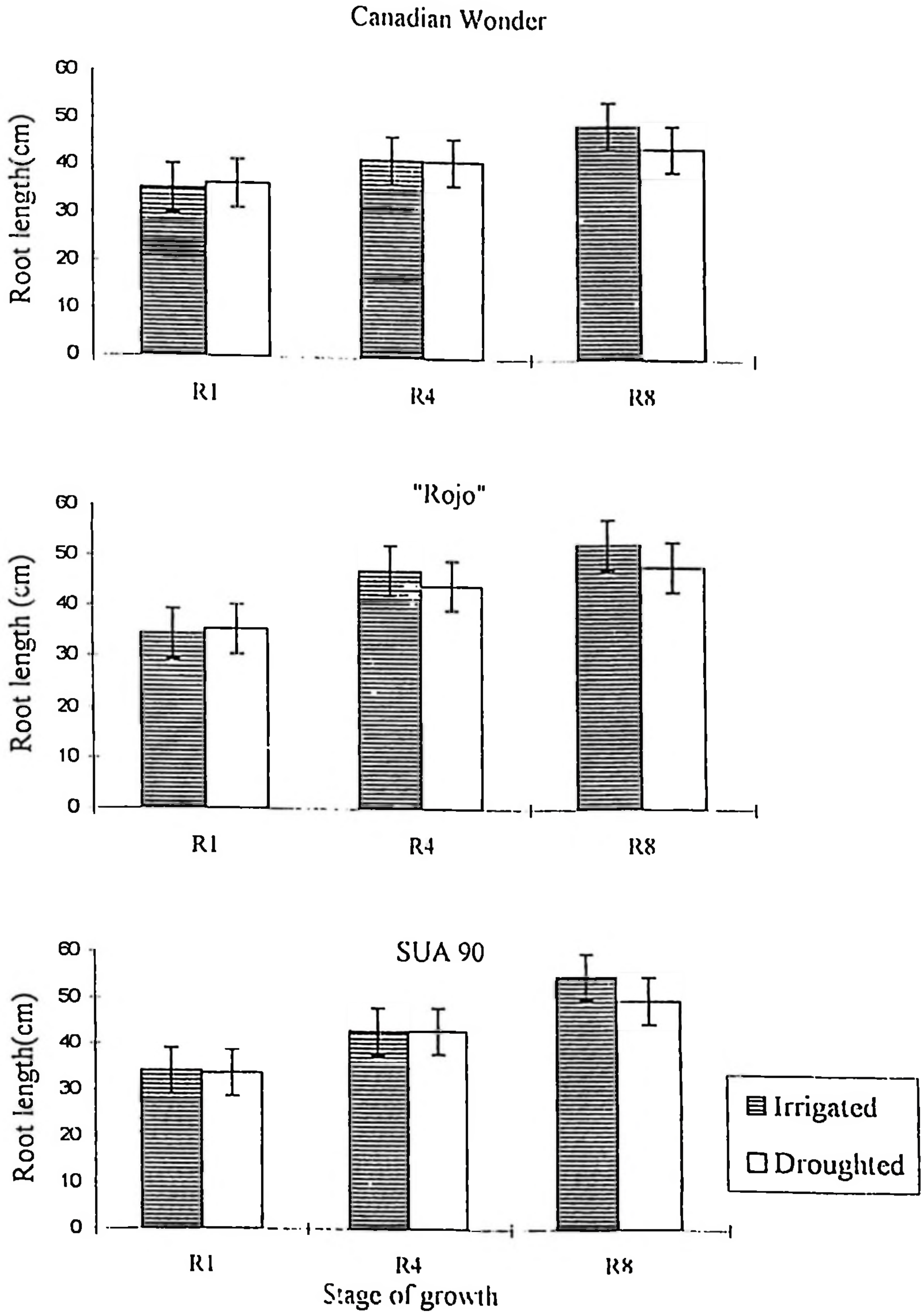

Fig.4b Changes of root length of three bean cultivars as influenced by irrigation regimes in the field.

Canadian Wonder had the lowest yield under both experiments (i.e 14.9 vs 1.6 g plant^{-1} for screen house and 1331.2 vs 247.2 kg ha^{-1}) for field experiments under irrigated and water stressed conditions, respectively.

For the yield components, SUA 90 had the highest pods plant^{-1} (10.5), seed pod^{-1} (6.5) but lowest 100 seed weight (30.5g). The highest 100 seed weight (seed size) was shown by Canadian Wonder under both treatments i.e. 44.0g under irrigated and 21.8g under droughted conditions (Table 7). This was followed by "Rojo (42.2g) under irrigated treatment and lastly SUA 90 (30.5g) under irrigated treatment. The same trend of results were obtained under field experiment as presented in the same Table.

Correlation coefficients between grain yield and other parameters were also determined (Table 8). Among yield components analysed, the highest correlation coefficients in the screen house, under irrigated treatment were obtained from seed pod^{-1} ($r = 0.94^{*}$) and pods plant^{-1} ($r= 0.98^{*}$). Correlation coefficients under droughted treatment for the same variables were: $r = 0.91^{*}$ and $r = 0.90^{*}$, respectively. From field experiment, seeds pod^{-1} and pods plant^{-1} correlated with yield, for irrigated treatment, $r = 0.76^{*}$ and 0.87^{*} ; while under droughted treatment $r = 0.90^{*}$ and 0.99^{*}, respectively.

Non significant correlations were obtained with 100 seed weight.Parameters that correlated significantly (P) with yield were: total dry weight at R4, R8 and R9; root length at R4; leaf number at R4; leaf area R4; leaf biomass R4; pod biomass at R8.

Table 7. Effect of drought on yield and yield components of three bean cultivars grown under screen-house and field conditions.

Treatments	Seed yield	Pods/ plant	Seeds/ pod	100sw (g)
		Screen house experiment		
	(g /plant)			
IR1 + CW	14.9c	7.5d	4.5c	44.0a
IR1 + "Rojo"	18.6b	8.3b	5.3b	42.2b
IR2 + SUA 90	20.8a	10.5a	6.5a	30.5c
IR 2 + CW	1.6f	3.0f	2.5c	21.8
IR2 + "Rojo"	3.4e	4.5e	3.8d	19.7
IR2 + SUA 90	10.4d	7.8c	6.5a	20.4e
Mean	11.6	7.10	4.85	29.77
SE±	1.47	0.29	0.30	1.52
CV(%)	4.7	8.15	12.43	3.49
		Field experiment		
	(kg /ha)			
IR1 + CW	1331.2c	10.0c	4.0c	43.4a
IR1 + "Rojo"	1814.6b	12.0b	5.0b	39.3b
IR1 + SUA 90	1943.3a	15.0a	6.0a	25.0e
IR2 + CW	247.2f	5.0d	2.0d	34.4c
IR2 + "Rojo"	901.9e	10.0c	4.0c	28.7d
IR2 + SUA 90	1208.d	12.0b	6.0a	22.7f
Mean	1241.1	10.7	4.5	32.3
SE±	1.6	0.3	0.2	0.1
CV(%)	11.7	7.8	14.6	0.5

Means in the same column followed by the same letter are not statistically different (P≤0.05) following mean separation test by DMRT.

Table 8a. Correlation coefficients between grain yield and other variable in common bean grown under irrigated and droughted conditions in the screen house.

Growth stage	R4		R8		R9	
Water regimes	IR1	IR2	IR1	IR2	IR1	IR2
Variables						
Leaf number	-0.63ns	0.87*	-	-	-	-
Leaf area	0.56ns	0.85*	-	-	-	-
Leaf dry weight	0.63ns	0.73*	-	-	-	-
Plant height	0.75ns	0.86*	0.85*	0.61ns	-	-
Total dry weight	0.98*	0.99*	0.99*	0.85*	0.91*	0.90*
Pods per plant	-	-	-	-	0.98**	0.90*
Pods dry weight	-	-	0.95*	0.99*	-	-
Seeds per pod	-	-	-	-	0.94*	0.91*
100 seed weight	-	-	-	-	-0.8ns	0.98*
Root length	0.94*	0.96**	-	-	-	-
Root dry weight	0.65ns	0.87*	0.72*	0.89*	-	-

*,** = Significant at 5% and 1% level respectively.

ns = Not significant.

Table 8b. Correlation coefficients between grain yield and other variables in commmon bean grown under irrigated and droughted conditions in the field

Growth stage	R4		R8		R9	
Water regimes	IR1	IR2	IR1	IR2	IR1	IR2
Variables						
Leaf number	0.98*	0.79*	-	-	-	-
Leaf area	0.27ns	0.98*	-	-	-	-
Leafdry weight	0.79*	0.95*	-	-	-	-
Plant height	0.99*	0.85*	0.85*	0.69ns	-	-
Total dry weight	0.97*	0.99*	0.85*	0.62ns	0.95*	0.87*
Pods per plant	-	-	-	-	0.87*	0.99*
Pod dry weight	-	-	0.95*	0.19ns	-	-
Seed per pod	-	-	-	-	0.76	0.90*
100 seed weight	-	-	-	-	0.7ns	0.98*
Root length	0.98*	0.99*	-	-	-	-
Root dry weight	0.79ns	0.83*	0.70ns	0.88*	-	-

4.9 Bean Crop Growth Simulations.

Values for the soil characteristics used to run the model are given in Table 9. The total soil profile depth was 100 cm. The drained upper limit for the site was between 0.199 to 0.250 cm^3. Other general characteristics are shown in Table 1. Weather variables that were used to run the model are shown in Appendix 5. The common bean genetic coefficients for the three common bean cultivars used in the study under irrigated conditions are shown in Table 10. The inputs used to run the model are shown in Appendix 6.

4.91 Cultivar genetic coefficients.

To get the best results on BEANGRO model performance, this study showed that calibration should start by predicting life cycle timing, then calibrate characteristics used to predict seed filling duration, average seed per pod, time to reach final pod filling, pod and seed yield, seed size, and finally total dry matter accumulation at harvest maturity. The maximum shelling percentage in the ECO file was found to be an important characteristics to be considered during the caliburation process.

Once the genetic coefficients in the CUL file and some crop constants in the SPE, and ECO files were estimated, they were fixed so the accuracy of the model could be dertermined against field data.

Table 9. Soil profile characteristics for the soils used to run BEANGRO MODEL at the SUA horticultural unit

SUMO980001		Moro.TZ		SACLLO	100	ALFSOL				TYPIC	TROPU-STIC				
SITE		COUNTRY		LAT		LONG	SCS	FAMILY							
MOROGORO		TANZANIA		-6.5		37.3	DARK	GRAYISH	BROWN	SAND	CLAY	LOAM	ISOHYPERTHEMIC. TYPIC PROPUSTIC		
SCOM	SALB	SLU1	SLDR	SLRO	SLNF	SLPF	SMHB	SMPX	SMKE	SGRP					
2.5YR	0.13	6.0	0.35	84.0	1.00	1.00	IB001	IB001	IB001	IB003					
SLB	SLMH	SLLL	SDUL	SLSA	SLRF	SLKS	SLDM	SLOC	SLCF	SLSI	SLCY	SLNI	SLHW	SLHB	SCEC
10	Ap	0.112	0.248	0.365	1.000	5.01	1.60	2.27	55.0	24.0	21.0	0.09	5.43	5.30	5.43
20	Ap	0.105	0.241	0.365	0.819	6.98	1.60	2.27	57.0	23.0	20.0	0.09	5.09	5.20	5.11
30	AB	0.110	0.246	0.365	0.268	7.08	1.60	1.15	59.0	18.0	23.0	0.08	4.25	5.20	3.74
40	B1	0.109	0.245	0.365	0.268	5.01	1.60	1.64	58.0	24.0	22.0	0.07	5.03	5.00	3.63
50	B1	0.111	0.247	0.330	0.138	5.01	1.70	1.80	58.0	24.0	18.0	0.07	5.03	5.00	3.33
60	B2	0.114	0.250	0.330	0.128	5.01	1.70	1.80	58.0	23.0	19.0	0.07	5.04	5.00	3.04
70	B2	0.104	0.240	0.365	0.128	5.02	1.60	1.60	59.0	20.0	21.0	0.09	5.13	5.05	2.44
80	B2	0.063	0.199	0.434	0.128	6.99	1.40	1.60	48.0	42.0	10.0	0.06	4.83	5.00	2.34
90	B3	0.063	0.199	0.434	0.100	6.25	1.40	0.55	48.0	42.0	10.0	0.05	4.80	5.10	2.14
100	B3	0.063	0.199	0.434	0.100	6.84	1.40	0.55	48.0	42.0	10.0	0.05	4.61	5.10	1.82

Values of SALB, SLU1, SLDR. SLRO, SLPF, SSKS, were estimated by Ritchie et al. (1990) procedure

Table 10. The common bean genetic coefficients used to run the simulation model

DRYBEAN GENOTYPE COEFFICIENTS - BNGRO980.CUL

VAR	VRNAME..........ECO	CSDL	PPSEN	EM-FL	FL-SH	FL-SD	SD-PM	FL-LF	LFMAX	SLAVR	SIZLF	XFRT	WTPSD	SFDUR	SDPDV	PODUR	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	
	15 IB0012 SUA 90		ANDDET	12.17	0.000	28.0	3.4	8.0	23.00	9.00	1.00	295.	133.0	1.00	0.550	15.0	
3.50	7.0																
IB0013	ROJO	ANDDET	12.17	0.000	40.0	10.0	25.0	25.50	22.00	1.00	355.	133.0	1.00	0.400	12.0	5.00	10.0
IB0014	Canadian Wonder~	ANDDET	12.17	0.000	24.5	2.0	9.0	27.50	7.00	1.00	300.	111.0	1.00	0.375	5.0		

Definitions

! ECO# Code for the ecotype to which this cultivar belongs (see *.eco file)
! CSDL Critical Short Day Length below which reproductive development progresses with no daylength effect (hour)
! PPSEN Slope of the relative response of development to photoperiod with time (1/hour)
! EM-FL Time between plant emergence and flower appearance (R1) photothermal days)
! Fl-SH Time between first flower and first pod (R3)(photothermal days)/
! Fl-SD Time between first flower and first seed (R5)/(photothermal days)/
! SD-PM Time between first seed (R5) and physiological maturity (R7)
! Fl-LF Time between first flower (R1) and end of leaf expansion/(photothermal days)
! LFMAX Maximum leaf photosynthesis rate at 30 C, 350 vpm CO2, and high light (CO2/m2-s)
! SLAVR Specific leaf area of cultivar under standard growth conditions (cm2/g)
! SIZLF Maximum size of full leaf (three leaflets) (cm2)
! XFRT Maximum fraction of daily growth that is partitioned to seed + shell
! WTPSD Maximum weight per seed (g)
! SFDUR Seed filling duration for pod cohort at standard growth conditions (photothermal days)
! SDPDV Average seed per pod under standard growing conditions (#/pod)
! PODUR Time required for cultivar to reach final pod load under optimal conditions (photothermal days)

4.9.2 Irrigated treatments.

4.9.2.1. Phenology.

The most important cultivar characteristic found to influence growth cycle in both bean cultivars was PHTHR (8) i.e FL-SD which is the time between first flower (R1) Aand first pod (R3) in photothermal days.

Under non stressed (irrigated) conditions, the model correctly predicted the dates for anthesis, dates for pod and seed set (with the differecnce of only 1 day between predicted and field determined dates) as shown in Table 11a for Canadian Wonder cultivar. The days to physiological maturity differed between predicted and field measured by 5, 4 and 7 days for Canadian Wonder, Rojo and SUA 90, respectively. The days for first flowering (anthesis date) for the three cultivars was 35 to 42 DAP under simulation conditions, and 33 to 41 DAP for field measured values. For physiological maturity the values ranged from 73 to 82 DAP under simulation conditions and 66 to 77 for field measured values. Under simulated and field measured conditions, cultivars Rojo and SUA 90 were estimated to mature slightly earlier than cultivar Canadian Wonder.

Table 11a. Summary of simulation outputs of bean performance under non limiting conditions for Canadian Wonder

Variable	Predicted	Measured
Anthesis date (DAP)[1]	42	41
First pod (DAP)	50	52
First seed (DAP)	55	56
Physiological maturity (DAP)	82	77
Pod yield (kg/ha)	1485	1568
Seed yield (kg/ha)	1193	1175
Shelling percentage (%)	80	74
Weight per seed (g)	0.42	0.43
Seed number (seed/m^2)	277	360
Seed/pod	3.50	4.00
Maximum LAI	3.90	2.95
Biomass (kg/ha) at R4	1566	1999
Biomass (kg/ha) at R9	4933	4863
Stalk (kg/ha) at R9	3419	3696
Harvest index	0.24	0.24
Final leaf number (main stem)	11.46	8.00

1 = Days after planting
R4 = 50% flowering
R8 = Physiological maturity
R9 = Harvest maturity
LAI = Leaf area index

b. "Rojo" bean cultivar under irrigated conditions

Viriable	Predicted	Measured
Anthesis date (DAP)	35	36
First pod (DAP)	43	43
First seed (DAP)	48	47
Physiological maturity (DAP)	74	70
Pod yield (kg/ha)	1736	2044
Seed yield (kg/ha)	1388	1580
Shelling percentage (%)	80	71
Weight per seed (g)	0.40	0.38
Seed number (seed/m^2)	349	440
Seed/pod	3.80	5.00
Maximum LAI	3.00	1.95
Biomass (kg/ha) at R4	1215	1830
Biomass (kg/ha) at R8	3968	4530
Stalk (kg/ha) at R9	2207	3079
Harvest index	0.35	0.32
Final leaf number (main stem)	9.58	7.00

c. SUA 90 bean cultivar under irrigated conditions

Variable	Predicted	Measured
Anthesis date (DAP)	35	33
First pod (DAP)	41	40
First seed (DAP)	48	44
Physiological maturity (DAP)	73	66
Pod yield (kg/ha)	1457	1874
Seed yield (kg/ha)	1157	1696
Shelling percentage (%)	79	67
Weight per seed (g)	0.36	0.24
Seed number (seed/m^2)	324	645
Seeds/pod	3.50	6.00
Maximum LAI	2.42	2.60
Biomass (kg/ha) at R4	1159	1199
Biomass (kg/ha) at R8	3713	3714
Stalk (kg/ha) at R9	2233	3372
Harvest index	0.31	0.34
Final leaf number (main stem)	9.58	8.00

4.9.2.2 Biomass production

Statistical analysis indicated significant differences ($P \leq 0.05$) of total dry matter (TDM) production at 50% flowering (R4) and physiological maturity (R8) as indicated in Figures 2a and 2b. Biomass at anthesis were under-predicted by the model by 22% compared to that measured under field conditions (1566 vs 1999 kgha^{-1}, respectively) for Canadian Wonder. However, TDM production at physiological maturity showed a close correspondence between simulated and that measured under field conditios 4933 vs 4863 kgha^{-1} respectively, with the difference of only 1.4% between the two values.

Similar trends were observed with cultivar Rojo at physiological maturity where the model under-predicted the biomass production at anthesis by 33.6% compared to that measured under field conditions i.e. 1215 vs 1830 kg ha$^{-1,}$ respectively (Table 11b). Similar observations for TDM production were recorded at physiological maturity where the model under-predicted TDM production by 12.4% (i.e. 3968 vs 4530 kg ha^{-1} for simulated vs field measured values, respectively as shown in Table 11b.

For cultivar SUA 90 both TDM production predicted by the model (1159 kgha^{-1}) and that measured under field conditions (1199 kgha^{-1}) were very close. The predicted and measured values differed by only 3.3%. Results recorded at physiological maturity for this variety showed that simulated value of TDM production was 3713 while that measured under field conditions was 3714 kgha^{-1} resulting into a difference of 0.02%.

4.9.2.3 Seed yield.

The simulated seed yields were more correctly predicted relative to field measured yield (1193 vs 1175 kg ha^{-1}), respectively ,as the diffence between the two values was only 2.2% for Canadian Wonder. However, seed yield was under-estimated by the model by about 4.3% (1388 vs 1580 kg ha^{-1}) for "Rojo" bean cultivar. As for results recorded for cultivar SUA 90, the model under-predicted seed yield by 8.4% (i.e. 1157 vs 1696 kg ha^{-1}).

Comparing simulated and field measured harvest index (HI) values, the results show that the bean model did predicted both economic and biological yield consistently in the three cultivars used was satisfactory as the values recorded were 0.24 vs 0.24 for Canadian Wonder, 0.35 vs 0.32 for "Rojo", and 0.31 vs 0.34 for SUA 90 under simulated and field measured values, respectively.

4.9.2.4 Seed yield Components

Seed number per m^2 were under-estimated by the model in all three cultivars. However, seed weight (size) predicted by the model using the Canadian Wonder bean cultivar corresponded very well with that measured under field conditions (0.42 vs 0.43g, respectively). Similar results were recorded with cultivar " Rojo" where the values were 0.40 vs 0.39g for predicted and field measured values respectively. But the model overpredicted the seed size for SUA 90, where predicted seed size was 0.36g, while that of measured under field conditions was 0.25g. In all cultivars, number of seeds per pod were under predicted by the model as compared to the value measured from the field.

Generally, maturity was over-predicted by 10 days, shelling percentage by 7%, LAI by 24%, while number of leaves from the main stem was by 30%. The model also under-predicted various variables including: pod yield by 5.3%, seed number by 23%, seed/pod by 12.5%, biomass at anthesis by 22, and stalks at harvest maturity by only 7.5% (Table 11a). Similar trends of results were observed when "Rojo" and SUA 90 were simulated under similar conditions (Tables 11b and 11c).

4.9.3 Drought stress treatments

Tables 12a, b and c show model predicted variables compared to those measured under field conditions. Days to physiological maturity between predicted and field measured, however, differed by 5.0, 5.0 and 1.0 days for cultivars Canadian Wonder, "Rojo" and SUA 90, respectively.

The range for first flowering of the three cultivars was 35 to 42 days after planting (DAP) under simulation conditions and 34 to 43 DAP under field conditions. Physiological maturity ranged between 68 and 76 for simulated values; and 69 to 71 under field conditions. Predicted values show that Canadian Wonder took the longest time to mature (76 DAP) followed by Rojo (74 DAP) and finally SUA 90 (68 DAP). Results on phenological stages were similar to those reported under irrigation treatments for bean cultivars used. Days to physiological maturity were between 68 and 76 under predicted values; and between 69 and 71 under field measured values.

4.9.3.1 Total dry matter

Total dry matter (TDM) from Canadian Wonder was correctly predicted by the model at anthesis resulting into 1722 kg ha^{-1} compared to 1703 kg ha^{-1} under field measured conditions. However, the model under-predicted TDM production at anthesis both for "Rojo" 1215 vs 1424 kg ha^{-1} and SUA 90 1159 vs 1376kg ha^{-1}, respectively. In addition, the model over-predicted TDM for Canadian Wonder at maturity by 43%; Rojo by 27%, but correctly predicted that of SUA 90 by 98%.

4.9.3.2 Seed yield

The predicted seed yield were higher (386kg ha^{-1}) than that recorded(215kg ha-1) under field measured conditions for cultivar Canadian Wonder. For Rojo cultivar, seed yield predicted was slightly closer to that measured under field conditions (733 Vs 704 kg ha-1) as the difference between the value were only 4%. The model, however, under predicted SUA 90 seed yield by 8.1% 898 Vs 977 kg/ha predicted Vs measured values, respectively).

4.9.3.3 Seed yield components

Seeds per m^2 were slightly overestimated by the model when Canadian Wonder was used; and slightly under estimated when Rojo and SUA 90 were used. Seed size was underestimated under Canadian Wonder, but overestimated when using "Rojo" and SUA 90. Also number of seeds per m^2 were overestimated using Canadian Wonder bean cultivar but underestimated whom cultivars Rojo and SUA 90 were used

Table 12a. Summary of simulation outputs of bean performance under droughted conditions for Canadian Wonder bean cultivar

Variable	Predicted	Measured
Anthesis date (DAP)[1]	42	43
First pod (DAP)	50	50
First seed (DAP)	55	54
Physiological maturity (DAP(	76	71
Pod yield (kg/ha)	678	720
Seed yield (kg/ha)	386	215
Shelling percentage (%)	57	27
Weight per seed (g)	0.14	0.25
Seed number (eed/m^2)	278	220
Seeds/pod	3.50	2.00
Maximum LAI	4.28	2.00
Biomass (kg/ha) at R4	1722	1703
Biomass (kg/ha) at R8	4166	2390
Stalk (kg/ha) at R9	3442	2190
Harvest index	0.09	0.09
Final leaf number (main stem)	11.46	8.00

1 = Days after planting
LAI = Leaf area index
R4 = 50% Flowering
R8 = Physiological maturity
R9 = Harvest maturity

c. "Rojo" bean cultivar under droughted conditions

Variable	Predicted	Measured
Anthesis date (DAP)	35	34
First pod (DAP)	43	41
First seed (DAP)	48	54
Physiological maturity (DAP)	74	69
Pod yield (kg/ha)	1058	1414
Seed yield (kg/ha)	733	704
Shelling percentage (%)	69	49
Weight per seed (g)	0.24	0.22
Seed number (seed/m^2)	305	360
Seed/pod	3.80	4.00
Maximum LAI	2.89	1.95
Biomass (kg/ha) at R4	1215	1424
Biomass (kg/ha) at R8	4412	3218
Stalk (kg/ha) at R9	3324	2514
Harvest index	0.17	0.22
Final leaf number (main stem)	9.98	7.00

c. SUA 90 bean cultivars under droughted conditions

Variable	Predicted	Measured
Anthesis date (DAP)	35	36
First pod (DAP)	44	44
First seed (DAP)	45	50
Physiology maturity (DAP)	68	69
Pod yield (kg/ha)	1146	1936
Seed yield (kg/ha)	898	977
Shelling percentage (%)	78	50
Weight per seed (g)	0.42	0.21
Seed number (seed/m^2)	212	642
Seeds/pod	3.5	6.00
Maximum LAI	2.42	2.45
Biomass (kg/ha) at R4	1159	1376
Biomass (kg/ha) at R8	3895	3815
Stalk (kg/ha) at R9	2219	2838
Harvest index	0.27	0.26
Final leaf number (main stem)	9.58	8.00

CHAPTER FIVE

5.0 DISCUSSION

5.1 Weather Conditions

Emergence and other growth stages took relatively more days under field conditions than under screen house conditions. This could have mainly due to lower temperatures and other environmental conditions that were prevailing during May to August 1998. The average temperature in the screen house was 36^{0}C, while under field conditions, the average temperature was 27.1^{0}C. Such results have been reported by Masaya and White (1991) in Central America; Rweyemamu (1995) at SUA, Morogoro Tanzania.

The effect of long days is to delay or stop the differentiation of flower buds. Most genotypes show a decreased rate of growth of flower buds under temperature regimes above 25^{0}C (Wallace,1985; Gniffke,1985). Another reason that contributed to these variations under both screen house and field conditions, is genetic variability among the cultivars.

5.2 Effect of Water Stress on Common Bean.

Growth and development of all three bean cultivars under moisture stressed conditions (droughted) was shorten. This means that, the cultivars completed their life cycle faster under droughted treatment in order to escape drought. Earliness is advantageous for crops where soil moisture is adequately early in the season but decline rapidly (White and Singh, 1991). On the other hand, growth and development period under well-watered treatment was longer than that of droughted treatment. This might be due to the effect of genetic factor among the cultivars and other climatic factors apart from soil moisture.

However, in modern crop production the object is to maximize growth rates and yields through both genetic and environmental manupulation. Genotypes can be changed by plant breeding and selection (White and Singh, 1991; White and Izquierdo, 1991; White *et al.,* 1994). The microclimate can be altered in many ways, such as site selection,tillage, irrigation, drainage, fertilization, pests control and numerous cultural strategies. The microclimate under this treatment was maintained, and thats why the plants grew and developed normally as compared to the plants of the other treatments.

When moisture is inadequate for plant growth and development, many physiological and biochemical processes are adversely affected (Kramer,1983). For example, moisture stress shortened the days to physiological and harvest maturity of all three cultivars of common bean. The plants were stunted in growth, no more leaves were formed, instead the already formed leaves were drooping and were not growing properly. Therefore, both the leaf surface area, leaf area duration, total leaf biomass, and other biomass components were significantly reduced under droughted treatment.

These findings can be related to that of (White and Izquierdo, 1994) who stated that, drought stress reduced cell expansion and division in common bean.

In general, Water stress reduced the number of days to physiological maturity, total biomass as a whole; that is, roots, stem, leaf and pods. It also reduced leaf number per plants and leaf area. Plant height, root length, Yield and Yield components of all three cultivars of common bean. Canadian wonder was more affected by water stress than the other two cultivars. That is "Rojo" and SUA 90.

5.2.1 Plant height

Plant heights were highest at R4 (i.e) 50% flowering) in all treatment for the three cultivars. The influence of irrigation on plant height recorded in this study (Figure b) shows that when bean crop is grown under adequate soil moisture crop growth is not affected as compared to when is grown under drought conditions. Such results have been reported by Mayaki *et al.* (1976) working on soyabean.. This was due to irrigation treatments resulting into increase in available soil water during the season as root zone depth increased..

Moreover, when bean crop was grown under droughted conditions the results showed that, water stress reduced total biomass as a whole including stem biomass. Low stem biomass could have been contributed to poor stem elongation and expansion, which in turn resulted into shorter plants as compared to those ones grown under irrigated treatments. The decline of plant height as plant age increased may have been due to the increase in evapotranspiration and cell senescence during the growing season. Another reason might be that of the translocation of photosynthates from the source to the sink.

5.2.2 Growth analysis

Results in this study show that most physiological traits analysed are controlled both genetically and environmentally (Table 4). These results show that crop growth is favoured particulary by water (Gardner *et al*; 1985) and cultivar characteristics.

Some values obtained for various physiological traits (Tables 5a and b) were slightly lower than those reported by other researchers working under different conditions and using different cultivars. For example, White (1981) working at the University of Califonia (USA) using cultivars Redkloud and Ex-Rico 23, reported the values for specific leaf area (SLA) being 500 and 450 cm^2/g) for the two cultivars, respectively,at R4. Also leaf area durations (LAD) values mentioned in the literature for both tolerant and susceptible bean cultivars ranged from 83 to 92 for tolerant cultivars; and from 74 to 80 for sesceptible cultivars.The values mentioned in the current study range from 8.94 to 22.3 under SUA conditions.

5.2.3 Leaf number, leaf area and leaf area index

Most non significant ($P \leq 0.05$) statistical influence of leaf number, leaf area and leaf area index at first flowering (R_1) for all cultivars (Table 6), shows that the crop was behaving in a similar manner before treatments were applied. However, significant effect of treatments applied for all bean cultivars at 50% flowering (R4) growth stage for the variiables in discussion does show that: bean crop grown under droughted condition may stop increasing at a relatively early stage because of lack of nodes for producing additional leaves. This is the reason why irrigated treatments resulted into higher number of leaves in this study than droughted treatments for all bean cultivars.

Further more, leaf initiation and expansion rates, differ greately among genotypes or cultivars. This was proven by Canadian wonder, "Rojo" and SUA 90 when grown in the screen-house and field conditions under two irrigation regimes. The results from other researchers (Fraser and Bidwell, 1974) show that, most bean crop undergo nearly complete leaf senescence before maturity, but non senescence also do occur (Fraser and Bidwell,1974). Other literature shows that, water stress does decrease leaf area (LA) and leaf area index (LAI) drastically at maturity (Mayaki *et al*; 1975), due to development of smaller leaves during vegetative growth stages. The current results do also show that, treatments applied did have significant ($P \leq 0.05$) effect on both LA and LAI at R_4 for both experiments conducted under screen house and field conditions. However, the LAI values reported in this study (ranging from 2.0 - 2.7) were slightly lower than those reported by other researchers who have recorded values of up 4.0 - 4.5 (White and Izquierdo, 1991) Fageria *et al*; (1997). This is probably due to the cultivar and environmental effects.

5.2.4 Biomass production

Water stress reduced total biomass at the later stages of growth (Figures 2 a and b). The three bean cultivars responded differently to the applied treatments. Such results show that genotypic differences are very important for response to drought stress. Similar results have been reported in other areas such as Mexico and Colombia where common bean is important (White and Singh, 1991).

The average values of total biomass produced under irrigated conditions were 5000, 5500 and 6000kg ha^{-1} for Canadian Wonder, Rojo and SUA 90 bean cultivars, respectively. These values are higher than those reported by (Massomo and Rweyemamu 1989) where cultivar TMO 216 (SUA 90) averaged 3359 kg ha^{-1} under rainfed conditions. But the values reported under droughted conditions were lower i.e 2000, 3000 and 3500 kg ha^{-1} for Canadian Wonder, Rojo and SUA 90 bean cultivars, respectively. This was true because water stress reduced total biomass as a whole (roots, stems, leaves, and pods). Other scientists found that, dry matter partitioning between roots, above ground vegitative growth and reproductive growth, are usually modified by water deficits (Samper,1984; Kramer and Boyer,1995). The response depends on the species, when the stress occur, its duration, and its severity. When water deficits was imposed to the three cultivars of common bean (Canadian wonder, "Rojo" and SUA 90), their response to water stress was different, although the moisture stress was imposed at the same time. The SUA 90 performed better than other cultivars in the screen house and field conditions, under both treatments.

5.2.5 Root length.

Cultivars Rojo and SUA which developed higher root biomass also had higher root length (Figures 4a, b and 5a, b) than cultivar Canadian Wonder. Literature shows that variation in root growth among species determine the difference in drought tolerance within and among species (Turner,1981). He was further reported that, greater rooting systems may indicate a greater adaptation to water deficits by plants, thus it can maintain a greater water potential of such plants under study. White and Castillo (1989) found root characteristics to be of primary importance in determining drought response in common bean and conversely that shoot characteristics are much less important.

The present results on root system show that, bean cultivars with longer and greater root density are relatively drought tolerance. This is because these cultivars managed to develop reasonably higher biomass and seed yield under water stressed conditions as compared to the other cultivar (Figures 2a, b and Table 7). Other reseachers found that, an increase in root weight may indicate a greater density of roots or a greater depth of roots (Richner *et al.*1996). These are both important in morphological adaptation to water deficitis (CIAT,1980). Cultivars "Rojo" and SUA 90 managed to develop higher root biomass, and root length as compared to Canadian wonder under both experiments, and under both treatments. This indicates an increase in the proportion of assimilate allocated to roots in these two cultivars. Partitioning of dry matter to roots may enhance water uptake (Fischer and Turner, 1978; White and Izquierdo,1994). The slight increase in root biomass from R4 and R8 growth stages does not agree with results reported by (Mayaki *et al.*, 1976) who observed that, root weight on soyabeans does decline after seed developments (R5) growth stage under irrigated and non irrigated conditions.

It seems that rooting systems helped SUA 90 and "Rojo" to extract soil water deeper than Canadian wonder, and so be able to tolerate drought and produce higher yields under drought condition, as compared to Canadian Wonder. Canadian Wonder, "Rojo" and SUA 90 responded differently to water stress. These cultivars managed to use one or more of the following physiological and morphological mechanisms to tolerate drought:

- Deep rooting systems
- Leaf curling, drooping or leaf shedding which reduced the rate of transpiration
- High leaf area which is accompanied by high photosynthetic rate.
- Early maturing i.e. drought escape through early maturing.
- Stunted in growth i.e. low accumulation of total drymass.

5.2.6 Yield and yield components

Cultivar SUA 90 and "Rojo" had also higher seed yield as compared to Canadian Wonder. Results show that water stress imposed at flower initiation did affect both flowering process and pod setting which resulted into low yield. Observations also showed that, under water stressed conditions the pods were small, most of them empty pods. Those ones, which managed to form seeds, the seeds were very small, and sometimes wrinkled. They were few, with low weight and quality. Under field conditions, seed yield was reduced by 53%.

However, the results on yield components do show that, high seed yield per plant was associated with high number of seeds per pod, and pods per plant. Similar results have been reported by (Nienhuis and Singh, 1986). Mkandawire and Gundo (1990) also found that moisture stress imposed to common bean during flowering and pod filling reduced yield and yield components significantly.

Literature shows that, yield is the result of photosynthesis where carbondioxide is fixed biochemically in the presence of radiant energy to form sugars (Henckel,1964; Adams,1973; Evans,1975; Gardner *et al.*,1985). The sugars formed from photosynthesis have to be directed to the yield of interest with minimum loss. Under the moisture stressed treatment, the yield was affected mostly because there was sevely leaf curling, shedding and wilting which indicates a reduction in cell turgor, closure of stomata, and reduction in cell enlargement. As a result both the leaf surface area and the rate of photosynthesis are severely reduced. The major disadvantage with a decrease in leaf expansion and an increase in leaf senescence is that there is often incomplete light interception. Thus, a net gain is reduced because an assimilating surface is greatly reduced. The closed stomata affected gaseous exchange for both photosynthesis and respiration (Henckel, 1964; White and Izquierdo, 1994).

Literature also shows that,during the reproductive growth stages, water is more critical in meristematic cells used in cell division (Eastin *et al.*, 1985). The reproductive cells are also sensitive to water, especially during interphase stage of cell division, which without enough moisture may cause mutation to occur, or produce sterile pollen and ovules, so resulted into low yield. This was true for Canadian Wonder, which was proved to be susceptible cultivar to water stress. There was alot of flowers and young pods abortion.

Yanez *et al.*(1984) found that flower buds in common bean with a high probability of abscising showed a wide range of abnormalities, including large number of ovules with necrosis and 15% of flower buds lacking embryo sac. Since pods abscised at early stage of development, one might suggest that the lack of fertilization is mainly possible for abscission. The causes of abscission varied greately with growing conditions and cultivar (Fraser and Bidwell, 1974; White and Izquierdo,1994). The abscission of leaves, flower buds, flowers and young pods were more severe under screen-house than field condition. This was probably due to the competition among the bean plants against space; and the effect of high temperature which facilitated the amount of water loss from the bean plants. The effects was more severe on susceptible cultivar (Canadian Wonder), followed by "Rojo" and finally SUA 90. Moreover, abscission may result from water stress or from competition among developing pods for nitrogen, other nutrients and carbohydrates. Another cause of abscission is probably related to hormonal regulation of abscission of younger developing structures in a raceme, mainly by the older fruits. Regulartory control could also be exerted through hormone availability, hormone balance, or hormone inhibition of assimilate mobilization to develop seeds (Izquierdo and Hosfield,1980).

Another reason for poor pod set assumes that, the other organ or older pods are competing successfully with the flowers and small pods for assimilate. The SUA 90 and "Rojo" to some extent had good yield under water stressed condition. Among the reasons might be that of greater rooting systems and remobilization of assimilates. If cultivars accumulate assimilate and nitrogen during vegetative growth, and is able to mobilize it during pod filling, this should delay senescence and lead to higher yields (White and Izquierdo, 1994).

In common bean and most other legumes, a large proportional of assimilates partitioned to reproductive growth phase migrates from the vegetative growth phase from the storage structures like roots, stems, and leaves (Izquierdo,1981; White and Izquierdo,1994;White and Singh,1995). This may explain why root biomass, root length, leaf biomass, leaf area, and leaf number correlated significantly with grain yield.

5.2.7 Simulated vs field measured data

5.2.7.1 Phenology and leaf area index (LAI)

The model showed that, moisture stress in this study did not have a significant influence on growth cycles compared to irrigated treatments (Tables 11a and 12a). This might have been caused by the low temperatures and other environmental factors recorded during the cropping season (Table 2), Similar growth habits of the grown cultivars was also reported by (Debouck,1991).

The low field measured LAI values compared to predicted values reported in this study may have resulted from the cultivar differences and the model which was not developed under Tanzanian environments. Another reason could be that of non-destructive method used to determine the leaf areas (as described in section (3.1.4.4).

5.2.7.2 Biomass production

The under prediction of above ground biomass by the model as compared to that measured under field conditions was unexpected. However, the close relationship between field measured and predicted biomass values at physiological maturity (Table 11a and b) determined under non-limiting conditions, indicates that the model correctly predicted the general crop performance in terms of dry matter accumulation at maturity. Such results are in agreement with the results reported by (White *et al.*, 1995) in Colombia where BEANGRO was used to study the bean response to water deficits.

5.2.7.3 Seed yield and yield components

The model predicted seed yield at 0% moisture content. Comparisons of predicted and field measured yield and yield components under both irrigated and drought-stressed conditions did show inconsistence for various variables (Tables 11 and 12). Some researchers have reported simulated results of yield that have consistently been higher than field measured results (White *et al.*, 1995; Wortmann, 1998). In the present study, cultivars Rojo and SUA 90 ,when grown under irrigated conditions, resulted in higher field measured seed yield than predicted values. Such results were evident also when cultivar SUA 90 was grown under drought-stressed conditions.

The results showing higher yields than those obtained under field conditions could be correlated with the fact that crop grown under field conditions encounter a number of biotic and abiotic constraints to yield (Wortmann, 1998). However, the present model does not consider such constraints nor does it simulates other nutrients with exception of nitrogen (Hoogenboom *et al.*, 1994). In addition to this, the model was initially developed under subtropical conditions(Hoogenboom *et al.*, 1987) and it has only been tested under tropical environment in very few locations including Tanzania (Rweyemamu, 1995; Wortmann, 1998). This means there is still a lot of room for testing and improving the model to fit the tropical environment.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

1. It can be concluded that water deficits have a negative effect in all growth parameters, seed yield and yield components of common bean. It is also noted that effects of stress levels differ on the responses by different bean cultivars. Among the physiological trait from growth analysis, specific leaf area, leaf area duration, and leaf area index were the most affected by drought. Root length and weight were also significantly affected by water stress in all cultivars. Canadian Wonder was more affected than the other two cultivars under both controlled and field conditions.

2. The BEANGRO simulation model indicated accurate predictions on growth phases, but inconsistent yield and yield components under water stress conditions. Generally, the model indicated that, specific leaf weight, specific leaf area, root weight and root length were important parameters to consider when studying the effect of water stress on common bean yield.

6.2 Recommendations

1. Common bean cultivars should be developed, selected and tested under relevant controlled and field conditions.

2. Breeding programmes should focus more attention on the identification of specific drought tolerance mechanisms such as specific leaf area, leaf area duration, leaf area index, leaf weight and root systems. These traits should be included in cultivars developed for drought tolerance.

3. Large- seeded common bean cultivars such as Canadian Wonder should not be encouraged under water stress conditions instead small and medium size seeded cultivars like SUA 90 and "Rojo" should be encouraged.

4. The above recommendations should be followed by multilocation studies with varying moisture availability and at different growth stages. This will help in identifying more important traits and eliminate those cultivars which may have low performance in yield under moisture stressed conditions.

5 All aspects of agronomy may affect the level of drought stress. For-example diseases, insects, and poor soil fertility may reduce the efficiency of root system in extracting soil moisture. It is therefore important to have good agronomic practices in order to manage and reduce drought.

6. It is important that Bean simulation model is developed under Tanzanian condition.

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Appendix 1a. Common bean water requirement (ETc) at different growth stages as determined under screen house conditions.

Date	Growth stage	Average number of days	ETo (mm per day)	Kc	ETc (mm per day)	Readily available water (min)	Deficit (min)
		Under irrigated conditions					
5.3.98	VO						
19.3.98	V3-V5	16	5.80	0.55	51	13	38
13.4.98	R1-R4	29	6.90	0.84	168	56	112
30.4.98	R4-R8	17	7.30	1.10	136	40	96
5.5.98	R8-R9	5	5.60	0.61	24	9	15
Total		67			379	118	261
			Under drought conditions				
5.3.98	VO						
19.3.98	VI-V5	16	5.80	0.55	51	13	38
13.4.98	R1-R4	29	6.90	0.84	168	45	123
30.4.98	R4-R8	13	7.30	1.10	104	15	89
5.5.98	R8-R9	3	5.60	0.61	10	1	9
Total		61			333	74	259

Appendix 1b. Common bean water requirement (ETc) at different growth stages as determined under field conditions.

Date	Growth stage	Average number of days	ETo (mm per day)	kc	ETc (mm)	Readily available water (mm)	Deficit (mm)
			Under irrigated conditions				
28.598	VO						
12.6.98	V3-V5	19	5.50	0.55	58	13	45
14.7.98	R1-R4	6.40	0.84	172	43	129	4.8.98
4.8.98	R4-R8	20	6.90	1.10	152	41	111
9.8.98	R8-R9	6	5.0	0.61	19	4	15
Total		77			401	101	300

Under drought conditions

Date	Growth stage	Average number of days	ETo (mm per day)	kc	ETc (mm)	Readily available water (mm)	Deficit (mm)
28.5.98	VO						
12.6.98	V1-V5	19	5.50	0.55	58	13	45
14.7.98	R1-R4	28	6.40	0.84	151	37	114
2.8.98	R4-R8	16	6.90	1.10	122	22	100
7.8.98	R8-R9	4	5.00	0.61	13	2	11
Total		67			344	74	270

Appendix 2a. Calculation of irrigation interval in the screen house experiment.

$$i = \frac{P \times Sa \times D}{ETc}$$

where I = Irrigation interval

P = Fractional of available soil water for common bean which is equal to 0.45

Sa = Total available soil water in sand clay loam soil which is 140 mm/m

D = Rooting depth in m.

Etc = Crop evapotranspiration in m/day or crop water requirement in mm/day.

$$i = \frac{0.45 \times 140 \text{ mm/m} \times 0.41 \text{ mm}}{5 \text{ mm/day}} = 5 \text{ days}$$

Irrigation interval under field conditions.

$$= \frac{0.45 \times 140 \text{ mm/m} \times 0.50 \text{ m}}{5 \text{ mm/day}} = 6 \text{ days}$$

Appendix 3a. Calculation of yield loss due to water stress under screen house conditions.

It is given by the following relationship:

$$1 - \frac{ya}{ym} = ky\left(1 - \frac{ETa}{ETm}\right)$$

where Ya = actual harvested yield in %
Ym = maximum harvested yield i.e. 100%
Ky = Yield response factor which is equal to 1.15 for total growing period of common bean.

ETa = actual evapotranspiration
ETm = maximum evapotranspiration

The average days of water supplied were: $\frac{27 + 30 + 29 =}{3}$ 61 days.

- The amount of water supplied was $\frac{29}{61}$ X 100 less than total water requirement

That is 333 mm - 158.8 mm = 174.83 mm

From the formula :- 174.8 = ETa
333.0 mm = ETm

Then $1.15\left(1 - \frac{174.8}{333.0}\right) = 0.55$ actual yield

- The yield loss was $\frac{100\%}{100} - \frac{55\%}{100} =$ 45%

Appendix 3b. Calculation of yield loss due to water stress under field conditions.

The same relationship was used
The average days of water supplied were:

$\frac{31 + 30 + 32}{3}$ which is equal to 31 days out of total growing period of 67 days.

- The amount of water supplied was $\frac{31}{67}$ X 100 less than total water requirement.

  That is 344 mm - 159 mm = 184.8 mm

  From the formula: 184.8 mm = ETa

  Then the actual yield is: $1.15\left(1 - \frac{184.8}{344}\right) = 0.53$

- The yield loss was $\frac{100\%}{100} - 53\% = 47\%$

Appendix 4. Meteorological data used in calculating Eto during the cropping season
Table 4.1 Daily Rainfall (mm/day)

Month	February	March	April	May	June	July	August
Day							
1	66.2	0.0	0.0	1.0	4.2	0.0	0.0
2	6.5	0.0	12.5	7.3	6.9	0.0	0.0
3	0.0	0.0	0.0	20.3	0.0	0.0	0.0
4	0.0	0.0	0.5	2.2	0.0	0.0	0.0
5	0.0	0.0	27.2	2.2	0.0	0.0	0.0
6	0.0	0.0	1.9	0.0	0.0	0.0	0.0
7	0.0	0.0	1.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.3	0.2	0.0	0.0	0.0
9	37.4	0.0	31.9	0.0	0.0	0.0	0.0
10	0.0	43.0	27.2	0.0	0.0	0.0	0.0
11	20.2	0.0	10.3	0.8	0.0	0.0	1.0
12	71.4	0.0	4.2	6.4	0.0	0.0	0.9
13	3.1	0.0	2.2	2.9	0.0	0.0	0.4
14	0.0	0.0	2.8	0.0	0.0	0.0	0.0
15	0.0	0.0	2.1	0.0	0.0	0.0	0.0
16	4.2	0.0	2.4	0.0	0.0	0.0	0.0
17	9.3	0.0	12.1	0.0	0.0	0.0	0.0
18	0.0	0.0	4.0	0.0	0.0	0.0	2.5
19	9.1	0.0	0.0	0.0	0.0	0.0	0.7
20	0.7	0.0	0.0	0.0	0.0	0.0	0.0
21	68.5	0.0	1.3	0.0	0.0	0.0	0.8
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	15.2	0.0	0.0	0.0	0.0	0.0
24	0.0	31.9	0.0	0.0	0.0	0.0	0.0
25	0.0	1.0	25.0	0.0	0.0	0.0	0.0
26	0.0	5.6	0.3	0.0	0.0	0.0	0.0
27	0.0	0.6	0.0	0.0	0.0	0.0	1.0
28	0.0	16.4	24.0	0.0	1.6	0.0	0.8
29		14.9	0.0	17.3	0.0	0.0	0.0
30		7.7	0.0	0.0	3.6	0.8	0.8
31		0.0		1.7		0.8	0.0
Mean	11.0	3.7	7.2	1.5	1.0	0.1	0.3
Total	299.3	114.8	215.8	45.0	31.0	4.4	9.9
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	71.4	43.5	31.9	20.3	17.3	3.6	2.5

Appendix 4 continued

Table 4.2 Daily Maximum Temperature (^0C)

Month	February	March	April	May	June	July	August
Day							
1	33.7	33.0	32.0	29.0	29.3	27.5	28.8
2	33.2	32.8	31.8	30.7	28.3	28.0	29.0
3	33.8	33.4	32.6	26.8	30.9	28.3	28.8
4	31.8	33.2	31.5	30.0	30.5	27.6	28.0
5	32.4	32.5	31.0	31.6	30.4	27.9	28.8
6	32.2	32.3	33.3	29.3	29.3	27.9	28.8
7	32.0	32.5	31.0	29.5	29.4	25.2	28.6
8	33.2	28.5	32.1	31.8	29.6	28.2	29.2
9	29.1	32.1	31.0	30.2	27.6	29.0	27.0
10	31.8	26.5	31.6	29.8	28.7	28.8	29.0
11	32.2	31.0	31.0	29.8	28.0	28.8	29.3
12	29.6	32.1	28.3	30.6	28.0	27.8	29.3
13	31.0	32.0	30.0	29.6	28.8	28.6	29.4
14	33.5	32.8	30.6	33.0	28.6	27.6	29.8
15	33.2	32.4	31.2	32.6	29.0	28.0	31.1
16	31.0	32.5	31.5	30.2	29.3	28.7	30.5
17	31.2	32.7	29.0	29.5	28.0	28.0	28.5
18	33.0	33.0	28.3	28.6	28.7	27.7	27.8
19	30.1	33.1	30.3	29.0	25.7	27.3	30.2
20	31.5	32.3	25.1	29.4	25.8	26.0	30.5
21	32.5	33.2	28.4	30.6	29.7	27.6	29.8
22	33.8	32.5	28.4	30.0	29.7	29.5	29.2
23	31.8	31.8	29.5	30.3	27.8	29.6	30.3
24	33.2	30.5	29.6	29.7	28.4	28.9	30.4
25	31.4	29.4	26.8	29.5	29.7	28.2	30.0
26	31.8	31.2	29.8	29.0	29.6	28.0	30.0
27	31.8	27.8	30.8	28.6	29.5	28.7	28.8
28	32.6	30.5	26.6	27.5	29.3	28.0	30.2
29		32.3	29.0	29.5	27.8	29.4	29.8
30		31.8	28.1	29.3	27.5	24.8	29.9
31		32.2		29.8		28.7	29.7
Mean	32.0	31.7	30.1	29.8	36.5	838.8	29.3
Total	896.1	984.1	903.2	924.8	1095.2	24.8	909.7
Min.	29.1	27.8	25.1	26.8	25.8	29.6	27.0
Max.	33.8	33.4	33.3	33.0	30.9		31.1

Appendix 4 continued
Table 4.3. Daily Minimum Temperature °C

Month	February	March	April	May	June	July	August
Day							
1	21.3	23.7	21.8	21.9	21.1	15.5	15.5
2	22.7	23.0	21.6	20.7	21.0	14.1	16.4
3	21.8	22.6	22.8	21.8	21.0	12.6	17.6
4	23.7	23.6	22.4	21.5	19.5	16.0	15.5
5	22.0	23.5	22.0	20.5	19.5	15.5	18.0
6	22.6	24.0	21.9	20.2	18.5	16.0	16.8
7	23.2	23.2	22.1	19.5	18.6	18.3	16.8
8	23.8	23.5	21.7	19.5	20.1	13.0	16.5
9	22.0	22.0	22.6	21.5	18.1	13.5	16.6
10	22.4	22.5	22.4	21.5	16.5	15.7	18.2
11	21.8	22.0	22.7	23.1	14.7	17.1	18.0
12	21.6	24.2	22.7	21.9	13.3	19.4	16.8
13	22.3	24.0	22.4	19.7	13.2	14.8	17.3
14	22.6	22.0	22.4	22.0	17.8	14.6	15.6
15	22.1	22.0	22.4	19.5	12.6	13.4	14.8
16	22.1	22.0	22.7	18.0	12.5	15.0	17.2
17	21.0	21.1	21.5	15.1	19.0	17.0	16.7
18	21.5	22.3	21.7	15.0	16.1	18.8	18.4
19	21.0	21.4	20.1	15.3	15.1	17.9	17.6
20	21.5	22.3	21.5	16.4	13.6	16.2	17.7
21	20.8	22.0	21.0	18.2	15.5	15.8	17.6
22	23.8	22.0	21.5	16.7	15.4	16.5	16.0
23	22.3	21.5	21.6	16.6	18.6	14.3	15.0
24	23.5	22.5	22.6.	15.7	20.0	17.6	16.7
25	23.5	22.5	22.0	16.9	19.7	16.5	16.9
26	23.0	22.1	21.0	19.5	15.5	17.7	15.1
27	21.5	22.3	20.5	20.4	19.0	14.0	18.8
28	23.0	21.4	21.4	15.0	17.9	17.0	16.4
29		21.2	21.5	15.1	19.2	16.4	20.2
30		21.6	21.9	14.1	14.0	19.6	19.7
31		21.8		19.5		19.5	19.6
Mean	22.3	22.5	21.9	18.8	17.7	16.1	17.1
Total	624.4	695.8	656.8	582.3	516.6	499.2	529.2
Min.	20.8	21.1	20.1	14.1	12.5	12.6	14.8
Max.	23.8	24.2	22.8	23.1	21.1	19.6	20.2

Appendix 4 continued

Table 4.4. Daily Maximum Relative Humidity (%)

Month	February	March	April	May	June	July	August
Day							
1	74.5	71.5	78.0	81.5	76.5	90.5	98.0
2	75.0	68.5	77.5	83.0	82.5	80.5	85.0
3	73.0	70.5	78.5	92.0	80.5	88.0	95.0
4	75.5	70.5	87.0	83.5	77.5	95.0	98.0
5	71.0	74.0	85.0	79.0	80.0	98.5	93.0
6	75.0	71.0	78.0	80.0	77.5	95.0	98.0
7	74.0	69.5	83.5	81.5	79.5	90.0	93.0
8	79.0	82.0	82.0	79.5	76.0	95.0	98.0
9	83.0	80.0	86.5	78.0	76.0	95.0	95.0
10	80.5	91.5	79.5	81.0	74.5	97.0	93.0
11	79.0	80.0	81.0	84.0	69.0	95.5	94.5
12	93.0	76.5	92.0	84.5	69.0	86.5	98.5
13	79.5	71.0	85.5	76.0	69.5	98.0	90.0
14	88.5	72.5	80.5	70.0	68.5	96.0	93.0
15	74.5	71.0	82.5	81.0	67.0	96.0	97.0
16	77.5	74.0	90.5	77.0	65.6	91.0	97.0
17	79.0	74.5	86.0	72.0	75.5	92.0	98.0
18	79.5	76.5	82.5	69.5	73.5	85.0	99.0
19	84.5	77.0	77.5	74.0	74.5	86.0	96.5
20	81.0	77.0	86.5	76.5	73.5	92.0	92.0
21	78.5	74.5	82.5	78.5	73.5	97.0	84.0
22	76.5	74.5	80.5	73.0	74.0	97.0	98.0
23	76.0	78.5	77.0	74.5	77.5	93.0	98.5
24	76.0	82.0	77.0	74.5	82.0	90.5	97.5
25	72.0	92.0	88.0	76.0	69.0	95.5	98.0
26	70.5	92.0	85.0	80.0	75.5	85.0	96.0
27	79.5	89.0	82.0	73.0	66.0	94.0	90.0
28	75.0	80.5	88.0	71.0	77.0	95.0	98.0
29		72.0	88.0	70.5	68.0	89.0	80.0
30		75.5	82.0	72.0	71.0	97.0	97.5
31		78.5		74.0		91.0	96.0
Mean	77.9	77.2	83.4	77.4	74.0	92.4	94.6
Total	2180.5	2393	2501.0	2400.5	2219.5	2863.0	2932.0
Min.	70.5	68.5	77.0	69.5	65.5	80.0	80.0
Max.	93.0	92.0	92.0	92.0	82.5	98.0	99.0

Appendix 4 continued

Table 4.5. Daily Minimum Relative Humidity (%)

Month	February	March	April	May	June	July	August
Day							
1	53.0	50.0	58.0	64.0	55.0	41.0	40.0
2	54.0	48.0	57.0	68.0	66.0	37.0	47.0
3	53.0	41.0	58.0	87.0	63.0	48.0	46.0
4	53.0	45.0	76.0	70.0	58.0	52.0	48.0
5	45.0	55.0	72.0	59.0	60.0	51.0	58.0
6	54.0	54.0	58.0	62.0	57.0	51.0	43.0
7	57.0	55.0	68.0	64.0	60.0	51.0	45.0
8	65.0	66.0	66.0	60.0	54.0	43.0	42.0
9	78.0	62.0	75.0	57.0	54.0	46.0	52.0
10	63.0	84.0	60.0	63.0	55.0	48.0	45.0
11	62.0	62.0	63.0	70.0	49.0	43.0	45.0
12	88.0	55.0	85.0	70.0	43.0	53.0	41.0
13	64.0	52.0	75.0	55.0	42.0	48.0	36.0
14	78.0	48.0	63.0	46.0	40.0	50.0	40.0
15	41.0	46.0	65.0	62.0	39.0	45.0	41.0
16	57.0	52.0	83.0	56.0	43.0	42.0	44.0
17	60.0	52.0	74.0	48.0	56.0	52.0	48.0
18	61.0	55.0	67.0	47.0	52.0	47.0	55.0
19	73.0	57.0	57.0	53.0	50.0	40.0	31.0
20	64.0	58.0	79.0	57.0	50.0	55.0	40.0
21	59.0	51.0	66.0	60.0	50.0	51.0	43.0
22	56.0	52.0	64.0	50.0	50.0	46.0	42.0
23	54.0	60.0	78.0	53.0	58.0	40.0	43.0
24	57.0	67.0	57.0	51.0	66.0	43.0	50.0
25	53.0	86.0	78.0	55.0	43.0	42.0	49.0
26	51.0	63.0	72.0	63.0	53.0	35.0	43.0
27	61.0	80.0	66.0	53.0	47.0	37.0	52.0
28	53.0	63.0	77.0	45.0	57.0	46.0	45.0
29		46.0	77.0	47.0	50.0	52.0	52.0
30		53.0	66.0	49.0	50.0	67.0	44.0
31		60.0		55.0		49.0	45.0
Mean	59.9	57.7	68.7	58.0	52.3	46.8	45.0
Total	1677.0	1788.0	2060.0	1799.0	1570.0	1451.0	1395.0
Min.	45.0	45.0	57.0	45.0	39.0	35.0	31.0
Max.	88.0	86.0	85.0	87.0	66.0	67.0	58.0

Appendix 4 continued
Table 4.6. Daily Sunshine Hours (hr/ Day)

Month	February	March	April	May	June	July	August
Day							
1	7.0	10.7	7.5	3.8	4.4	7.8	7.9
2	6.7	10.6	10.5	9.3	4.3	9.3	6.9
3	9.4	10.8	7.7	0.0	6.1	9.5	7.3
4	6.8	10.0	5.5	6.3	7.1	6.4	6.9
5	9.6	8.5	5.6	10.0	8.1	5.0	2.0
6	8.4	8.5	9.3	5.5	6.8	6.3	5.4
7	8.5	9.4	6.2	4.6	7.1	2.1	7.6
8	6.6	0.1	9.4	8.9	5.4	8.9	8.3
9	8.4	4.9	5.6	9.0	5.4	9.6	2.7
10	10.7	0.2	5.2	2.4	8.4	5.5	5.2
11	7.4	8.3	4.9	2.4	9.8	5.9	6.4
12	6.4	8.2	1.8	3.5	6.4	5.0	6.0
13	2.3	10.4	7.2	2.0	10.8	8.0	10.1
14	5.2	10.5	4.1	7.6	10.8	8.8	9.8
15	5.9	10.4	7.1	11.0	10.7	6.3	10.6
16	2.5	8.5	7.6	6.8	8.6	8.1	9.1
17	3.4	10.5	1.9	9.6	3.5	5.9	3.6
18	7.3	8.7	1.8	8.8	8.2	3.4	3.7
19	3.4	7.4	9.0	9.4	3.0	4.6	10.5
20	6.4	7.9	0.0	9.1	7.7	3.7	9.4
21	6.3	7.7	3.2	9.6	8.2	5.5	6.9
22	8.6	5.9	3.3	9.6	6.0	8.6	8.0
23	5.1	8.1	0.9	9.6	1.7	5.4	10.2
24	10.0	4.2	0.4	10.7	3.9	2.8	10.1
25	4.9	1.8	5.8	6.0	6.6	9.0	6.8
26	8.7	4.7	8.1	6.7	7.8	9.7	9.7
27	9.2	1.4	1.9	4.9	8.1	9.8	7.7
28	9.5	6.1	3.6	10.6	8.1	4.8	6.2
29		7.4	2.4	8.2	6.6	5.4	6.4
30		8.9	8.1	9.0	0.9	4.6	6.8
31		10.1		5.1		4.4	3.9
Mean	6.7	7.5	5.1	7.1	7.0	6.3	7.2
Total	186.6	230.8	152.5	219.1	208.6	196.4	169.0
Min.	0.4	0.1	0.0	0.0	1.7	0.9	2.7
Max.	10.7	10.8	10.5	11.0	10.8	9.8	10.6

Appendix 4 continued

Table 4.7 Daily wind Run (mls/day)

Month	February	March	April	May	June	July	August
Day							
1	53.4	144.7	61.6	52.6	35.6	49.1	51.3
2	62.3	109.8	61.0	42.6	26.0	39.1	70.8
3	49.6	105.1	42.2	61.3	45.9	56.7	61.6
4	50.8	102.4	37.3	48.0	29.5	65.0	66.0
5	99.8	197.5	46.7	36.5	33.5	44.0	47.2
6	138.8	146.9	47.2	37.6	35.8	66.0	64.8
7	100.8	113.7	41.7	29.6	30.8	37.7	59.4
8	67.3	50.6	32.4	36.6	40.2	51.6	57.8
9	30.0	59.6	40.4	51.3	57.3	50.2	53.1
10	64.4	40.6	38.1	34.7	39.9	52.7	62.7
11	74.7	146.2	40.5	34.7	39.8	57.3	74.4
12	61.3	172.7	41.5	22.0	36.3	32.7	72.5
13	30.4	79.4	40.7	34.2	42.3	54.8	69.5
14	28.0	70.2	41.1	41.4	38.5	54.3	62.8
15	66.5	63.6	45.1	42.8	48.8	55.7	57.8
16	49.9	74.8	39.2	40.7	66.1	69.0	71.9
17	59.3	63.2	20.8	43.0	36.8	66.4	49.1
18	73.9	49.2	37.6	33.3	48.8	58.2	42.9
19	36.4	77.4	49.5	38.0	33.4	65.6	89.6
20	82.5	33.3	20.1	37.0	53.7	32.7	88.7
21	40.1	50.8	12.6	38.3	43.7	44.1	66.9
22	58.9	58.7	13.7	38.6	37.4	55.5	76.9
23	83.6	53.6	10.4	33.9	28.5	56.2	80.6
24	152.5	35.7	11.4	52.2	31.1	66.2	92.1
25	118.6	40.4	8.8	33.0	43.3	77.8	72.2
26	99.1	43.1	12.6	27.1	75.6	70.1	86.9
27	65.7	33.0	14.6	29.2	49.9	74.6	59.3
28	92.5	47.9	11.2	40.8	68.5	56.7	87.4
29		63.7	10.4	42.5	51.7	50.8	65.7
30		44.9	10.7	52.0	47.6	62.3	68.7
31		43.4		31.2		44.4	57.1
Mean	71.1	77.8	31.3	39.2	43.2	55.4	67.3
Total	1991.1	2410.9	940.1	1215.8	1296.3	1717.4	2086.3
Min.	30.0	33.3	8.8	22.0	26.0	32.7	42.9
Max.	152.5	192.3	61.6	61.3	75.6	77.8	89.6

Appendix 4 continued

Table 4.8. Daily Evaporation (mm/day)

Month	February	March	April	May	June	July	August
Day							
1	3.5	7.5	6.0	3.3	4.4	4.5	4.0
2	7.0	7.0	5.0	4.5	3.0	5.0	4.0
3	6.0	6.5	4.0	2.2	3.5	3.5	4.0
4	3.5	7.5	6.2	3.2	3.5	2.0	3.5
5	6.5	8.0	2.4	5.0	3.5	3.5	3.0
6	6.5	6.0	5.5	3.0	2.5	2.5	4.0
7	5.5	6.0	3.8	2.7	3.5	3.0	4.0
8	5.4	2.5	6.4	4.0	3.0	3.5	3.5
9	3.5	4.5	2.2	4.5	4.0	3.5	3.0
10	7.7	5.0	3.7	2.8	3.0	3.0	3.4
11	7.7	5.0	3.7	2.8	2.5	3.0	2.4
12	3.1	5.6	3.2	2.9	4.0	2.5	6.5
13	2.0	6.5	4.3	1.9	4.0	3.5	5.5
14	4.2	6.0	2.6	5.5	5.0	3.5	5.5
15	4.3	7.0	4.4	5.5	3.5	4.0	5.5
16	4.3	5.5	3.1	3.5	3.5	4.5	5.5
17	2.5	6.0	3.0	4.5	3.0	2.5	3.0
18	6.1	4.5	3.0	3.5	3.5	4.0	2.7
19	2.2	5.0	4.0	3.5	3.0	3.0	6.0
20	2.2	4.5	1.3	4.0	3.5	3.0	5.5
21	4.0	5.0	2.5	4.0	3.0	2.5	4.8
22	6.0	5.2	3.0	3.0	3.0	4.5	4.5
23	4.5	4.9	2.0	4.5	2.0	3.5	6.0
24	6.5	3.0	4.5	4.5	2.5	4.5	5.0
25	6.0	3.1	1.8	4.0	3.5	4.5	6.5
26	6.5	3.1	3.0	3.6	3.5	5.5	5.0
27	5.5	2.4	4.0	3.5	3.6	5.5	4.3
28	5.0	4.0	1.9	4.0	4.3	3.0	6.0
29		5.0	2.2	4.2	3.0	3.6	4.3
30		4.5	2.5	4.2	4.0	1.8	4.5
31		5.0		2.2		3.0	3.0
Mean	6.3	5.1	3.5	3.7	3.3	3.5	4.5
Total	175.2	159.3	105.6	114.4	99.6	109.4	138.4
Min.	2.0	2.5	1.3	1.9	2.0	1.8	2.4
Max.	7.7	7.5	6.0	5.5	4.4	5.5	6.5

Appendix 5. Example of the weather variables (SUMO9801.WTH) used toun the BEANGRO crop model during the February to August, 1998 cropping season.

Weather **input file :** Morogoro,Tanzania

Institute	Latitude	Longtude	Elevation
SUA Morogoro	-6.5	37.3	525

DATE	SRAD	TMAX	TMIN	RAIN
98032	21.2	33.7	22.3	66.2
98033	21.9	33.2	23.7	6.5
98034	23.2	33.8	21.8	0.0
98035	18.8	31.8	23.7	0.0
98036	22.7	32.4	22.0	0.0
98037	21.2	32.2	22.6	0.0
98038	21.5	32.0	23.2	0.0
98039	18.2	33.2	23.8	0.0
98040	10.6	29.1	22.0	0.0
98041	21.5	31.8	22.4	37.4
98042	20.6	32.2	21.8	0.0
98043	15.2	29.6	21.6	20.2
98044	15.0	31.0	22.3	74.1
98045	13.2	31.5	22.6	3,1
98046	20.6	33.2	22.1	0.0
98047	12.7	31.0	22.1	0.0
98048	11.0	31.2	21.0	4.2
98049	19.1	33.0	21.5	9.3
98050	10.1	30.1	21.0	0.0
98051	20.4	31.5	21.5	9.1
98052	19.1	32.2	20.8	0.7
98053	21.8	31.8	23.8	68.5
98054	17.1	33.2	22.3	0.0
98055	23.9	31.4	23.5	0.0

98056	19.4	31.8	23.0	0.0
98057	22.7	31.8	23.5	0.0
98058	21.5	32.6	23.5	0.0
98059	19.6	31.4	23.0	0.0
98060	23.4	33.0	23.7	0.0
98061	22.8	32.8	23.0	0.0
98062	22.9	33.4	22.6	0.0
98063	21.3	33.2	23.6	0.0
98064	21.9	32.5	23.5	0.0
98065	18.9	32.3	24.0	0.0
98066	21.1	32.5	23.2	0.0
98067	9.8	28.5	23.5	0.0
98068	15.9	32.1	22.0	0.0
98069	7.7	26.5	22.5	0.0
98070	21.1	31.0	22.0	43.0
98071	19.6	32.1	24.2	0.0
98072	21.5	32.0	24.0	0.0
98073	23.4	32.8	22.0	0.6
98074	23.2	32.4	22.0	0.0
98075	19.5	32.5	22.0	0.0
98076	23.2	32.7	21.1	0.0
98077	20.6	33.0	22.3	0.0
98078	19.5	33.1	21.4	0.0
98079	18.7	32.3	22.3	0.0
98080	19.2	33.2	22.0	0.0
98081	16.2	31.8	22.0	0.0
98082	21.0	30.5	21.5	15.2
98083	15.9	29.4	22.2	31.9
98084	12.6	31.2	22.8	1.0
98085	13.3	27.8	22.1	5.6

98086	9.3	30.5	22.3	0.6
98087	16.9	32.3	21.4	16.4
98088	21.2	31.8	21.2	0.0
98089	18.2	32.2	21.6	0.0
98090	21.3	30.5	21.8	0.0
98091	18.1	32.0	21.8	0.0
98092	22.2	31.8	21.6	12.5
98093	18.7	32.6	22.8	0.0
98094	15.1	31.5	22.4	0.5
98095	13.8	31.0	22.0	27.2
98096	21.5	33.3	21.9	1.9
98097	15.1	31.0	22.1	1.0
98098	17.5	32.1	21.7	0.3
98099	15.4	31.0	22.6	31.9
98100	15.9	31.6	22.4	27.2
98101	16.2	31.0	22.7	10.3
98102	11.5	28.3	22.7	4.2
98103	16.8	30.0	22.4	2.2
98104	12.6	30.6	22.4	2.8
98105	18.6	31.2	22.4	2.1
98106	15.8	315	22.7	2.4
98107	10.7	29.0	21.5	12.1
98108	16.8	28.3	21.7	4.0
98109	18.1	30.3	20.1	0.0
98110	4.5	25.1	21.5	0.0
98111	12.6	28.4	21.0	1.3
98112	18.7	30.0	21.5	0.0
98113	104	29.5	21.6	0.0
98114	11.4	29.6	22.6	0.0

98115	8.8	26.8	22.0	25.0
98116	12.6	29.8	21.0	0.3
98117	14.6	30.8	20.5	0.0
98118	11.2	26.6	21.4	24.0
98119	10.4	29.0	21.5	14.9
98120	10.7	28.1	21.9	7.7
98121	12.7	29.0	21.9	1.0
98122	18.4	30.7	20.7	7.7
98123	6.7	26.8	21.8	20.3
98124	17.4	30.0	21.5	2.2
98125	23.7	31.6	20.5	2.2
98126	16.2	29.3	20.2	0.0
98127	14.8	29.5	19.5	0.0
98128	20.7	21.8	19.5	0.2
98129	20.4	30.2	21.5	0.0
98130	12.7	29.8	21.5	0.0
98131	13.1	29.8	23.1	0.8
98132	11.7	30.6	21.9	6.4
98133	21.8	29.6	19.7	2.9
98134	22.8	33.0	22.0	0.0
98135	17.5	32.6	19.5	0.0
98136	18.5	30.2	18.0	0.0
98137	17.5	29.5	15.1	0.0
98138	19.5	28.6	15.0	0.0
98139	19.0	29.0	15.0	0.0
98140	23.6	29.4	14.4	0.0
98141	20.0	30.6	18.2	0.0
98142	19.0	30.3	16.7	0.0
98143	19.0	29.7	16.6	0.0
98144	19.0	29.5	15.7	0.0

98145	16.9	29.0	16.9	0.0
98146	14.3	28.6	18.6	0.0
98147	12.5	27.5	20.4	0.0
98148	21.3	29.5	15.0	0.0
98149	18.3	25.3	15.1	0.0
98150	19.7	29.8	14.1	0.0
98151	8.9	26.5	19.5	0.7
98152	17.5	29.3	21.1	4.2
98153	13.7	28.3	21.0	6.9
98154	17.1	30.9	21.0	0.0
98155	17.1	30.5	19.5	0.0
98156	16.5	30.4	19.5	0.0
98157	16.8	29.3	18.5	0.0
98158	15.7	29.4	18.6	0.0
98159	15.0	29.6	20.1	0.0
98160	12.7	27.6	18.1	0.0
98161	15.5	28.7	16.5	0.0
98162	18.0	28.0	14.7	0.0
98163	18.2	28.0	13.3	0.0
98164	20.5	28.8	13.2	0.0
98165	21.0	28.6	17.8	0.0
98166	21.3	29.0	12.6	0.0
98167	19.2	29.3	12.5	0.0
98168	10.5	28.0	19.0	0.0
98169	16.3	28.7	16.1	0.0
98170	10.6	25.7	15.1	0.0
98171	16.4	25.8	13.6	0.0
98172	17.6	29.7	15.5	0.0
98173	16.5	27.8	15.4	0.0

98174	9.8	29.6	20.0	0.0
98175	12.1	29.7	18.6	0.0
98176	12.43	29.6	19.7	0.0
98177	17.1	29.5	15.5	0.0
98178	17.8	29.3	19.0	1.6
98179	15.9	27.8	17.9	17.3
98180	15.0	27.5	19.2	0.0
98181	19.8	27.5	14.0	0.0
98182	15.4	28.0	15.5	0.0
98183	18.4	28.3	14.1	0.0
98184	17.5	27.6	12.6	0.0
98185	13.4	27.9	16.0	0.0
98186	13.7	27.9	15.5	0.0
98187	15.3	25.2	16.0	0.0
98188	10.4	28.2	18.3	0.0
98189	16.5	29.0	18.0	0.0
98190	18.3	28.8	13.5	0.0
98191	14.6	28.8	15.0	0.0
98192	15.9	27.8	17.1	0.0
98193	11.4	28.6	19.4	0.0
98194	16.5	27.6	14.8	0.0
98195	17.8	28.0	14.6	0.0
98196	18.3	28.7	13.4	0.0
98197	17.7	28.0	15.0	0.0
98198	13.8	27.7	17.0	0.0
98199	12.4	27.3	18.8	0.0
98200	13.0	26.0	17.9	0.0
98201	12.1	27.6	16.2	0.0
98202	14.9	29.6	15.8	0.0

98203	19.5	28.9	16.5	0.0
98204	15.0	28.2	14.3	0.0
98205	11.5	28.0	17.6	0.0
98206	15.9	28.7	16.5	0.0
98207	18.2	28.0	17.7	0.0
98208	20.1	29.4	14.0	0.0
98209	13.7	24.8	17.0	0.0
98210	16.0	28.7	16.4	0.0
98211	7.5	27.5	19.6	0.0
98212	12.6	26.5	19.5	0.0
98213	14.9	28.8	15.5	0.0
98214	15.7	29.0	16.4	0.0
98215	17.4	28.8	17.6	0.0
98216	14.8	28.0	15.5	0.0
98217	8.7	28.8	18.0	0.0
98218	14.9	28.8	16.8	0.0
98219	16.4	28.6	16.0	0.0
98220	17.7	29.2	16.5	0.0
98221	12.2	27.0	16.6	0.0
98222	15.5	29.0	18.2	0.0
98223	17.6	29.3	18.0	1.0
98224	19.2	29.3	16.8	0.9
98225	20.4	29.4	17.3	0.4
98226	20.8	29.8	15.4	0.0
98227	19.5	31.1	14.8	0.0
98228	18.0	30.5	17.2	0.0
98229	11.5	28.5	16.5	0.0
98230	11.4	27.8	18.4	2.5
98231	20.2	30.2	17.6	0.7

98232	19.9	30.5	17.7	0.0
98233	21.1	29.8	17.6	0.8
98234	16.8	30.3	16.0	0.0
98235	17.3	30.4	15.0	0.0
98236	20.6	30.0	16.7	0.0
98237	20.8	30.0	16.9	0.0
98238	13.6	28.8	15.1	1.0
98239	19.3	20.2	18.8	0.8
98240	15.7	29.8	16.4	0.0
98241	17.5	29.9	20.2	0.8
98242	16.6	29.7	19.7	0.0
98243	17.5	29.5	19.6	0.0

Appendix 6. Example of the input file (SUMO9801.BNX) used to run the BEANGRO crop model.

EXP. DETAILS: 1998 BEAN EXP ON DROUGHT STUDIES AT SUA MOROGORO, TANZANIA.

TREATMENTS							FACTOR LEVELS									
N	R	0	C	TNAME	CU	FL	SA	IC	MP	MI	MF	MR	MC	MT	ME
01	1	1	1	IR (CAN. WONDERS)	1	1	1	1	1	1	1	1	0	0	0
02	1	1	1	IR (ROJO)	2	1	1	1	1	1	2	1	0	0	0
03	1	1	1	IR (SUA 90)	3	1	1	1	1	1	3	1	0	0	0
04	1	1	1	DRT (CAN. WONDER)	1	1	1	1	1	1	4	1	0	0	0
05	1	1	1	DRT (ROJO)	2	1	1	1	1	1	5	1	0	0	0
06	1	1	1	DRT (SUA 90)	3	1	1	1	1	1	6	1	0	0	0

CULTIVARS

C	CR	INGENO	CNAME
1	BN	IB0014	Canadian Wonder+
2	BN	IB0013	ROJO
3	BN	IB0012	SUA 90

FIELDS

L ID FIELD WSTA.... FLSA FLOB FLDT FLDD FLDS FLST SLTS SLDP ID S SOIL
1 SUMO0001 SUMO9801 -99 0 SU000 00000 00000 00000 SACLLO 100 SUMO980001

INITIAL CONDITIONS

C	PCR	ICDAT	ICRT	ICND	ICRN	ICRE
1	FA	98032	1	-99	1.00	1.00

C	ICBL	SH20	SNH4	SN03	SAEX
1	10	0.35	2.5	3.5	6.62
1	20	0.35	2.5	2.8	5.85
1	30	0.35	2.0	2.8	3.96
1	40	0.25	2.0	2.8	2.91
1	50	0.24	2.0	2.8	2.02

Appendix 6 (Cont.)

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1       60      0.25    1.5     2.8     1.47
1       70      0.20    1.5     2.8     2.05
1       80      0.17    1.5     2.8     1.64
1       90      0.16    1.5     2.89    1.71
1       100     0.14    1.5     2.8     1.54

*PLANTING DETAILS
P       PDATE EDATE PPOP    PPOE    PLME    PLDS    PLRS    PLRD    PLWT    PAGE    PENV
        PLPH
1       98148   98157   22.0    22.0    S       R       50      0       1.0     55      -99
        -991.0

IRRIGATION AND WATER MANAGEMENT
I       EFIR    IDEP    ITHR    IEPT    IOFF    IAME    IAMT
1       0.75    -99     -99     -99     R8      -99     -99
I       IDATE   IROP    IRVAL
I       98163   IR001    58.0
I       98195   IR001   172.0
1       98216   IR001   152.0
1       98221   IROO1    19.0

FERTILIZERS (INORGANIC)
F       FDATE   FMCD    FACD    FDEP    FARMN
1       98148   FE002   AP004   4.0     15
1       98173   FE002   AP004   4.0     15

2       98148   FE014   AP004   4.0     40
2       98148   FE014   4.0
2       98184   AP015   AP004   4.0     40


RESIDUES AND OTHER ORGANIC MATERIALS

R       RDATE RCOD    RAMT    RESN    RESP    RESK    RINP    RDEP
1       98018   IB001   2000    -99     -99     -99     100.0   25.0

SOIL ANALYSIS
A       SADAT SMOC    SMNI    SMHW    SMHB    SMPX    SMKE
1       98018   -99     IB001   SA009   -99     -99     IB001   SA005
A       SABL    SADM    SAOC    SANI    SAHW    SAHB    SAEX    SAKE
1       10.0    1.9     2.27    2.5     5.50    -99     6.12    0.60
1       20.0    1.7     2.27    2.5     5.50    -99     5.85    0.60
1       30.0    1.8     1.15    2.0     5.30    -99     3.96    0.29
```