Pak. J. Bot., 39(2): 463-474, 2007.

EFFECTS OF ENVIRONMENTAL STRESS ON GROWTH, RADIATION USE EFFICIENCY AND YIELD OF FINGER MILLET (*ELEUCINE CORACANA*)

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Abstract

Finger millet landraces viz., TZA-01 and TZM-01 were grown in glasshouses under two moisture regimes (fully irrigated and after drought) to investigate the effects of environmental stress on the growth, SPAD measurement, radiation use efficiency and yield of finger millet *(Eleucine coracana*). The drought treatment was imposed at 28 DAS beyond which no irrigation was applied to the droughted treatment. Growth and development were monitored between 21 DAS and 105 DAS. Soil moisture had an effect on the growth of both the landraces. Drought reduced leaf area, dry matter accumulation, seed weight, radiation use efficiency and yield of finger millet. LAI increased significantly in all the treatment between 28 DAS and 84 DAS, thereafter there was a sharp decline in LAI for TZM-01 under both irrigation and drought. Maximum LAI values (5) in irrigated TZA-01 at 105 DAS and minimum LAI value (2) was recorded in droughted TZA-01 and TZM-01 at 105 DAS. There was a big difference in dry matter production at final harvest between the irrigated and droughted plants. Drought had significant ($p<0.009$) effect on grain yield of two finger millet landraces. The maximum grain yield (4.88 t ha^{-1}) was recorded under irrigated TZA-01 followed by irrigated TZM-01, where (3.22 t ha^{-1}) grain yield was recorded. The minimum grain yield (1.92 t ha^{-1}) was recorded in droughted TZM-01. Biomass was affected significantly ($p<0.028$) by drought. Maximum radiation use efficiency was recorded as 3.11g MJ^{-1} of the accumulated intercepted radiation.

Introduction

Agriculture is highly dependent on weather and, therefore, changes in global climate could have major effects on crop water needs and yields and thus world food supply. The general circulation model (GCM) studies estimated an average increase in global surface temperature of about 4C (2.8-5.2C) and an increase in global precipitation of 10.1% (7.12-15.8%) (Jones *et al*., 1985). Potential effects are difficult to assess not only because of the uncertainty in the magnitude of changes in climate variables, but also because of uncertainties in crop response to weather, soil and management factors. Assessments are needed to provide decision-makers with the information they need to develop appropriate plans to reduce the expected climate change or to adopt them. Results suggest that yields of many crops will decrease in some regions, primarily because of shorter crop growth duration under elevated temperature and increase in other climate-change scenarios, and that crop production in arid-semiarid tropical areas would be affected more than in temperate regions. Water stress becomes more severe under climate change because higher temperature coupled with higher radiation receipts increases evapo-transpiration (ET). Yield decreases for irrigated crops far less that for dry land crops. An adequate water supply is one of the most important factors in crop production. The amount of irrigation water needed for crops depends on climates (rainfall, temperature, solar radiation) and crop and soil characteristics. Under climate change scenarios, demand for irrigation water will increase due to large decreases in summer rainfall and increases in temperature and radiation. Irrespective of the degree of climate change at any location, the risk of climatic variability within and between seasons is likely to be greatest in vulnerable tropical environments where the availability of soil moisture and high temperatures are already limitations to crop growth.

One option to reduce the potential impacts of climate change on food security is to assess the contribution that previously underutilized food crops can make to agriculture in those region where limitations such as drought are likely to increase.

Finger Millet, known locally as Ragi in the Indian sub-continent is mostly cultivated as a base crop in a mixed cropping. The crop can be cultivated across a range of soil moisture availabilities. Seeds of local landraces may be consciously or unconsciously mixed along with the seeds of high yielding varieties of other species and these combinations ensure a high degree of stability of the whole cropping system in variable environments. Production of all millets in Pakistan is about 190,000 t, of which 97 % is pearl millet, 1% finger millet, 1% proso millet and 1% foxtail millet (Anon., 1992-94). Finger millet yields rather bitter flour that is solely used for human consumption. A shift in farming systems traditionally devoted to the crop has occurred due to more farmers favoring irrigated transplanted finger millet cultivation to traditional rain fed farming which is liable to frequent droughts. Yields of finger millet per unit area of land have increased due to adoption of improved cultivation practices. At the same time, the land area cultivated has continually dropped due to shift from highland to lowland areas (www.gov.lk). Finger millet is a popular food among diabetic patients in the countries like India and Sri Lanka. Its slow digestion indicates low blood sugar levels after a finger millet diet thereby producing a safer food for diabetics.

The objectives of the present study were:

1. To establish the fundamental relations between major climatic factors and the growth and yield of the finger millet crop.
2. The major emphasis was on the response of glasshouse grown finger millet to soil moisture as this is the most likely constraint to future crop production.
3. An improved understanding of the environmental influences on crop growth and yield which could be used to determine the optimum soil moisture management strategies and agronomic practices for different climates and soils.

Materials and Methods

Site and glasshouse environment: The experiment was conducted in the Tropical Crop Research Unit (TCRU) glasshouses, University of Nottingham, UK, between May and November 2004.The environment in these glasshouses is controlled in order to mimic the conditions in the natural environment in the tropics. Each glasshouse has a total cropping area of 32 m^2 divided into two halves: the north bay and the south bay. The soil is a sandy loam and each bay can be considered to have an independent soil profile since it is isolated from the external soil by a heavy duty butyl liner on the sides as well as at a depth of 1.25m. The glasshouses are programmed to control temperature which was maintained at 28 ± 5°C during the course of this experiment. The design and environmental control of these glasshouses have been described by Monteith *et al.,* (1983) and Clifford *et al.,* (1993).

Treatments and measurements: Two landraces (TZM- 01 and TZA- 01) from Tanzania were used in this study. The seed was sown on 20 May 2004 at a spacing of 35cm between the rows and 12 rows in one bay using a seed rate of 400 seeds per row. The growth and yield of two landraces were studied under full irrigation and drought conditions. Two landraces were allocated to a glasshouse which was designated as the irrigated glasshouse while the other was the droughted glasshouse. All the plots were originally irrigated with similar amounts of water from sowing until 28 DAS, after which no further irrigation was supplied to the droughted plots. At this stage, each profile had at least 270mm of water (field capacity for this soil (Shamudzarira, 1996). Irrigation was applied weekly to the irrigated glasshouses, aiming at replenishing the amount of water that was lost in the previous week. Intercepted radiation was measured using tube solarimeters above and below the crop canopy in each glasshouse (Gallagher & Biscoe, 1978). The difference between radiation quantities above and below the canopy gave the fractional light interception (f) of the crop. These values were recorded by a data logger and saved on a computer every hour between 21 and 105 DAS. Dry matter production and partitioning was measured through growth analysis (on 10 randomly chosen plants) conducted at fortnightly intervals starting at 21 DAS.

Measurements of chlorophyll content and SPAD calibration: The determination of gas exchange parameters and the comparison of these data between and within landraces relate their similarities or differences in terms of photosynthetic activity. One possible reason for similarity or dissimilarity of photosynthetic activity can lie in the constitution of the photosynthetic apparatus, and in the chlorophyll content in particular. This is why the gas-exchange parameters have been related to an estimation of the leaf greenness at the moment of the measurement. Leaf greenness can be estimated using a SPAD meter (Minolta, 502). To our knowledge, the nature of the exact relationship between SPAD value and actual chlorophyll content, as well as any information about chlorophyll content of finger millet, have not been investigated before. Thus, as the gas-exchange parameters have been related to SPAD measurements, it was necessary to determine the exact relationship between the value indicated by the SPAD meter and the real chlorophyll content, and the ratio between chlorophyll a and b. Attempts to relate gas exchange parameters and anatomical features and especially chlorophyll content or its estimation have been done on other plants: cotton (Pettigrew & Meredith, 1994; Pettigrew *et al*., 1993), maize (Earl & Tollenaar, 1997), *Argyranthemum coronopifolium* (Derralde *et al*., 1998), sorghum (Rao & Das ,1982) and coffee (Da Matta *et al*., 1997). Although the method is common, the exact nature of the link between SPAD readings and chlorophyll contents is species-dependent (Marquard & Tipton, 1987; Yadava, 1986) and instrument- dependent, and therefore requires a specific calibration of the instrument for each species.

SPAD measurement: On June 2004, 10 middle leaflets of finger millet were selected within a experimental crop stand grown in the TCRU glasshouses. These samples were split between the two different landraces (10 leaflets of each landrace: TZM-01 and TZA-

01). The leaflets were chosen to represent at large range of colour. Then, SPAD measurements were made on the selected leaves. The chlorophyll extraction was performed following a slightly modified version of the method described by Marquard & Tipon (1987): Single (53 mm^2) disks were taken from each leaflet, weighed and immersed in 10ml DMF (Dimethyl formamide), and put immediately in the dark .The absorbance was measured 245 h later, using a spectrophotometer (SP 6-500 UV, Pye Unicam Ltd , Cambridge ,UK) at 647 and 664.5 nm. The data analysis was performed with Genstat and with Excel (regression and comparison of regressions for the calibration of the SPAD meter).

Growth analysis: A 25cm long row from each plot was harvested at ground level weekly and fortnightly leaving appropriate borders. A total of 8 growth analyses were conducted at 21, 28, 35,42, 56, 70, 84 and 105 DAS. Dry weight of component fraction of plant (leaf, stem, and panicle) was determined. All the samples were taken to dry in an oven at 80 ^{o} C to a constant weight. Also, an appropriate sub- sample of green leaf lamina was used to record leaf area on an area meter (Licor model 3100).

Final harvest: An area of 1.5m x 1.5m from each plot was harvested and a sub sample of 20 plants was taken for the determination of final growth analysis e.g., final plant height in centimeter, number of leaves per plant, leaf area, stem area, number of finger per panicle, panicle weight, number of seeds per panicle, 100- seed weight and total seed weight per panicle.

Statistical analysis: All the data obtained in this study were analysed by GENSTAT statistical package. The graphs were compared using analysis of variance (in GENSTAT) from the ANOVA output at 1 % or 5 % probability level.

Results

Results from the glass house experiment conducted in TCRU 2004 to determine the physiological response of finger millet to soil moisture showed that the daily mean air temperature, saturation deficit (daylight hours) and intercepted radiation logged throughout the season in each glass house (Table 1). In general the control system maintained the environment throughout the season in all the glass houses within acceptable levels. Saturation deficit was maintained below 2 kPa in all the glass houses (ranging from1.05 to1.37 kPa).

The change in LAI with time increased significantly in all the treatments between 28 DAS and 84 DAS, thereafter there was a sharp decline in LAI for TZM-01 under both irrigation and drought (Fig. 1). Under drought the LAI for both TZA-01 and TZM-01 was stable between 28 DAS and 70 DAS, after which it fell sharply. In contrast, the LAI for irrigated TZA-01 continued to increase and reached maximum values at 105 DAS. TZM-01 under irrigation maintained its LAI value of 4-5 between 42 DAS and 84 DAS, whereas the LAI for TZA-01 declined from 5 to 3 between 70 DAS and 105 DAS. However, in TZM-01 the LAI recorded under irrigation was always higher than the LAI recorded under the drought treatment at 70 DAS and then sharply declined up to 105 DAS. The minimum LAI value (2) was recorded in droughted TZA-01 and TZM-01 at 105 DAS.

Table 1. Glasshouse system performance for the 2004 finger millet study.

House	Mean Temperature °C		Mean daylight Saturation Deficit (kPa)	
	Target	Actual	Target	Actual
1	28 ± 5	28.3 ± 0.2	≤ 2	1.08 ± 0.1
2	28 ± 5	28.2 ± 0.2	≤ 2	1.37 ± 0.1
3	28 ± 5	28.1 ± 0.2	≤ 2	1.18 ± 0.1
4	28 ± 5	28.1 ± 0.2	≤ 2	1.05 ± 0.1

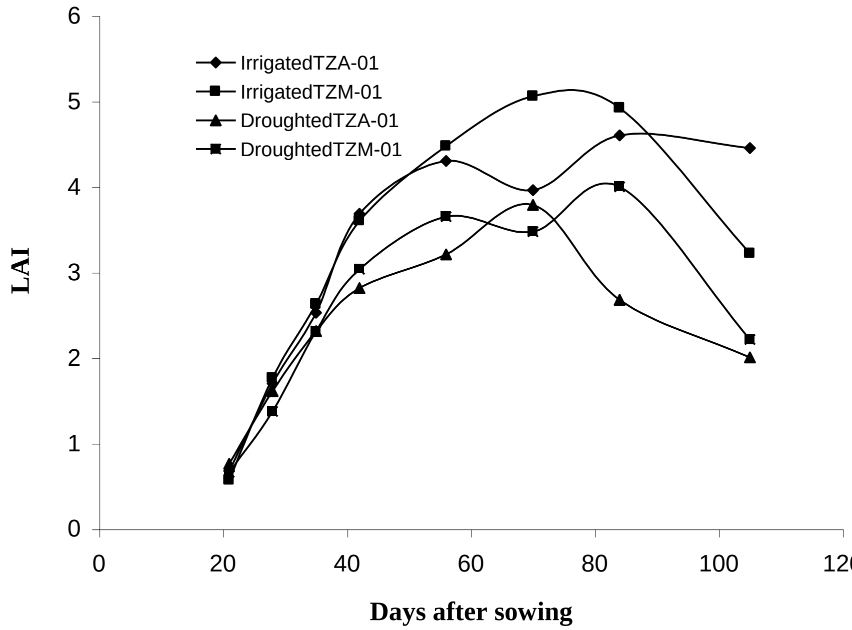

Fig. 1. Effect of drought and irrigation on leaf area index of two finger millet landraces.

Chlorophyll content or SPAD measurement values was significantly different between the treatment (p< 0.001), harvest dates was significantly different (p<0.001) and drought x harvest was also significant (p<0.001). The leaf greeness of the leaves were increasing with each successive harvest date from an average of 29 to 40 from 20 DAS to 41 DAS. Plants which were irrigated had higher leaf greeness than those which were droughted (Fig. 2). Significant difference were observed from 55 DAS and at 83 DAS where on average 39 leaf greeness and 42 greeness was recorded under droughted TZA-01 and irrigated TZM-01. The minimum leaf greeness value (29) was recorded in droughted TZA-01 as compared to irrigated TZM-01. The maximum value was recorded (42) in irrigated TZM-01 at 83 DAS. Beyond this there was a rapid decline in droughted TZA-01 and droughted TZM-01 as compared to irrigated TZA-01 and irrigated TZM-01. The maximum leaf greeness was recorded at 104 DAS in irrigated TZA-01 which was 40 and 37, respectively. There were non-significant difference among landraces, drought x landraces and landraces x harvest.

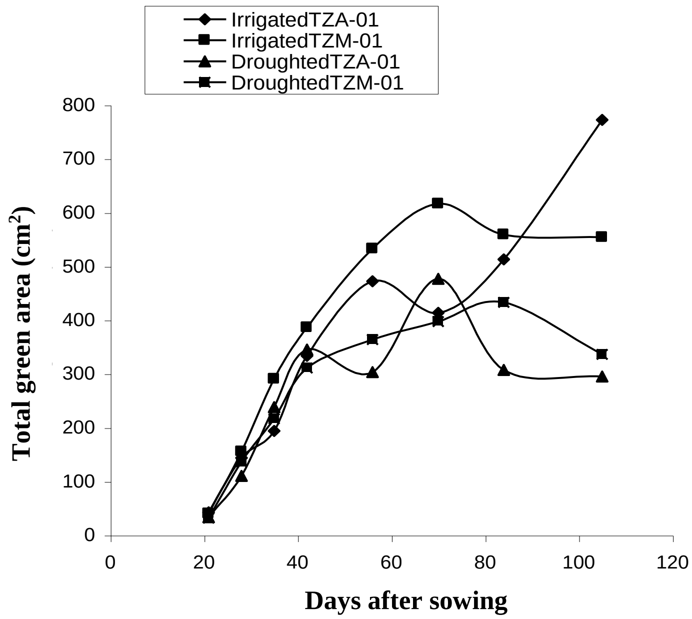

Fig. 2. Effect of drought and irrigation on the total green area per plant of two finger millet landraces.

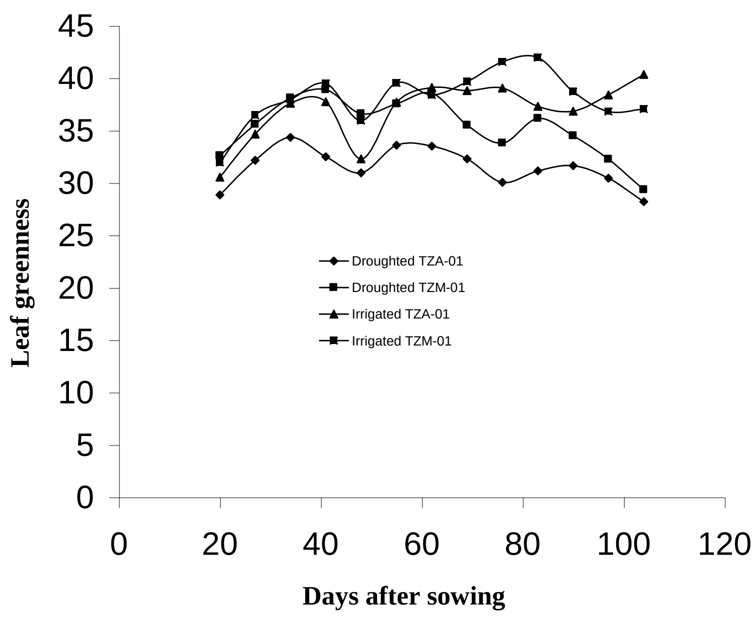

Fig. 3. Effect of drought and irrigation on the leaf greenness of two finger millet landraces.

Total green area per plant differed significantly ($p<0.049$) under droughted and irrigation treatments. Landrace is not significantly different. There were significant differences between different harvest ($p<0.001$), interaction between drought x harvest ($p<0.001$), landrace x harvest ($p<0.005$) and drought x landrace x harvest ($p<0.001$). The total green area per plant increased rapidly from 28 DAS to 105 DS under irrigated TZA-01 and TZM-01 as compared to droughted TZA-01 where steadily or slow increase in total green area upto 105 DAS. Drought had significant effect on landraces with time. The maximum total green area per plant was recorded in irrigation TZA-01 as compared to droughted TZA-01.The minimum total green area per plant was recorded in droughted TZA-01 (Fig. 3).

Total dry matter increased steadily in the two landraces between 21 DAS and 56 DAS (Fig. 4). Beyond 70 DAS there was very limited accumulation of dry matter in droughted TZA-01 and TZM-01. In contrast, for irrigated TZA-01, dry matter accumulation was always higher under irrigated and droughted TZA-01 and TZM-01. At the time of final harvest (105 DAS), there was a significant differences ($p<0.001$) among the different harvest. Drought has significant effect with time on the dry matter accumulation. There was a big difference in dry matter production at final harvest between the irrigated and droughted plants. The difference in dry matter production between the irrigation treatment was $300gm^{-2}$ and 200 gm^{-2} for TZA-01 and TZM-01 than droughted TZA-01 and TZM-01, respectively.

There were non-significant differences ($p<0.073$) in grain yield between the irrigated and droughted plants of the finger millet and significant differences ($p<0.009$) in two landraces viz., TZA-01 and TZM-01. As regard the landraces the maximum grain yield (3.41 t ha^{-1}) was recorded in TZA-01 whereas minimum grain yield (2.57 t ha^{-1}) was produced in TZM-01. Drought had significant ($p<0.009$) effect on landraces. The maximum grain yield (4.88 t ha^{-1}) was recorded under irrigated TZA-01 followed by irrigated TZM-01 where 3.22 t ha^{-1} grain yield was recorded. The minimum grain yield (1.92 t ha^{-1}) was recorded in droughted TZM-01. Biomass was affected significantly ($p<0.028$) by drought. Landraces had no significant effect and interaction of drought and landraces was also non-significant. Drought had no significant effect on harvest index of both the landraces. On average the harvest index ranged from 0.20 to 0.29 (Table 2).

Total daily irradiance ranged from 2.2- 8.1 MJm^{-2} during the growing season. Intercepted radiation is shown in Table 3. The total seasonal intercepted radiation was from 362 to 698 MJm^{-2}. Regression analysis showed that total accumulated intercepted radiation was significantly different ($p<0.001$) and (R^2 =0.9928and Y= 6.5507x –99.118) in irrigated TZM-01 and in case of TZM-01 droughted (R^2=0.94 and Y=3.3312x) (Fig. 5). (R^2 = 0.98) variation in the data and slope is (Y=4.843x-69.187) in irrigated TZA-01), In case of TZA-01 droughted (R^2= 0.96 and Y= 4.376x) (Fig. 6). Regression analysis of the end of the season biomass at harvest as a function of accumulated intercepted radiation from 21 DAS to 105 DAS is shown in Fig. 5 and 6. According to the predicted line, RUE was $3.11gMJ^{-1}$. Radiation use efficiency was not significantly different in droughted and irrigation treatment. Differences between landraces were also non-significant and interaction between drought x landraces was also non-significant. On an average the radiation use efficiency ranged from 2.02 to $3.11gMJ^{-1}$ (Table 2).

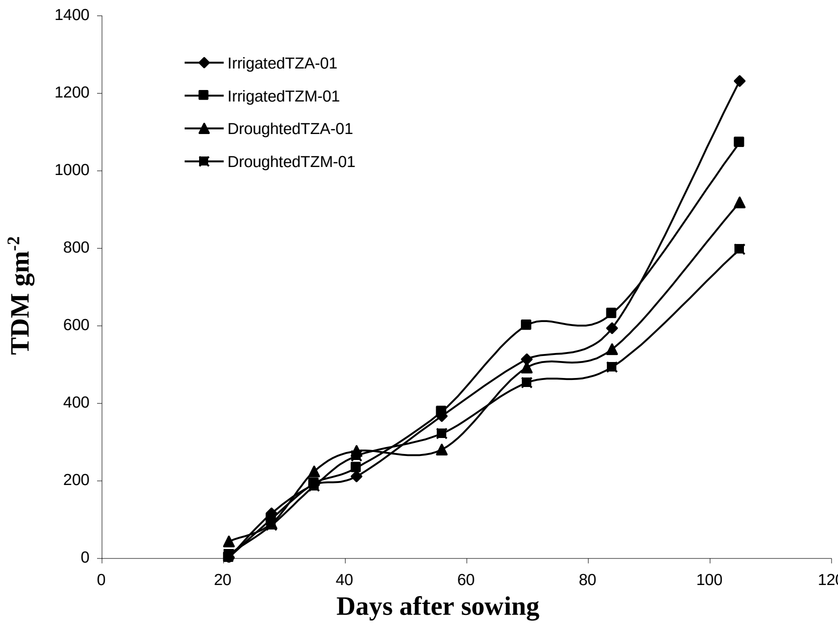

Fig. 4. Effect of drought and irrigation on the total dry matter (TDM) of two finger millet landraces.

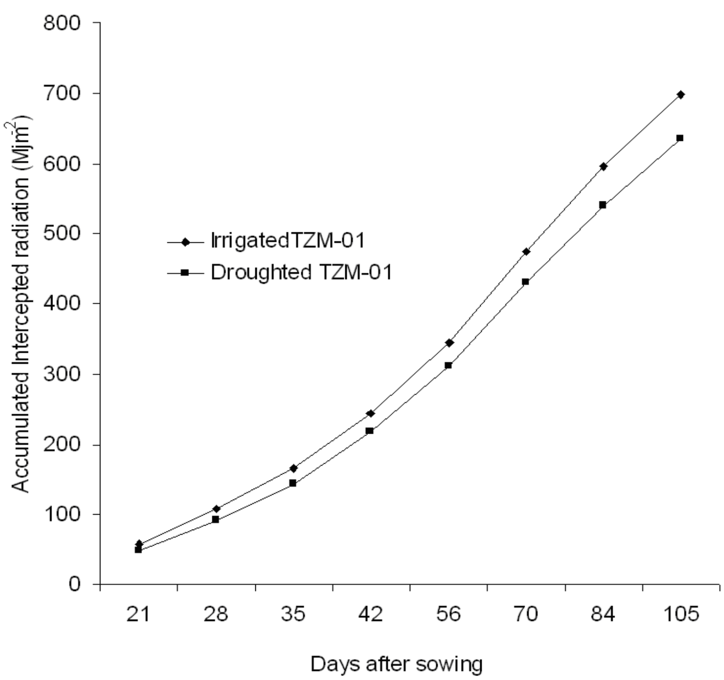

Fig. 5. Effect of drought and irrigation on the accumulated intercepted radiation on finger millet landraces TZM-01.

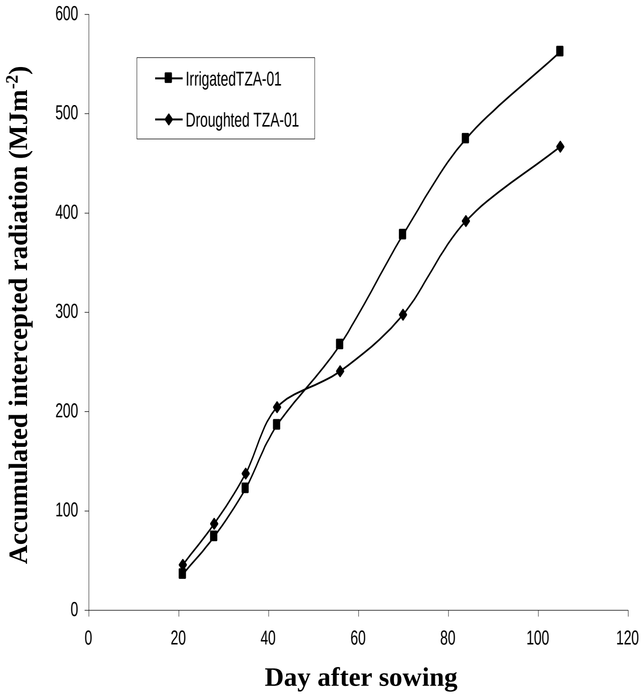

Fig. 6. Effect of drought on the accumulated intercepted radiation on two finger millet landraces.

Table 2. Effect of drought and irrigation on grain yield, total biomass, H.I. and RUE of two finger millet landraces.

Treatments	Grain yield (tha^{-1})	Biomass (tha^{-1})	H.I.	RUE (gMJ^{-1})
Drought	1.93 b	9.63b	0.20 NS	2.10 NS
Irrigation	4.05 a	14.64a	0.28	2.82
Landrace				
TZA-01	3.41 a	13.98a	0.23 NS	2.56 NS
TZM-01	2.57 b	10.29b	0.25	2.36
Drought x Landrace				
Irrigated TZA-01	4.88 a	18.14a	0.27 NS	3.11 NS
Irrigated TZM-01	3.22a	11.14b	0.29	2.53
Droughted TZA-01	1.94b	9.82b	0.20	2.02
Droughted TZM-01	1.92b	9.44b	0.21	2.19
Statistical summary				
P value	$p<0.009$	$p<0.028$	$p<0.178$	$p<0.2960$
S.E.D.	0.0783	0.856	3.55	0.4186
d.f	2	2	2	2

Table 3. Maximum daily and total seasonal interception of radiation by the finger millet crop.

Glasshouse and landraces	Maximum daily intercepted radiation (MJm^{-2})	Total intercepted radiation (MJm^{-2}) between 21DAS and 105 DAS
Droughted TZM-01	3.22	362.58
Droughted TZA-01	6.39	466.02
Droughted TZM-01	6.85	634.52
Droughted TZA-01	7.63	661.24
Irrigated TZM-01	7.76	410.61
Irrigated TZA-01	2.21	561.56
Irrigated TZM-01	7.95	698.01
Irrigated TZA-01	8.1	582.89

Discussion

Plant growth, development and the subsequent yield are influenced by the environmental conditions in which plants are grown. These conditions include moisture, solar radiation, temperature, soil acidity etc. Most crops in the tropics are grown under poor environmental conditions such that their full productivity is never realised. Inadequate soil moisture content and low nutrient fertility are the biggest limitations to crop production. Exploration of crops which can survive in these harsh environments is of paramount importance to sustain agricultural production in the tropics. Thus the need for increased food production in the tropics and the whole world due to population pressure calls for a new challenge to develop crops which have been looked at as minor crops previously, like finger millet. In studies involving water stress, the severity of stress that the crop experiences is critical to the interpretation of the results obtained. Unless the drought was severe enough to cause some physiological response in the crop, the said water stress cannot be considered significant for the purpose of the study. In addition the stress has to be high enough to enable one to discern differences among landraces. A similar concern was expressed by Dencic *et al*., (2000) who found no differences in the response of 21 wheat landraces to imposed drought .The results reported here show a clear subjection of the two finger millet landraces to a progressively severe treatment of soil moisture stress. The reduction in the growth and development of both the landraces in this study between 35 DAS and 105 DAS. In addition, the similarity in the moisture content at the time of imposing drought treatment (i.e. at 28 DAS) indicates the uniformity of the condition in the glasshouses with respect to soil moisture content, thereby making it possible to compare the response of the landraces to soil moisture status. Apart from the uniformity in the soil moisture content the four glasshouses had similar conditions with respect to temperature and saturation deficit.

This study has demonstrated that drought has a significant influence on the vegetative and reproductive growth of finger millet. Apart from the water use, the rest of the parameters recorded in the study were dependent on soil moisture content. The trend of LAI development found in this study is typical of most crops, which increase their LAI until they reach a peak value, beyond which LAI reduces as the crop senesces. The highest (peak) LAI value of 5 was recorded in irrigation TZM-01 while the corresponding values for the TZA-01 was slightly lower. The highest value observed in this study is equal to 5.4 reported by Collinson *et al.*, (1997) for irrigated TZM-01 could be attributed to possible variations in environmental conditions and plant growth.

Apart from LAI, other variables (dry matter production, final yield and seed weight) were also strongly affected by drought. The reduction in dry matter production as a result of moisture stress is consistent with the general behavior of closure of stomata for water saving purposes (Willmer & Fricker, 1996). As the stomata close in response to low water supply, there is low CO_2 fixation. Apart from reducing cell division and enlargement, water stress is reported to be restrictive to almost all aspects of cellular metabolism (Jones, 1992). The result in decrease in dry matter production and yield is evident in this study. There was considerable tolerance to drought as the crop produced a minimum of 580g m^{-2} and 192g m^{-2} of biomass and seed yield, respectively. Maximum grain yield (4.05tha^{-1}) was recorded in irrigation and minimum grain yield (1.93 t ha^{-1}) in case of drought. Maximum grain yield (4.88 t ha^{-1}) was recorded in irrigated TZA-01 followed by irrigated TZM-01 where grain yield was recorded (3.22 t ha^{-1}). Drought caused significant reduction in maximum biomass production by changes in the amount of intercepted radiation. Radiation use efficiency was not significantly different in droughted and irrigation treatments. Drought has no significant effect on landraces with respect to radiation use efficiency. Maximum radiation use efficiency was 3.11g MJ^{-1} of the accumulated intercepted radiation. RUE ranged from 2.02 to 3.11g MJ^{-1} of accumulated intercepted radiation (Jamieson *et al*., 1995).

The major emphasis in this project was on the response of glasshouse grown finger millet to drought with special reference to potential changes in climate, to improve understanding of the environmental influences on crop growth and yield. This understanding will be used to determine optimum soil water management strategies and agronomic practices for different climates and soils. These latest production technologies and agronomic practices will be very helpful to strengthen the research activities and teaching skills in the field of agronomy. In future it would be useful to test the potential for finger millet production in Pakistan, perhaps through a research link with the University of Agriculture, Faisalabad. This would provide an avenue for yield improvement in different crops under the agro-ecological conditions of Pakistan.

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(Received for publication 10 November 2005)