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

MUHAMMAD MAQSOOD AND *S.N. AZAM ALI

Department of Agronomy, University of Agriculture, Faisalabad 38040, Pakistan
**School of Biosciences, Division of Agricultural Sciences, Sutton Bonington Campus, University of Nottingham,Loughborough, Leicestershire , LE 12 5 RD UK.*
Email: drmaqsoodbajwa@yahoo.co.in

Abstract

Two finger millet landraces were grown in glasshouses under two moisture regimes (fully irrigated and subjected to drought) to investigate the effects of environmental stress on the growth, development, radiation use efficiency and yield of finger millet (*Eleucine coracana*), in two landraces viz., TZA-01 and TZM-01. 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. Drought significantly reduced the number of leaves per plant, leaf area per plant from 42 DAS to 105 DAS. 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

Finger millet (*Eleucine coracana*) 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. Finger millet is reported to be resistant to flood, drought, pest and diseases. However, the crop is susceptible to lodging and the seeds have no dormancy period. In Pakistan, finger millet is mainly cultivated along the southern coast. 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). In India and Nepal it is mainly cultivated in the North western part of the Kolli hills. The crop is grown in Anuradapura, Monoragala, Hambantoda, Kegalla, Ratnapura, Nuweraliya Ampara Badulla and Jaffna districts of Sri Lanka. Finger millet is an important food crop grown in rain fed uplands in the dry zone and intermediate zone of Sri Lanka .It is one of the few crops that can be grown in low land paddy fields during yala season if water logging is prevented. Finger millet grows well in all well-drained soils but the silt loams are the most desirable. It grows well on reddish brown earth, calcic red yellow latasols and sandy regosols. 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 objective of this study was to establish the fundamental relations between major climatic factors and the growth and yield of the finger millet crop. 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. An improved understanding of the environmental influences on crop growth and yield will 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 and the experiment 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. At 21 days after sowing (DAS) the crops were thinned to maintain the optimum plant population. 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. Crop emergence was recorded every day at 0900 h between 3 and 12 DAS, using the central 5 rows from each plot and expressed as percentage of total seed sown. 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.

Leaf number was recorded twice per week using 10 randomly chosen (tagged) plants in each plot. Dry matter production and partitioning was measured through growth analysis (on 10 randomly chosen plants) conducted at fortnightly intervals starting at 21 DAS.

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 statistical 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

Glass house experiment was conducted in TCRU 2004 to determine the physiological response of finger millet to soil moisture. The daily mean air temperature, saturation deficit (daylight hours) and intercepted radiation logged throughout the season in each glass house are shown in 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 from 1.05 to1.37 kPa).

Emergence count (%): Germination is a crucial stage in seedling establishment and hence plays a key role in crop production (Khajeh *et al*., 2003). The minimum number of seedling emerged 15% in landrace TZM- 01 during the third day after planting and it increased rapidly during fourth day after planting the seed, which was 49 % seedling emerged and then increased slightly up to 12 days after planting the seed, which was 65 % seedlings emerged (Fig. 1). In case of landrace TZA-01 during third day after planting the seed, the maximum number of seedling emerged was 22% and it increased rapidly during the fourth day after planting the seed, which recorded 53% seedling emerged as compared to landrace TZM-01. There was a non-significant difference between the landraces under study (Fig. 1).

Table1. Glasshouse system performance for the 2004 finger millet study.

House	Mean Temperature ºC		Mean daylight Saturation Deficit (kPa)	
	Target	Actual	Target	Actual
1.	28 ± 5	28.3 ± 0.2	≤ 2	1.08 ± 0.1
2.	28 ± 5	28.3 ± 02	≤ 2	1.20 ± 0.1
3.	28 ± 5	28.2 ± 0.2	≤ 2	1.37 ± 0.1
4.	28 ± 5	28.1 ± 0.2	≤ 2	1.18 ± 0.1
5.	28 ± 5	28.1 ± 0.2	≤ 2	1.05 ± 0.1

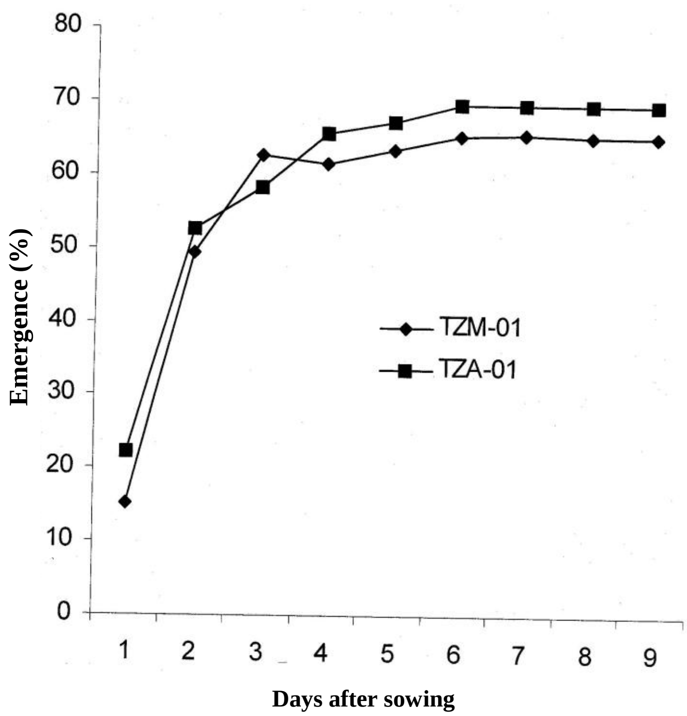

Fig. 1. Emergence percentage of two finger millet landraces in the glasshouses.

Number of leaves per plant: The number of leaves per plant in the two landraces followed a linear at the beginning with a slow initial phase followed by a phase of rapid accumulation and finally a tailing off (Fig. 2). The number of leaves progressively increased from 25 DAS until 88 DAS, After which there was no further increase in leaf number except in the irrigation treatment for TZA-01 (Fig. 2), With the exception of TZM-01, there were more leaves produced (per plant) under irrigation than under the drought. Irrigated TZM-01 for example produced 21 leaves per plant while the corresponding value for the drought treatment was 19. Under irrigation, TZA-01 produced the lowest number of leaves (20 per plant) while the highest number was observed in TZM-01 (Fig. 2). For the drought treatment the number of leaves was similar among the two landraces, but the irrigated TZM-01 had the highest number of leaves per plant.

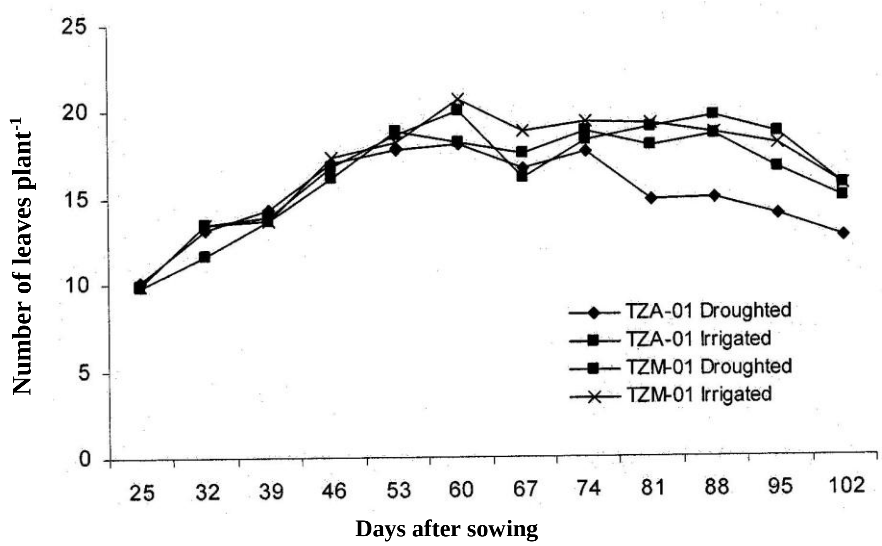

Fig. 2. Effect of drought and irrigation on number of leaves per plant.

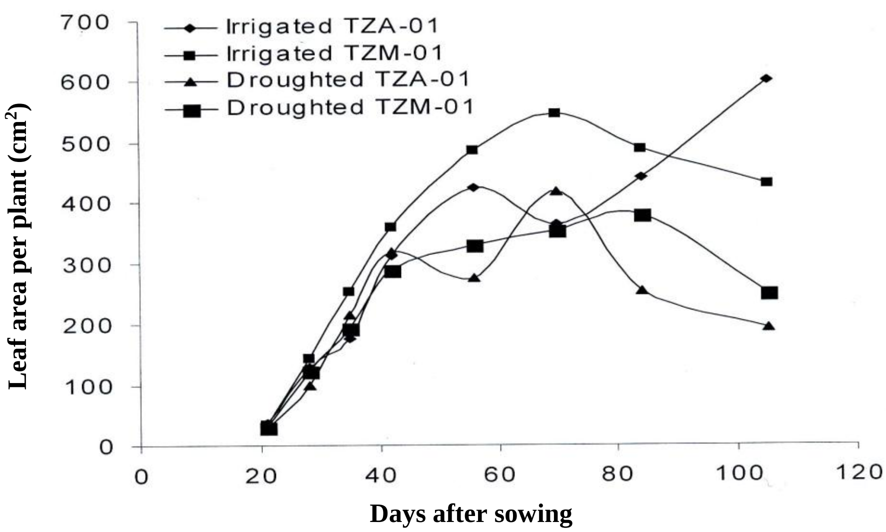

Fig. 3. Effect of drought and irrigation on the leaf area per plant of two finger millet landraces.

Leaf area per plant: The leaf area per plant increased significantly ($p<0.057$) in all the treatment between 21 DAS and 84 DAS (Fig. 3). Thereafter there was a sharp decline in leaf area per plant under both irrigation and drought. Under irrigation condition the leaf area per plant for both landraces TZA-01 and TZM-01 was stable between 56 DAS and 70DAS, after which it fell sharply, In contrast, the leaf area per plant for droughted TZA-01 and TZM-01 landraces continued to decrease and reached the minimum value at 105 DAS. Whereas the leaf area per plant in droughted TZA-01 declined from 42 DAS to 105 DAS (Fig. 3). The maximum leaf area per plant was always higher in irrigated TZM-01 than the irrigated TZA-01 except at 105DAS.

Plant height (cm): Plant height increased rapidly in the two landraces between 21 DAS and 35 DAS. Beyond 42 DAS, there was very slow increase in plant height in droughted TZM-01 and droughted TZA-01. There was a rapid increase in plant height in irrigated TZM-01 as compared to irrigated TZA-01. The maximum plant height (115cm) was recorded in the irrigated TZM-01 at 70 DAS and the minimum plant height (101cm) was recorded in the droughted, TZM-01 at 84 DAS and droughted TZA-01 (104 cm) at 84 DAS (Fig. 4). The plant height at 84 DAS was similar in irrigated TZA-01 and droughted TZA-01 and the maximum plant height (113 cm) was recorded in irrigated, TZM-01 (Fig. 4).

Stem area per plant (cm ^{2}): Stem area per plant showed a significant difference ($p<0.019$) among droughted and irrigated treatment. The stem area per plant had no significant differences among landrace and drought x landrace. Different harvest dates were significantly different ($p<0.001$) from one another, drought x harvest and drought x landrace x harvest was also significantly different ($p<0.001$) from one another. The stem area per plant under irrigated TZA-01 and TZM-01 was higher than the stem area per plant under droughted TZA-01 and TZM-01.The stem area per plant increased significantly in all the treatments between 28 DAS and 105 DAS. Thereafter, there was a rapid increase in stem area in all the treatments under droughted and irrigated TZA-01 and TZM-01. The maximum stem area was recorded in irrigated TZA-01 (170cm^2) followed by TZM-01 (123cm^2). The minimum stem area per plant was recorded under droughted TZM-01 (86cm^2) (Fig. 5).

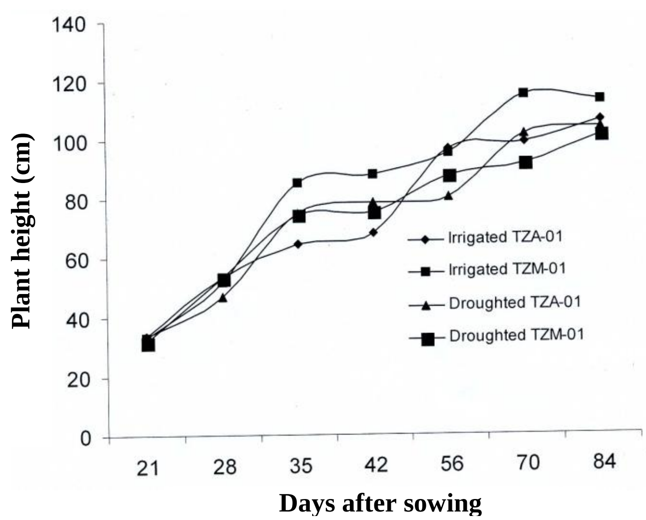

Fig. 4. Effect of drought and irrigation on plant height of two finger millet landraces.

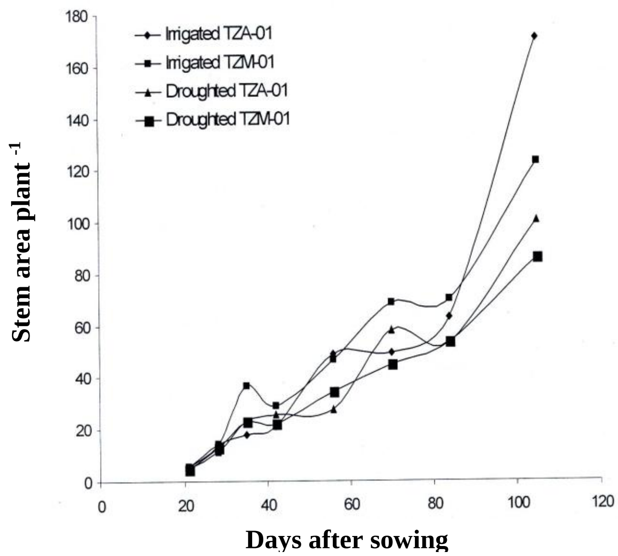

Fig. 5. Effect of drought and irrigation on stem area per plant of two finger millet landraces.

Number of finger, 100-seed weight and total seed weight plant^{-1}: The number of fingers per plant did not differ significantly between the drought and irrigation treatments. Landraces differed significantly ($p<0.044$). Drought had no significant effect on landraces. On an average the number of fingers per panicle ranged from 7-10. As regard 100-seed weight, there were non-significant differences among landraces and interaction of landraces and drought was also non-significant. Total seed weight was also non-significant between droughted and irrigated treatments.

Grain yield, biomass (t ha^{-1}) and harvest index: 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 i.e., TZA-01 and TZM-01. 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 TZA-01 under irrigated followed by 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).

Radiation: Measurements of the light interception were available in all the glasshouses (Table 3). Total daily irradiance ranged from 2.2- 8.1 MJm^{-2} during the growing season. 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 = 0.98) variation in the data and slope is (Y=4.843x-69.187) in TZA-01) and (R^2 =0.9928and Y= 6.5507x –99.118) in TZM-01 (Fig.6). In case of TZA-01 droughted (R^2= 0.96 and Y= 4.376x) and in case of TZM-01 droughted (R^2=0.94 and Y=3.3312x) (Fig.7). 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 Figure 6 and 7. Regression analysis revealed that only first order polynomial terms were significant ($p<0.001$) in predicting biomass as a function of total intercepted radiation. 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).

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	9.63	0.20	2.10
Irrigation	4.05	14.64	0.28	2.82
Landrace				
TZA-01	3.41	13.98	0.23	2.56
TZM-01	2.57	10.29	0.25	2.36
Drought x Landrace				
Irrigated TZA-01	4.88	18.14	0.27	3.11
Irrigated TZM-01	3.22	11.14	0.29	2.53
Droughted TZA-01	1.94	9.82	0.20	2.02
Droughted TZM-01	1.92	9.44	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

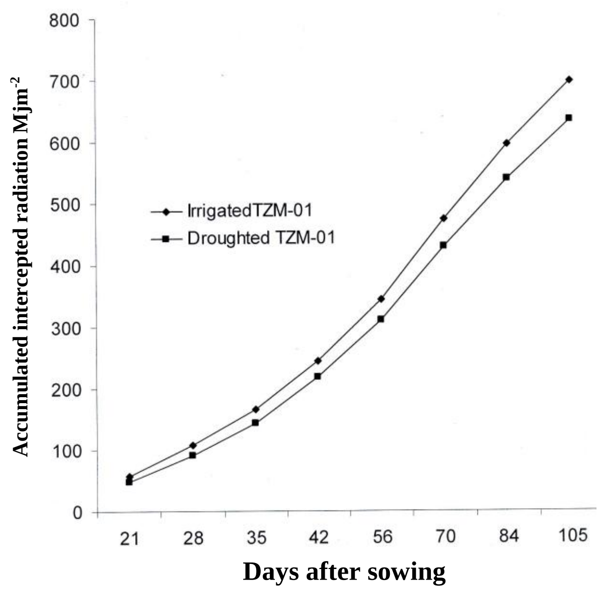

Fig. 6. Effect of drought and irrigation on the accumulated intercepted radiation on finger millet landraces TZM-01.

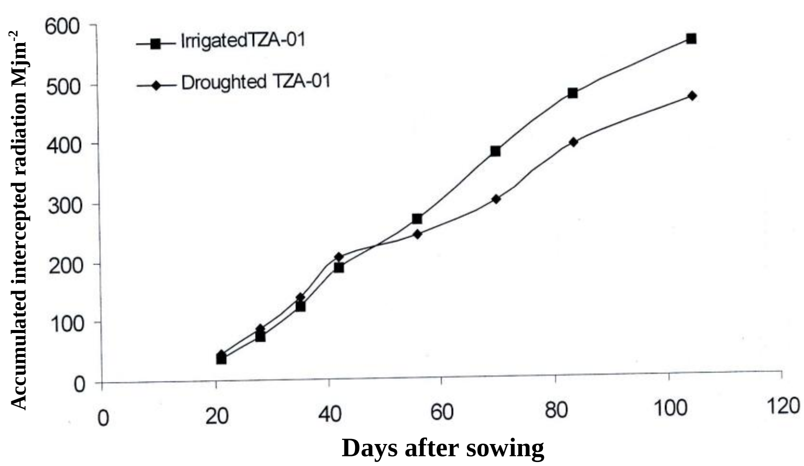

Fig. 7. Effect of drought on the accumulated intercepted radiation on two finger millet landraces.

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 and 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. There was 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.

The present 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. There was a decline in leaf production as a result of drought. Similarly there was a notable restriction in canopy size under the drought treatment due to reduction in leaf production, especially beyond 56 DAS for droughted TZA-01 and droughted TZM-01 while the irrigated plants actively produced leaves until close to 95 DAS. As a result, both TZA-01 and TZM-01 had more leaves under the irrigated treatment than under the drought treatments. The reduction of leaf number in droughted TZA-01 and droughted TZM-01, as observed in this study, could probably be one of the mechanisms for reducing the total leaf area under the limited soil moisture content, a drought tolerance mechanism that Jones (1992) considered as a water conservation strategy. With a small leaf area a crop is able to limit water loss because the size of the evaporating surface is small.

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 of 4.88 t ha^{-1} was recorded in irrigated TZA-01 followed by irrigated TZM-01 where grain yield recorded was 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.

References

Anonymous. 1996. *The world Sorghum and Millet economies: facts, trends and outlook. FAO, Rome, Italy*.

Anonymous. 2003. *Ecocrop 1 and 11.Revised version.Land and water Digital Media Series 4. FAO, Rome, Italy*.

Azam-Ali, S.N. and G.R. Squire. 2002. *Principles of tropical agronomy*. CABI Publishing, Oxon, UK.

Azam-Ali, S.N., P.J. Gregory and J.L. Monteith. 1984. Effects of planting density on water use and productivity of pearl millet (*Pennisetum typhoides*) grown on stored water. 1. Growth of roots and shoots. *Expl. Agric*., 20: 203-214.

Azam-Ali, S.N., P.J. Gregory and J.L. Monteith. 1984. Effects of planting density on water use and productivity of pearl millet (*Pennisetum typhoides*) grown on stored water.2. Water use, light interception and dry matter production. *Expl. Agric*., 20: 215-224.

Bonhomme, R. 2000. Beware of comparing RUE values calculated from PAR vs solar radiation or absorbed vs intercepted radiation. *Field Crops Res*., 68: 247-252.

Clifford, S.C., C.R. Black, J.A. Roberts, I.M. Stronach, P.R. Singleton-Jones and S.N. Azam-Ali. 1995. The effect of elevated atmospheric CO_2 and drought on stomatal frequency in groundnut (*Arachis hypogaea* L. *Journal of Experimental Botany*, 46: 847-852.

DOE. 1988. Possible impacts of climate change on the natural environment in the UK. London.UK Department of Environment.

Earl, H.J. and R.F. Davis. 2003. Effect of drought stress on leaf and whole canopy radiation use efficiency and yield of maize. *Agron. J*., 95: 688-696.

Gallagher, J.N. and P.V. Biscoe. 1987. Radiation absorption, growth and yield of cereals. *J. Agric. Sci. Camb*., 19: 47-60.

Hatch, U., S. Jagtap, J. Jones and M. Lamb. 1999. Potential effects of climate change on Agricultural water use in the southeast U.S. *J. Am. Water Resour. Assoc*., 35: 1551-1561.

Jamieson, P.D., R.J. Martin, G.S. Francis and D.R. Wilson. 1995. Drought effects on biomass production and radiation use efficiency in barley. *Field Crops Res*., 43: 77-86.

Jones, H.G. 1992. *Plants and microclimate; a quantitative approach to environmental Physiology* (2nd Edition). Cambridge University Press, Cambridge, UK.

Khajeh-Hosseini, A.A. Powell and I.J. Bingham. 2003. The interaction between salinity stress and seed vigour during germination of soybean seeds. *Seed Sci. & Technol*., 31: 715-725.

Lecoeur, J. and B. Ney. 2003. Change with time in potential radiation use efficiency in field pea. *Eur. J. Agron*., 19:91-105.

Monteith, J.L. 1965. Evaporation and environment. In: *The state of Water in living organisms. Symp. Soc. Experimental Biol*., 19: 205-234.

Monteith, J.L. and J. Elston. 1983. Performance and productivity of foliage in the field. In: *The growth and functioning of leaves*. (Eds.): J.E. Dale and F.L. Milthorpe. Cambridge University Press, London, pp.499- 518.

Pandey, R.K., J.W. Maranville and M.M. Chetima. 2000. Deficit irrigation and nitrogen effects on maize in a sahelian environment: 1 Grain yield and yield components. Agric. *Water Manage*., 46: 1-13.

Penman, H.L. 1953. The physical basis of irrigation control. *Rep.13th Int. Hort.Cong*., 2: 913-912.

Purcell, L.C., R.A.Ball, J.D. Reaper and E.D. Vories. 2002. Radiation use efficiency and biomass production in soyabean at different plant population densities. *Crop Sci*., 42: 172-177.

Squire, G.R. 1979. The response of stomata of pearl millet to atmospheric humidity. *J. Exp. Bot*., 30(118): 925-933.

Squire, G.R., C.R. Black and P.J. Gregory. 1981. Physical measurements in crop Physiology .II. Water relations. *Exp. Agric*., 17: 225-242.

Squire, G.R. 1990. *The physiology of tropical crop production*. CAB International, 771-102.

Steel, R.G.D. and J.H. Torrie. 1986. *Principles and procedures of statistics*. Mc Graw Hill Book Co; Inc. Singapore; 172-177.

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