

Influence of Water Stress and Micro-Meteorological Changes on Pearl Millet Productivity under Arid Zone Agroforestry Systems

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ABSTRACT

Micro-meteorological investigations (air temperature, relative humidity profiles up to 150 cm height, thermal time, water balance and radiation interception) were carried out in rainfed stands of pearl millet (*Pennisetum glaucum* L.R.Br. cv. HHB-67) sown on 3rd July 1998, as intercrop with *ber* (*Zizyphus mauritiana*), *khejri* (*Prosopis cineraria*) and *babul* (*Acacia nilotica*) in Jodhpur. Micro-climatic modifications by these agroforestry systems during various crop growth stages have been described and compared with open (bare field without trees / crop) field. Influence of microclimate on the crop growth/ productivity and vice versa was also discussed. The study has revealed that the air temperature inside the crop canopy was lower by 0.2 to 1.2 °C and relative humidity was higher by 2 to 7%, respectively, in comparison to uncropped (open) field. Radiation interceptions by pearl millet at peak day hour during vegetative stage varied between 32 and 64% in different treatments. The highest interception was 77% when intercropped with *ber*, followed by *khejri* (74%) and *babul* (67%) during the crop reproductive stage. Average albedo (%) of the crop varied between 20 and 22%. Besides these, saturation vapour pressure deficit (SVPD) was also lower by 2 to 3 mb in the intercrop field in comparison to open field.

Actual evapo-transpiration (AET) of pearl millet during kharif 1998, under moderate agricultural drought conditions, was 195 mm against the mean seasonal AET value of about 300 mm. Ratio of AET to potential evapo-transpiration (PET) varied between 0.19 and 0.59 during different growth stages of the crop. The low AET was mainly due to large crop water stress index, CWSI (0.41 to 0.81), which caused adverse effect on growth and productivity of intercrop in all the treatments. On an average, pearl millet crop height at harvest was 107, 105 and 67 cm when intercropped with *ber*, *khejri* and *babul*, respectively. Grain yield of pearl millet was 190, 370 and 522 kg ha⁻¹ sown with *babul*, *khejri* and *ber*. Pearl millet productivity was more by 41 to 175% intercropped with *ber* in comparison to sown with *khejri* and *babul*. These suggest that despite of drought, improved environmental conditions could be useful for better productivity from agri-horticulture system compared to other conventional agroforestry systems in the region.

Key words : Micro-climatic changes, crop water stress index, arid zone, agricultural drought, pearl millet intercrop with jujube, agro forestry systems.

Introduction

Research works done in the past have attributed to agroforestry system a capacity for the beneficial modification of microclimates (Huxley, 1983; Singh *et al.*, 1998a). Microclimatic studies have recently begun for agrihorticulture and agroforestry systems in Indian arid zone (Singh *et al.*, 2001a&b; Singh *et al.*, 2002). Limitations in the study of microclimate often rest not in the collection of data but in the choice of appropriate forms of analysis (Monteith *et al.*, 1981). Measurement of environmental variables (amount and distribution of rainfall, air temperatures, relative humidity, saturation vapour pressure deficit etc.) in crop

management and an understanding of crop response to these factors is important in assessing a crop's potential productivity for various agroclimatic situations and management practices. Therefore, in this paper we present results from rain-fed stands of pearl millet at CASRI, Jodhpur during 1998 rainy seasons, which allow micro-climatic comparisons to be drawn among agroforestry systems.

Material and Methods

Experiments on pearl millet (*Pennisetum glaucum* L.R.Br. cv. HHB-67) were conducted during kharif (July to September) in 1998 at the

Central Arid Zone Research Institute, Jodhpur (26.3°N, 73.02°E). Three treatments of rainfed pearl millet sown as intercrop with *ber*, (*Zizyphus mauritiana*), *khejri* (*Prosopis cineraria*) and *babul* (*Acacia nilotica*) were maintained to conduct the experiment. Normal annual rainfall at C.R. Farm, Jodhpur is about 389.3 mm, with the major part about 85 to 90 percent received during southwest monsoon (*kharif*) season between end of June and September. The soils in the experimental area have developed from rhyolite and modified by alluvial and aeolian activities and belong to the family of coarse loamy mixed hyperthermic of Camborthids as per soil taxonomy. The surface layer is fine sandy in texture with 6.55 per cent clay and 0.52 per cent silt. the subsoil is non-calcareous loamy sand. the soils are low in organic carbon (0.16 per cent). The moisture contents at field capacity and at -15 bar tension were equivalent to 9.5 and 3.0 per cent water content on weight basis, respectively.

These trees were planted eight years ago with row spacing of 6 x 6m. Inter rows spacing was used to grow short duration pearl millet as intercrop. The inter-and intra-row spacing for pearl millet crop were maintained at 40 cm and 10 cm, respectively. At the beginning of the growing season, 10 representative plants were marked in each treatment (5x2m) to record phenological and growth data. These crop data were collected on every alternate day to work out their relationships with thermal time (Singh *et al.*, 1998b). Micro-meteorological observations were recorded at periodical intervals three times (09:00 A.M., 12:00 Noon and 03:00 P.M.) during the daytime from July to September in all the treatments. Profiles of radiation, humidity and air temperature were measured. Air temperatures and humidity profiles were recorded using an Assman Psychrometer. Saturation vapour pressure deficit (SVPD) is also worked out for different cropping systems. Tube solarimeter was used for measurement of radiation interception by the canopy. Energy balance parameters over the intercrop canopy also measured using Funk type net radiometer and heat flux plate. Latent heat and sensible heat is worked out using energy balance equation as described in Practical Micro-climatology (Slatyer and McIlroy, 1961).

Raman Rao *et al.* (1981) and Sastri *et al.* (1982) classified the agricultural droughts based on moisture adequacy index, which is ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET) i.e. values of AET / PET during different stages of crop growth were used to classify the agricultural drought. Crop water stress index (CWSI) and stress duration was also worked out based on ratio of AET / PET, moisture storage (S_m) value and length of dry spell. The potential evapotranspiration (PET) values were computed using Penman's equation (Rao *et al.*, 1971). the actual evapotranspiration (AET) and the S_m values were arrived at from the water balance computations using the book-keeping procedure of Thornthwaite & Mather (1955) with water holding capacity of root zone.

Results and discussions

Pearl millet (cv. HHB-67) crop were sown on July 3, 1998 as intercrop with *ber* (*Zizyphus mauritiana*), *khejri* (*Prosopis cineraria*) and *babul* (*Acacia nilotica*) at C.R. Farm Jodhpur. The crop emergence took place after 3 to 4 days. First leaf appeared at thermal time of 81 °Cd in all treatments. Generally, 8 to 10 leaves were common on main stem of each plant. Last leaf appeared on the main stem between 842 and 948 °Cd, which was around at 40 DAE. On average, for production of each leaf on the main stem 81 to 101 degree days (°Cd) were needed after the appearance of first leaf. First primary tiller appeared after 3 to 4 leaves on the main stem, which took place at around 257 °Cd. The crop took minimum 864 °Cd thermal time to reach at flowering stage (40 DAE) and 1404 to 1616 °Cd for physiological maturity (65 to 75 DAE).

Micro-climatic investigations and pearl millet

Air temperature profile observed at 5, 50, 100 and 150 cm height inside the pearl millet field sown as different intercrop against bare (open) field is presented in Fig. 1. Micro-meteorological observations revealed that air temperature was dropped by 0.2 to 1.2°C at vegetative and maturity stage of pearl millet grown in different systems in comparison to uncropped (open) field. Air temperature profiles measured inside the crop canopies further indicated that air temperature at 5

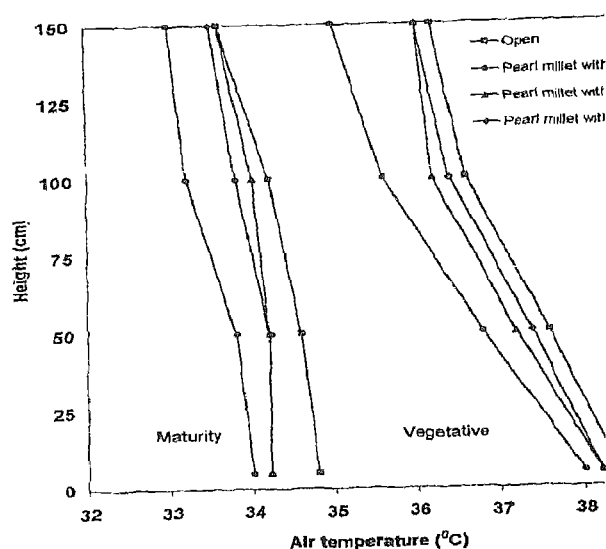


Fig. 1. Air temperature ($^{\circ}\text{C}$) profile inside and outside the pearl millet intercrop canopies at 36 and 79 DAE (August 11 and September 23, 1998) under different cropping systems.

cm height inside the canopies was less by 0.2 to 0.4 $^{\circ}\text{C}$ in comparison to bare field (38.4 $^{\circ}\text{C}$) at the same height during the noon hour. The air temperature above the crop canopy (150 cm height) was less by 1.2 $^{\circ}\text{C}$ in agrihorticulture and 0.2 $^{\circ}\text{C}$ in other systems in comparison to open field (36.2 $^{\circ}\text{C}$). The saturation vapour pressure deficit (SVPD) during peak day hours ranged between 15 and 27 mb in the pearl millet field with *ber* and between 16 and 28 mb in the other intercrops against between 18 and 30 mb outside uncropped field. The extra dropping of air temperature by at least 0.2 to 1.0 $^{\circ}\text{C}$ and lower SVPD by at least 1 mb during the noon period in the agrihorticulture (pearl millet+*ber*) field as compared to the other intercrop field may minimize the adverse effects of temperature stress, forcing to early maturity, to intercrop with *ber* during the drought situation.

Similarly, relative humidity (RH) at 5, 50, 100 and 150 cm heights inside different intercrop fields was recorded more by 2 to 7% in comparison to the atmospheric relative humidity of 50-55% and 57-60% during vegetative and maturity stage, respectively. This increase in RH was mainly contributed by extra-transpired water vapour through leaves of pearl millet and perennial trees, which was perhaps trapped inside the canopy,

depending upon wind velocity and turbulence motion. this increase in RH in agrihorticulture (pearl millet + *ber*) field was supported by lesser SVPD (15 to 27 mb) than other intercrop field (16 to 28 mb) and open (uncropped) field (18 to 30 mb) during the peak day hours.

Energy balance over pearl millet intercrops

Study has revealed that 51% of the net radiation (R_n) energy available over the pearl millet with *ber* is being utilized by the crop in latent heat (evapotranspiration, LE), whereas pearl millet sown with *babul* utilized only 47% of the net radiation energy in the evapotranspiration (LE) processes (Fig. 2a, b). Sensible heat was considerably more than latent heat particularly during the afternoon period over pearl millet sown with *babul*, which indicated the intercrop suffered with acute shortage of soil moisture in the root zone during the *kharif* 1998.

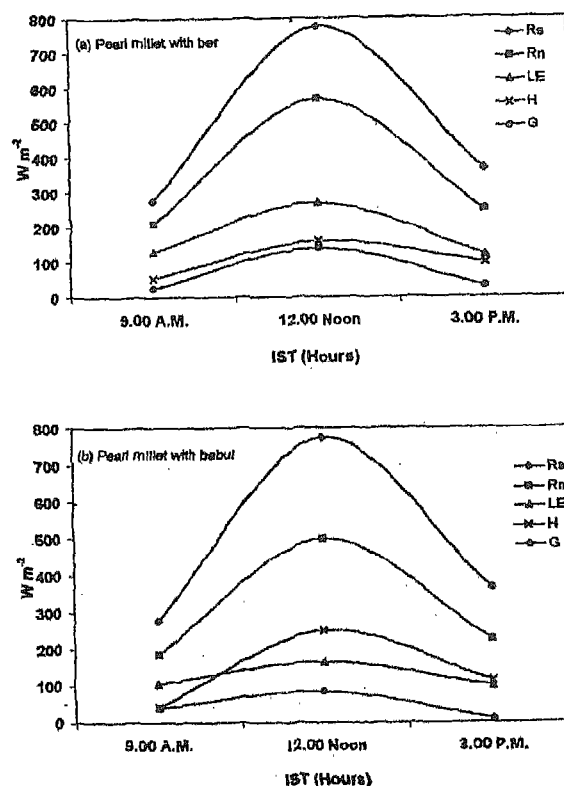


Fig. 2. Energy balance distribution over pearl millet intercrop with (a) *ber* and with (b) *babul* during day timings at 36 DAE on August 11, 1998.

Water balance of pearl millet intercrop field

The climatic water balance study has revealed that pearl millet crop experienced mild to severe water stress, which has adversely affected the crop growth and yield during the *kharif* 1998, with the result poor crop growth and low crop yields (190 to 522 kg ha⁻¹) were recorded with respect to all treatments. The intercrop had experienced severe agricultural drought during seedling and early vegetative stage. Afterwards it suffered with mild and moderate drought with water stress duration of 21 days during vegetative and reproductive stage, which further adversely affected the crop production. As such the moisture storage (S_m) values calculated through water balance were ranged between 21 and 23 mm during different crop growth stage. According to climatic water balance, actual evapotranspiration (AET) of the crop was poor (22 mm) during the three weeks of seedling stage. Afterwards, due to betterment in the rainfall situations, the intercrop could improve its growth and actual evapotranspiration worked out to be 81 and 62 mm during the four weeks of vegetative and reproductive stage each, respectively (Table 1). Further, the AET value was 30 mm

during the two weeks of physiological maturity stage. In this way, the total seasonal actual evapotranspiration (water use) by pearl millet intercrop was only 195 mm during the drought year 1998 against the normal AET value of about 300 mm for optimum crop yield. Also, moisture adequacy index (i.e. ratio of actual evapotranspiration, AET to potential evapotranspiration, PET) was low and varied between 0.19 and 0.59. The crop water stress index (CWSI) was highest (0.81) during seedling stage followed by reproductive stage (0.57) and lowest (0.41) during the crop vegetative stage. This has adversely affected the crop growth and development during seedling and reproductive stages and ultimately productivity was considerably reduced.

Pearl millet productivity in relation to rainfall and radiation distribution

A seasonal (July-Sept) rainfall of 214.4 mm occurred during cropping season of 1998 and it was erratically distributed over 12 rainy days. Poor rainfall of 9 mm during 3 weeks of seedling stage was not adequate to support the crop growth and

Table 1. Actual evapotranspiration (AET), crop water stress index (CWSI) and drought intensity during different growth stages of pearl millet at CR farm, Jodhpur during *kharif* 1998

Parameters	Seedling stage (S) Week No.28-30	Vegetative stage (V) (Week No.31-34)	Reproductive stage (R) (Week No.35-38)	Crop cycle (Week No. 28-38)
Rainfall (mm)	9.0	99.9	55.5	166.7
Rainy days	2	3	4	10
Mean SVPD (mb)	27	17	22	22
AET (mm)	22	81	62	195
AET/PET	0.19	0.59	0.43	0.42
S_m (mm)	21	23	23	22
CWSI	0.81	0.41	0.57	0.58
Stress period (days)	14	14	7	35
No. of days max. temp. exceeded or equaled to 37°C	03	12	08	24
Drought intensity	Severe drought	Mild drought	Moderate drought	Moderate drought

Note: S_m stands for average moisture storage values in the soil profile calculated through water balance.
Week No. 28 starts from July 9 and week No. 38 ends on September 23.

Table 2. Growth and yield of pearl millet in relation to light interception under different cropping systems during *kharif* 1998 at C.R. farm, Jodhpur

Rain (mm) (July- Sept)	Rainy days (July- Sept)	Treatments	Mean plant height (cm) at			Radiation interception (%) at			Al- bedo (%)	Yield (kg ha ⁻¹)
			36 DAE	54 DAE	79 DAE	36 DAE	54 DAE	79 DAE		
214.4	12	Pearl millet + <i>ber</i>	61	87	107	57	77	68	22	522
										(41 to 175)
		Pearl millet + <i>khejri</i>	53	74	105	57	73	68	20	370
		Pearl millet + <i>babul</i>	51	67	67	45	66	56	21	190

Note : Figures in parenthesis indicate per cent increase in yield of intercrop with *ber* over the intercrop with *khejri* and *babul*.

ultimately crop suffered with severe water stress during the seedling and initial vegetative stage. After 13th of July, there was a break in monsoon rain for 19 days. Due to this gap in rainfall, crop experienced severe agricultural drought during the last two weeks of seedling stage. Moreover, the temperature during the rainless period had also touched 40°C, which has also aggravated the drought and ultimately the initial crop growth was adversely affected. Second spell of monsoon became active on August 2 and precipitated 42.6 mm on the same day. Afterwards, monsoon became feeble. Two weeks of dry spell was observed from August 12, 1998, which has caused mild drought during vegetative stage of the crop in the region. In third spell of monsoon, a low-pressure system arrived and showered 52.6 mm rain on August 26, 1998. It remained active up to August 29, 1998. Again after a rainless period of 10 days, it started raining on September 9 and more or less continued up to September 24, 1998. During this phase, Jodhpur region received 52.4 mm of rain. But, before receiving this rain, crop suffered a lot due to water stress at seedling and vegetative stages and ultimately pearl millet crop yield was poor particularly from the two conventional agroforestry systems. Rainfall during middle of September (late reproductive and maturity stage) could not be useful to recover the crop growth and productivity.

The average height of the crop was recorded maximum up to 107.0 cm intercrop with *ber* (jube) and minimum up to 67.0 cm sown as

intercrop with *babul* during the drought year 1998. Light interceptions by intercrops were between 32 and 64% during vegetative stage (Table 2). The highest interception was 77% when intercropped with *ber*, followed by *khejri* (74%) and *babul* (67%) during the crop reproductive stage. Average albedo (%) of the crop varied between 20 and 22%. The pearl millet crop growth remained higher in the intercrop with *ber* compared with other treatments. The highest crop yield was obtained 522 kg ha⁻¹ from intercrop with *ber* followed by intercrop with *khejri* (370 kg ha⁻¹) and lowest (190 kg ha⁻¹) by intercrop with *babul*. Hence, crop yields were recorded higher by 41 to 175 per cent from intercrop with *ber* over the other two cropping systems. Further, the study has also supported our earlier observation that crop growth and yield is more in agrihorticulture field (Singh *et al.*, 2002) than sole crop and other system due to favourable micro-climatic conditions inside the agrihorticulture system.

Despite of moderate agricultural drought during *kharif* 1998, the microclimatic modification and improvement created inside agrihorticulture field had favoured the pearl millet growth and development over the other conventional systems. This modification could ultimately result into enhancement of grain yield of pearl millet intercrop with *ber* (jube) by about 41 to 175 per cent in comparison to other systems. This reaffirmed the earlier observations that crop growth and yield are more in agri-horticulture field than other conventional system of farming in the arid zone.

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