551.5 : 63

Contribution of water and radiation to growth and yield of pearl millet in Deccan plateau - A case study

A.S. BALLAL and H.P. DAS

Meteorological Office, Pune – 411 005, India

सार - इस शोध-पत्र में सोलापुर में बाजरा के लिए वाष्पन-वाष्पोत्सर्जन की आवश्यकता तथा फसल के लक्षणों का अध्ययन करने के लिए 1991से 1999 की अवधि के कृषि मौसम विज्ञान के ऑकड़ों का उपयोग किया गया है। फसल से संबंधित स्थितियों, जल उपयोग की क्षमता तथा विकिरण उपयोग की क्षमता का पता लगाया गया और इन पर विचार किया गया है। यह प्रयोग फसल की आई.सी.टी.पी.- 8203 और श्रद्धा नामक दो किस्मों पर किया गया है।

इस अध्ययन से यह पता चला है कि बाजरा की फसल में बालें आने तथा बाली में फूल आने की अवस्था में जल की अधिकतम मात्रा में खपत हुई है। फसल में बाली आने के साथ-साथ उसमें फूल आने के दौरान, आई.सी.टी.पी.- 8203 की किस्म के लिए लगने वाले कुल जल में से लगभग 50 प्रतिशत जल की खपत हुई है जबकि श्रद्धा किस्म में इन अवस्थाओं में लगभग 60 प्रतिशत जल की खपत हुई है। फसल की दोनों किस्मों में बालें आने के दौरान फसल की अन्य संबंधित स्थितियों की अधिकतम सीमा देखी गई है। फसल की बढ़वार के दौरान प्रकाश संश्लेषित विकिरण की क्रियाशीलता अधिकतम पाई गई है। श्रद्धा की किस्म की अपेक्षा आई.सी.टी.पी.- 8203 की किस्म में विकिरण के उपयोग की क्षमता अधिक पाई गई है।

ABSTRACT. In this study the agrometeorological data for the period from 1991 to 1997 have been used to study evapotranspiration demand and crop characteristics of pearl millet at Solapur. Crop coefficients, water use efficiency and radiation use efficiency have been worked out and discussed. This has been done for two varieties of the crop *viz.*, ICTP-8203 and Shraddha.

The study revealed that pearl millet crop consumed maximum amount of water during earhead emergence phase, followed by flowering phase. During earhead emergence and flowering phase together, ICTP-8203 variety used nearly 50% of total water used while shraddha consumed about 60%. The highest values of crop coefficient are seen during earhead emergence phase for both the varieties. Maximum photosynthetically active radiation is availed by the crop during its vegetative phase. Radiation use efficiency is more for ICTP-8203 variety than Shraddha variety.

Key words – Crop coefficient, Water use efficiency, Photosynthetically active radiation, Radiation use efficiency.

1. Introduction

Among the coarse grains, Pearl millet [*Pennisetum glaucum* (L.)] or Bajra is a major cereal grown by farmers, after sorghum, in the dry tracts of India. Pearl millet production in India is mostly contributed by Rajasthan, Maharashtra, Uttar Pradesh, Gujarat and Haryana accounting for 87.7% of area and 77.5% of the production (Ghonsikar and Shinde, 1997). It is mostly grown as a rainfed crop in sandy and often shallow soils having depleted fertility. Such areas are characterised by short and highly variable rainy season (2-4 months) with 20 to 80 cm of rainfall, high temperature and high potential evapotranspiration rates and are thus, agroclimatically unsuitable for other crops.

Pearl millet efficiently uses soil moisture and nutrients. It is preferred by farmers as a low cost, low risk option, not by choice, but by necessity (Harinarayana, 1986). Due to its extensive and deep root system extending up to 120 cm (Michael, 1990), Pearl millet is more drought resistance and has higher plasticity than many other cereals.

In view of its importance to farmers in low rainfall zones in India, a study of pearl millet has attracted attention of many research scientists, (Reddy *et al.* 1978; Gupta, 1980; Venkataraman, 1988; Joshi, 1989; Jadhav *et al.* 1991; Shaikh 1991, *etc.*). Solapur is located in the drought prone area of Maharashtra in the Deccan plateau in which pearl millet is grown predominantly. Jadhav *et al.* (1994) studied pearl millet at Solapur in relation to Growing Degree Days (GDD) and found that this crop should be grown after the start of rainy season so that more GDD gets accumulated. Evapotranspiration requirements to aid irrigation scheduling, water consumption of the crop, water use efficiency, crop

TABLE 1

Crop Information

Year	Vareity	Date of sowing	Date of harvesting	Crop duration (days)	Maximum plant height (cm)
1991	ICTP - 8203	21 June 1991	18 September1991	90	147
1992	ICTP - 8203	21 June 1992	18 September 1992	90	118.7
1993	ICTP - 8203	07 July 1993	06 October 1993	92	143.8
1994	ICTP - 8203	11 July 1994	26 September 1994	78	103.3
1995	Shraddha	02 July 1995	14 September 1995	75	160
1997	Shraddha	08 July 1997	28 September 1997	83	57

TABLE 2

Rainfall, total water used, evaporation, potential evapotranspiration, grain yield, WUE, dry matter production short wave radiation and PARUE

Year	Rain (mm)	Total water used (ET) (mm)	Evaporation (EP) (mm)	Potential evapotranspiration (PET) (mm)	Grain yield (q/ha)	WUE (kg/ha/mm)	Dry matter production (q/ha)	Short wave radiation (PAR) (MJ/m^2)	PARUE (g/MJ)
1991	285.4 (19)	247.1	475.7	455.5	23.55	9.53	80.00	719.6	1.44
1992	329.7 (20)	290.5	524.6	398.2	23.11	7.96	76.00	750.3	1.32
1993	397.5 (27)	321.1	578.9	449.8	28.99	9.03	73.96	749.1	0.987
1994	108.1 (12)	145.1	451.2	382.6	5.56	3.83	13.20	596.5	0.22
1995	283.6 (18)	276.3	443.7	429.1	24.94	9.03	52.96	678.2	0.77
1997	116.9 (8)	180.0	719.3	495.9	8.13	4.52	14.77	685.9	0.22

Note: Figures in parenthesis represent number of rainy days.

coefficients, radiation use efficiency *etc.* are some of the fields for which basic information at Solapur is unfortunately lacking.

In the present study an attempt has been made to examine the above aspects and determine how best the results could be interpreted to enhance yield of pearl millet at this location.

2. Material and method

The study pertains to experimental observatory at Solapur (17° 41′ N, 75° 44′ E and 479 m.a.s.l.). Data for the year 1991 to 1997 for kharif season were used. The soil around Solapur is mainly medium black, with field capacity 18 cm, wilting point 9 cm and bulk density 1.26 gm/cm^3.

At this location crops are grown purely on rainfed conditions. Two hybrid varieties of pearl millet *viz.*, ICTP-8203 for the years 1991 to 1994 and Shraddha variety during 1995 to 1997 were grown in the field. During 1996, after sowng, there was no adequate rainfall to allow the crop to complete its growth cycle. As a result, the crop was harvested only as fodder. This study as such, utilizes only two years data *i.e.*, 1995 and 1997 for Shraddha variety. Details on dates of sowing, crop duration, maximum height of plants *etc.* are presented in Table 1 for both the varieties.

The evapotranspiration (ET) was measured through gravimetric lysimeters located in the crop field. The evaporation (EP) values have been taken from U.S. open pan evaporimeter. Meteorological data were collected from the Observatory located close to the field. The total solar

radiation (Rs) used was computed indirectly from Angstrom standard formula.

$$Rs = RA\ (a + b\ n/N)$$

where RA is the theoretical amount of radiation that would reach the earth surface in the absence of the atmosphere, n is the actual duration of sunshine hours, N is the maximum possible duration of sunshine and a and b are constant, Rs was then used to find Radiation Use Efficiency (RUE) as below :

$$RUE = \frac{\text{Cereal yield } (g/m^2)}{\text{Amount of cumulative radiation absorbed } (MJ/m^2)}$$

As is well known it is not the incoming radiation but a component of it known as Photosynthetically Active Radiation (PAR) which directly help plant photosynthesis and convert it into biomass. PAR in the present work was calculated by multiplying the total radiation by 0.45 as was proposed by Howell et al. (1983) and adopted by Rosenthal and Gerik (1991) for cotton and was used to calculate RUE i.e., photosynthetically Active Radiatioin use efficiency as was done by Jadhav et al. (1993). Potential Evapotranspiration (PET) was computed using Penman and Monteith's modified equation.

3. Results and discussions

3.1. Crop characteristics

In the first two years, ICTP-8203 was sown in third week of June while other two years the sowing was delayed and completed only in first week of July. The Shraddha variety was sown during first decade of July. The crop duration during first three years of the first variety was about 90 days while in 1994 it was about 80 days. In contrast for Shraddha the duration was 75 days in the year 1995 and 84 days in the year 1997.

The maximum height of the plant appears to be related not only to the total rainfall during the growth phase i.e., sowing to harvest (Fig.1), but also on the distribution of rainfall (Table 2). As reflected in number of rainy days, high and well distributed rainfall allowed and helped the ICTP-8203 strain to attain its maximum height (147 cm in 1991). Although comparatively, the crop duration for Shraddha variety was less, it seems to use water rather more judiciously. Because of this, the crop attained nearly 160 cm height in the year 1995 but low and unevenly distributed rainfall during 1997, resulted in poor growth and the variety could attain hardly 57cm in height. A comparison of plant height of MH-179 variety of pearl millet at Pune by Shaikh
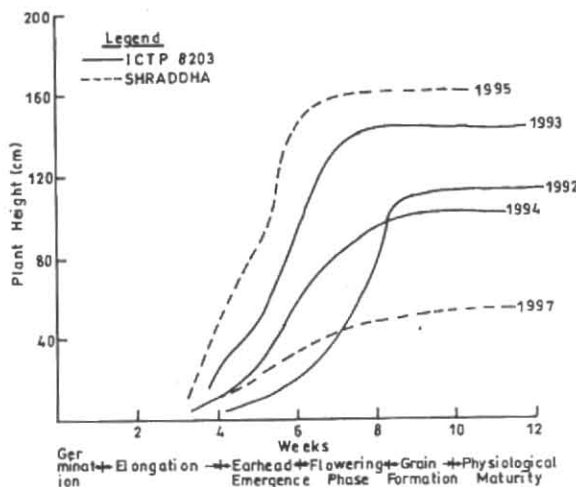

Fig. 1. Progress of plant height (cm)

(1991) revealed that in general, the variety used in the present study attained somewhat higher height upto 43 DAS (days after sowing). The maximum height attained (during flowering phase) in this study was much less than that of MH-179.

3.2. Water requirement

Information on the crop season rainfall and the water used i.e., ET is given in Table 2 for both the varieties. The total water use irrespective of variety appears to be a direct function of rainfall. The higher the rainfall, the higher is the ET loss. For the ICTP-8203 variety, when the rainfall was nearly 400 mm, the ET loss was nearly 320 mm in the year 1993 while in 1994 when the rainfall was just 108 mm, the ET loss came drastically down to nearly 145 mm. More or less the same results hold good for Shraddha variety. On an average, first variety utilises almost 250 mm of water while the second variety uses comparatively about 20 mm or 10 % less moisture.

The maximum cumulative water use was on an average about 250 mm varying from 290 mm in 1992 to lowest 145 mm in the year 1994 for ICTP - 8203 variety. For the two years considered for Shraddha, it was 276.3 mm and 180 mm with an average of 228 mm. Rai et al. (1989) found water use as high as 410 mm which seems nearly 80% higher than the varieties used in the study. In other words both varieties used in the study, consumed less water than the varieties used by Rai et al. (1989). Gupta (1980) obtained water used by pearl millet as 290 mm under control conditions which generally compares with the values found in the study.

TABLE 3

Mean weekly water use (mm) pattern in different growth phases and water use (%) as function of total ET

Phenological phases	ICTP - 8203		Shraddha	
	Mean weekly water use (mm)	Mean weekly PAR (MJ/m^2)	Mean weekly water use (mm)	Mean weekly PAR (MJ/m^2)
Germination	11.2 (4.4)	8.41	10.3 (4.7)	8.55
Vegetative	46.9 (18.5)	23.00	47.7 (21.7)	22.34
Earhead emergence	69.7 (27.3)	15.50	71.3 (32.3)	18.78
Flowering	58.7 (23.0)	15.51	57.5 (26.1)	17.78
Grain formation	39.3 (15.4)	14.42	25.7 (11.7)	18.11
Physiological maturity	29.5 (11.5)	18.07	7.9 (3.6)	8.00

Note : Figures in parenthesis represent % of total water use

The mean weekly total water used in the different growth phases for the two varieties is given in Table 3 alongwith its contribution to the total water use. It is seen that during germination phase *i.e.*, first week after sowing (WAS), vegetative phase (2 - 4 WAS) and after grain formation phase, pearl millet required less amount of water. Maximum water is used during earhead emergence phase (5 - 6 WAS) followed by flowering phase (7 - 8 WAS). This is true for both varieties. Up to end of vegetative phase ICTP - 8203 used nearly 23% water and shraddha 26%. During earhead emergence and flowering phase together the water used exceed 50% of the total water used in their entire growth cycle prominently so for the second variety, except grain formation and physiological maturity phase when ICTP - 8203 variety used more water than the shraddha. In the rest of the growth phases, shraddha used more water than ICTP - 8203. Phasewise the average daily water used (mm) for ICTP - 8203 variety in germination, vegetative, earhead emergence, flowering, grain formation and physiological maturity phases were 1.6, 2.2, 5.0, 4.2, 2.8 & 2.1 respectively and for shraddha variety it is 1.5, 2.3, 5.1, 4.1, 1.8 & 1.1 respectively. Average water used per day for ICTP - 8203 was 3.0 mm and for shraddha variety it was slightly less *i.e.*, 2.7 mm.

The water used per day was 3.0 mm in the year 1991, 1992 & 1993 for ICTP - 8203 but was quite low *i.e.*, 1.9 mm/day in 1994, the year of lowest rainfall. In sharp contrast, the shraddha variety used more water, which was 3.7 mm in the year 1995. Even when the rainfall was lowest among the years considered in the study, water used / day was 2.0 mm compared to low rainfall year of 1994 for ICTP - 8203 when it was 1.9 mm. Rai *et al.* (1989) observed that

the daily average water used for Bajra to be lowest *i.e.*, 2.5 mm/day in the initial emergence and maximum of 7.4 mm/day in the vegetative phase.

3.3. *Water use efficiency*

Water use efficiency (WUE) can be defined as the ratio of yield to total ET and is expressed in the units of kg/ha/mm. Recently Payne (1997) found a strong linear correlation between yield and WUE for pearl millet in the Sahel. A high seasonal rainfall (exceeding 440 mm) need not give higher WUE as can be seen in Table 2. It is seen that the WUE for ICTP - 8203 was highest *i.e.*, 9.5 kg/ha/mm in 1991 and lowest of 3.8 in the year 1994, the corresponding figures for shraddha were 9.0 and 4.5 kg/ha/mm. On an average these values appear lower than those found by Gupta (1980) but more than by Shaikh (1991) who found it 6.25 kg/ha/mm in Pune conditions.

3.4. *Crop coefficient (Kc)*

The ratio of ET to potential evapotranspiration (PET) furnishes values for crop coefficient (Kc). A knowledge of Kc seems necessary to determine water requirement of the crop. For each year for both the varieties Kc was computed and the mean depicted in Fig. 2. The highest value of Kc for the ICTP - 8203 variety was observed in the 6 WAS in all the years except 1993 when it was a week earlier, though in same phase. Interestingly for the shraddha variety the highest value of Kc was found to occur one week earlier in 5 WAS. Another noteworthy feature observed was that the highest Kc was 1.07 for the ICTP - 8203 variety where as for the shraddha variety it was less than 1.0 *i.e.*, 0.9. In this
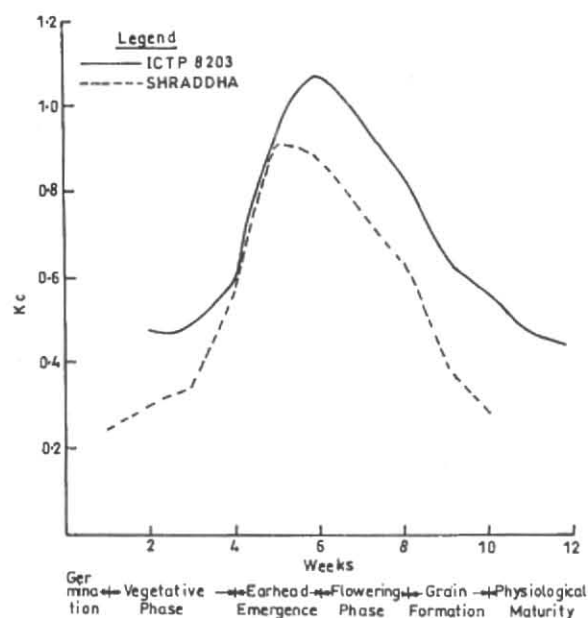
Fig. 2. Weekly pattern of crop coefficient (Kc)

Fig. 3. March of weekly evapotranspiration/evaporation ratio

connection it is important to note that Das *et al.* (1996) found the highest value of Kc *i.e.*, 1.10 for pearl millet at Hissar but occured at 9 WAS in the flowering phase.

3.5. *Evapotranspiration / Evaporation (ET/EP) ratio*

Under given atmospheric conditions, ET/EP ratio gives to what extent the water requirement of growing crops are met. Venkataraman (1988) worked out these ratio for pearl millet at Jodhpur and found moisture extraction of HB - 3 variety of 13 cm was better than the 10 cm used by BJ - 104 variety. In the present study the ratio worked out for each week for both the varieties (Fig. 3) revealed that maximum ET equalled EP after a month of sowing and remained so till about grain formation phase. For ICTP - 8203 the moisture requirement was found nearly half of pan evaporation and for shraddha variety for the year 1995, it was 0.62. In the year 1994 and 1997, when the rainfall was less in amount for the ICTP - 8203 variety, only 1/3 of its water requires could be met, whereas for the shraddha variety it was hardly 1/4. From the above, it seems shraddha extracts water rather sluggishly than ICTP-8203. The highest value of 1.26 of ET/EP ratio for ICTP-8203 was seen in the year 1993 during earhead emergence phase (5 WAS). For shraddha variety, the highest value of 1.29 of ET/EP ratio was also seen in the earhead emergence phase (5 WAS) in the year 1995.

3.6. *Radiation use efficiency*

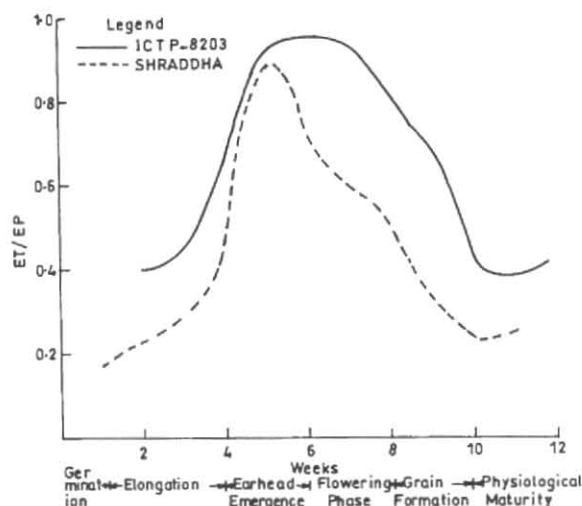Solar radiation is the primary source of energy for biological activities of plants. Whereas incident solar radiation is related to crop production, absorbed photosynthetically active radiation (PAR) is related to crop growth and development rates. One of the important aspects of crop growth influencing dry matter productioin and yield is the development of leaf canopy and its effect on efficiency of PAR. Gallaher and Biscoe (1978) observed that PAR bears close relationship to dry matter production and yield of cereal crops. Though there is some variation of PAR rates between C_3 and C_4 crops, it is seen that the same is slightly more in C_4 crops like pearl millet.

Total solar radiation is measured at a few locations in India. However, it is not the total radiation but PAR which is important in crop growth. But unfortunately photosynthetically active radiation (PAR) is not measured as routine observation. In view of its importance, Nathan (1982) found high correlation between PAR with total radiation for New Delhi.

Total PAR consumed by pearl millet at Solapur and its percentage to the total during different phytophases are given in Table 3. It is seen that maximum PAR is used during vegetative phase when the crop is actively growing for both varieties followed by earhead emergence and flowering. Jadhav *et al.* (1993) observed similar results for sorghum at Solapur. Photosynthetically active radiatioin use efficiency (PARUE) is found maximum in 1991 and 1992 *viz.*, 1.44 and 1.32 g/MJ respectively. In 1993 PARUE for ICTP-8203 is nearly 1.0. For the shraddha variety for 1995, it is less than 0.8. In strikingly low rainfall year of 1994 and 1997 the PARUE is 0.22 for both strains and indicates that PARUE gives better results only in interaction with sufficient rainfall. Ram Niwas *et al.* (1997) in their study of effect of row

direction on RUE of pearl millet in New Delhi, observed rather high values exceeding 3.00 for 3 varieties of Bajra. The values obtained in the present study, as such does not seen to be significantly low, keeping in view that the crop at Solapur was raised purely on natural rainfall. It is also possible that besides water, chilling effect of night temperature could have decreased PARUE in our study as was observed for sorghum at Solapur by Jadhav *et al.* (1993).

4. Conclusions

The following conclusions could be drawn from the study :

(*i*)　Weekly water used by pearl millet crop is found to be maximum (*i.e.* about 70 mm) during earhead emergence phase (5-6 WAS), followed by flowering phase (7-8 WAS)

(*ii*)　During earhead emergence and flowering phase together, ICTP-8203 variety consumed 50.3% of total water used while shraddha consumed 58.4% of total water used.

(*iii*)　ICTP-8203 variety utilized about 250 mm of water while shraddha used 230 mm of water.

(*iv*)　Well distributed rainfall of about 400 mm could give about 28 q/ha pearl millet yield.

(*v*)　Highest value of crop coefficient is found during earhead emergence phase for both the varieties.

(*vi*)　Maximum PAR is used during vegetative phase when the crop is actively growing.

(*vii*)　On an average PARUE for ICTP-8203 variety is found to be slightly more than 1.0 while for the shraddha it is nearly 0.80.

Acknowledgement

References

Das, H.P., Kashyapi, A. and Apte, S.G., 1996, " Evapotranspiration and soil moisture balance in relation to yield of pearl millet (*Pennisetum glaucum*)", *Mausam*, **47**, 73-80.

Gallaher, J.N. and Biscoe, P.V., 1978, "Radiation absorption, growth and yield of cereals", *J. Agric. Sci.*, (Cambridge), **91**, 47-60.

Ghonsikar, G.P. and Shinde, V., 1997, "Nutrient management practices in crops and cropping systems", Scientific publishers., P.B.No.91, Jodhpur, India 78.

Gupta, J.P., 1980, "Effect of mulches on moisture and thermal regimes of soil and yield of pearl millet", Annals of Arid Zone, **19**,132-138.

Harinarayana, G., 1986, "Pearl millet in Indian Agriculture, Proceedings of the International Pearl Millet Workshop", 7-11 April 1986, ICRISAT Centre, India.

Howell, T.A., Meek, D.W. and Hatfield, J.L., 1983, "Relationship of photosynthetically active radiation to short wave radiation in the San Joaquin Valley", *Agric. Meteorol.*, **28**, 157-175.

Jadhav, A.S., Shaikh, A.A. and Harinarayana, G., 1991, "Response of rainfed pearl millet (Pennisetum glaucum) to inoculation with nitrogen fixing bacteria", *Ind. J. Agril. Sci.*, (61C4), 268-271.

Jadhav, J.D., Mokashi, D.D., Shewale, M.R., Gaikwad, C.B. and Patil, J.D., 1994, "Thermal requirement for pearl millet crop", Annals of Arid Zone, **33**, 299-302.

Jadhav, J.D., Patil, C.B., Gaikwad, C.B., Mokashi, D.D. and Patil, J.D., 1993, "Radiation use efficiency in dry land winter sorghum (Sorghum bicolor) at different sowing periods", *Indian J. Agril. Sci.*, **63**,12, 842-843.

Joshi, N.L., 1989, "Efficient use of energy inputs in rainfed pearl millet", *Agril. Ecosystem and Environ.*, **25**, 91-102.

Michael, A.M., 1990, "Irrigation, Theory and Practice", Vikas Publishing House Pvt. Ltd., 579, Massid Road, Jangpura, New Delhi , 511p.

Nathan. K.K., 1982, "Note on relationship between photosynthetically active radiation and total radiation", Annals of Arid Zone, **21**, 259-261.

Payne, W.A., 1997, "Managing yield and water use of pearl millet in the Sahel", *Agron. Jour.*, **89**, 481-490.

Rai, V.V. Bishnoi, O.P., Singh, D. and Sharma, R.C., 1989, "Actual evapotranspiration in pearl millet (*Pennisetum glaucum*) and wheat (*Triticu aestivum*)", *Ind. J. Agri. Sci.*, **59**,179-180.

Ram, Niwas, Sastri, C.V.S. and Attri, S.D., 1997, "Influence of direction of sowing on radiation use efficiency of pearl millet", *Annals of Arid Zone*, **36**, 4, 345-348.

Reddy, K.A., Reddy, B.B., Balaswamy, K. and Venkatachari, A., 1978, "Effect of soil moisture and organic mulches on corn planted indifferent pattern", *Expl. Agric.*, **14**, 389-394.

Rosenthal, W.D. and Gerik, T.J., 1991, "Radiation use efficiency among cotton cultivars", *Agron. Jour.*, **83**, 655-658.

Shaikh, A.A.R., 1991, "Response of pearl millet to moisture conservation techniques", Nitrogen and phosphate fertilisation", M.Sc. Thesis, Mahatma Phule Agric. Univ., Rahuri (India).

Venkataraman, S., 1988, "Some lysimetric observations on the water requirements and water use of pearl millet hybrids at Jodhpur", *Annals Arid Zone*, **27**,157-159.