

Water requirement and water use efficiency of Sorghum and its irrigation planning under limited water resources in arid and semi arid regions of India

R. P. SAMUI, GRACY JOHN, M. P. S.PILLAI and S. P. RANSURE

Meteorological Office, Pune - 411 005, India

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e mail : rsamui @ yahoo.com

सार – इस शोध पत्र में अकोला, परभनी, राहुड़ी और कोयम्बतूर में सोरघम के लिए जल की आवश्यकता और जल उपयोग क्षमता का अध्ययन किया गया है। इस अध्ययन से सोरघम के लिए खपत की जाने वाली जल की मांग और उपज के लिए जल उपयोग क्षमता को समझा जा सका है। इनसे प्राप्त हुए परिणामों का उपयोग सोरघम के उत्पादन के लिए उपलब्ध वर्षा और सीमित जल स्रोतों दोनों के कुशल प्रबंधन के लिए किया जा सकता है।

अकोला और परभनी में गैर सिंचित खरीफ सोरघम के लिए मौसमी वाष्पन-वाष्पोत्सर्जन (ई. टी.) की कमियों और सुवितरित सामान्य और कम वर्षा वाले वर्षों के लिए राहुड़ी और कोयम्बतूर में रबी सोरघम हेतु मौसमी ई. टी. की कमियों का अध्ययन किया गया। सामान्य वर्षा वाले वर्षों में ई. टी. की कमियाँ कम वर्षा वाले वर्षों की तुलना में अधिक थी। तथापि, सामान्य वर्षा वाले वर्षों की अपेक्षा कम वर्षा वाले वर्षों के दौरान जल उपयोग की क्षमता अधिक पाई गई है। मौसमी ई. टी. उपज आपस में सकारात्मक रूप से सहसंबंधित पाए गए हैं किंतु अकोला, परभनी, राहुड़ी के लिए नगण्य तथा कोयम्बतूर (5% स्तर) के लिए महत्वपूर्ण था। अकोला और परभनी में क्रमशः लगभग 486 मि. मी. और 470 मि. मी. के मौसमी ई. टी. हेतु अनुकूलतम उपज देखी गई है। कोयम्बतूर में 416 मि. मी. के मौसमी ई. टी. के लिए अधिकतम उपज देखी गई जबकि राहुड़ी में ई. टी. की कमी लगभग 475 मि. मी. होने पर पैदावार अधिकतम थी। खरीफ मौसम के लिए जल उपयोग क्षमता (डब्ल्यू यू ई.) 6.3 से 12.2 मि. मी. के मध्य और रबी सोरघम के लिए 5.5 से 10.1 मि. मी. पाई गई है। फसल के प्रारम्भिक बढ़वार की अवस्थाओं के दौरान उपज सहसंबंध नगण्य पाई गई है और बाली में फूल आने की अवस्था के दौरान यह चरम पर पहुँच गया। तदनन्तर फसल पकने से लेकर फसल काटने की अवस्था के दौरान यह क्षीण हो गया।

इस अध्ययन से यह पता चला है कि कम वर्षा वाले वर्षों के दौरान सभी केंद्रों के लिए जीवन रक्षक सिंचाई का उपयोग करने की आवश्यकता विचाराधीन है। यदि सीमित सिंचाई उपलब्ध हो तो फसल की बढ़ोतरी की अवस्था (बीज बोने के पश्चात् 25–35 दिन) और फूल के परिपक्व होने की अंतिम अवस्था – बाली में फूल आने की अवस्था (बीज बोने के पश्चात् 55–65 दिन) में सिंचाई की जाए। फूल के परिपक्व होने की अंतिम अवस्था सबसे अधिक नाजुक अवस्था देखी गई है और यदि केवल एक सिंचाई उपलब्ध हो तो, वह इस अवस्था के दौरान की जाए। इस अवस्था में जल प्रतिबल के कारण पैदावार में 35 से 40% तक की कमी पाई गई है।

ABSTRACT. Water requirement and water use efficiency of sorghum was studied at Akola, Parbhani, Rahuri and Coimbatore. The study enables to understand the consumptive water demand of sorghum and water use efficiency in relation to yield. The results can be used for efficient management of both rainfall and limited water resources available for sorghum production.

Seasonal Evapotranspiration (ET) losses were studied for non- irrigated kharif sorghum at Akola and Parbhani and for Rahuri and Coimbatore seasonal ET losses were studied for rabi sorghum for well distributed normal and deficit rainfall years. In the normal rainfall years ET losses were more compared to deficit rainfall years. However, water use efficiency was found higher during deficit rainfall years than normal rainfall years. The seasonal ET- yield relationship was found positively correlated but insignificant for Akola, Parbhani, Rahuri and significant for Coimbatore (5% level). At Akola and Parbhani optimum yields were observed for seasonal ET of around 486 mm and 470 mm respectively. At Coimbatore maximum yield was observed for seasonal ET of 416 mm whereas at Rahuri yield was maximum when ET loss was about 475 mm. Water Use Efficiency (WUE) ranged from 6.3 to 12.2 mm for kharif season and 5.5 to 10.1 mm

for rabi sorghum. Crop coefficient Kc was found negligible during early growth stages and reached peak during flowering stage and declined subsequently during maturity to harvesting stage.

The study revealed that during deficit rainfall years life saving irrigation need to be applied for all stations under consideration. If limited irrigation is available irrigations at vegetative stage (25-35 days after sowing) and at boot-flowering stage (55-65 days after sowing) be given. The boot stage is found to be the most critical stage and if only one irrigation is available, it may be given at this stage. Water stress at this stage is found to cause reduction in yield by 35 to 40%.

Key words – Crop coefficient, Evapotranspiration, Sorghum, Water use efficiency.

1. Introduction

Water requirement of a crop may be defined as the quantity of water required by a crop in a given period of time for its normal growth under field conditions at a place. Dry land rain-fed agriculture with life saving irrigation accounts for most of the food and fibre production in the semi- arid regions of India. Mean annual rainfall in this region ranges from 40 to 100 cm which meets water requirement of crops such as sorghum, pulses, millet, cotton etc. Sorghum is one of the major dry land staple crops in semi - arid tropics of India. The area of sorghum cultivation is about 14 to 15 million ha and annual production is 8.5 to 9.5 million tons with a mean yield of 7 to 8 q/ha, where as the hybrid variety has a grain yield of around 40 to 50 q/ha.

Being a deep rooted crop sorghum has excellent drought tolerance and is grown under stored soil water in deep soil applying one or two life saving irrigations at critical growth stages. Occasional droughts and dry spells over the regions point to the need for improved farm water management to sustain better crop yield. This involves life saving irrigation at some of the critical growth stages of the crop. For this purpose the water requirements of major crop varieties at their critical growth stages need to be known for optimum utilization of available water resources. The use of irrigation to overcome water stress conditions normally lead to significant increase in grain production. Several studies have reported Water Use Efficiency (WUE) to be higher during water stressed condition when irrigation applied at critical stage of crop development. Deficiencies in management and input supply appear to be the main constraints for not being able to achieve required growth rate in sorghum production.

Thus an attempt has been made in this study to understand the consumptive water demand of sorghum during different phenological stages and water use efficiency in relation to final yield and also ET-yield relationship at different locations in semi-arid regions of India.

2. Materials and method

In deciding water used by sorghum, evapotranspiration (ET) was considered as the consumptive use (CU). Lysimetric evapotranspiration data of kharif sorghum for Akola (20° 42' N, 77° 02' E), Parbhani (19° 16' N, 76° 47' E), and rabi sorghum for Coimbatore (11° 00' N, 71° 00' E) and Rahuri (19° 24' N,

74 39' E) were used. Weekly Potential Evapotranspiration (PET) and ET/PET (crop coefficient Kc) values were computed using methodology given by Doorenbos and Pruitt (1975). Weekly rainfall of good (normal) and deficit rainfall years, cumulative ET and rainfall probability at 50 % and 70% levels at the four stations have been presented in Figs. 1(a-d). Tables 1 to 4 depict year wise evapotranspiration, potential evapotranspiration, rainfall, yield and water use efficiency of sorghum at different stations. The evapotranspiration-yield relationship and Kc values are computed and presented in Figs. 2(a-d) and Figs. 3(a-d).

3. Results and discussion

3.1. Seasonal ET losses

For some selected years comprising good and deficit rainfall of each of the four stations, water use efficiency of sorghum showed that good rainfall and water use pattern during the crop growing season were comparable to that of potential evapotranspiration. Akola received good rainfall (741 mm) during the year 1981. The seasonal ET was 451 mm in 1981. The Evapotranspiration increased gradually with the advancement of the growth stage of the crop and reached maximum at about 13th week after sowing at flowering stage [Fig. 1(a)]. Evapotranspiration showed steady increase from 4th week after sowing till 13th week and remained steady thereafter. The PET during the crop growing season varied in a narrow range between 4.8 mm to 6.5 mm and was higher than the ET loss of the crop. In 1981, the rainfall was evenly distributed throughout the growing period which resulted in optimum

TABLE 1

Seasonal evapotranspiration, potential evapotranspiration, rainfall, yield (observed & predicted) and water use efficiency of Sorghum at Akola (kharif)

Year	Variety	Total			Yield - (Q/ha)		WUE (kg/ha/mm)
		ET (mm)	PET (mm)	R/F (mm)	Observed	Predicted	
1981	CSH-5	451	672	741	46.6	46.9	9.56
1982	CSH-5	554	710	392	40.3	48.7	7.27
1983	CSH-5	639	722	680	40.4	44.0	6.32
1987	CSH-9	486	735	426	57.9	50.9	11.91
1988	CSH-9	522	666	452	57.9	51.3	11.09

TABLE 2

Seasonal evapotranspiration, potential evapotranspiration, rainfall, yield (observed & predicted) and water use efficiency of Sorghum at Parbhani (Kharif)

Year	Variety	Total			Yield - (q/ha)		WUE (kg/ha/mm)
		ET (mm)	PET (mm)	R/F (mm)	Observed	Predicted	
1980	CSH-6	470	719.00	295.20	28.8	38.0	6.13
1981	CSH-6	470	657.00	560.60	57.3	38.0	12.18
1985	CSH-6	522	767.00	347.50	22.8	23.0	5.44
1988	CSH-9	413	706.00	440.20	28.3	42.6	6.85
1989	CSH-9	479	647.00	519.70	27.7	28.0	5.77

TABLE 3

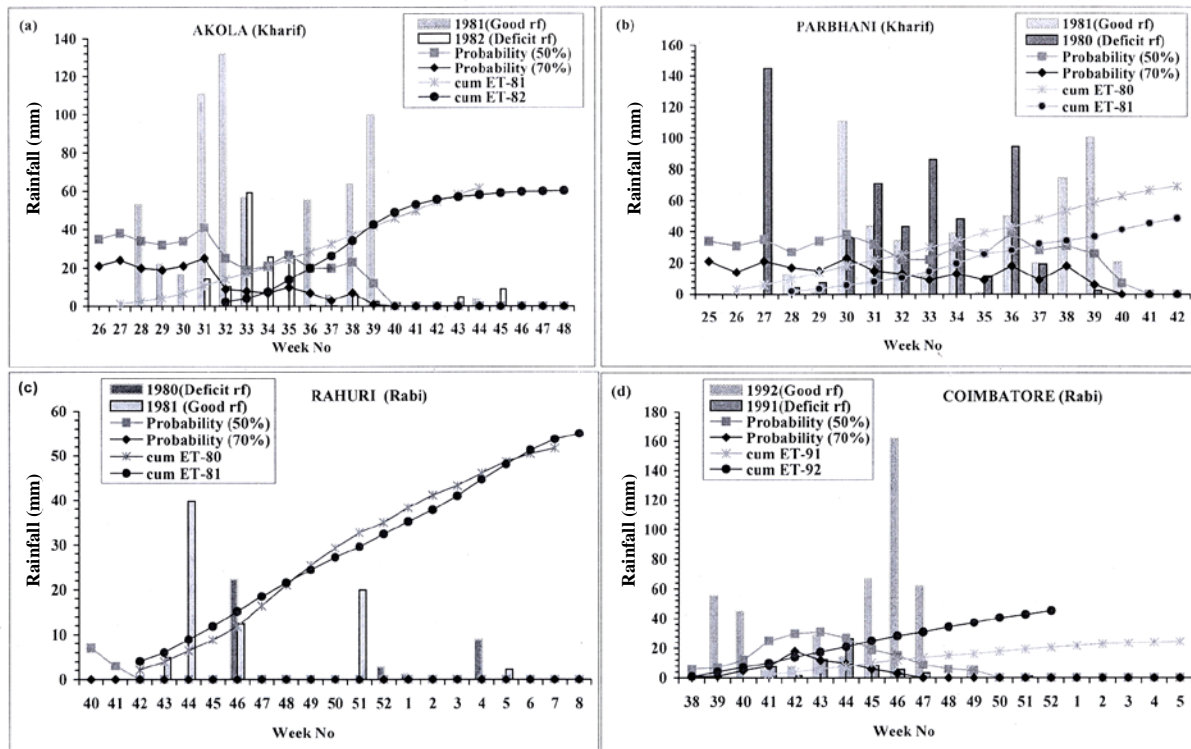
Seasonal evapotranspiration, potential evapotranspiration, rainfall, yield (observed & predicted) and water use efficiency of Sorghum at Rahuri (Rabi)

Year	Variety	Total			Yield - (q/ha)		WUE (kg/ha/mm)
		ET (mm)	PET (mm)	R/F (mm)	Observed	Predicted	
1978	CSH-5	475	711	-	42.6	51.2	10.09
1979	CSH-5	576	618	-	41.3	49.1	7.16
1980	CSH-8R	371	573	36.1	38.5	34.5	9.01
1981	CSH-8R	429	562	82.8	36.5	43.9	8.51
1982	CSH-8R	461	528	60.6	39.8	49.5	8.63

TABLE 4

Seasonal evapotranspiration, potential evapotranspiration, rainfall, yield (observed & predicted) and water use efficiency of Sorghum at Coimbatore (Rabi)

Year	Variety	Total			Yield - (q/ha)		WUE (kg/ha/mm)
		ET (mm)	PET (mm)	R/F (mm)	Observed	Predicted	
1989	CO-26	370	674	359.2	25.63	28.0	6.90
1991	CO-26	168	574	66.1	19.52	19.9	7.77
1992	CO-26	312	397	415.8	26.63	19.3	7.35
1993	CO-25	416	519	452.0	39.45	28.2	9.48
1994	CO-25	331	470	366.1	18.14	21.2	5.48



Figs. 1(a-d). Weekly rainfall distribution in excess and deficit rainfall years along with probability of rainfall at 50 & 70% levels

utilization of soil water and higher yield (43.1 q/ha). During the year mean maximum ET of 4.6 mm was observed during 13th week after sowing (40th std. week). Even though the year 1981 was a good rainfall year, the actual rainfall was well below the assured rainfall at 70% level during 7th and 8th week after sowing.

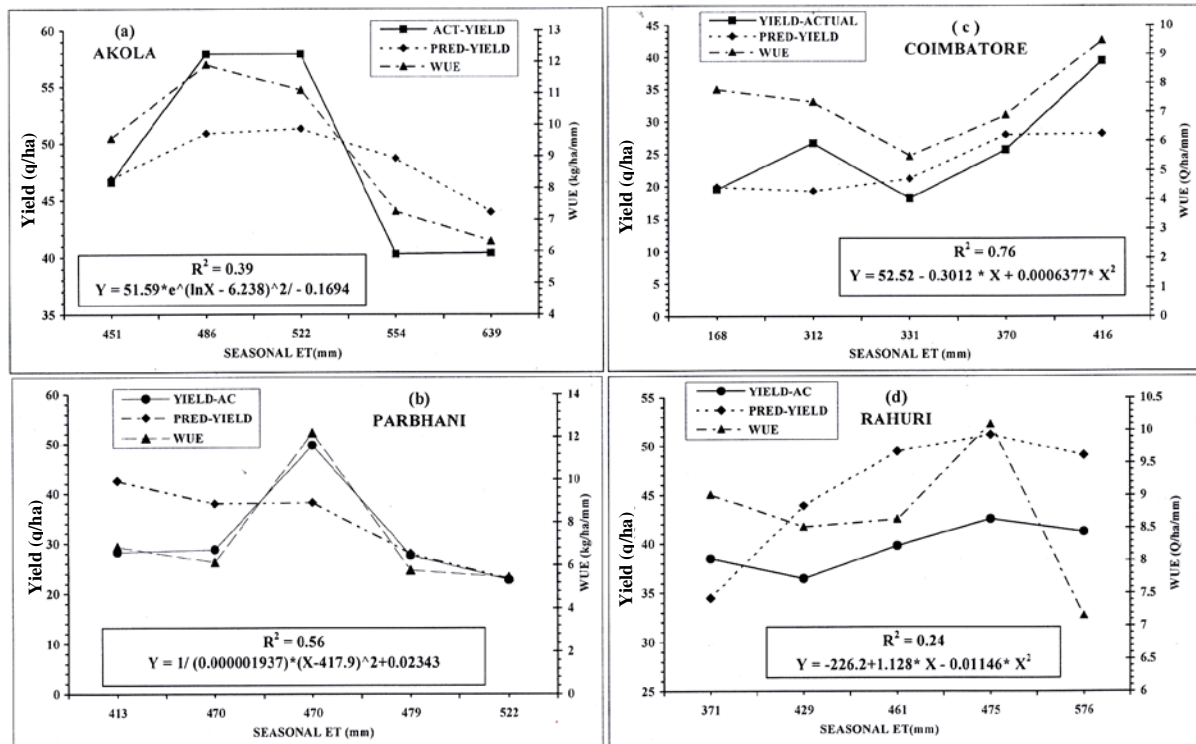
The year 1982 was a deficit rainfall year at Akola (392 mm). Maximum ET value of 8.5 mm was observed during 9th week after sowing (39th std. week). There was a steep increase in ET from 2.2 mm to 8.5 mm from 1st week after sowing till 9th week after sowing (WAS), thereafter sharp decrease in ET was observed at around 10th week after sowing till maturity. Maximum PET of 7.0 mm was observed during 7th WAS. Even though the crop received some rainfall during the vegetative growth period, during early flowering stage and grain formation period it did not receive rainfall resulting in comparatively low yield (40.3 q/ha).

At Parbhani non-irrigated kharif sorghum was raised with stored soil moisture accumulated during south-west

monsoon season. During 1981, the crop had experienced good and well distributed rainfall (560.6 mm). The evapotranspiration varied from 1.5 mm to 5.9 mm during the crop growth stages and maximum ET was observed (5.9 mm) during 8th week after sowing. The cumulative ET was 470 mm during the growth period and yield was 57.3 q/ha. Good rainfall during the active growth stage contributed towards better yield.

The year 1980 had experienced deficit rainfall (295 mm) which resulted in less ET in the crop growing period. Evapotranspiration varied from 1.1 mm to 5.7 mm and maximum ET was observed during 11th WAS. Yield was found to be low (28.8 q/ha) during the year. At Parbhani, the kharif crop was non-irrigated and water stress during the grain filling period might have caused reduction in yield. During the deficit rainfall year WUE was found to be relatively high at 6.1kg/ha/mm.

At Rahuri, rabi sorghum was grown under irrigated conditions. The year 1981 was a good rainfall year



Figs. 2(a-d). Relationship of yield, water use efficiency and seasonal evapotranspiration

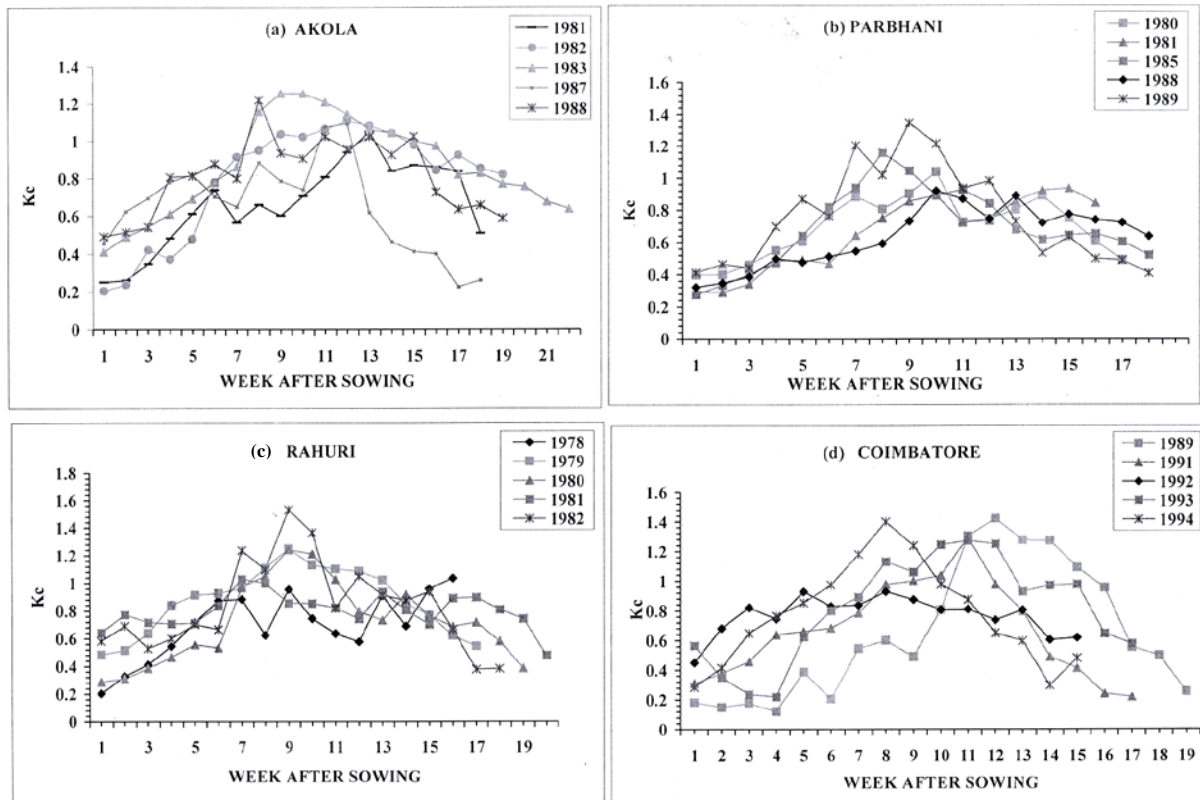
(82.8 mm) and ET varied from 2.3 mm to 3.5 mm during the crop growth period. Irrigation was supplied during critical growth stages to overcome water stressed condition. This had resulted in optimum utilization of available water and better yield (36.5 q/ha). In 1980, the rainfall (36.1 mm) was deficit and there was wide fluctuation in water use of the crop. Evapotranspiration varied from 1.2 mm to 4.7 mm and highest ET was observed during 7th WAS. As the year was a deficit rainfall year, the water requirement of the crop was fully met by irrigation. Hence yield remained nearly same as that of good rainfall year. The Kc value varied between 0.28 and 1.6 during the growth period [Fig. 3(c)].

At Coimbatore rabi sorghum was raised providing irrigation at critical growth stages. In 1992, a good rainfall year ($r/f = 415.8$ mm), ET ranged from 2.5 mm to 4.4 mm during the crop growing period. Highest ET of 4.4 mm was observed during the 6th week after sowing and thereafter gradual decrease in ET was observed. The crop received well distributed rainfall from early growth stage till maturity. The observed yield was 26.6 q/ha.

The year 1991 was a deficit rainfall year ($r/f = 66.1$ mm). Evapotranspiration varied between 0.6 mm and 2.4 mm during the crop growing period. Even though the crop received irrigation, less rainfall during the critical growth stages might have caused reduction in yield (19.5 q/ha).

3.2. Seasonal ET - yield relation

Seasonal ET- yield relationship has been worked out for Akola, Parbhani, Rahuri and Coimbatore and presented in Figs. 2(a-d). At Akola and Parbhani the crop was grown during kharif season and at Rahuri and Coimbatore it was grown during rabi season with supplemental irrigation. At Akola seasonal ET ranged from 412 mm to 699 mm and grain yield ranged from 40 to 58 q/ha. The WUE ranged from 6.3 mm to 11.9 mm. The relationship between seasonal ET and yield was found insignificant ($R^2 = 0.39$) at Akola [Fig. 2(a)]. Optimum yield was observed for seasonal ET of about 486 mm. Thereafter sharp decrease in yield was observed with increase in ET. Excess vegetative growth might have



Figs. 3(a-d). Crop coefficient (K_c) of sorghum at Akola, Parbhani, Rahuri and Coimbatore

resulted in reduction in yield (Bapat, 1981). Water Use Efficiency showed decreasing trend with increase in seasonal ET of about 500 mm.

At Parbhani, maximum yield and WUE was observed for seasonal ET of about 470 mm and sharp decrease in yield and WUE was observed with further increase in ET. The relationship of seasonal ET and yield was found insignificant ($R^2 = 0.56$).

At Coimbatore seasonal ET of 416 mm was found to produce maximum yield [Fig. 2(c)]. The seasonal ET-Yield relationship at Coimbatore was found positive ($R^2 = 0.76$) and significant at 5% level. At Rahuri maximum yield was observed for seasonal ET of 475 mm [Fig. 2(d)]. Seasonal ET and yield relationship was found positive ($R^2 = 0.24$) but insignificant.

Experimental evidence in different parts of the country during kharif has clearly indicated that under rain

fed conditions, onset of the first monsoon shower is the most optimum time for sowing and progressive delay caused substantial reduction in yield (Bapat, 1981). The rabi sorghum yield increased by about 81 % by advancing the sowing by one month. The studies indicate that the most optimum time of sowing is about three weeks earlier to conventional time of sowing of the crop in the locality. Early sowing helps to take advantage of stored moisture in the soil prior to sowing.

The best fit equation developed between seasonal ET and yield showed the difference between observed and predicted yield was found less at Akola, Rahuri and Coimbatore. For Parbhani the difference was found more during the years 1981 and 1988.

3.3. Crop coefficient K_c

Weekly crop coefficient (K_c) values for each of the year were worked out for Akola, Parbhani, Rahuri and

Coimbatore and presented in Figs. 3(a-d). In general, K_c varied from 0.2 to 0.5, 0.6 to 0.75, 0.80 to 1.6 and 0.3 to 0.8 respectively at seedling, vegetative, flowering and maturity stages of the crop.

At Akola K_c ranged from 0.22 to 1.30. It was below 0.5 for the first 3-4 weeks after sowing. It reached maximum during elongation, vegetative stages and decreased slowly at maturity stage Fig. 3(a). At Parbhani K_c values ranged from 0.3 to 1.4 and K_c value increased considerably after 4-5 weeks after sowing. K_c value was maximum during vegetative phase and decreased towards maturity. It was below 0.5 for first 3 to 5 weeks after sowing, then increased to a maximum of 1.4 during elongation and vegetation period (at week Nos. 9 to 10) and then decreased slowly during maturity stage.

The value of K_c ranged from 0.28 to 1.5 at Rahuri and 0.20 to 1.4 at Coimbatore. At Coimbatore it exceeded 1.0 from 8th to 13th weeks for some years [Fig. 3(d)]. For all the stations it was observed that K_c was negligible during the initial growth stages, increased gradually with the crop growth stages, reached peak during flowering stage and declined subsequently during maturity to harvesting stages.

3.4. Irrigation scheduling and water management

Although sorghum is considered drought tolerant and able to give reasonable crop yields under dry land conditions, it responds well to irrigation. Under ideal conditions sorghum has an extensive and fibrous root system. The depth of rooting for most varieties is about 2.0 m. However, some varieties extract soil water as deep as 3.3 m. To capitalize on these deep moisture extraction possibilities during later part of the growing season, it is important to maintain surface moisture during the seedling stage, 3 to 4 weeks after planting to encourage development of a strong secondary crown root system (Doorenbos *et al.*, 1975).

The irrigation experiments indicate that the seasonal consumptive use of water by CSH-1 variety was 331 mm and the estimated irrigation requirement was 170 mm. The rate of water use by sorghum is at its peak at flowering stage and rises rapidly 20 days after planting till 65 days and remains almost the same till dough stage, but later falls rapidly with advancement in maturity (Dancette, 1978). It is estimated that a 100 -120 days crop may have a consumptive use of water of about 450 mm to 500 mm.

Thus it is recommended that if limited irrigation is available, irrigations at 30-35 days after planting and at boot- flowering stage (55-60 days) be given. These two irrigations both in kharif and rabi seasons have been found to be most beneficial compared to other treatments. If sufficient irrigation is available, irrigation at following stages may be given as follows:

- | | |
|-------------------------------------|----------------|
| (i) Vegetative stage | – 25 - 30 days |
| (ii) Boot stage | – 50 - 55 days |
| (iii) Flowering and grain formation | – 70 - 75 days |
| (iv) Grain filling | – 90 - 95 days |

The most critical stage is boot stage and if only one irrigation is available, it may be given at this stage. It has been observed that 35 to 40 % less in grain yield would occur if there is moisture stress at this stage. Water stress during the grain filling period is more harmful than during vegetative period. Some genotypes will delay development when exposed to severe stress during late vegetative growth and resume it when water is again available.

4. Conclusions

(i) Non - irrigated kharif sorghum and irrigated rabi sorghum grown at different locations have shown different consumptive use. The seasonal water use was more than that of seasonal rainfall except at Coimbatore due to available stored water in the soil.

(ii) The consumptive use of water by sorghum was maximum during the 7th to 12th weeks after sowing (WAS) which coincides with active vegetation and flowering stage of the crop. In order to get optimum yield and overcome water stress conditions, the crop needs to be irrigated not only at this stage but also at vegetative stage during deficit rainfall years.

(iii) It may be possible to predict the yield of sorghum by measuring the seasonal ET (either by lysimetric or by water balanced techniques).

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