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551.573 : 633.15 (213.52)

The evapotranspirative demand and water use efficiency of maize crop (*Zea mays* L.) in the semi-arid tract of India

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सार — भारत में शुष्क भूमि पर खेती करने के लिए मक्का एक प्रमुख फसल है। भारत के शुष्क खेती स्थानों में से से नई दिल्ली, राजेन्द्रनगर और बिल्लौरी को पांच वर्षों के आंकड़ों का उपयोग पैन-वाष्पीकरण के संदर्भ में मक्का की फसल के लिए अपेक्षित वाष्पन-वाष्पोत्सर्जन तथा सौर विकिरण की आवश्यकता को ज्ञात करने के लिए किया गया है। मौसम के घटकों के साथ जीव सांख्यिकी अभिलक्षणों, जैसे कि पौधे की ऊंचाई का तुलनात्मक विश्लेषण भी किया गया है। मक्का के लिए जल की आवश्यक मात्रा का निर्धारण किया गया है और शोध-पत्र में उस पर विचार भी किया गया है।

विश्लेषण से पता चला कि मक्का के पौधे को अपनी पुष्पन अवस्था में जल की सर्वाधिक मात्रा की आवश्यकता होती है। पौधे के अंकुरित होने की अवस्था से ई टी/ई पी अनुपात धीरे-धीरे बढ़ने लगता है और बीज के बोने के 8 से 10 सप्ताह के बाद ई टी/ई पी अनुपात अधिकतम हो जाता है। यह अनुपात पौधे की ऊंचाई के साथ सार्थक रूप में सह-संबंधित है। ई टी/आर एस वक्र, सिग्माकपी वक्र की भांति बना और पुष्पन अवस्था में इसका मान अधिकतम था। मक्का की फसल के लिए जल की मात्रा की आवश्यकता समय और स्थान के अनुसार व्यापक रूप से परिवर्तित होती रहती है।

ABSTRACT. Maize is an important component of the dry land farming system of India. In the present study, data for five years' period for three stations, *viz.*, New Delhi, Rajendranagar and Bellary in the dry farming tract of India have been utilized to understand evapotranspirative demand of the crop in relation to pan-evaporation, and solar radiation. Biometric characteristic, *e.g.*, height of the plant has also been analysed *vis-a-vis* meteorological factors. Water use efficiency of maize has also been worked out and discussed.

The analysis indicated that the maize plant uses maximum water during the flowering stage. The ET/EP ratio gradually increases from germination attaining a maximum value 8 to 10 weeks after sowing. This ratio is found to be significantly correlated with the plant height. The ET/R_s curve was found to follow a sigmoid pattern reaching maximum during flowering stage. The water use efficiency of maize crop varies over wide margins in time and space.

Key words — Maize, Evaporation, Evapotranspiration, Solar radiation, Water use efficiency, Weeks after sowing, Flowering.

1. Introduction

In semi-arid region of India, crop production is primarily limited by inadequate water. Of basic importance to this area is the development of water conservation practices that maximises water use efficiency of plants grown in that area. To achieve this objective a better understanding of the soil, plants and meteorological factors that influence water use by crops under field conditions, is needed. Indeed, irrigated agriculture is based on the strong relation between the plant growth and water used. However, this relationship is quite complex and is inter-related with many other factors of which climate is very important. Stanhill (1961), Dovrat *et al.* (1968) and Lomas and Schlesinger (1970) have obtained closely agreeing results for crops grown under commercially optimum conditions in Israel for lucerne. The "commercial optimum" was defined as the commercially grown crop with the highest yield-water requirement ratio. Reddy and Bheemaiah (1991) found that cob length and girth, seeds cob and weight of maize are not influenced by soil types.

The study reported here aims at determining the relative evapotranspiration of maize crop. The effects of climate and crop characteristics such as age and crop height on relative evapotranspiration has also been studied.

2. Material and method

The study pertains to three agricultural meteorological observatories, *viz.*, New Delhi (28°04'N, 77°10'E), Rajendranagar (17°19'N, 78°23'E) and Bellary (15°19'N, 76°51'E) all located in the semi-arid tracts of India. The experimental field data from 1983-1986 and 1988 at New Delhi, 1981 and 1983-1986 at Rajendranagar and 1984-1988 at Bellary, for the kharif season were used. The soil at New Delhi was mainly sandy silty loam, at Rajendranagar sandy clay loam and at Bellary clay silty loam. The maize crop was raised mainly in a rainfed culture in all the above cases. Details about variety used, dates of sowing and harvesting, maximum height of plants etc are given in Table 1. From the daily weather data, weekly totals of various agrometeorological parameters, from the date of sowing to harvest, were computed.

The evapotranspiration (ET) was measured through gravimetric lysimeters located in the crop fields. The lysimeter consists of sensitive dormant type weighing machine of two tonne capacity, erected in the middle of the crop field on a reinforced concrete structure. A steel tank. 1.3 × 1.3 × 0.9 m in size in which plants are grown, is mounted on the platform of the machine such that its rim is in level with the surrounding soil surface. The evaporation (EP) values have been taken from US open pan evaporimeter. The solar radiation R_s used was computed from Angstrom relationship :

$$R_s = (a + b\ n/N)\ R_A \qquad (1)$$

where, R_A is the theoretical amount of radiation that would reach the earth's 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 constants. The sunshine hours were recorded by Campbell-Stroke solarimeter.

3. Results and discussion

3.1. *Water use during the growing period*

Some studies on water use by maize have been conducted by Indian agricultural scientists. For instance, Chowdhury *et al.* (1992) observed that water use by maize is not much dependent on total seasonal rainfall and that ET/EP ratio is significantly correlated to leaf area index. Jadhav and Jadhav (1992) found Water Use Efficiency (WUE) of maize was more under non-mulch conditions than under mulch treatments. In the present study water use pattern, WUE has been examined in depth. The total water input (rainfall + irrigation) and total water use for each of the three stations are given in Table 2 for different years.

At New Delhi the water use was much less than at other two stations. The lowest water was consumed in 1984 and was 245 mm whereas in 1988 maize used largest amount of water, *i.e.*, 360 mm. The mean water use comes out as 294 mm. The water use at Rajendranagar varied from 322 mm in 1984 to 420 mm in 1986 with an average of 362 mm. ET varies from 354 mm in 1985 to 431 mm in 1988 with an average of 381 mm at Bellary. Thus it is clear that maize in Bellary needs more water for growth and development than the other two stations.

It is also seen from the table that water input generally exceeded total (ET) during the growing season. This indicates that excess water was made available to the crop over and above its evapotranspirative demands. In case of New Delhi, in 1988, water input was high, *i.e.*, 773 mm but the water use was only 360 mm or only 46.6% of the water input. From 1983 to 1985 also the water use was found to be less than the total water input. In 1986, the crop used a little more water than what was available. The extra water came from the soil moisture storage (Pdumin 1972).

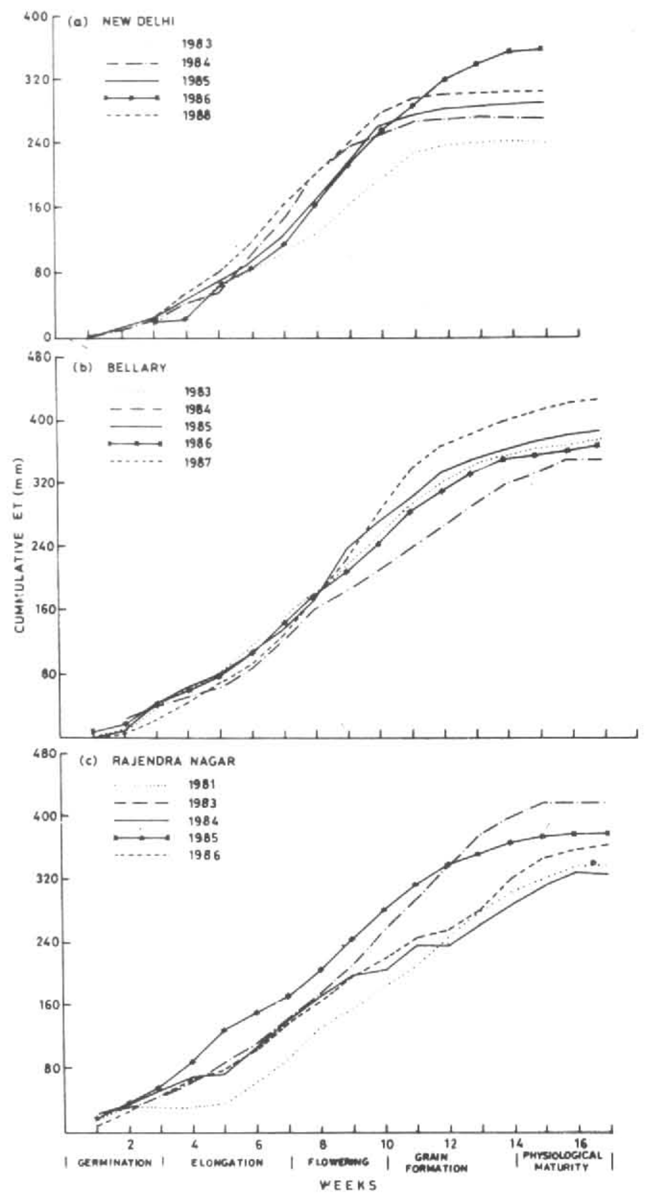

Fig. 1. Cumulative evapotranspiration during different years : (a) New Delhi, (b) Bellary, and (c) Rajendranagar

At Rajendranagar in 1981, 1983 and 1984, water use was about less than half of the available water. While in 1985 and 1986 demand and supply matched. For Bellary in 1986, 1988 and 1984 the maximum ET was 17, 11 and 9% less respectively than the total water input. In 1987 the total water input was 5.1% more than

TABLE 1

Crop information

Year	Name of variety	Date of sowing	Date of harvest	Crop duration (days)	Max. plant height (cm)
		New Delhi			
1983	Ganga-2	19 Jul 1983	21 Oct 1983	93	190
1984	Ganga-2	13 Jul 1984	19 Oct 1984	98	200
1985	Ganga-2	18 Jul 1985	14 Oct 1985	88	197
1986	Ganga-5	15 Jul 1986	18 Oct 1986	95	141
1988	Ganga-sf-2	12 Jul 1988	21 Oct 1988	102	180
		Rajendranagar			
1981	Synthetic-B2	4 Jul 1981	23 Oct 1981	111	181
1983	CM-202	7 Jul 1983	2 Nov 1983	118	170
1984	CM-104	11 Jul 1984	23 Oct 1984	104	NA
1985	Ganga-5	17 Jul 1985	1 Nov 1985	107	194
1986	CM-104	17 Jul 1986	31 Oct 1986	106	NA
		Bellary			
1984	Deccan	27 Jul 1984	16 Nov 1984	112	140
1985	Deccan	29 Jul 1985	19 Nov 1985	113	148
1986	Deccan	30 Jul 1986	13 Nov 1986	105	NA
1987	Deccan	27 Jul 1987	23 Nov 1987	119	NA
1988	NLD	2 Aug 1988	26 Nov 1988	117	201

TABLE 2

Total water input and water use during the growing period (mm)

Station	Year	Rainfall during growing period (mm)	Irrigation amount (mm)	Total water input (mm)	Total water used (mm)
New Delhi	1983	617	Nil	617	290
	1984	414	Nil	414	245
	1985	402	82	484	275
	1986	167	128	295	308
	1988	647	126	773	360
Rajendranagar	1981	674	80	754	329
	1983	823	Nil	823	367
	1984	349	224	573	322
	1985	200	174	374	375
	1986	342	80	422	421
Bellary	1984	165	242	407	370
	1985	294	263	357	354
	1986	229	224	453	377
	1987	243	156	399	371
	1988	347	139	486	431

the demand, while in 1985 the water use nearby equalled the water input.

The cumulative evapotranspiration is shown in Fig. 1 for all the years, for each station. At New Delhi the cumulative water consumption does not differ much till about 7 Weeks After Sowing (WAS) in different years. However, in 1988, ET gradually increased to attain a value of 360 mm, while in 1984, the crop probably suffered from lack of moisture, the corresponding value attained is just 240 mm. The cumulative week to week ET remained highest in 1986 at Bellary when the crop appeared actively growing till the flowering stage. The lowest ET was in 1985, the

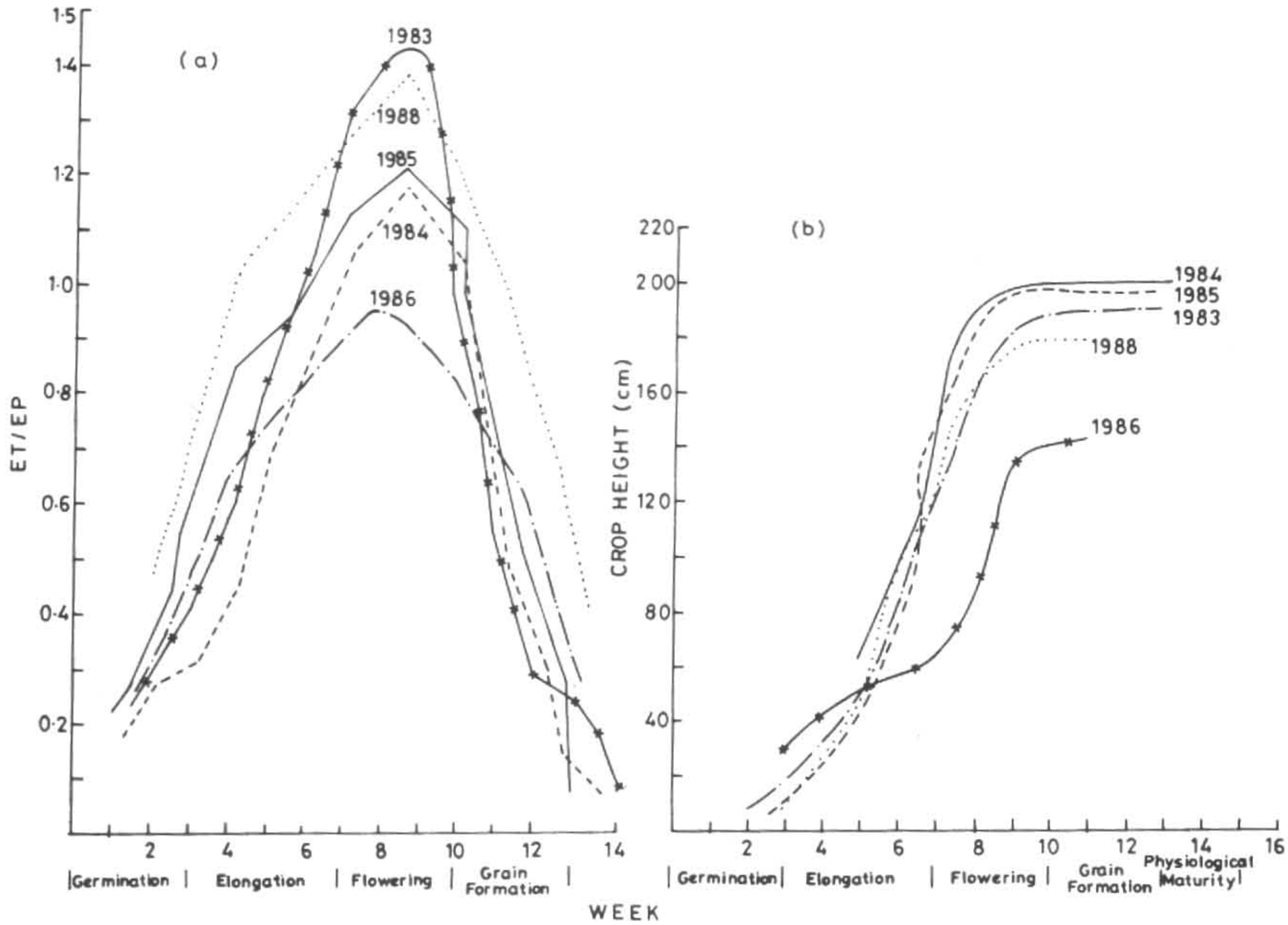

Fig. 2. (a) March of weekly evapotranspiration-evaporation ratio, and (b) plant height (cm) for New Delhi

TABLE 3

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

Stage	New Delhi		Rajendranagar		Bellary	
	Mean weekly total water use	Water use % of total ET	Mean weekly total water use	Water use % of total ET	Mean weekly total water use	Water use % of total ET
Germination (1st to 3rd WAS)	8	8.1	14	11.5	11	8.7
Elongation (4th to 7th WAS)	16	21.7	20	21.9	18	18.9
Flowering (8th to 10th WAS)	35	35.6	36	29.6	42	33.1
Grain formation (11th to 13th WAS)	22	22.4	27	22.2	30	23.6
Physiological maturity (14th to 16th WAS)	12	12.2	18	14.8	20	15.7
SED	1.96		2.10		2.35	
C.D.	4.16		4.45		4.99	

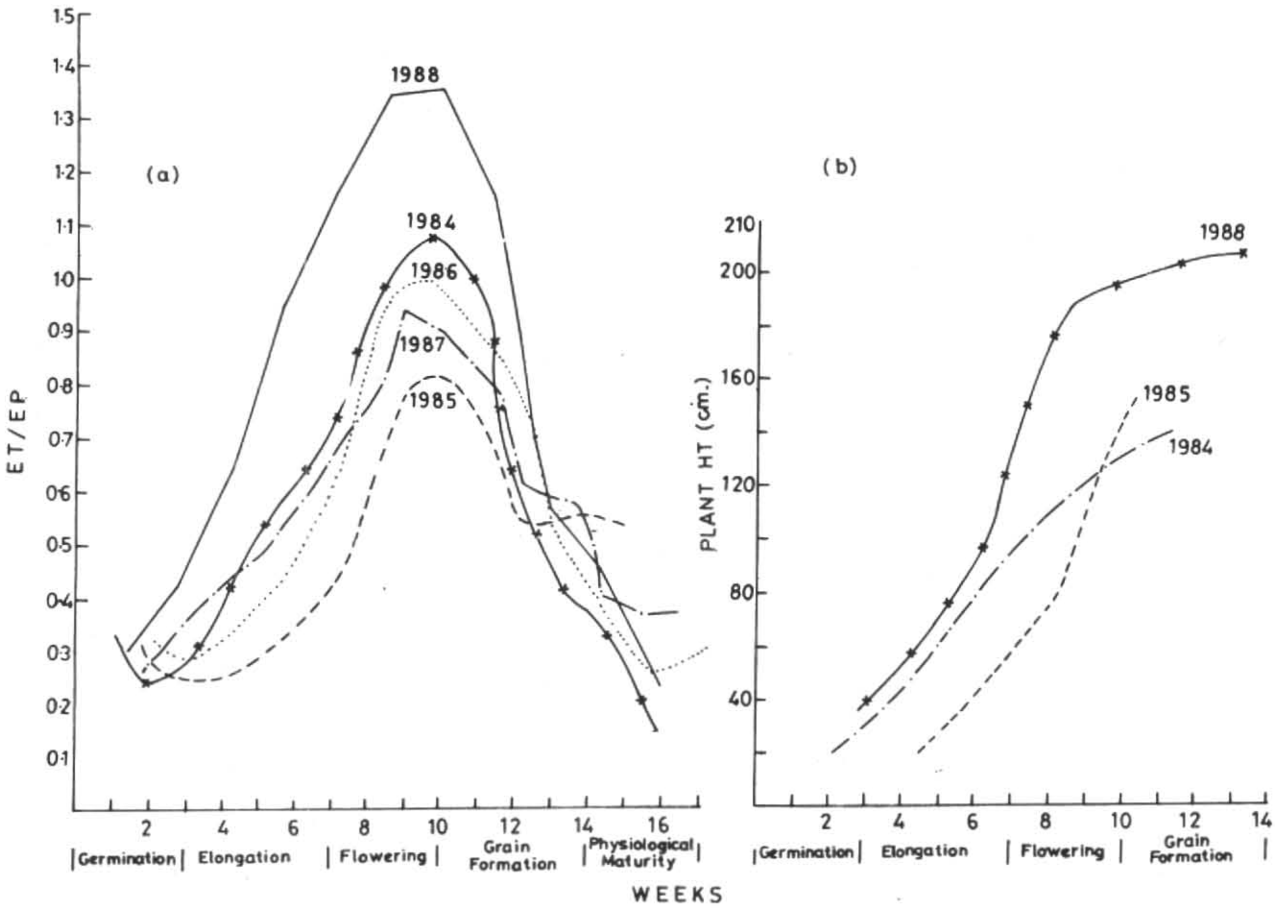

Fig. 3. (a) March of weekly evapotranspiration-evaporation ratio. and (b) plant height (cm) for Bellary

difference becoming marked 8 WAS onwards and reaching as high as 80 mm at maturity period. At Rajendranagar while in 1985 cumulative soil water content was large till grain formation stage, the lowest cumulative ET are seen in 1984 till 13 WAS. The difference between highest and lowest values increases progressively from about 6 WAS and attain value of 100 mm at maturity.

The mean weekly ET for 5 major growth stages is shown in Table 3. Some difference in ET in some of the stages is evident, though by and large, they are comparable. These differences arise chiefly because dissimilar weather that prevailed at the three locations during the crop season, soil factors & different cultivars used. During germination, the ET is nearly 1½ times at Rajendranagar than that at other two stations, presumably because of high amount of stored water at the beginning of crop season.

A two-way analysis of variance of the data was also done for the three stations for comparison of mean ET at different years and different phases. For this purpose years were treated as replication and ET in different phases as treatment. The results of this analysis are also given in Table 3.

The comparison of the mean values of the weekly water use has been done on the basis of Critical Difference (CD). It can be seen from the mean values that in case of New Delhi and Rajendranagar, there is no significant difference between the weekly water use during the elongation and physiological maturity stages. Similarly, the mean values in germination and physiological maturity stages are not significantly different from each other at these stations. The mean weekly water use during the flowering stage at both the stations is significantly higher than those during the other stages. In case of Bellary, mean weekly water use during elongation stage does not differ significantly from physiological maturity stage. Like New Delhi and Rajendranagar, at Bellary also the mean weekly water use is highest in the flowering stage.

Another noteworthy feature is the maximum ET use by maize. This occurs invariably during flowering

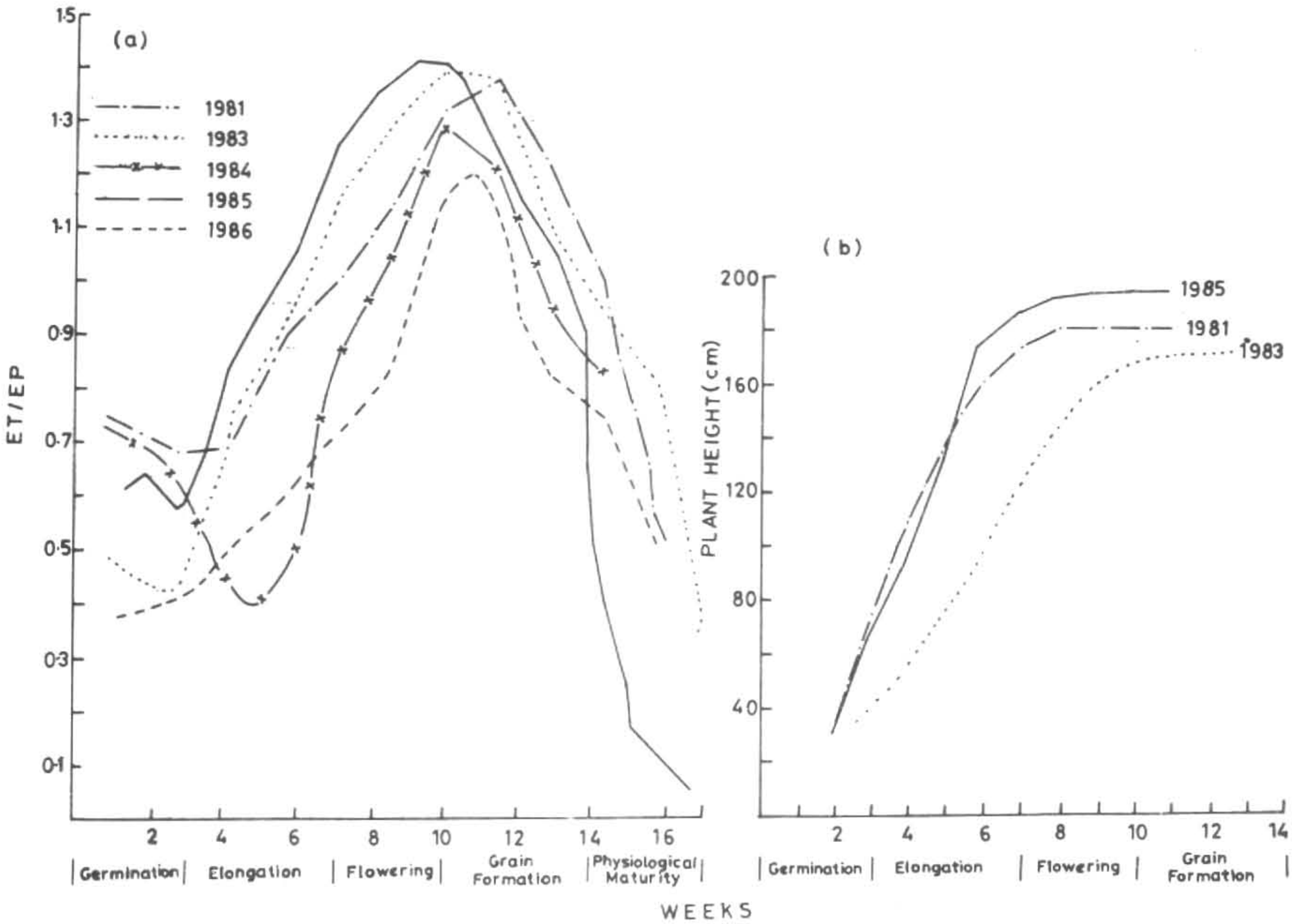

Fig. 4. (a) March of weekly evapotranspiration-evaporation ratio, and (b) plant height (cm) for Rajendranagar

and among the three stations it is highest, *i.e.*, 42 mm per week at Bellary.

3.2. *Evapotranspiration-Evaporation ratio*

It is clear from above that differences in ET was due to differences in moisture availability, soil types and strains. In estimating the irrigation requirements of a crop, the search for a constant ratio between evapotranspiration (ET) from the crop to evaporation (EP) is often attempted. Analysis of ET/EP ratio would, however, permit study of relative water content in each case and allow comparison among different cultivars, the effect of climatic factors being minimised. Denmead and Shaw (1959) found for eleven sites in Iowa (U.S.A.) that prior to flowering the ET/EP ratio in maize increases in a sigmoid manner from 0.36 at germination to peak of 0.81 at flowering and declined rapidly thereafter. Fristschen and Shaw (1961) found that the peak ET/EP ratio of 0.86 was reached at flowering stage. The average ET/EP ratio was 0.70 for New Delhi and 0.79 for Rajendranagar and 0.65 for Bellary. This compares reasonably well

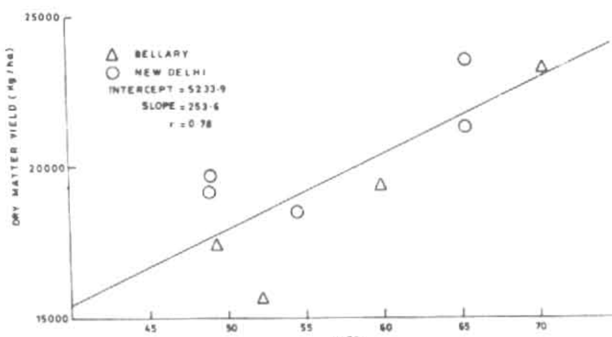

Fig. 5. Yield-water use (*W*/EP) relationship

with the average ratio of 0.76 to 0.79 found by Cackett and Meterler Kamp (1964), except for Bellary where the value is found to be marginally less.

The ET/EP ratio for the three locations is shown in Figs. 2-4. In the case of New Delhi (Fig. 2), the average maximum ET/EP = 1.10 was noticed during flowering stage with a range of 0.90 to nearly 1.40. The largest values seen in 1988 during the entire crop season were

TABLE 4

Maize yield, water use, daily pan evaporation and *m*-factor

Station	Year	Dry matter yield *(D)* (kg/hec)	Water use *(W)* (mm)	Daily average free water evaporation (EP) (mm)	*m*-factor (kg/hec/day)
New Delhi	1983	18509	290·	5.3	338
	1984	19775	245	5.0	403
	1985	23627	275	4.2	361
	1986	19231	308	6.3	394
	1988	21562	360	5.5	329
Bellary	1984	19097	370	6.2	320
	1985	17361	354	7.1	351
	1986	15416	377	7.2	295
	1987	—	371	6.4	—
	1988	23250	431	6.1	330

due to well distributed rainfall. During 1984, till about 5 WAS, the ratio remained low since the roots were unable to extract adequate moisture due to lack of rainfall/irrigation water during sowing. In Bellary (Fig. 3), the ET/EP ratio gradually increased from the beginning and attained the mean value of 1.0 at the time of flowering stage with a range of 0.75 to 1.35. During 1985, however, the highest ratio was 0.75 apparently because the water was limiting.

Fig. 4 shows the pattern of ET/EP ratio for Rajendranagar. The highest weekly value was significantly larger, *i.e.*, 1.42 at this location. A noteworthy feature is, general increase in ET/EP ratio throughout the growing season in all years, even the lowest maximum value in 1986 reached 1.15. Rainfall during the period in nearly all years was substantial and the soil surface can be considered as fallow due to insufficient foliage cover. The evapotranspiration from this, *i.e.*, nearly fallow but wet surface, was thus comparatively more. Hanks *et al.* (1968) also found that ET exceeds EP for native grass. At the start of growing season there was a slight decline in ET/EP ratio during 3rd or 4th WAS. After 4th WAS, however, the ratio gradually increases reaching a peak during flowering and falls steeply thereafter.

3.3. *ET/EP in relation to plant height*

The progressive increase in ET/EP ratio during the growing season reflects the progress in plant growth. For a tall crop such as maize the variations in this ratio can be correlated with the corresponding values of increase in height of the crop. This is particularly so up to the flowering stage of the crop growth, after which the plant height remains generally constant. The increase in height of the crop for these stations during the period from germination to flowering is also shown in Figs. 2-4 alongwith the ET/EP ratios for convenience of comparison. It is seen that, the height of the plant increases linearly with increase in ET/EP ratio. The correlation worked out between ET/EP and plant height till end of the flowering stage was 0.92 for Bellary, 0.84 for New Delhi and 0.83 for Rajendranagar. Such a high and statistically significant correlation brings out the dependence of plant height on the availability of soil moisture in relation to atmospheric demand.

3.4. *Evapotranspiration (ET)-Solar radiation (R_s) relationship*

Carrekar (1963) had shown that the solar radiation method for estimating ET can be used to predict irrigation needs when ET/R_s is known. The two variables ET and R_s can be used in ratio form (ET/R_s) which reflects the combined effect of the energy balance components during various stages of the plant growth. In the semi-arid environment of all the stations the ET/R_s values for maize revealed similar pattern. For invidual stations ET/R_s ratio are shown in Fig. 6 for each year.

The ET/R_s ratio increases as the vegetative cover develops. The low ratio in the early stage of the crop cycle is a result of the presence of a large proportion of bare ground that cannot be kept wet all the time by ordinary irrigation practices. The maximum ET/R_s ratio is reached at flowering stage and decreases almost linearly later because of the senescence of the crop. The maximum values of ET/R_s ranged from 0.5 to 0.7 at Rajendranagar, 0.5 to 0.9 at Bellary and from 0.6 to 0.9 at New Delhi. For sandy clay loam for cotton, Namken *et al.* (1968) found that maximum ratio ranged from 0.42 to 0.73. ET/R_s values were found to be invariably above 0.5 during the period of maximum water use at all the three locations.

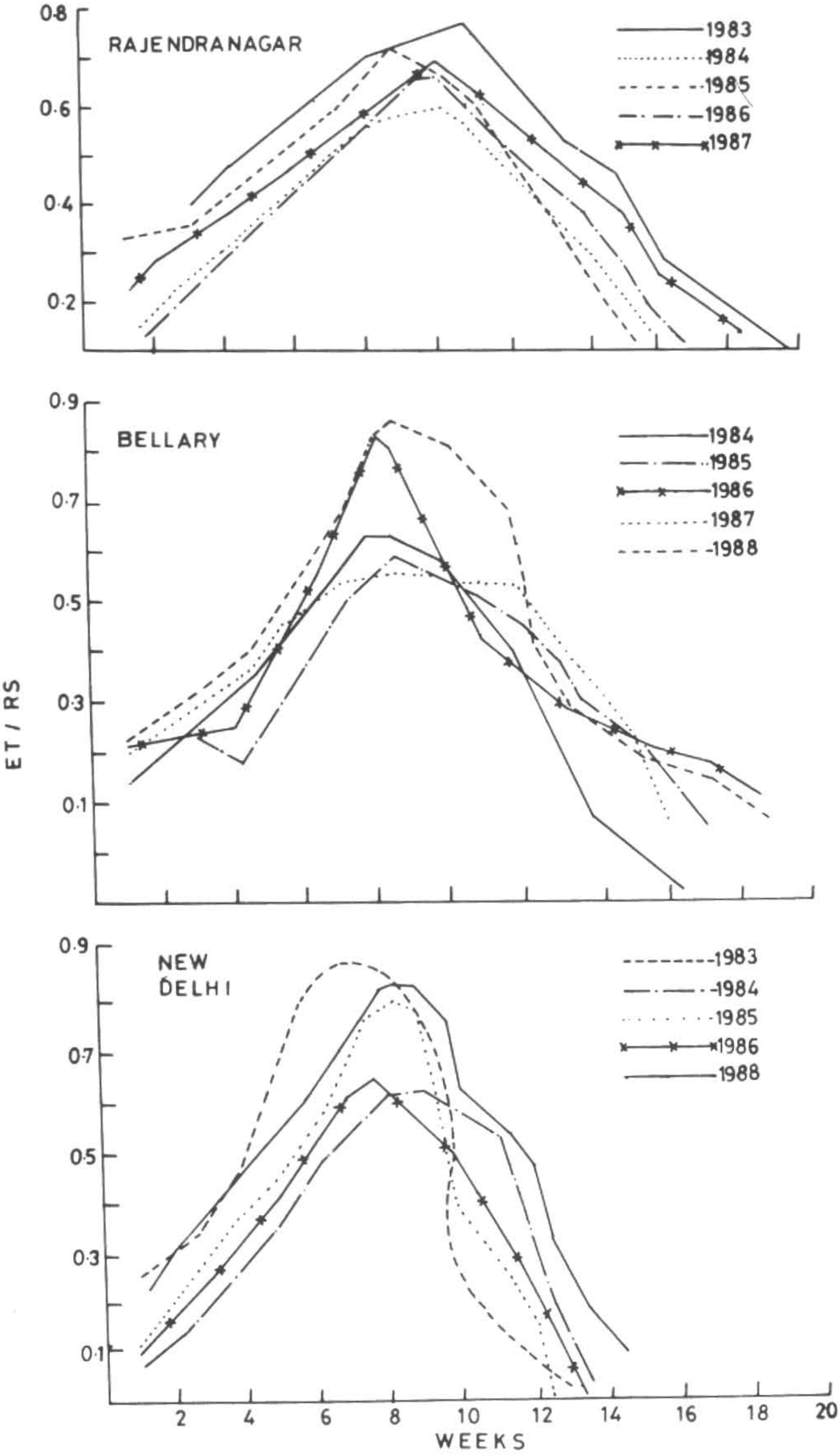

Fig. 6. March of evapotranspiration-solar radiation ratio during different years

The rapid decline of ET/R_s ratio after attaining peak indicates reduced transpiration rates after the lack of available water in the root zone begins to limit plant evaporation. Leaf area index for field crop is closely associated with the plant height. In the present study the maximum ET/R_s ratios were generally observed at the time when the plant had reached maximum height. Increased leaf area and concurrent increase in the percentage of the ground shaded by the plant canopy probably explains much of the increase of the ratio during that time. Subsequently, though the plant height remains unaltered, rapid senescence leads to reduced plant evaporation and hence reduced ET/R_s ratio.

3.5. *Water use efficiency*

DeWit (1958) established relationship between transpiration and dry matter production for different crops. For crops growing in arid climates, he proposed the relation as :

$$D = \frac{m \times W}{EP} \quad (2)$$

where. D is total dry matter production, which is a function of total transpiration (W) during growth and of daily free water evaporation (EP) and m is a constant (in kg/hec) and can be compared with the ratio W/EP which is expressed in days. For instance, if the water use is equal to 300 mm and the daily free-water evaporation is 5 mm/day, the ratio W/EP equals 60 days. In Table 4 crop yields, the total water use during the growing period and m factors are presented. This is given only for New Delhi and Bellary as yield data for Rajendranagar were not available.

It is obvious from the table that range of m values is quite large. The m values at New Delhi ranged from above 329 to 403 while at Bellary from 295 to 351. Wide variation in m values may be attributed to the different plants species used in different years for both the stations. It may be pointed that in the central coastal plains of Israel, Lomas *et al.* (1974) found the m values ranging from 250 to 440 kg/hec/day, whereas DeWit assessed the value of the m coefficient for maize as about 290 kg/hec/day in great plains of U.S.A.

In Fig. 5 the dry matter yields shown in Table 4 (for both stations) are plotted against W/EP ratios expressed in days. A linear relationship between the two is clearly seen. The line represents the relationship between yield and water use.

The line could be represented by the following equation :

$$D = 5233.9 + 253.6 \left(\frac{W}{EP}\right) \quad (3)$$

The correlation coefficient between D and (W/EP) was 0.78 and it was significant at 5% level. It is, thus, obvious that the crop yield depends on the water use per unit evaporation.

4. Conclusions

The following conclusions could be drawn from the study :

(i) The water used by maize in Bellary is comparatively more than in New Delhi and Rajendranagar.

(ii) The maximum ET use by maize is noticed during the flowering stage.

(iii) The ET/EP ratio gradually increases from germination and attains the peak value at flowering stage,

(iv) ET/EP ratio of the plant increases linearly with increase in height of the plant up to the flowering stage.

(v) The maximum values of ET/R_s are attained during flowering stage and vary from 0.5 to 0.9 at all the locations.

(vi) The water use efficiency of maize crop (which differs yearwise and locationwise) is significantly different within the crop growth stages and in particular it is significantly high during the flowering stage.

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