Mausam, (1981), 32, 2, 195-200

633.1 : 628.8

Use of modified Blaney and Criddle formula for estimating water requirements

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(*Received 4 August 1980*)

ABSTRACT. Experimental values of crop growth stage coefficients (K_c) were determined for paddy and sugarcane using lysimetric data recorded at Canning, Nellore, Annamalainagar and Anakapalle. K_c varies with the type of the crop, location and season. The seasonal variation of K_c is similar to potential evapotranspiration (PET).

1. Introduction

The value of data on irrigation water requirements (IWR) is well recognized by administrators and engineers where water supply and water need (PET) are not in balance. Knowledge of IWR is necessary for planning both large and small projects. On the farm, water need estimates are helpful for determining the irrigation method, system design, irrigation schedule etc.

The water resources of India are limited. Irrigated acreage in India is increasing at a rapid rate. Some States cannot support further irrigation. Hence it is necessary that water be distributed with much greater efficiency to the area of greatest need. To accomplish this, accurate and extensive estimates of IWR will be needed. Since the introduction of the concept of Potential Evapotranspiration (PET) by Thornthwaite (1948) and Penman (1948), several techniques have been proposed for the calculation of PET by means of (*a*) direct measurements, *viz.*, lysimeters, energy budget and mass transfer theories of evaporation and (*b*) estimates from measured evaporation and empirical relationships with meteorological parameters. Among the methods using meteorological parameters, the semi-empirical technique developed by Penman is the most useful. However, this method requires a number of meteorological parameters which are not recorded at most of the locations in India.

The empirical formula developed by Thornthwaite where PET is related to mean air temperature and length of day light is not considered quite satisfactory because it overestimates PET in summer and underestimates in winter.

Blaney and Criddle (1950) suggested another empirical formula to relate PET to meteorological parameters for the first time, a crop factor was also introduced by them.

At present, there is no universally accepted empirical method for estimating IWR. Often, because of the difficulty of obtaining accurate direct measurements of evapotranspiration (water need) under field conditions, empirical methods are used. The agronomic and climatic conditions may be different from those under which the empirical formulae were originally developed. In such

TABLE 1

Monthly crop growth stage coefficients (*Kc*) and PET/EP ratios
Canning (22° 15′N, 88° 40′E)

Parameter	Crop variety :	Paddy/Jaya			Paddy/mut-1				Paddy/mut-1		
	Date of sowing :	2 Aug 1975			1 Jan 1976				30 Jun 1976		
	Date of transplanting :	3 Sep 1975			17 Feb 1976				10 Aug 1976		
	Date of harvest :	3 Dec 1975			10 May 1976				20 Oct 1976		
	Crop duration :	91 days			83 days				72 days		
		Sep	Oct	Nov	Feb	Mar	Apr	May	Aug	Sep	Oct
Total PET (mm)		146.2	143.2	132.1	51.4 (12)	163.3	208.8	69.4 (10)	71.8 (22)	117.0	65.5 (20)
Total EP (mm)		—	—	—	51.9 (12)	157.9	208.5	65.7 (5)	72.2 (22)	105.0	64.0 (20)
Kc		0.9	0.9	1.1	0.8	0.9	1.0	0.9	0.5	0.6	0.5
PET/EP		—	—	—	0.9	1.0	1.0	1.0	1.0	1.1	1.0

Parenthesized figures indicate number of observations.

TABLE 2

Monthly crop growth stage coefficients (*Kc*) and PET/EP ratios
Nellore (14° 27′ N, 79° 59′ E)

Parameter	Crop variety :	Paddy H/9					Paddy 2508			
	Date of sowing :	16 Aug 1975					26 Jan 1976			
	Date of transplanting :	8 Sep,. 1975					19/21 Feb 1976			
	Date of harvest :	28 Jan 1976					20 May 76			
	Crop duration :	123 days					91 days			
		Sep 75	Oct 75	Nov 75	Dec 75	Jan 76	Feb 76	Mar 76	Apr 76	May 76
Total PET (mm)		125.9 (23)	43.1 (11)	147.0	133.6	99.1 (28)	20.9 (4)	180.1	284.3	241.8
Total EP (mm)		128.8 (23)	50.2 (11)	99.6	101.4	88.1 (28)	24.4 (4)	179.5	188.4	244.8
Kc		0.8	0.6	1.0	1.0	0.8	1.0	1.0	1.4	1.0
PET/EP		1.0	0.9	1.5	1.3	1.1	0.9	1.0	1.5	1.0

	Crop variety :	Paddy Co-29				Paddy H/9		
	Date of sowing :	29 May 1976				8 Sep 1976		
	Date of transplanting :	25 Jun 1976				23 Oct 1976		
	Date of harvest :	30 Sep 1976				28 Feb 1977		
	Crop duration :	98 days				98 days		
		Jul 76	Aug 76	Sep 76	Nov 76	Dec 76	Jan 77	Feb 77
Total PET (mm)		189.5	275.4	189.5	96.0	131.9	173.3	128.1
Total EP (mm)		158.1	166.6	166.9	—	—	—	—
Kc		0.9	1.3	0.9	0.6	0.9	1.2	0.9
PET/EP		1.2	1.7	1.1	—	—	—	—

Parenthesized figures indicate number of observations.

TABLE 3

Monthly crop growth stage coefficients (*Kc*) and PET/EP ratios
Annamalainagar (11° 24′ N, 79° 44′E)

Parameter	Crop variety :	Paddy A.U.I.		
	Date of sowing :	12 Sep 1976		
	Date of transplanting :	28 Oct 1976		
	Date of harvest :	12 Jan 1977		
	Crop duration :	77 days		
		Nov 76	Dec 76	Jan 77
Total PET (mm)		120.0	145.7	124.0
Total EP (mm)		105.0	119.9	141.3
Kc		0.7	0.9	0.8
PET/EP		1.1	1.2	0.9

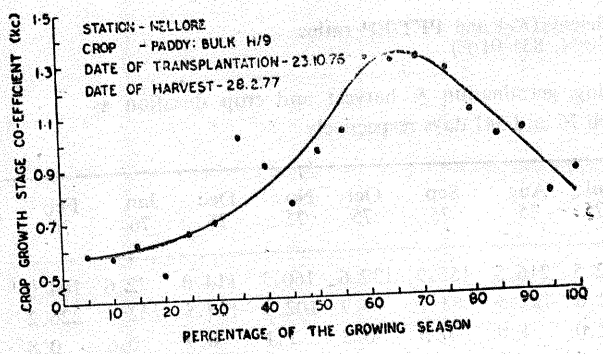

Fig. 1

circumstances it is especially important to test the accuracy of the methods before initiating their use in a given area. In the present study, an attempt is made to test the utility of the modified Blaney-Criddle method. In this study the terms consumptive use, irrigation water requirement, potential evapotranspiration and water need are used synonymously.

2. Modified Blaney-Criddle method

The original Blaney-Criddle (BC) method was developed by Blaney-Criddle by modifying the Blaney-Morin (BM) formula,

$$u = k\ t\ p\ (144 - h) \qquad (1)$$

where,

u = monthly consumptive use (inches)

k = monthly crop coefficient

t = mean monthly temperature (°F)

p = monthly percentage of annual day light hours

h = mean monthly humidity

Since humidity measurements are not readily available for many areas, Blaney-Criddle omitted the humidity factor and obtained :

$$u = k\ f \ldots\ldots\ldots\ldots\ldots$$

where, $f = 0.01\ t\ p$

The above equation is often expressed as :

$$U = \Sigma\,(kf) = K\,\Sigma\,F = KF \qquad (2)$$

where capital letters indicate seasonal values.

The method was further modified by Phelan and first reported by Quakenbush and Phelan (1965). It is assumed that the most important factors influencing 'k' are temperature and stage of crop growth. The coefficient 'k' is then expressed as :

$$k = k_t\ k_c$$

where,

k_t = temperature growth stage coefficient.

k_c = crop growth stage coefficient.

The coefficient k_t was removed by correlating the coefficient k with temperature. A regression analysis resulted in the equation :

$$k_t = 0.0173\ t - 0.314$$

The coefficient k_t is independent of crop type.

The modified B. C. formula then becomes :

$$u = 0.01\ tp\ k_c\ (0.0173\ t - 0.314) \qquad (3)$$

In this formula the temperature factor appears twice, once as a growth stage factor and once as a climatic factor.

The following assumptions are made in the formula:

(*i*) Seasonal or monthly consumptive use is proportional to the climatic factor (F or f).

(*ii*) Water is not a limiting factor at any stage of crop growth.

(*iii*) Factors like fertility, productivity of soil etc do not differ significantly from location to location.

3. Data and method

Under a five-year plan scheme, the Division of Agricultural Meteorology of the India Meteorological Department has set up volumetric lysimeters at Canning, Nellore and Annamalainagar for studying actual evapotranspiration (AET) of paddy and gravimetric lysimeters at Anakapalle for studying AET of sugarcane. The crops were raised as per the existing agronomic practices at the station. In the case of paddy, AET values were taken as PET for the purpose of the present study as there is no shortage of water during crop growth. At Anakapalle all AET

TABLE 4

Monthly crop growth stage coefficients (*Kc*) and PET/EP ratios
Anakapalle (17° 38′N, 83° 01′E)

Sugarcane Co-419 crop variety with dates of planting, germination & harvest and crop duration as 20 Mar 75, 1 Apr 75 & 23 Feb 76 and 341 days respectively

Parameters	Mar 75	Apr 75	May 75	Jun 75	Jul 75	Aug 75	Sep 75	Oct 75	Nov 75	Dec 75	Jan 76	Feb 76
Total PET (mm)	129.7	185.9	197.7	220.0	212.5	216.5	158.9	139.6	160.3	114.0	72.6	104.0
Total EP (mm)	198.4	219.5	237.0	179.1	142.6	122.5	84.7	70.9	102.9	104.5	132.4	226.2
Kc	0.7	0.9	0.8	1.0	1.0	1.0	0.8	0.8	1.1	0.9	0.6	0.8
PET/EP	0.7	0.9	0.8	1.2	1.5	1.8	1.9	2.0	1.5	1.1	0.5	0.5

TABLE 5

Evapotranspiration of paddy at Cuttack (ten day periods)

Month		Measured PET (mm) (1)	Computed PET using B-C method (mm) Surya Rao *et al.* (2)	Computed PET B.C. method using *Kc* values of Canning (3)	Difference (1)—(2) (mm) (4)	Difference (1)—(3) (mm) (5)
			1971			
Feb	I	40.00	54.69	36.30	—14.69	+3.70
	II	46.00	80.35	36.30	—34.35	+9.70
	III	37.00	62.40	41.90	—25.40	—4.90
Mar	I	53.00	80.35	45.00	—27.35	+8.00
	II	56.00	76.88	51.60	—20.88	+4.40
	III	65.00	73.91	62.20	—8.91	+2.80
Apr	I	70.00	58.34	67.60	+11.66	+2.40
	II	73.00	48.09	63.50	+24.91	+9.50
	III	73.00	62.57	63.70	+10.43	+9.30
May	I	64.00	69.93	70.40	—5.90	—6.40
			1972			
Feb	I	41.10	52.07	36.10	—10.97	+5.00
	II	48.30	53.17	31.50	—4.87	+16.80
	III	52.30	92.88	40.40	—40.58	+11.90
Mar	I	64.40	69.60	52.80	—5.20	+11.60
	II	65.10	70.87	57.90	—5.77	+ 7.20
	III	71.30	70.10	61.00	+1.20	+10.30
Apr	I	67.60	63.25	69.90	+4.35	—2.30
	II	71.20	70.95	68.30	+0.25	+2.90
	III	79.80	85.09	77.00	—5.29	+2.80
May	I	81.10	52.07	81.80	+29.03	—0.70
			1973			
Feb	I	42.80	81.50	37.60	—38.70	+5.20
	II	52.30	85.85	44.20	—33.55	+8.10
	III	59.00	83.99	44.70	—24.99	+14.30
Mar	I	56.10	90.68	48.50	—34.58	+7.60
	II	56.00	69.17	55.10	—13.17	+0.90
	III	61.70	82.63	59.40	—20.93	+2.30
Apr	I	71.80	81.87	71.90	—10.07	—0.10
	II	71.00	90.00	74.40	—19.00	—3.40

values during monsoon season were considered and during other season, values on days immediately following irrigation only were considered. The mean of such values was taken as representing PET for the whole month. Observations on daily AET loss during every crop season were commenced soon after transplantation of paddy and planting of sugarcane. All the data on meteorological elements were taken from nearby Agromet. observatories. Monthly percentage of annual daylight hours, appropriate to the latitude, were picked up from standard tables. Using these data in the modified B.C. formula the crop coefficients were determined on a monthly basis.

4. Results and discussion

Monthly crop growth stage coefficients (K_c) for paddy, for Canning, Nellore and Annamalainagar computed from the measured PET, temperature and monthly percentage of annual daylight hours are given in Tables 1-3. It may be seen that K_c at all the three locations and for all the varieties of paddy gradually increases with the advancement of the crop season, reaches a peak value and diminishes. This is clearly brought out in Fig. 1 where K_c is plotted against growth stage in respect of paddy (Bulk H/9) at Nellore.

The K_c values for surgarcane are presented in Table 4. These are higher than those of paddy but the seasonal variation is similar to that of paddy. These are comparable with those appearing in literature and mentioned by Dastane (1967).

5. Pan coefficient and crop growth stage coefficient

PET is determined by environmental factors as well as the physiology of plants. Since evaporation from free water surface integrates many of the weather factors it may be assumed that the influence of environmental factors may be represented by pan evaporation (EP). Hence the variation in the ratio of PET to EP (pan coefficient) may be taken as the effect of the physiology of plants which corresponds to the ratio of consumptive use (U) to the seasonal consumptive use factor (F) in the original B.C. formula. The ratios of PET to EP are also presented in Tables 1-3. The two ratios are not always in agreement. This discrepancy may be due to the fact that the influence of weather parameters on a growing plant is not aways the same as the influence of weather parameters on a free water surface. This requires a further study.

Surya Rao *et al.* (1974) determined the consumptive use values for paddy at Cuttack. On comparison with the measured values they found large differences betwen estimated and observed values (Table 5). By using K_c values experimentally determined at Canning, as in this study, water use estimates for the same seasons at Cuttack were also computed. These water use estimates were within reasonable limits of the actual values. The large differences noticed by Surya Rao *et al.* (1974) may perhaps be due to use of crop coefficients developed elsewhere in a different agroclimatic zone.

The Blaney and Criddle method in estimating consumptive use will be more useful provided crop coefficients are determined experimentally at specific locations and adopted for regions of similar climates and crops.

Acknowledgements

The authors are thankful to Dr. A. K. Mukherjee, Director Agricultural Meteorology for his encouragement. Thanks are also due to Shri B. Srinivasamurthy, Meteorologist for going through the paper and giving his valuable comments.

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