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Estimating Evapotranspiration of Wheat Crop in Black Soil

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ABSTRACT

Estimation of evapotranspiration of wheat crop in black soils of Navsari (lat. 20°.57′ N and long. 72°.54′ E) was made by various empirical meteorological formulae and their validity was tested by determination of actual evapotranspiration under field conditions. Blaney-Criddle formula based on a constant 'K' value of 0.75 was found to give the best estimate of the evapotranspiration. In this paper an effort has been made to determine the 'K' values for different stages of crop growth for accurate seasonal estimation of evapotranspiration values.

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INTRODUCTION

It is a common knowledge that evapotranspiration of crops should be known for planning, construction, operation and maintenance of multipurpose projects, proper planning of farm irrigation system layout and improving farm irrigation management. The basic question as to when and how much to irrigate gains a special significance when it is especially known that any moisture deficiency in critical period during growing season is a major deterent to peak yields. Accurate estimation of evapotranspiration will go a long way in solving many irrigation problems.

Evapotranspiration is a physical phenomena governed by the incident energy at a place (Penman, 1948 and Thornthwaite, 1948). It proceeds at a potential rate up to a point depending on the depth and concentration of crop growth (Lemon, 1956; Philip, 1957; Marlett, 1958; Holmes and Robertson, 1959; Denmead and Shaw, 1952; Fritchen and Shaw, 1961). Hence, climatological approach has been used by and large, in estimating the evapotranspiration from a field. Under a given set of atmospheric, plant and soil moisture conditions actual evapotranspiration is always equal to or less than potential evapotranspiration, but the estimates of the latter are more easily obtainable. The loss of water through the evapotranspiration is entirely a function of meteorological parameters and soil factor has little importance. It will affect only when moisture supply is limited.

A large number of formulae for estimating potential evapotranspiration involve either special measurement of empirical coefficient of limited regional applicability (Baier, 1963) or are not flexible enough to make efficient use of meteorological factors which are available for a certain location and period.

Penman (1948) method is physically the most sound and provides usually the best estimates (Stanhill, 1961). However, it requires observations of vapour pressure, wind, sunshine and temperature. These are often incomplete or not at all available.

In view of above, evapotranspiration formulae suggested by Blaney-Criddle (1945), Thornthwaite (1948), Ianov (1966) and Hargreaves (1956) were used for estimating evapotranspiration. These formulae are simple and involve temperature, sunshine hours and humidity data, which are easily available at any meteorological station. As an alternative to using an empirical formula to estimate evapotranspiration, USWB Pan Evaporimeter was used to obtain an estimate of evaporating power of atmosphere. In addition to this, constants in these empirical formulae were determined and compared from actual evapotranspiration measurements in the field.

METHODS AND MATERIALS

An experiment was planned at N. M. College of Agriculture Farm, Navsari (Lat. 20°57′ N, long 72°.54′ E) to determine the actual evapotranspiration from wheat crop. The physical characteristics of the soil in 0-120 cm layer are shown in Table 1 (Annonymous, 1975).

The field of 85 m×37 m in size was ploughed and a basal dose of 60-60-0 kg/ha of N, P_2O_5 and K_2O, respectively, was applied. Wheat 'J-24' was sown on December-11, 1976 at the rate of 100 kg seed per ha. Experimental details are given in Table 2.

TABLE 1

Soil physical characteristics of experimental field.

Sr. No.	*Depth (cm)*	*Soil physical characteristics*					
		Clay %	*Silt %*	*Sand %*	*Field capacity (FC)*	*Permanent Wilting % (PWP)*	*Bulk Density (BD) g/cc*
1.	0—15	59·37	21·30	16·24	31·00	18·00	1·44
2.	15—30	56·32	20·65	17·15	31·00	18·00	1·50
3.	30—45	—	—	—	31·00	18·00	1·50
4.	45—60	—	—	—	31·00	18·00	1·50
5.	60—75	—	—	—	30·00	18·50	1·50
6.	75—90	—	—	—	30·00	18·50	1·50
7.	90—105	—	—	—	30·00	18·50	1·50
8.	105—120	—	—	—	30·00	18·50	1·50

TABLE 2

Details of experiment on wheat crop for determination of actual evapotranspiration.

Depth of irrigation water applied, mm	$R_1 = 0{\cdot}60$	$R_2 = 0{\cdot}75$	$R_3 = 0{\cdot}90$	$R_4 = 1{\cdot}05$
	Cumulative pan evaporation (mm)			
$I_1 = 60$	100·0	80·0	66·6	57·1
$I_2 = 80$	133·3	106·6	88·8	76·1

I_1 and I_2 = Depth of irrigation water applied.

R_1, R_2, R_3 and R_4 = ratios of depth of irrigation water (IW) to cumulative pan evaporation (CPE).

Design: RBD
Plot size: (i) Gross: 6.08 m × 8.00 m
(ii) Net: 4.95 m × 7.00 m.
Replications: Four

First irrigation of 12 cm was applied on December 11, 1976 immediately after sowing to facilitate the germination of wheat. The soil, being black and having high percentage of clay, has a tendency of cracking and forming a crust on the surface. Second irrigation of 8 cm depth was, therefore, applied on December 19, 1976 to facilitate germination and establishment of crop. Subsequent irrigations of 60 and 80 mm each, as measured by water meter, were applied on the basis of IW/CPE ratios of 0.60, 0.75, 0.90 and 1.05. The cumulative pan evaporation (CPE) values were taken from USWB Pan Evaporimeter installed in the centre of field.

Soil moisture samples were collected from depths of 0-15, 15-30, 30-45, 45-60, 60-75, 75-90, 90-105 and 105-120 cm before and after the third day of each irrigation. Samples were oven dried and percentage moisture content was worked out from the soil moisture data so obtained.

Evapotranspiration values for different growth stages were estimated by Thornthwaite (1948), Blaney-Criddle (1945), Hargreaves (1956) and Ionav (1966) formulae using the available meteorological data at the centre. The data on sunshine hours used in Blaney-Criddle formula were taken for Surat station (Longitude: 72°.52′ E and Latitude: 20°.12′ N.) which is at a distance of 30 km from Navsari as the same were not available at this centre. The value of constant 'K' in Blaney-Criddle formula was taken as 0.75 suggested for small grain (Israelsen and Hansen, 1962).

RESULTS AND DISCUSSION

The quantity of water applied, number of irrigations given, grain and straw yields and the net profit for each treatment are given in Table-3. In treatments $I_1 R_2$, $I_2 R_4$, $I_2 R_3$ and $I_2 R_4$, total number of 6, 6, 6 and 8 irrigations with total depth of 440, 520, 520 and 560 mm water, respectively, were applied. The data on yield were statistically analysed

TABLE 3

Effect of irrigation of yield of wheat 'J-24'.

Sr. No.	*Ttreatment*	*No. of irrigations*	*Total quantity of water applied (mm)*	*Yield, kg/ha*		*Net Profit (Rs/ha)*
				grain	*Straw*	
1.	I_1 R_1	5 (2 + 3)	380	3033·33	3814·58	1990·61
2.	I_1 R_2	6 (2 + 4)	440	3355·55	3993·69	2314·92
3.	I_1 R_3	7 (2 + 5)	500	2905·54	3897·85	1660·19
4.	I_1 R_4	8 (2 + 6)	560	3631·08	4381·18	2503·86
5.	I_2 R_1	4 (2 + 2)	360	2118·10	2364·55	908·64
6.	I_2 R_2	5 (2 + 3)	440	2544·44	3039·53	1293·33
7.	I_2 R_3	6 (2 + 4)	520	3605·54	4320·76	2580·53
8.	I_2 R_4	6 (2 + 4)	520	3483·32	4279·10	2425·66
		S.Em ±		167·03		
		C.D. at 5%		573·25		

and the same for above treatments were found significantly superior to those for $I_1 R_1$, $I_1 R_3$, $I_2 R_1$ and $I_2 R_2$. However, treatment $I_2 R_3$ gave the highest profit (Rs. 2580/ha) and hence for calculating the actual evapotranspiration, the details of this treatment only were considered.

The actual evapotranspiration calculated from soil moisture data before and after irrigation, measured values of evaporation by USWB Pan Evaporimeter and the estimated values of evapotranspiration using various empirical formulae are given in Table-4. Evapotranspiration in the initial and final stages is less, while the same reaches its peak between 51-70 days of crop growth stages. These results are in line with similar studies for wheat crop grown on light soils of Rajasthan (Ram and Singh, 1976) and for peanut grown on sandy soil at Southern Coastal plain in Isreal (Goldberg, Cornal and Sadan, 1971). This was because of the fact that when the crop was in the initial stage and plant cover was thin, large part of evapotranspiration was through evaporation and its magnitude depended largely on the moisture content of the upper soil layer, while at the later stages (during grand growth and flowering stages) evapotranspiration was represented largely by transpiration from much larger exposed surface area of the plants, giving rise to higher evapotranspiration values. At maturity, when the crop was drying, transpiration was reduced to a great extent, thereby reducing the evapotranspiration (Table 4).

To find out closeness of fit between the estimated and observed values of evapotranspiration, 'R' values were calculated by the following formula:

$$R = \sqrt{1 - \frac{\Sigma (X_o - X_c)^2}{\Sigma (X_o - \overline{X})^2}}$$

Where:

R = Closeness of fit
X_o = Observed value
X_c = Calculated value
$\overline{X}$ = mean of the observed value

The highest value of 'R' 0.71 was obtained with USWB Pan Evaporimeter and

TABLE 4

Actual and estimated evapotranspiration by different formulae.

Sr. No.	*Crop growth stages (days)*	*Actual* ET (mm)	EO (mm)	*Calculated* ET_H (mm)	ET_B (mm)	ET_{Ha} (mm)	ET_I (mm)
1	0–9	32·1	33·2	24·8	36·9	38·4	38·8
2.	10–29	71·4	86·7	48·9	85·8	146·5	110·2
3.	30–50	66·1	90·8	37·1	93·8	122·0	97·6
4.	51–70	122·2	84·6	42·1	86·6	162·0	129·6
5.	71–87	75·3	84·7	67·1	83·2	163·3	121·0
6.	88–95	46·3	49·9	39·5	42·8	107·9	69·9
Total	0–95	413·4	429·9	259·5	429·1	740·1	567·1
	'R'		0·71*	NS	0·71*	NS	NS

Where: ET = Actual evapotranspiration worked out from soil moisture data.
EO = Measured pan evaporation by USWB Pan Evaporimeter ET_H, ET_B ET_H, and ET_I were estimated evapotranspiration values using thornthwaite, Blaney-Criddle, Hargreaves and Ianov formula, respectively.

estimated value of evapotranspiration by Blaney-Criddle formula meaning thereby that these estimated values of evapotranspiration were closely related with actual values of evapotranspiration. Evaporation values for a particular location depend on the temperature, humidity and wind velocity. Hence, evaporation values will change from season to season and year to year for the same place. Thus, they cannot be relied upon for estimating evapotranspiration with fair accuracy. Therefore, one is left with the most reliable formula ($R = 0.71$) significant at 5% level, as given by Blaney-Criddle for estimation of evapotranspiration.

Value of 'K' in Blaney-Criddle formula (1945) was calculated for various crop growth stages from the actual evapotranspiration and meteorological data on mean temperature and sunshine hours, with the help of the following formula in CGS system:

$$K = \frac{ET}{(4.5t + 80) \times p} \times 100$$

Where:

K = Constant

ET = Actual evapotranspiration in cm (Table 4)

t = Temperature in °C

p = per cent sunshine hours

'K' = is a function of meteorological parameters and crop growth stages (Annonymous, 1970) and is defined as,

$$K = Kt \times Kc$$

Where: Kt = a climatic coefficient which is related to mean air temperature (t)

and t = mean air temperature in °C

Kc = a coefficient reflecting the growth stage of the crop.

The values of constant 'Kt' for different crop growth stages as calculated from the mean air temperature (1976-77) are shown in Table 5. From the calculated values of 'K' and 'Kt', the crop growth stage coefficient (Kc) was calculated and tabulated.

Daily and monthly evapotranspiration values for December, January, February and March during 1976-77 were calculated from the actual evapotranspiration values (Table 4). The 'K' values in Blaney-Criddle formula were estimated for the above months from actual evapotranspiration values. Similarly 'Kt' values were calculated from the mean

TABLE 5

Seasonal variation of temperature and crop growth stage coefficients in Blaney Criddle formula.

Sr. No.	*Crop growth stages (days)*	*Temperature (°C)*	*Sunshine hours (per cent)*	*Value of coefficient* Kt	$K = \frac{ET}{(4.5t+80) \times p} \times 100$	KC
1.	0–9	23·5	2·48	0·97	0·70	0·72
2.	10–29	22·6	6·27	0·94	0·63	0·67
3.	30–50	20·5	7·00	0·88	0·55	0·63
4.	51–70	21·9	6·86	0·92	1·00	1·09
5.	71–87	26·0	5·69	1·05	0·67	0·64
6.	88–95	27·7	2·76	1·10	0·82	0·75

TABLE 6

Temperature coefficient (Kt) and crop growth stage coefficient (Kc) in Blaney-Criddle formula based on average monthly temperature of season (1976-77).

Sr. No.	*Month*	*Temperature (°C)*	*Sunshine hours (per cent)*	*Value of coefficient*		
				Kt	*K*	*Kc*
1.	December	23·4	8·85	0·97	0·65	0·67
2.	January	20·9	10·39	0·89	0·55	0·62
3.	February	23·4	9·55	0·97	0·93	0·96
4.	March	28·4	10·43	1·12	0·71	0·63

monthly temperature for the corresponding months. The crop growth stage coefficient 'Kc' were calculated (Table 6) from the 'K' and 'Kt' values.

If 'K' value in Blaney-Criddle formula could be determined with fair accuracy and generalised, the same could be used for estimation of evapotranspiration with precision for irrigation scheduling and water budgeting in a given catchment. Keeping this in view the average mean monthly temperature for a period of six years (1971-76) was taken to generalize the 'Kt' values for life cycle of wheat crop in this region. 'Kc' values were taken the same as in Table-6. From the given value of 'Kt' and 'Kc' in Table-7, 'K' values were calculated.

Using 'K', temperature and per cent sunshine hours as in Table 7, daily

TABLE 7

Temperature coefficients (Kt) crop growth stages coefficient (Kc) and the constant 'K' in Blaney-Criddle formula based on mean monthly temperature (1971-76).

Sr. No.	*Month*	*Average mean monthly temperature (°C)*	*per cent sunshine (hr)*	*Value of Coefficient*		
				Kt	*Kc**	*K*
1.	December	21·6	9·31	0·91	0·67	0·61
2.	January	20·4	9·65	0·87	0·62	0·54
3.	February	23·1	9·84	0·96	0·96	0·93
4.	March	26·4	9·65	1·06	0·63	0·67

* Value of 'Kc' same as in Table—5.

TABLE 8

Actual and estimated evapotranspiration by Blaney Criddle formula based on different values of coefficient (K).

Sr. No.	*Period*	*Actual ET (mm)*	*ETB (mm) K = 0·75*	*ETB K = based on 6-year climatological data*
1.	0–9	32·1	36·1	31·5
2.	10–29	71·4	85·8	66·9
3.	30–50	66·1	93·8	62·6
4.	51–70	122·2	86·6	104·3
5.	71-87	75·3	83·2	89·6
6.	88-95	46·3	42·8	35·2
	Total	413·4	429·1	390·1
	"R" (Closeness of fit)		0·71*	0·93**

evapotranspiration values were calculated by Blaney-Criddle formula and are summed up for different growth stages in Table-8. The closeness of fit between estimated and actual evapotranspiration values was found to be 0.93, which was an improvement over 'R' value of 0.71 obtained for constant K = 0.75.

Evapotranspiration for wheat crop for months of December, January, Februry and March can be estimated for black soils of Navsari Zone quite accurately by using 'K' values 0.61, 0.54, 0.93 and 0.67, respectively, alongwith average mean monthly temperature and sunshine hours by Blaney-Criddle formula.

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