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CLIMATOLOGICAL APPROACH FOR ESTIMATING EVAPOTRANSPIRATION OF UPLAND PADDY

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ABSTRACT

Studies were conducted to establish an equation which would be useful in predicting evapotranspiration (ET) for upland paddy. The parameters of the equation are temperature, sunshine hour, wind velocity and relative humidity in the form of equation ET = P[(TSW/R)]x100. In order to find out the evapotranspiration, the predetermined value of P, i.e. the evapotranspiration constant is required for estimating ET. A quadratic equation ($P = 0.00001772 + 0.00107045W - 0.00006049W^2$) has been developed for estimating P following a curvilinear relationship of P with weeks of growth W.

INTRODUCTION

For a particular geographic location the moisture status of soil, cropping practices, soil type, infiltration rate, topography and soil treatment methods are generally constant. Thus, the only variable that can be analysed in order to predict the probable evapotranspiration is the climatic parameters. Penman (1948) suggested a formula based on the combination of energy balance and aerodynamic transport conditions which use various climatic components. But the Penman's equation needs extensive calculations as well as sophisticated instrumentation to record these variables. This made its use limited. Later on Blaney Criddle (1950) developed a formula to estimate evapotranspiration considering the climatic variables like temperature and extend of day time hours. Due to simple calculations involved in Blaney Criddles formula it is very widely used to estimate ET practically. Christiansen (1968) developed a method to find out potential evapotranspiration utilising the pan evaporation data. To assess correct pan evaporation he took into account all the possible climatic parameters for estimating ET. Thus, to estimate the evapotranspiration by Christiansen method is also a lengthy process and requires sophisticated climatic instrumentation.

Although Blaney Criddle's formula has its own simplicity in calculation but it has certain limitations. It considers only climatic factors and they do not represent the actual water needs for all places. This formula gives good estimate in arid conditions only. Besides these two the other important limitation is the correct estimate of crop coefficient K which represents a three fold increase from minimum yield to maximum yield under

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extreme moisture stress conditions (Sammis, et al., 1982). It is observed that for upland condition in humid area, apart from temperature and bright sunshine hours, ET is also greatly influenced by relative humidity as well as wind velocity. Therefore, these factors need to be considered for better estimation of ET for upland paddy in humid area in particular. In the present study, an attempt has been made to develop an equation to estimate the consumptive use of paddy and similar other crops under upland conditions which would be reliable and simple in calculations so that an idea is available to the scientists and in turn to the farmers for planning of efficiently irrigation and water management systems.

MATERIALS AND METHODS

The field experiments were conducted in the Central Farm of Orissa University of Agriculture and Technology, Bhubaneswar (20°15 N longitude and 85°52 E latitude) consecutively for five years in the Kharif season from 1981 to 1985. The altitude of the experimental station is 25.9 metre from the mean sea level. Mean annual rainfall at Bhubaneswar is about 1500 mm. The mean maximum temperature during the hotest month of May and June varies from 38°C to 40°C and the mean minimum temperature during the colder months of December and January varies from 11°C to 13°C. Average wind velocity for Bhubaneswar is 6.5 km/hr. The physical characteristics of soil of the experimental site (Before experimentation) is given in Table 1.

Table 1 Physical characteristics of soil(Before experimentation)

Sl.No.	Properties	Soil depth(cm) 0-22	Soil depth(cm) 22-75
1	Mechanical composition		
	Sand(%)	76.5	61.5
	Silt(%)	10.7	10.8
	Clay(%)	12.8	27.7
	Texture	Sandy loam	Sandy clay loam
2	Colour	2.5 YR 5/6 Reddish	2.5 YR 4/8 Brown red
3	Bulk density(gm/cm^3)	1.8	1.7
4	Porosity(cm^3/cm^3)	0.35	0.42
5	Field capacity(cm^3/cm^3)	0.16	0.23
6	Wilting point(cm^3/cm^3) (Sunflower method)	0.08	0.10
7	Hydraulic conductivity(cm/hr)	3.8	2.4
8	Steady state infiltration rate(cm/hr)	2.0	-
9	pH	5.1	5.3

The primary parameters affecting climatic conditions prevailing during the crop growth period for all the five years are shown in Table 2 weekwise in Kharif.

Table 2 Five year's average weekly temperature, sinshine hour, wind velocity and relative humidity (For the period July 1st to September 30th)

Sl. No.	No.of weeks (from 1st July)	Temperature (°C)	Bright sunshine hours (hour)	Wind velocity (km/hr)	Relative humidity (%)
1	1	29.15	3.64	8.62	81.5
2	2	29.70	5.62	8.28	80.8
3	3	29.03	3.94	7.32	83.6
4	4	29.27	5.60	8.44	83.9
5	5	28.88	4.46	7.36	84.5
6	6	28.80	5.68	9.64	84.8
7	7	28.83	4.08	8.16	85.5
8	8	28.56	4.28	8.48	85.6
9	9	28.53	3.98	6.62	84.9
10	10	28.50	4.26	8.04	85.9
11	11	28.45	5.46	6.00	85.6
12	12	28.67	6.34	7.02	84.3
13	13	29.06	7.74	4.38	82.0

The rainfall data are recorded daily at OUAT meteorological observatory. The weekly total rainfall data during the experiment period is given in Table 3.

The evapotranspiration was measured by two gravimetric type of lysimeters installed by India Meteorological Department, Pune. The lysimeter consists of a steel tank (1.3 m x 1.3 m x 0.9 m) mounted on the platform of the machine and was filled with soil. There was provision in each tank to collect the percolated water. The capacity of weighing of each tank is 2000 kg and it can read correctly upto 200 grams. The observations were recorded every day at 7.30 a.m. in kilogram and the difference in weight of two consecutive days multiplied by its conversion factor was added with the effective rainfall which indicated the amount of water lost through evapotranspiration in a day.

Table 3 Five years weekly total rainfall in mm (for the period July 1st to September 30th)

Sl.No.	No.of weeks (from 1st July)	Year				
		1981	1982	1983	1984	1985
1	1	24.90	0.00	59.10	12.10	47.50
2	2	18.20	0.10	27.80	93.20	248.30
3	3	65.60	11.30	136.10	62.70	64.80
4	4	12.60	36.00	112.70	191.40	3.60
5	5	51.70	91.40	89.20	104.50	168.30
6	6	114.30	98.80	149.50	104.10	96.60
7	7	151.20	63.10	203.70	79.40	56.30
8	8	66.40	189.60	82.00	225.70	85.30
9	9	49.50	97.10	96.00	137.10	45.90
10	10	64.10	67.50	83.30	143.60	65.00
11	11	50.20	92.10	74.90	58.60	66.60
12	12	2.50	123.10	21.80	41.80	159.80
13	13	70.00	3.70	61.40	36.00	26.00

Upland paddy was sown with no irrigation condition for all the five years. Same crop was also grown around the lysimeters to stimulate the natural micro-climatic condition. The rainfall data and other parameters of climatological variables were recorded from the OUAT Meteorological Observatory. For estimating the ET constant K by Blaney Criddle method, the percent sunshine hour was calculated considering 12 hours as total day length.

RESULTS AND DISCUSSION

The primary climatological variables for evapotranspiration are temperature, sunchine hours, wind velocity and relative humidity and hence a combined relationship for ET with all the above mentioned parameters may be expressed, as

$$ET \propto \frac{TSW}{R}$$

as $$ET = P \times \frac{TSW}{R}$$

where ET is the evapotranspiration in mm/day, T is the average temperature in °C, S is the sunchine hours, W is the wind velocity in km/hr, R is the relative humidity in percentage and P is a constant known as evapotranspiration constant. As the relative humidity is expressed in percentage, hence the final form of the equation will become,

$$ET = P \times \frac{TSW}{R} \times 100$$

with the help of above formula, knowing the actual evapotranspiration from lysimetric observations, the evapotranspiration constant P was found out for different years taking the primary factors of climatological data into account. Also, taking the lysimetric data into account as actual evapotranspiration, the crop consumptive use coefficient (K) values were also computed weekwise for the period (July 1st to September, 30th)for all the five years. Five years weekly average evapotranspiration and its value of P and K and their percentage deviation has been tabulated in Table 4.

Table 4 Five years weekly average evapotranspiration and its value of P and K and their percentage deviation

Sl. No.	No.of weeks (from 1st July)	ET (mm/day)	P	Blanney Criddles K	Percentage deviation of P over K
1	1	2.00	0.0017	0.0256	93.35
2	2	2.66	0.0015	0.0218	93.11
3	3	3.21	0.0031	0.0380	91.84
4	4	3.71	0.0021	0.0308	93.18
5	5	3.99	0.0037	0.0419	91.16
6	6	4.55	0.0024	0.0376	93.61
7	7	5.95	0.0049	0.0684	92.83
8	8	7.95	0.0066	0.0876	92.46
9	9	6.00	0.0069	0.0712	90.30
10	10	5.43	0.0047	0.0602	92.19
11	11	4.59	0.0048	0.0397	87.90
12	12	4.21	0.0028	0.0312	91.02
13	13	3.76	0.0032	0.0226	85.84

It is observed from the above table that the percentage difference of P over K indicates the better efficiency of the equation over the Blanney Criddle equation. It may be due to inclusion of two important climatic parameters, i.e. wind velocity as well as relative humidity. The difference between the weekly values of P and K were tested statistically and found to be significant at 1% level ($t = 4.637$). The equation used to find out P was also tested statistically and found to be effective for 66 percent of the variation ($R^2 = 0.658$).

For a comparison study, seasonal evapotranspiration values by Blanney Criddle, Thornthwaite, Penman, Lysimeter and newly established by P value methods were estimated and tested statistically to know whether the values by different methods are correlated to each other. Seasonal ET values by different methods are given in Table 5.

Table 5 Comparison of seasonal evapotranspiration values by Blannery Criddle, Thornthwaite, Penman, Lysimeter and P value methods.

Sl. No.	Year	Seasonal ET values, cm				
		Blanney Criddle Method	Thornthwaite method	Penman method	Lysimeter method	P method
1	1981	69.02	60.63	40.09	44.97	42.35
2	1982	69.52	64.36	43.78	43.50	45.88
3	1983	69.16	61.67	39.99	44.78	39.78
4	1984	68.44	57.54	42.67	38.71	41.43
5	1985	68.10	55.49	36.77	43.84	29.88

It is observed that evapotranspiration computed by Penman, Lysimeter and P method is quite close to each other. However, a significance test was conducted taking all the methods into account to know their correlation with each other and found to be significant at 1% level with a coefficient of variation of 7.005 percent.

Estimation of P

Weekly average P values were plotted against the respective weeks as shown in Fig.1 and a curvilinear relationship was found amongst the values. A quadratic equation has been developed by using the least square techniques (Appendix-I). The final equation is in the form of $P = 0.0001772 + 0.00107045W - 0.00006049W^2$ where P is the constant for evapotranspiration (ET) and W is the number of weeks during the growth period of the crop.

CONCLUSIONS

Computation of evapotranspiration by this equation is easier and realistic because of the involvement of simple mathematical calculations of climatic data which are recorded directly in the filed. No conversion of any of the parameters is needed as is

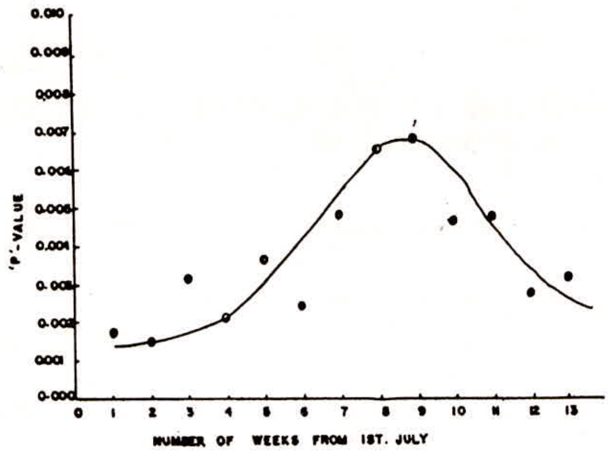

FIG.1 RELATIONSHIP BETWEEN 'P' AND THE NUMBER OF WEEKS 'W'- AFTER SOWING

usually done in most of the emperical equations. It is nearer to the reality in the sense that all the important parameters like temperature, sunshine hours, wind velocity and relative humidity are taken into account in this case. Although this equation has been developed for upland paddy, it may equally hold good for other crops in upland condition. Evapotranspiration constant P value will vary from crop to crop. Hence research need to be carried out to find out P value for different crops.

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Appendix-I

Details of formulation of the quadratic equation for weekly average P values with respect to respective weeks.

No.of weeks	P
1	0.0017
2	0.0015
3	0.0031
4	0.0021
5	0.0037
6	0.0024
7	0.0049
8	0.0066
9	0.0069
10	0.0047
11	0.0048
12	0.0028
13	0.0032

Let number of weeks denote (X) and values of P with respect to weeks denote (Y).

To fit a second degree curve, let the equation be of the form

$$Y = \beta_o + \beta_1 X + \beta_2 X^2 \qquad \ldots (1)$$

To linearize it, put $X^2 = Z$

So, equation (1) becomes

$$Y = \beta_o + \beta_1 X + \beta_2 Z \qquad \ldots (2)$$

Now, applying ordinary least square method to model (2) we get,

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2$$

which is the model of multiple regression equation. Hence, constructing a table for multiple linear regression equation, we can fit the required second degree equation.

To linearize, from second degree equation to multiple regression equation, we put the given data of Y as y, but in case of X_1, we put it as x_1 and the value of $X^2 = x_2$. Now, a table is constructed as below for calculation of the normal equations as it is required by the least square method for the best fitting of the linear regression equation. The normal equation will be of the form,

$$b_1 \Sigma x_1^2 + b_2 \Sigma x_1 x_2 = 1$$

$$b_1 \Sigma x_1 x_2 + b_2 \Sigma x_2^2 = 0$$

$$b_1 \Sigma x^2 + b_2 \Sigma x_1 x_2 = 0$$

$$b_1 \Sigma x_1 x_2 + b_2 \Sigma x^2 = 1$$

TABLE FOR MULTIPLE REGRESSION EQUATION

Y	X_1	X_2	$x_1 = X_1 - \bar{X}_1$	$x_2 = X_2 - \bar{X}_2$	$y = Y - \bar{Y}$	$x_1 y$	$x_2 y$	x_1^2	x_2^2	$x_1 x_2$
0.0017	1	1	-6	-62	-0.002	0.012	0.124	36	3844	372
0.0015	2	4	-5	-59	0.0022	0.011	0.1298	25	3481	295
0.0031	3	9	-4	-54	-0.0006	0.0024	0.0324	16	2916	216
0.0021	4	16	-3	-47	-0.0016	0.0048	0.0752	9	2209	141
0.0037	5	25	-2	-38	0	0	0	4	1444	76
0.0024	6	36	-1	-27	-0.0013	0.0013	0.0351	1	729	27
0.0049	7	49	0	-14	0.0012	0	0.0168	0	196	0
0.0066	8	64	1	1	0.0029	0.0029	0.0029	1	1	1
0.0069	9	81	2	18	0.0032	0.0064	0.0576	4	324	36
0.0047	10	100	3	37	0.001	0.003	0.0370	9	1369	111
0.0048	11	121	4	58	0.0011	0.0044	0.0638	16	3364	232
0.0028	12	144	5	81	-0.0004	-0.0045	-0.0729	25	6561	405
0.0032	13	164	6	106	-0.0005	-0.003	-0.053	36	11236	636

Here, $\Sigma y = 0.0484$ $\Sigma x_1 = 91$ $\Sigma X_2 = 819$

$\bar{y} = 0.0037$ $\bar{x}_1 = 7$ $\bar{x}_2 = 63$

$\Sigma x_1 y = 0.0407$, $\Sigma x_2 y = 0.4487$, $\Sigma x_1^2 = 182$

$\Sigma x_2^2 = 37674$ and $\Sigma x_1 x_2 = 2548$

Now, the first set normal equations are as follows,

$$b_1 x\ 182 + b_2 x 2548 = 1$$

$$b_1 x 2548 + b_2 x 37674 = 0$$

Again, the second set of normal equations are as follows, i.e.

$$b_1 x 182 + b_2 x 2548 = 0$$

$$b_1 x 2548 + b_2 x 37674 = 0$$

Now, solving the first set of normal equation we get

$$b_1 = 0.0103396 = C_{11}$$

and $b_2 = -0.006993 = C_{12}$

Again, solving the second set of normal equation we get

$$b_1 = -0.006993 = C_{21}$$

$$b_2 = 0.0004995 = C_{22}$$

Now, actual b_1 is equal to

$$b_1 = C_{11}\Sigma x_1 y + C_{12}\Sigma x_2 Y$$
$$= 0.103396 \times 0.0407 + (-0.006993) x 0.4487 = 0.00107045$$

Again, actual b_2 is given by

$$b_2 = C_{12}\Sigma x_1 y + C_{12}\Sigma x_2 y$$
$$= (-0.006993) x 0.0407 + 0.000499 x 0.4487 = -0.00006049$$

Now, $b_o = \bar{Y} - b_1\bar{X}_1 - b_2\bar{x}_2$
$$= 0.0037 - (0.00107045 x 7) - (-0.00006049) x 63 = 0.00001772$$

Hence, the required second degree equation to fit the curve is of the form

$$Y = b_o + b_1 X + b_2 X^2$$

Now, in place of Y put the symbol P which represents the P values with respect to respective weeks and in place of X_1 put the symbol W which represents the respective weeks. Therefore, the final equation is of the form as,

$$P = 0.00001772 + 0.00107045W - 0.00006049W^2$$