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A METHOD FOR ESTIMATING CROP ACTUAL EVAPOTRANSPIRATION

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Abstract

The reliability of Rhenals and Bras (1981) model in estimating actual evapotranspiration in Samaru for a wheat crop was tested and result is herein presented. This model incorporates climate, crop and soil characteristic factors in estimating actual evapotranspiration. Actual evapotranspiration values estimated using the model were compared with actual evapotranspiration amounts estimated from open pan evaporation data.

The mean difference between the average daily evapotranspiration obtained by Rhenals and Bras (1981) model and those from open pan evaporation data was 0.20 mmday^{-1} and was not statistically significant at 0.05 level of significance. The tested model is found reliable in estimating the crop actual evapotranspiration.

1. Introduction

Knowledge of water requirements of crops is needed for scheduling irrigation, for planning farm irrigation system, for the design of irrigation projects and for water resources development. Estimating the quantity of water to be added to the field and timing of application are major tasks in irrigation scheduling. Proper irrigation schedule can only be put in place when the crop actual evapotranspiration amount can be estimated.

Potential evapotranspiration, which is the amount of water loss from a surface completely covered with vegetation when there is sufficient water in the soil at all times, is easily estimated from observed meteorological data and the use of some empirical equations which abound in literature. Examples of such equations are those of Penman (1948), Blaney-Criddle (1950) and Thornthwaite (1948). Evapotranspiration is a physical process that essentially determines crop water requirement. It depends on climatological factors, soil moisture content and crop characteristics.

There are two methods commonly employed in measuring actual evapotranspiration of crops. The first is by direct monitoring of the changes in soil moisture content with time. This method is also referred to as soil moisture depletion method. The change in moisture content over a given time is taken as the crop's actual evapotranspiration. This method is completely soil-based as the influence of climatological factors and crop characteristics are not directly considered. The other method is by multiplying values of potential evapotranspiration estimated from meteorological data for the area by the crop coefficient (K_c) obtained for that area. This latter method does not consider the influence of the soil factors in obtaining the crop actual evapotranspiration.

Rhenals and Bras (1981) suggested a simple model for estimating the crop actual evapotranspiration amounts on weekly basis. This model incorporates the climatological, soil and

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crop characteristic factors in estimating crop actual evapotranspiration. In the experiment reported herein the procedure detailed by Rhenals and Brass (1981) was used to estimate weekly actual evapotranspiration amounts for a wheat crop and the estimated values were compared with evapotranspiration amounts estimated from open pan evaporation data. This was done with the objective of validating the model for use in Zaria, Nigeria.

2. Materials and methods

2.1 Actual evapotranspiration

The actual evapotranspiration during week *k*, ET_{ak}, from a given cropped area is represented by Equations 1 – 3 (Rhenals & Bras, 1981):

$$ET_{ak} = 0\,; \qquad 0 \le S_g \le W_p \qquad (1)$$

$$ET_{ak} = a_k ET_{pk} \frac{S_g - W_p}{F_c - W_p}\,; \qquad W_p \le S_g \le F_c \qquad (2)$$

~~(2)~~

$$ET_{ak} = a_k ET_{pk}\,; \qquad S_g \ge F_c \qquad (3)$$

Where:

W_p = permanent wilting point

F_c = field capacity

S_g = gravimetric soil moisture content in week *k*

a_k = empirical coefficient

ET_{pk} ET_{ak} = potential evapotranspiration during week *k*

While the potential evapotranspiration is an adequate indicator of the climatological factor, the values of the empirical coefficient a_k represent the crop characteristics and other factors not explicitly included in the model (Rhenals and Bras, 1981).

Since soil moisture content varies within the week, Rhenals and Brass (1981) suggested a choice of a representative value for soil moisture content in a given week. The representative value chosen is the weighted average soil moisture content for the week defined by:

$$S_k = \alpha_1 \left(S_{0k} + U_k\right) + \alpha_2 S_{fk}\,; \qquad S_{0k} + U_k \le F_c \qquad (4)$$

$$S_k = \alpha_1 F_c + \alpha_2 S_{fk}\,; \qquad S_{0k} + U_k = F_c \qquad (5)$$

Where:

S_k = weighted average of soil moisture content for week *k*

S_{0k} = soil moisture content at the beginning of week *k*

S_{fk} = soil moisture content at the end of the week *k*

U_k = amount of irrigation water to be applied at the root zone during week k.
α_1 and α_2 = constants such that $\alpha_1 + \alpha_2 = 1$

(Rhenals and Bras (198 1) suggested that $\alpha_1 = \alpha_2 = 0.5$)

Thus,

$$ET_{ak} = a_k ET_{pk} \frac{S_k - W_p}{F_c - W_p} \quad ; \qquad W_p \le S_k \le F_c$$

(6)

2.2 Field experimentation

A land area of 0.05 ha at the Ahmadu Bello University Farm, Shika, Zaria (11° 11' N; 7° 35' E) was seeded to wheat (*Triticum aestivum L.)* using 42 check basins (3 m x 3 m size) for the experiment. The soil textural class was clay loam. Table 1 shows some soil physical properties of the experimental site. Planting was done on the 4th of December, 1991. The seeds were broadcast at the rate of 100 kgha^{-1} as recommended by the Institute for Agricultural Research (I.A.R.), Zaria.

Table 1: Some soil properties of the experimental plots

Soil depth (cm)	0 – 15	15 – 30	30 – 45	45 – 60
Soil textural class	Loam	Clay loam	Clay loam	Clay loam
Bulk density (gcm^{-3})	1.48	1.44	1.43	1.27
Field capacity (% by weight)	18.7	17.8	21.4	22.4
Permanent wilting point (% by weight)	6.9	7.6	12.9	10.3

Compound fertilizer was applied as basal dosage at the rate of 60 kgha^{-1} by broadcasting. Top-dressing was carried out 4 weeks after plant emergence using urea, also at the rate of 60 kgha^{-1}. The crops were irrigated at intervals of 7 days throughout the growing season. Irrigation was done by applying the amount of water needed to raise the soil moisture content of the crop root zone to field capacity. Water from a reservoir located 80 m away from the experimental plot was applied using a potable water pump.

Gravimetric soil moisture measurements were taken on the 2nd, 4th and 6th days after irrigation and on the 7th day just before another irrigation. Soil samples were collected from the soil surface down to a depth of 600 mm at 150 mm intervals. The samples were collected from 6 basins selected randomly within the experimental plots. Sampling was maintained in the selected basins for the first week. Subsequently, other basins were selected for other weeks. The soil samples were oven dried in the laboratory for 24 hours at a temperature of 105 °C to determine the soil moisture content.

2.3 *Estimates of model parameters, a_k*

Equation 2 is a linear equation with a_k as the slope, and can be determined if the other components of the expression: actual evapotranspiration (ET_a), potential evapotranspiration (ET_p), soil moisture content at the field capacity and wilting point are known.

To facilitate the estimation of *ak* for each week, daily amount of actual evapotranspiration (ET_a) is required. To obtain this, a model proposed by Yaron *et al.* (1973) which showed the relationship between daily evapotranspiration and soil moisture variation over time was employed. Yaron *et al.* (1973) suggested that daily evapotranspiration (ET) is subject to the following general law.

$$ET = \frac{dM}{dt} = a + bM \tag{7}$$

Where:
M = the daily mean soil moisture content (% by weight)
a and b are parameters to be estimated

Igbadun (1992) evaluated Equation 7, and obtained the parameters, a and b for wheat crop on a clay-loam soil. The parameters, shown in Table 2, and the soil moisture contents determined were used in Equation 7 to obtain the ET for the days of soil sampling. The ET_p for each day of soil sampling was also estimated from open pan evaporation data. Equation 2 then becomes a linear equation in which the only unknown is a_k and it is obtained using a curve-fitting technique.

2.4 *Estimation of weekly crop actual evapotranspiration*

Having obtained the values of a_k for each week, Equation 6 was used to obtain weekly crop actual evapotranspiration. The weighted average of soil moisture content for week k was estimated using Equation 5. Rhenals and Bras (1981) suggested that $\alpha_1 = \alpha_2 = 0.5$.

Table 2: Estimates of parameters a and b in $ET = a + bM$*

Soil depth (cm)	0 – 15		15 – 30		30 – 45		45 – 60	
	a	b	a	b	a	b	a	b
Days after planting								
28 – 34	-0.454	0.066	-0.085	0.011	-0.112	0.009	-0.071	0.007
35 – 41	-0.916	0.133	-0.416	0.055	-0.187	0.015	-0.089	0.007
42 – 48	-0.810	0.117	-0.438	0.058	-0.267	0.021	-0.176	0.017
49 – 55	-0.019	0.148	-0.418	0.055	-0.323	0.253	-0.229	0.022
56 – 62	-0.934	0.135	-0.326	0.043	-0.124	0.010	-0.021	0.002
63 – 69	-1.090	0.158	-0.407	0.062	-0.137	0.011	-0.049	0.004
70 – 76	-0.867	0.128	-0.373	0.049	-0.158	0.012	-0.207	0.020
77 – 83	-0.980	0.129	-0.500	0.066	-0.030	0.023	-0.012	0.001
84 – 90	-0.504	0.073	-0.402	0.053	-0.412	0.032	**	**

* Source: Igbadun (1992)
** No significant change in moisture content in the layer

2.5 Estimation of ET_p from pan data

Potential evapotranspiratrion was estimated from open pan evaporation data for the growing season. The open pan evaporation data were obtained from the Institute for Agricultural Research Meteorological station in Samaru. The summation of the daily values for each week was multiplied by a pan coefficient of 0.7 (Mazumder, 1983).

3. Results and discussion

3.1 Estimates of a_k values

Table 3 shows the values of a_k for each week and the correlation coefficient (r). Data collection started at 30 days after planting, when the crop had been established.

Table 3: Estimated weekly a_k values

Week	Days from planting	a_k	r
1	30-36	0.88	0.988
2	37-43	0.92	0.998
3	44-50	1.06	0.997
4	51-57	1.07	0.989
5	58-64	1.09	0.899
6	65-71	1.28	0.988
7	72-78	1.30	0.951
8	79-85	1.35	0.999
9	86-92	0.88	0.981

The table shows that a_k which represents the crop characteristics and other factors not explicitly included in the model, increased with increase in the growth of the crop. The highest value was recorded at the dough development stage of the crop. Thereafter, the value decreased as the crop attained full maturity. This trend is very similar to that of crop coefficients whose values also rose to peak at flowering and seed development and decreased as the crop attained maturity. Rhenals and Bras (1981) and Cordova and Bras (1979) took the value of a_k as 1.00 for all weeks, while an average value of 1.09 for a_k was obtained for wheat in this study.

3.2 Estimates of weekly actual evapotranspiration

Table 4 shows the estimated crop ET_a values using Equation 6. The values of a_k, ET_p and the soil characteristic factor $(S_k-W_p)/(F_c-W_p)$ for each week of the growing season are also shown.

Table 4 shows that the estimated ET_a values rose from crop establishment to the peak value at 72-78 days after planting and then decreased as the crop attained full maturity. This behaviour agrees with the general trend of crop water use for annual crops. The low value of ET_a recorded at week 5 (58-64 days after planting) may be attributed to low evaporative demand as the value of the ET_p for that week was lower compared to the week before and after it.

Table 4: Estimated weekly crop actual evapotranspiration

Week	Days from planting	a_k	ET_p (mm)	$\frac{S_k - W_p}{F_c - W_p}$	ET_a (mm)
1	30-36	0.88	40.4	0.69	24.5
2	37-43	0.92	44.0	0.62	25.1
3	44-50	1.06	45.7	0.62	30.0
4	51-57	1.07	48.5	0.63	32.7
5	58-64	1.09	43.2	0.57	26.8
6	65-71	1.28	50.7	0.53	34.2
7	72-78	1.30	53.8	0.53	36.7
8	79-85	1.35	40.5	0.53	29.0
9	86-92	0.88	38.5	0.67	22.7

3.3 Comparison of actual evapotranspiration estimates

The values of crop ET_a estimated from Rhenals and Bras (1981) Model and evapotranspiration calculated from open pan data are shown in Table 5. The average daily evapotranspiration (mmday^{-1}) values are shown in parentheses. The table shows that the average evapotranspiration per day for the two methods increased with increase in crop growth up to a peak and then declined. The average evapotranspiration estimated using the procedure detailed by Rhenals and Bras (1981) did not differ considerably from open pan estimates. The mean difference between the model estimated evapotranspiration and that of open pan method was 0.20 mmday^{-1}. A t-test also showed that there was no difference in the means of the two methods.

Table 5: Comparing evapotranspiration estimates

Week	Days from planting	ET_a* (mm)	Open pan *ET* (mm)
1	30-36	24.5 (3.5)	16.2 (2.3)
2	37-43	25.1 (3.6)	23.0 (3.3)
3	44-50	30.0 (4.2)	27.5 (4.0)
4	51-57	32.7 (4.7)	31.5 (4.5)
5	58-64	26.8 (3.8)	33.3 (4.8)
6	65-71	34.2 (4.9)	41.7 (5.9)
7	72-78	36.7 (5.2)	43.4 (6.2)
8	79-85	29.0 (4.1)	29.4 (4.2)
9	86-92	22.7 (3.2)	26.6 (3.8)

*Values in bracket are average evapotranspiration amounts in mm/day

4. Conclusion

Rhenals and Bras (1981) detailed procedure for estimating actual evapotranspiration of crop was tested. This model incorporates soil, plant and climatological factors in estimating crop actual evapotranspiration. Average daily evapotranspiration values obtained using the model were not statistically different from those estimated from open pan evaporation data at 0.05 level of significance. The model is found adequate in estimating crop actual evapotranspiration for the studied crop and location where *a* and *b* for Equation 7 had been previously determined.

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