EVAPOTRANSPIRATION ESTIMATES IN A SEMIARID CLIMATE

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INTRODUCTION

Evapotranspiration formulas which utilize routine meteorological data have been developed by Thornthwaite (16), Blaney and Criddle (1), and Penman (7, 8, 9). Some of the methods are based upon empirical correlations of measured evapotranspiration and air temperature (1, 16) whereas others (7, 8, 9) account for the radiant energy available at the evaporating surface. Each of these methods has enjoyed considerable success in the area for which it was developed and when applied under restrictive conditions similar to those which prevailed during its period of empirical evolvement.

Unfortunately, each of the methods noted above is used under widely differing climatic types where the crop development, soil moisture, and environmental conditions are at variance with those for which the method was originally developed.

This manuscript compares estimated evapotranspiration by these empirical methods to lysimeter measurements of actual evapotranspiration from irrigated alfalfa in a semiarid climatic region at Swift Current, Saskatchewan. The applicability of the empirical estimates is evaluated for the purpose of day-to-day irrigation scheduling and long-range irrigation planning.

METHODS

Lysimeter and Observation Site

Evapotranspiration from alfalfa was measured by a lysimeter located in the center of an irrigated area of 3.7 acres. The irrigated area was surrounded by extensive dryland cereal and forage crops and was subject to severe advection (3) as are irrigation projects throughout the Canadian Prairie. Soil moisture within the irrigated area was maintained between field capacity and 50 percent available moisture by supplementing the natural precipitation with sprinkler irrigation. During the test period (June 25 to September 12, 1967) a total of 12.91 inches of irrigation water was applied in nine applications. Precipitation during the period was 3.96 inches.

The lysimeter was six feet in diameter by five feet deep and weighed approximately 15,000 pounds. The soil, classified as Wood Mountain silt loam (5), was excavated and back-filled in six-inch layers. The lysimeter was supported on three temperature-compensated strain gage load cells connected to a strip chart recording potentiometer. Changes in lysimeter weight were recorded on a 2 mv scale. The chart was read to the nearest 0.01 mv which represented a weight change of 1.4 pounds, equivalent to 0.01 inches of water. Periodic calibrations throughout the summer indicated that the measurement system maintained this sensitivity and was not affected by temperature variations when the recorder was closely coupled to the load cells and their power supplies.

Thornthwaite Formula

Thornthwaite (16) proposed a method which relates potential evapotranspiration to mean air temperature and latitude. The solution of his equation requires only the mean air temperature for the desired period and the location of the station. Tables and nomographs can be easily constructed to give potential evapotranspiration (PE) as a function of mean temperature.

Blaney-Criddle Formula

H. F. Blaney and W. D. Criddle (1) also proposed a method which relates evapotranspiration (or consumptive use, CU) to mean temperature and the percentage of daytime hours in the period of observation. In addition, this method incorporates a factor which varies for crops and takes a value of 0.85 for alfalfa.

Both the Thornthwaite and the Blaney-Criddle methods were originally intended for seasonal or monthly use. However, they are widely used over weekly and even daily periods.

Penman Formula

Penman (7, 8) has derived a formula for calculating natural evaporation by combining energy balance and aerodynamic theories. The original method was based on relationships of sunshine, vapor pressure, temperature and wind velocity and was designed to estimate evaporation from an open water surface (Ew). An empirical coefficient was then used to convert estimated evaporation to evapotranspiration from vegetated surfaces. Later, Penman and Schofield (9) modified the equation to compute evapotranspiration (E) directly from turf by the inclusion of a stomata-daylength factor. A solar radiation term dominates the Penman and Penman-Schofield equations. This term is usually calculated from sunshine data and in view of the importance of the term (2, 15), this test included measured short wave radiation and net all-wave radiation as primary components in modified versions of Penman’s equations.

Net radiation (R) was measured continuously with a ventilated net radiometer (14) installed at a height of six feet over the irrigated alfalfa and the remaining supporting data were measured in an adjacent agrometeorological enclosure which included an Eppley pyranometer, a Campbell-Stokes sunshine recorder, and an instrumented Stevenson screen.

Observations were obtained on 53 days during the period June 25 to September 12, 1967. Data were en-
tered on I.B.M. cards and estimated evapotranspiration was calculated and results were analyzed on an I.B.M. 1130 computer at the Defence Research Station, Suffield, Alberta. In addition to analyses on a daily basis, the data were analyzed in groups of consecutive three-, five-, and seven-day periods by using mean values for the available periods.

RESULTS AND DISCUSSION

Evapotranspiration (PE) as calculated by the Thornthwaite method has been plotted (figure 1) against actual evapotranspiration measured by the lysimeter. Figure 1A indicates the scatter of daily values about the linear regression line. Even though a significant correlation was obtained, the standard error of the predicted evapotranspiration by Thornthwaite's method is 0.08 inches per day or about 30 percent of the mean daily evapotranspiration from alfalfa at Swift Current. On a daily basis, only 27 percent of the variation in actual evapotranspiration is accounted for by its regression against the Thornthwaite estimate.

Sections B, C and D of figure 1 show the effect of calculating the daily evapotranspiration over three, five, and seven consecutive-day periods by using data averaged over those periods. The correlation between measured and calculated evapotranspiration fell off markedly when calculated over three-day periods, but improved as the length of the observation period increased. Although only five or seven-day periods were available, the correlation of the two methods was good. The linear regression fitted the plotted points quite well and accounted for 79 percent of the variation in actual evapotranspiration.

In all sections of figure 1 it is evident that the Thornthwaite method seriously underestimated actual evapotranspiration in this semiarid climatic region by about 40 percent as indicated by the differences in mean values. Reasons for the failure of this method have been thoroughly discussed by Pelton et al. (6).

The performance of the Blaney-Criddle method (CU) was almost identical to that of the Thornthwaite method, and the correlation with measured evapotranspiration was much lower than that found under more humid conditions by Stephens and Stewart (12), and by Stern and Fitzpatrick (13). This similarity to Thornthwaite's method was expected because both methods are based on the mean air temperature during the observation period. The Blaney-Criddle method underestimated actual evapotranspiration by 31 percent on a daily basis and by 34 percent on a seven-day basis.

Penman's estimate of evaporation from an open water surface, $E_0$, is plotted in figure 2 against measured evapotranspiration. A radiation term dominates the Penman equation and the original equation ($E_0I$) for which this term was calculated from sunshine data was modified. Data in section B ($E_0II$) figure 1 were obtained by using the measured short wave radiation to calculate the Penman radiation function and those in section C ($E_0III$) were obtained by replacing the Penman term with measured net radiation. Each modification improves the correlation slightly but not to the same degree that has been shown in other climatic areas (4, 10, 11, 15). Figure 2A shows that sunshine data caused the Penman relationship to overestimate actual evapotranspiration by about seven
Figure 2. Relationships between measured evapotranspiration (ET) and Penman's evaporation from an open water surface (E₀), calculated from A—sunshine data, B—incident short wave radiation and C—net radiation.

Figure 3. Relationships between measured evapotranspiration (ET) and Penman's E₀ for clear and cloudy days.

Figure 4. Relationship between measured evapotranspiration (ET) and Penman's evapotranspiration from turf, Eᵣ.

percent whereas the use of short wave radiation leads to an underestimate of 16 percent and net radiation causes an underestimate of only three percent on a daily basis.

The original Penman equation, figure 3 and each of the modified versions, gave higher correlation coefficients when the regression was calculated for cloudy days only (i.e., days with less than 75 percent of the maximum possible sunshine) than when calculated for clear days (75 to 100 percent of the maximum possible sunshine) or all days. The authors feel that this is because crop plants react more quickly to variations in direct solar radiation than would be indicated by Penman's equation and suggest that this may be an area in which Penman's equation could be modified for use under predominantly clear-sky conditions.

Grouping the Penman E₀ data into three-, five-, and seven-day periods failed to improve the correlation or predictive ability of these methods over the single day relationship to any marked degree.

Penman's value for evapotranspiration from turf, Eᵣ, is plotted in figure 4 as calculated from sunshine data. This method does not improve the correlation of calculated and measured evapotranspiration over that of the E₀ values, figure 2A, but it does reduce the absolute value of the calculated data substantially causing an underestimate of about 30 percent.

The Penman Eᵣ calculations responded to the modifications which used short wave and net radiation to about the same degree as the E₀ calculations. They also followed the pattern of the E₀ behavior in the clear and cloudy day separation and the three-, five, and seven-day groupings.

Studies in more humid regions (2,
CONCLUSIONS

Analyses of the data reported here indicate that the mean temperature methods of Thornthwaite and Blaney and Criddle cannot be used to predict the evapotranspiration or day-to-day water requirement of irrigated crops in this semiarid region of the Canadian Prairie. They do, however, provide a reasonable estimate of longer term irrigation needs and appear to be the best methods available for predicting weekly or seasonal water requirements from meteorological data for irrigation planning purposes.

Net radiation cannot be used as the sole predictor of evapotranspiration in this climatic region. This probably results from the fact that a relatively greater proportion of the available solar energy goes into sensible heat than into latent heat whereas the reverse is true of more humid climates. The importance of net radiation as a component of evapotranspiration relationships cannot be discounted, however, because this term does influence considerations.

Penman's method for estimating evaporation from an open water surface is the best of the empirical methods tested for estimating irrigation requirements on a daily basis. However, even when measured values of net radiation are used in this method about 35 percent of the daily variation in actual evapotranspiration is still unaccountable. Improvements in the Penman equation are available and one of these suggests the use of a more suitable function of wind travel over the crop (4, 15). This further complicates an already difficult procedure and for these reasons the Penman method in any form cannot be recommended for general use by the irrigation farmer. It will, however, remain a valuable research technique.

Each of the empirical methods discussed here requires further testing for possible use in estimating irrigation requirements of crops other than alfalfa in the semiarid region, and each deserves a thorough evaluation for monthly and seasonal use.

SUMMARY

Empirical methods of estimating evapotranspiration from meteorological data proposed by Thornthwaite, Blaney and Criddle, and Penman have been evaluated for application on the Canadian Prairie. Lysimeter observations were used as the standard of comparison over 53 days in the 1967 growing season.

The Thornthwaite and Blaney-Criddle methods are inadequate to describe the actual evapotranspiration regime on a daily basis but predict the water requirement of alfalfa on a weekly basis with reasonable accuracy. Penman's method can account for about 65 percent of the variation in daily evapotranspiration and requires extensive modification before it can be recommended for general use in this semiarid climatic region.

REFERENCES


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TABLE II. RESULTS OF DRYING BARLEY

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<th>Trial Number</th>
<th>$\Delta w$ ((\text{lbs/lb grain}))</th>
<th>$T - T_x$ ((^\circ\text{F}))</th>
<th>$T$ ((\text{hours}))</th>
<th>$W_w$ ((\text{ft}^3 \times 10^6))</th>
<th>$Q'$ ((\text{est.})$ ((\text{ft}^3 \times 10^6))</th>
<th>$Q$ ((\text{actual})$ ((\text{ft}^3 \times 10^6))</th>
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The change in air flow with respect to time, Figure 5, is partially attributed to an increase in static pressure due to a reduction in volume or gain in density as the grain dried.

The significant result of the drying experiments is the ratio of the estimate, $Q'$, (calculated from the recorded values of $t$ and $t_w$) to the total quantity of air pumped, $Q$, which may be noted in Table 2. Values of $Q'/Q$ much greater than one are attributed primarily to errors in $Q$, which were calculated from measurements of the air velocity. The gradient across the inlet duct was steep and a small change in position of the air probe would alter the measured air volume $Q$ significantly. The possibility of values greater than one due to $Q'$ seems remote. This would occur only if the air picked up more moisture than that specified at equilibrium. In this regard, equilibrium was close to the saturation curve. In view of this, and the foregoing, reasonable values of air flow apparently can be estimated from the amount of moisture to be removed and the prevailing wet and dry bulb temperatures, provided the air flow is not large.

CONCLUSIONS

An equation was developed to assist in estimating the quantity of air required to dry grain and hay. The wet and dry bulb temperatures of the Edmonton area, on a per week basis from August to November inclusive, were processed to simplify the use of the equation for small grains.

The validity of estimating the required air flow from the wet and dry bulb temperatures appears reasonable, provided the air flow is not large.

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Tempering the air by as little as 5° to 19°F provides for drying under adverse climatic conditions and/or on a 24-hour basis.

REFERENCES