Determining Evapotranspiration Rates and Soil Moisture Levels With Climatological Data[1]

R. Turner, University of California, Davis and Dan Wiersma.
Purdue University

Evapotranspiration is the term used to designate the process of water movement in the vapor state from the earth's surface to the atmosphere. Hydrologically it includes evaporation from open water surfaces, the surface soil, and transpiration by plants. It does not include the water moved downward out of the root zone.

Evapotranspiration is primarily an energy controlled process. However, it is influenced by soil, plant and atmospheric factors which govern the absorption and distribution of energy at evaporating surfaces, and by the flux of liquid water to, and water vapor from such surfaces.

In a previous paper (7), with the hydrologic equation on long term precipitation and runoff records, the author determined the average annual evapotranspiration for all the watersheds of Indiana. He showed that the average evapotranspiration for the state was about 27 inches per year. This is approximately 70 percent of the annual precipitation. The influence of evapotranspiration and precipitation characteristics on soil moisture deficits was also noted, and in turn, the influence of such moisture deficits on plant growth responses.

Thus, agriculturally, the soil moisture deficit during the growing season is of extreme economic importance. Soil moisture can be determined by taking samples; however this is time consuming and expensive if done on an intensive scale. It would be helpful to have a simple means of estimating or predicting the soil moisture condition at any geographic location, or for a general area. Since atmospheric conditions have such a dominant influence on the rate of evaporation, relating any one or several of the atmospheric parameters to evapotranspiration and in turn to soil moisture deficit has obvious possibilities. This is especially true if measurements can be made in the normal Weather Bureau station network. Empirical equations using mean air temperature as a basis for evaluating the evapotranspiration rate have been developed by Blaney-Criddle (1), Thornthwaite (6), and Holdridge (3), among others. Evaporimeter devices such as the Class A Evaporation Pan, Livingston atmometer, Bellani Plates, and Piche blotting paper have also been used for estimating evapotranspiration. The vapor flow, and surface energy balance methods offer good physical basis for making fairly accurate estimations of evapotranspiration, however, the complicated instrumentation and calculations make these latter methods less practical. Penman (4) has developed a formula which includes net radiation, saturation deficit, and wind speed which has proven quite successful, but has the

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same drawback of tedious computations. Tanner (5) has made a simple relationship of net radiation to evapotranspiration which in some areas may be adequate. The purpose of our study was to determine the adaptability of the more promising methods now in use for estimating evapotranspiration under the climatic regime that prevails in Indiana. Also each of the climatic parameters measured were examined as to their relationship with the evapotranspiration process.

The experimental data was taken on one crop, corn, for the period July 11 to September 5, 1958 at the Purdue Sand Experimental field near Culver, Indiana. The soil type is a Coloma loamy sand which is excessively drained, and has low available water retaining characteristics. Daily evapotranspiration was determined by taking daily soil samples and measuring the change in moisture gravimetrically. This method has obvious limitations, but a large number of samples were taken to reduce the sampling error. An official weather observation station is located on the field and the climatic measurements used for the study included precipitation, maximum and minimum air temperatures, relative humidity, wind speed at 2 meters above the ground surface, evaporation from a U. S. Weather Bureau Standard Class A pan, and evaporation from a black and a white Livingston Atmometer. Net radiation was calculated from a formula given by Penman (4).

The daily water use ranged from 0.07 to 0.32 inches per day with the maximum occurring on August 12. For a seven day period, the maximum average use rate observed was 0.23 inches per day, which occurred the second week of August when the corn was in the tasseling stage. The overall seasonal average was 0.16 inches per day.

Comparisons are made of the measured daily water use with the Blaney-Criddle, the Thornthwaite, and the Penman formulas; the difference between black and white Livingston atmometers, and the Class A Pan. Correlations were also made with the climatic factors of net radiation, mean daily temperature, relative humidity, mean daily wind velocity in miles per hour, and actual sunshine hours. The correlation coefficients of these are given in Table 1.

Of the climatic factors, net radiation showed the highest correlation with water use rates. This fits nicely with the theoretical concept that evapotranspiration is primarily a result of the energy balance occurring on the earth's surface. Sunshine hours are also fairly well correlated with daily water use. This may be reflected by the high correlation of sunshine hours and net radiation, which was 0.71.

The factors of relative humidity, wind velocity and temperature are poorly correlated with the measured water use. The high relative humidity and frequent cloudiness that prevailed during most of the study period undoubtedly reduced the correlation of temperature with water use rates. A critical examination of the original climatogical data reveals that the negative correlation of wind velocity with evapotranspiration was due to the interaction between climatic factors. The data showed that when wind velocity increased water use rates decreased because of cloudiness, low net radiant energy, and high humidity. These factors overshadowed the generally negligible effects of wind velocity.

TABLE 1. Correlations of the Measured Daily Water use with the Climatic Factors; With the Estimated Daily Evapotranspiration by Formula; and that Estimated with Evaporimeter.

	Correlation Coefficient (r)
Climatic Factor	
Net radiation	0.77
Mean daily temperature °F	0.28
Relative humidity, percent	—0.29
Mean daily wind velocity, mi/hr.	—0.16
Actual sunshine, hr/day	0.54
Formulas	
Blaney-Criddle	0.11
Thornthwaite	0.25
Penman	0.92
Evaporimeters	
Livingston atmometers	0.82
Weather Bureau Class A Pan	0.47

The two empirical equations, Blaney-Criddle and Thornthwaite, which use temperature as the primary basis for estimating evapotranspiration are both poorly correlated with daily water use. It is interesting to note that the correlation between computed water use by the Thornthwaite equation and measured water use ($r=0.25$) is almost the same as that between daily mean temperature and observed water use rates ($r=0.28$). Also if a plot is made of the measured daily water use and those estimated by the Thornthwaite formula early in the season the estimated rates tend to be higher than the measured, and during the latter part of the season the estimated tend to be lower than the measured. This can be explained by the energy balance as early in the season the energy flux is into the soil, and later in the season energy flux is out of the soil. Also during the early part of the season the corn crop may not have had a complete canopy, thus tending to lower the actual rate.

An evaporimeter is an integrator of the same climatic factors as those involving evapotranspiration. The difference in evaporation between a black and a white Livingston atmometer was found to be well correlated with measured water use, $r = 0.82$. This method has been reported by Halkias et al. (2). Because of the simplicity and low cost, this method shows considerable promise. The correlation of the Class A Pan and measured water use was not as high as other workers have reported in the literature. The advantage of this method is that many weather stations make routine pan evaporation measurements.

Finally, from the table 1 the high correlation between the measured water use and that computed by the Penman formula should be noted (Fig. 1). This again likely reflects the close association between

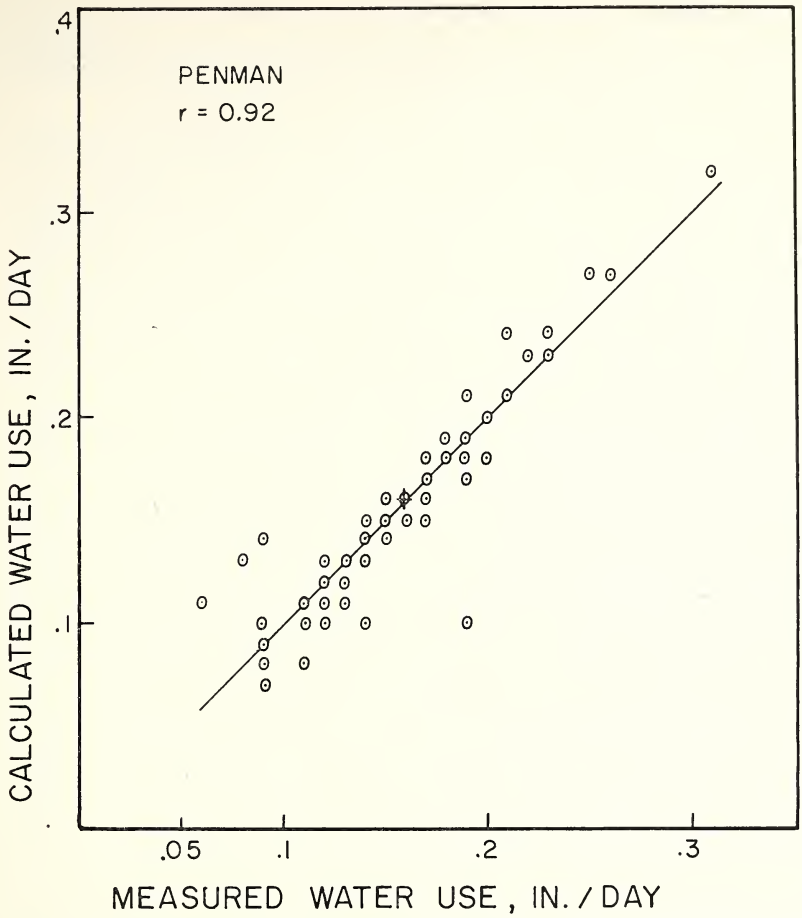

Figure 1. Relation of the Daily Evapotranspiration Rates Estimated by the Penman Formula to the Measured Daily Water Use Rates.

available energy and evapotranspiration, since the net radiation term has a prominent part in the equation. If net radiation data is available, solution of Penman's formula is relatively simple. However, if it must be computed, the equation is very complicated and time consuming. The energy balance approach is very promising; however, it is not likely to be generally adopted as a prediction technique unless net radiation measurements become more widely available and the information put on computer programs for computation.

It would be expected that the correlation coefficients of these various methods for estimating evapotranspiration and the measured water use would be greater as the time interval was increased. When weekly rates were compared, the coefficients were higher for the Livingston atmometers, and the Penman formula, but decreased for the Thornth-

waite, Blaney-Criddle, and the Class A Pan. However, it was interesting to note that the estimated daily water use rate averaged for the period July 11 to September 5 was 0.16 inches for all the methods which was identical to the measured average.

The results of the study indicated that if reasonably precise estimates of evapotranspiration are to be made over short periods of time, some measurement of radiation should definitely be considered. The evaporimeter has definite limitations, however it indirectly involves radiation, and because of its simplicity will receive future consideration. Any prediction formula relying mainly on temperature were of little value for estimating on a daily or weekly basis, however, when considering a seasonal water use was the same as the measured. This can be reasoned from the fact that temperature is a conservative parameter.

Literature Cited

1. BLANEY, H. F. and CRIDDLE, W. D. 1950. Determining Water requirements in irrigated areas from climatological and irrigation data. U.S.D.A. S.C.S. Technical Publication 96.
2. HALKIAS, H. A., VEIHMEYER, F. J. and HENRICKSON, A. H. 1955. Determining water needs for crops from climatic data. Hilgardia **24**
3. HOLDRIDGE, L. R. 1959. Simple method for determining potential evapotranspiration from temperature data. Science **130.** 572.
4. PENMAN, H. L. 1956. Estimating evapotranspiration. Transactions American Geophysical Union. **37**:43-46.
5. TANNER, C. B. 1960. Energy balance approach to evapotranspiration from crops. Soil Science Society America, Proceedings. **23**:1-9.
6. THORNTHWAITE, C. U. 1948. An approach toward a rational classification of climate. Geophysical Review **38**:55-94.
7. WIERSMA, DAN. 1961. Increasing crop potentials through water availability. Proceedings of the Indiana Academy of Science. **71**:347-352.