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ESTIMATING POTENTIAL EVAPOTRANSPIRATION FROM SCREENED PAN EVAPORATION*

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ABSTRACT

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Placing a 5-cm mesh wire screen cover on a USWB Class A pan reduced evaporation 12.8% below that of an open pan. A near 1:1 relationship was observed between screened pan evaporation and potential evapotranspiration computed from the combination equation, Van Bavel (1966) and Tanner and Pelton (1960), using the roughness length parameter $Z_0 = 1$ in the wind term. The heat and momentum transfer coefficients were empirically estimated. The Penman (1948) equation underestimated screened pan evaporation for wind levels exceeding 64 km/day. Open pan evaporation, calculated by the method of Kohler et al. (1955), approximated screened pan evaporation, but the variance associated with regression was appreciably more than that for the combination equation, $Z_0 = 1$. The analysis suggests that, if potential evapotranspiration estimated by a modified form of the combination equation with $Z_0 = 1$ gives a good estimate of potential evapotranspiration, then a screened evaporation pan would also give an acceptable estimate, provided the pan is surrounded by well-watered, reasonably short vegetation.

INTRODUCTION

Evaporation from open pans is a useful source of information for estimating upward water vapor flux from bodies of water and vegetated land surfaces. The reliability of evaporation measurements from open water pans depends upon the type of pan, installation, calibration, and interpretation of evaporation data in relation to the local environment (Pruitt, 1966) and accuracy of water-level measurement (Phene and Campbell, 1975). The usefulness of a field pan as a reliable evaporimeter may be questionable due to practical difficulties. Animals may consume and pollute water in open pans.

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Wire fencing or other obstructions, near the pan, may alter the wind structure over the pan site and increase deposition of foreign matter (Pereira, 1957). Stanhill (1962) reported that water from a United States Weather Bureau Class A pan, covered with an 0.8-cm mesh wire netting, evaporated at a rate 10.4% less than that from an open pan. These evaporation rates were measured in pans installed on bare, non-irrigated soil, within a 40 x 40 m fenced meteorological enclosure in an environment which was quite different from grass or tree-covered terrain of the semihumid climate in the southeastern USA.

Screen covers prevent water consumption by animals, reduce evaporation, and could be chosen so as to regulate the magnitude of evaporation to approximate actual evapotranspiration. Screens reduce the absorption of radiant energy and introduce an element of roughness that increases the thickness of the diffusion boundary layer, which, in effect, may be similar to roughness introduced by crops growing on wet soil. A screened pan can be a more practical tool for estimating crop water requirements than an open evaporation pan.

The effect of a wire-screen cover on the evaporation from a USWB Class-A pan was studied in the semihumid climate of Florence, South Carolina. Water loss by screened pan evaporation was compared with open pan evaporation, computed pan evaporation (Kohler, 1955) and potential evapotranspiration, as estimated from the combination equations of Penman (1948) and Van Bavel (1966).

EQUIPMENT AND METHODS

The screen cover

The supporting frame for the wire screen consisted of a 137-cm square angle-aluminum base with four vertical posts, 33.5 cm high at the corners, with 5-mm diameter wire strung tightly between the posts (see Fig.1). Hexagonal galvanized wire, 1 mm in diameter by 5 cm mesh, was stretched over the frame. This method of support minimized shadows at low sun angles. One side of the lower edge of the frame was attached to the wooden pan support with hinges to facilitate access to the pan for cleaning and manual measurements. The horizontal plane of the screen covering the pan was approximately 1.87 m^2 and 8 cm above the rim of the pan.

Covered and open pan measurements

Two pans, one open and the other screened, were equipped with duplicate electric float-activated sensors, Phene and Campbell (1975). The sensors had a sensitivity of $4.542 \pm .001$ V cm^{-1} of displacement and were mounted in a plexiglass base that fitted into the top of a standard cylindrical stilling well. The electronically activated float system enabled evaporation to be measured

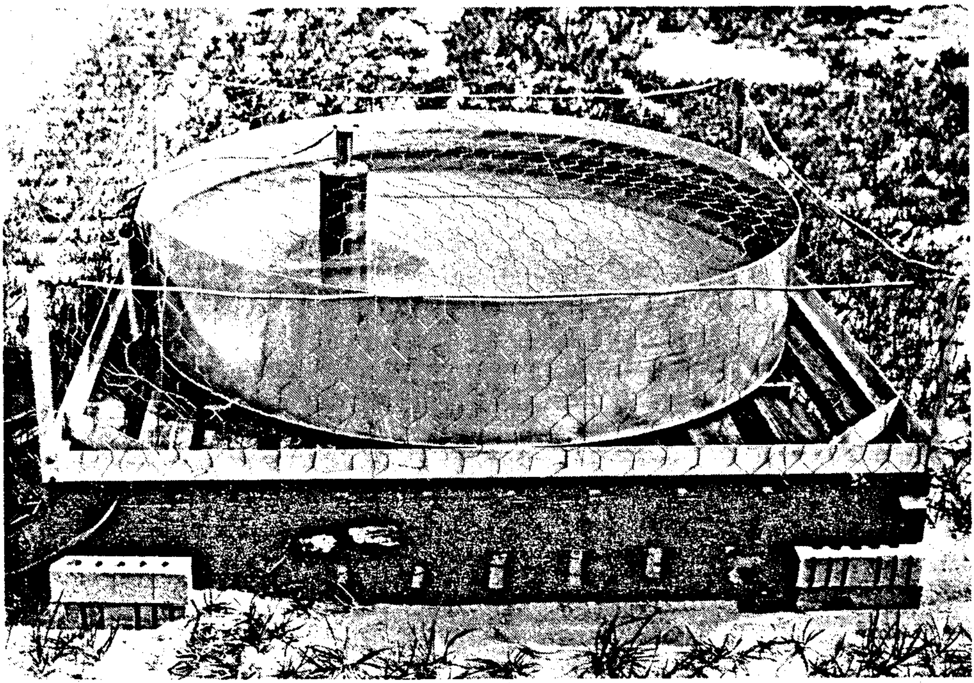

Fig. 1. Evaporation pan showing screen cover and electric transducers.

hourly and recorded on an automatic data acquisition system. Daily measurements made with the conventional micrometer were compared with hourly summations of the electronically sensed measurements. Evaporation was measured from open and screened pans between February 9 and May 3, 1974, only days without rain are reported. Rainfall was frequent enough during the measurement period to keep the soil surface moderately wet.

Covered pan evaporation and climatic relationships

The evaporation pan and the weather measuring instruments, used for calculating potential evapotranspiration, were located in a 30- by 30-m grassed area, surrounded by fields of cotton, corn, and soybeans. All evaporation and weather measurements at the field site were recorded hourly during the summers of 1973 and 1974. Daily computed evapotranspiration values sums of hourly calculations, except the daily totals used to calculate pan evaporation by the equation of Kohler et al. (1955).

Potential evapotranspiration was computed by the combination equation of Penman (1948), E_{PEN}, and also by the combination equation, E_{Z1}, presented by Van Bavel (1966), which included a wind term suggested by Businger (1956). Constants in Penman's equation were modified to calculate hourly values of potential evapotranspiration as follows (in mm h^{-1}):

$$E_{PEN} = [(\Delta/\gamma)(R_n - G)L^{-1} + 10.83 \cdot 10^{-3}(1 + 0.15W)(e_a - e_d)][(\Delta/\gamma) + 1]^{-1} \quad (1)$$

For the combination equation, E_{Z1}, the constant 0.0042 is derived for wind measurements at 2 m and a roughness length parameter, $Z_0 = 1$:

$$E_{Z1} = [(\Delta/\gamma)(R_n - G)L^{-1} + 0.0042W(e_a - e_d)][(\Delta/\gamma) + 1]^{-1} \quad (2)$$

Open pan evaporation, E_{PAN}, was computed by the method of Kohler et al. (1955) with the constants indicated (in mm day^{-1}):

$$E_{PAN} = 25.4[0.295(e_a - e_d)]^{0.88}(0.37 + 0.00195U) \quad (3)$$

where Δ = slope of saturated vapor pressure — temperature curve (mbar °C^{-1}); γ = psychrometric constant (mbar °C^{-1}); R_n = net radiation (cal. cm^{-2} h^{-1}); G = soil heat flux (cal. cm^{-2} h^{-1}); L = latent heat of evaporation = 585 cal. g^{-1}; W = wind (km h^{-1}); U = wind (km day^{-1}); e_a = saturated vapor pressure (mbar); e_d = vapor pressure (mbar); $(e_a - e_d)$ = hourly vapor pressure deficit (mbar).

RESULTS AND DISCUSSION

Comparison of screened and open pan evaporation

Daily evaporation measurements made during a 41-day period are grouped in Table I into low, medium, and high evaporation days. These data show that the percentage difference between the open and screened pan evaporation values was, essentially, independent of the daily amount of evaporation between 0.18 and 0.58 cm day^{-1}. Evaporation from the screened pan, E_{SP}, averaged 12.8% less than that from the open pan, E_{OP}. Total evaporation determined by hook micrometer measurements (Table I) agreed with summed, electronically sensed, measurements.

Hourly open and screened pan evaporation measurements for a 3-day period (Fig.2) show the open pan rate was higher than the screened pan rate between 12h00 and 24h00 daily. Beginning at 12h00, the average open pan evaporation was 13.6, 13.9, 16.2, 15.2, 13.9 and 10.2% more than that for the screened pan for successive 2-h intervals, respectively. The average difference between open and screened pan evaporation was 13.8% during this 3-day period, which almost agrees with the 12.8% difference for the entire test period. The difference in evaporation rate between the open and screened pans was maximum in the late afternoon between 16h00 and 18h00. Evaporation difference between the two pans was 14% of the daily evaporation and 16% of the evaporation during the period from 12h00 to 24h00. Hourly evaporation during the lowest evaporation period of each day, usually just before sunrise, was 0.01—0.02 mm h^{-1}.

TABLE I

Comparison of evaporation from open and screened pans for three periods differing in daily evaporation

Evaporation period	Julian days	Number of days	Average daily pan evap. (cm day^{-1})		Av. daily difference (%)
			open	screened	
LVDT Sensor					
Low	40—45	6	—0.217	—0.187	18.7
Medium	52—68	9	—0.478	—0.422	11.4
High	87—123	26	—0.580	—0.509	12.0
Weighted av.	41		—0.504	—0.443	12.8
Hook micrometer:					
Low	40—45	6	—0.212	—0.193	13.9
Medium	52—68	9	—0.472	—0.424	9.9
High	87—123	26	—0.576	—0.492	13.5
Weighted av.			—0.500	—0.433	12.7

Pan evaporation and potential evapotranspiration

Daily values of E_{Z1} and E_{SP} are plotted in Fig.3 in relation to time for a 27-day period in May and June, 1973. Linear regression equations of daily values of E_{Z1} presented as a function of E_{SP} (Fig.4) have the same slope of 0.94 in 1974 and 1974. Computed R^2 values account for 93 and 96% of the variance associated with E_{Z1} for 1973 and 1974, respectively. Regression equations for the $E_{Z1} - E_{SP}$ relationship were remarkably similar in 1973 and 1974 and they differed only slightly from the 1:1 relationship. Evapotranspiration calculated from E_{Z1} exceeded by 2% that measured by E_{SP},

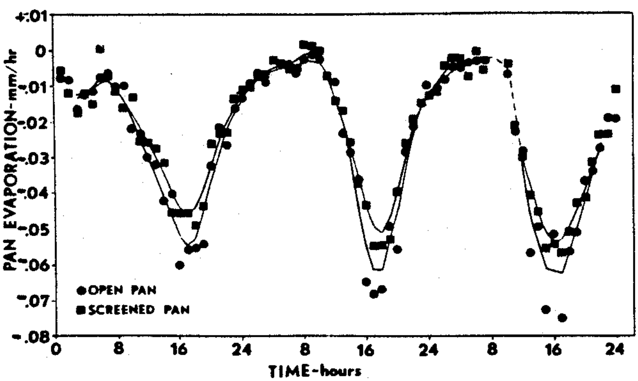

Fig. 2. Hourly evaporation for open and screened pans for a 3-day period.

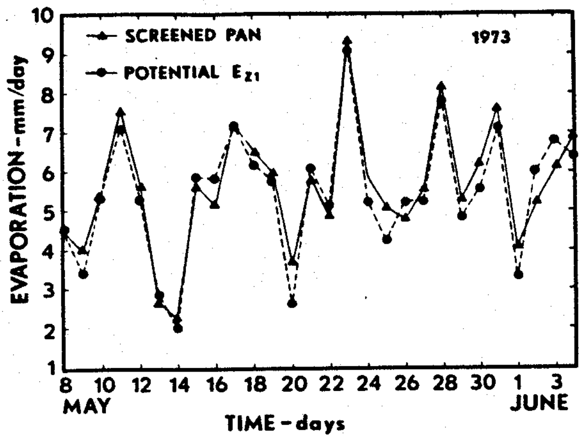

Fig. 3. Daily evaporation for open and screened pans for 27-day period beginning 8 May 1973.

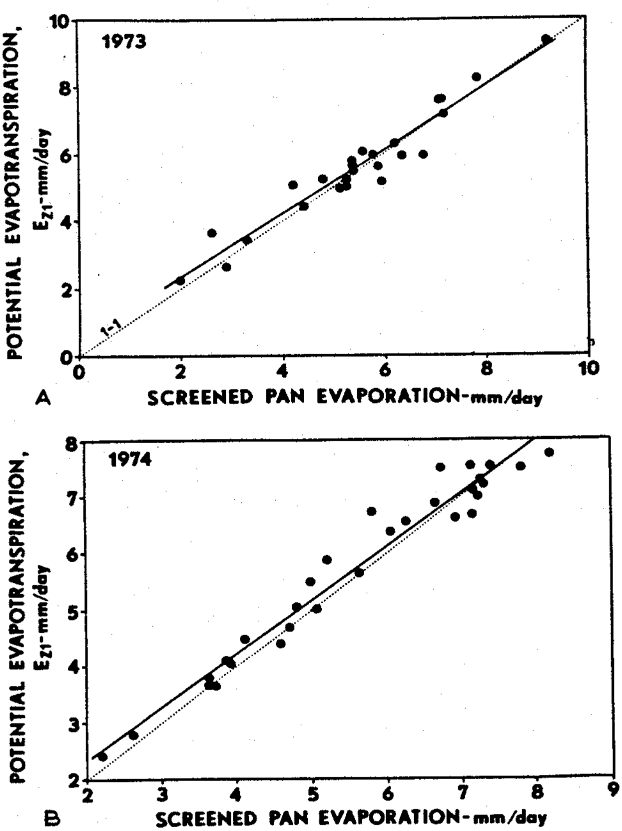

Fig. 4. Relationship between computed potential evapotranspiration (E_{Z1}) and evaporation from a screened USWB Class-A pan.
A. For 25 days in May and June 1973: $E_{Z1} = 0.454 + 0.94\ E_{SP}$; $R^2 = 0.93$.
B. For 30 selected days between May and September 1974: $E_{Z1} = 0.447 + 0.94\ E_{SP}$; $R^2 = 0.96$.

and, for many purposes these values could be considered equivalent. Computed E_{Z1} exceeded measured E_{SP} on low evaporation days and this difference narrowed to a negligible amount on high evaporation days. These data show that once the roughness coefficient was determined, E_{SP} predicted E_{Z1} very well.

Evidence that E_{Z1} or E_{SP} are acceptable estimates of evapotranspiration under the prevailing conditions at Florence, S.C., can be partially inferred from the studies of Makkink (1957), Van Bavel (1966), Tanner and Fuchs (1968), Wright and Jensen (1972), McGuinness and Bordne (1972), and Jensen (1974). Several of these investigations, using $Z_0 = 1$ to calculate E_{Z1} reasonably estimated actual evapotranspiration for moderately tall crops, like tall grass or alfalfa, in moderate winds. The use of Z_0 values > 1 for tall crops, like corn, gives high estimates of evapotranspiration which suggest that Z_0 could be a function of wind as suggested by Monteith (1963). This speculation seems reasonable, since the leaves of many crops tend to orient with the wind and present a smoothed canopy surface in moderate-to-high wind.

The R^2 value for the relation between E_{PEN}, calculated from eq.1, and E_{SP} was 0.88 and the slope was 0.69 (Fig.5). Calculated E_{Z1} values, shown in Fig.4, more nearly correspond with a 1:1 relationship for E_{SP} than that for E_{PEN}. Evaporation differences between the two combination relationships E_{Z1} and E_{PEN} can be attributed to their different wind functions in the convective term of eqs.1 and 2. The effect of the different wind functions is illustrated in Fig.6 where the ratio of E_{Z1} to E_{PEN} is plotted as a function of increasing wind speed, from 32 to 200 km day^{-1}. The regression line is defined by the equation $E_{Z1}/E_{PEN} = 0.91 + 0.0014W$. At a wind speed of 64 km day^{-1}, E_{Z1} is equal to E_{PEN} and for higher winds E_{Z1} exceeds E_{PEN}. Further discussion of these equations has been presented in articles by Tanner and Pelton (1960), Tanner and Fuchs (1968), Bartholic et al. (1970), and Jensen et al. (1974).

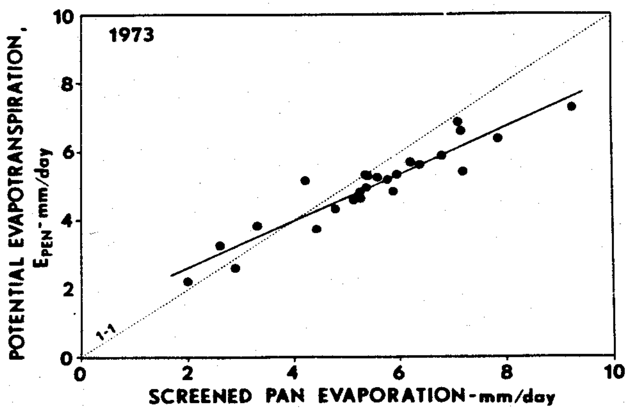

Fig.5. Relationship between computed potential evapotranspiration (E_{PEN}) and evaporation from a screened USWB Class A pan for 25 days in May and June 1973.

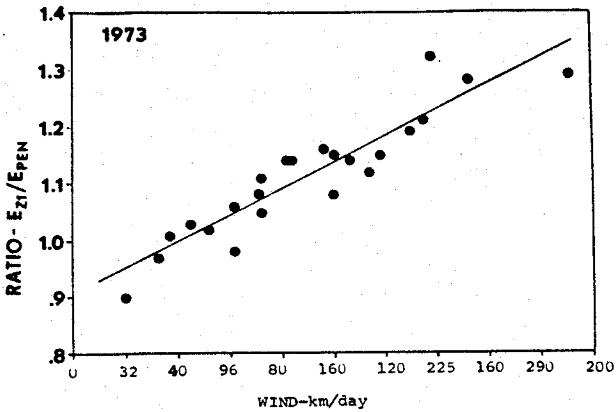

Fig.6. Relationship between the ratio of computed E_{Z1}/E_{PEN} and wind speed measured at 2 m.

Measured and calculated pan evaporation

Fig.7 shows pan evaporation, E_{PAN}, calculated from eq.3 and plotted as a function of E_{SP}. The R^2 value for the regression analysis of these data was 0.82 and the slope was 1.09. Although the evaporation rate, E_{PAN}, exceeded E_{SP} by 9%, total E_{PAN} was approximately equivalent to total E_{SP}. Since measured open pan evaporation, E_{OP}, given in Table I, exceeded E_{SP} by 12.8%, equation 3 slightly underestimated open pan evaporation at Florence, S.C.

The R^2 value for the relationship between E_{PAN} and E_{SP}, in Fig.7, is lower than that for the relationship between E_{Z1} and E_{SP}. This is probably because E_{Z1} and E_{SP} were measured and computed hourly and summed to give the daily total; whereas, E_{PAN} was calculated from vapor pressure values obtained

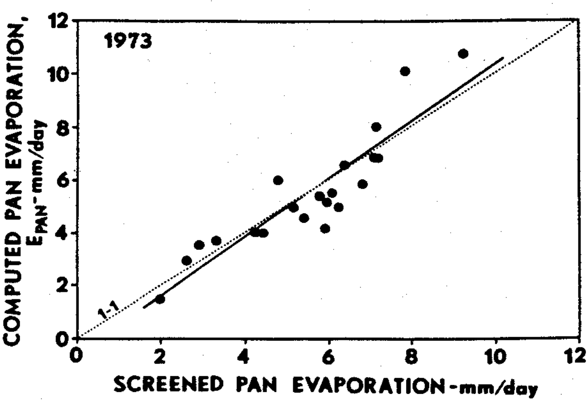

Fig.7. Computed open pan evaporation E_{PAN} shown in relation to screened pan evaporation E_{SP}.

from averaged hourly values and daily wind. Averaging vapor pressure differences gives greater weight to the night-time hours when evapotranspiration is normally low.

CONCLUSION

A screen placed over an open USWB pan prevented water consumption by animals and permitted more accurate evaporation measurements. An evaluation of the effect of the screen on evaporation showed that the cover reduced evaporation 12.8% over that from an open pan in the semihumid climate of the southeast. Since pans are useful evaporimeters for estimating potential evapotranspiration and for applying irrigation water, screened pan evaporation data were compared with the Penman and the combination (Van Bavel, 1966) methods for estimating potential evapotranspiration. Daily potential evapotranspiration values computed by combination equation using a roughness length, $Z_0 = 1$ agreed in magnitude and were highly correlated with daily values of screened pan evaporation measurements made in 1973 and 1974. Computed values by the Penman equation were generally lower than those for screened pan evaporation, particularly on days when evaporation exceeded 64 km day^{-1}.

Not only did screened pans give greater confidence in pan evaporation readings but the measurements also agreed with potential evapotranspiration calculated by one of the better known forms for estimating potential evapotranspiration from weather parameters.

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