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Author(s): William P. Lowry
Source: *Ecology*, Vol. 37, No. 3 (Jul., 1956), pp. 419-430
Published by: Wiley on behalf of the Ecological Society of America
Stable URL: https://www.jstor.org/stable/1930163
Accessed: 20-05-2024 11:44 +00:00

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EVAPORATION FROM FOREST SOILS NEAR DONNER SUMMIT, CALIFORNIA, AND A PROPOSED FIELD METHOD FOR ESTIMATING EVAPORATION

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INTRODUCTION

The measurement of evaporation from the earth's surface has devolved to several quite standard methods or techniques depending upon the accuracy of "measurement" (actually, approximation) desired by the worker for his study. The theories behind these several methods vary from complex mathematical statistical theories of turbulence to simple linear correlations of two or three variables (Anderson *et al.* 1950, Water Loss Investigations 1952). As might be expected, the complex approaches require equally complex instrumentation, and results are constantly under fire from opponents of the particular approach. The less complex techniques are not very elegant mathematically, but they have consistently given quite useful and apparently quite valid results with relatively little in the way of instrumentation (Anderson *et al.* 1950: 67). Despite the fact that simple approximation methods, such as the "vapor pressure deficit" approach, frequently give more usable and probably equally accurate results, these methods also come under fire (Thornthwaite 1940). Often the criticisms lack a constructive aspect, and under certain circumstances serve only to becloud the issues. This paper is an attempt to place the standard ecological evaporation techniques in a more encouraging light and to suggest a few modest improvements.

THE VAPOR PRESSURE DEFICIT APPROACH

The term "Vapor Pressure Deficit" has been used to mean either the difference between the saturation vapor pressure of the air and the ambient vapor pressure of the air $(E_s - E_a)$; or the difference between the saturation vapor pressure of a water or land surface and the ambient vapor pressure of the air $(E_b - E_a)$. The original statement of this variable as a measure of evaporation (rate) seems to have come from Dalton (1802) when he proposed a simple equation for evaporation rate from a water surface:

$$V = C(E_w - E_a) \qquad (1)$$

V = evaporation rate (mass per unit area per unit time)

E_w = saturation vapor pressure of water surface

E_a = ambient vapor pressure of free air near water surface

C = a proportionality factor most frequently formulated as a function of the barometric pressure at the station and the mean wind speed at which E_a is taken.

Since the measurement of a surface temperature can become quite a touchy problem, Penman (1949) points out that it is generally advisable to measure and use the other form of vapor pressure deficit in approximating evaporation rates: the expression $(E_s - E_a)$ referred to above, using the saturation vapor pressure of the air near the surface. An example of the use of this latter version of vapor pressure deficit in approximating evaporation appears in a recent study by Kucera (1954) in which an empirical expression of the form:

$$V = A + B\,(E_s - E_a) + Cu \qquad (2)$$

was derived where:

V = evaporation rate

$(E_s - E_a)$ = vapor pressure deficit as just described,

u = wind speed near the ground, and

A, B, C = constants.

Thornthwaite (*op. cit.*) goes to great pains to show why relationships such as (2) cannot physically be depended upon to give reliable measures

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of evaporation rate. Specifically, he cites several examples, in which an increase in the vapor pressure deficit, of the form $(E_s - E_a)$, could be accompanied by a decrease in evaporation rate, and vice versa. These hypothetical situations are completely correct as given, but one finds on further consideration that such situations are quite uncommon in nature. That is, V and $(E_s - E_a)$ generally change in direct proportion to one another in natural situations; so that although equation (2) cannot be rigorously derived, it is nevertheless quite dependable and useful in most commonly occurring environments.

So, we have mentioned two general relationships, (1) and (2), upon which most of the standard field methods for approximating evaporation rate are based. A simplification of (2) which is frequently observed to give good results may be written:

$$V = B\,(E_s - E_a) \qquad (3)$$

where the symbols are as before and the wind is ignored. Now let us examine a study which makes use of these relationships.

Observations of Evaporation from Forest Soils

The evaporation studies described below were originally carried out in an attempt to devise a method of estimating quantitatively the evaporation from soils in a specific area by means of a few simple instruments and records. In this case, the area is near Soda Springs, California, just west of Donner Summit, at an elevation of about 7,000 feet in the Sierra Nevada. (Fig. 1.)

The study was begun by placing an evaporation station in a semi-open site such that almost no direct sunlight would fall on it, but with almost complete freedom of horizontal wind movement near the ground. A pan having a 1000 cm^2 cross-sectional area and approximately 10 cm in depth was filled with soil and litter in as natural an arrangement as possible, and then the pan and soil were placed snugly in the resulting hole in the forest floor. The effect was to be that of introducing the pan into the plot without disturbance of the litter consistency or subsoil arrangement. That this was accomplished might be evidenced by the fact that two small pine seedlings continued to grow in the pan during the entire experiment at this site.

This station was located beneath a clump of trees at the edge of a park-like stand of mixed pine and fir of mature second-growth with an average height about 50 feet. This edge of the stand was near the bank of a mountain stream, and the effect was that of the pan being beside a wind channel in trees having almost no branches lower than the average midwinter snow pack depth of about 8 feet. (Fig. 2.)

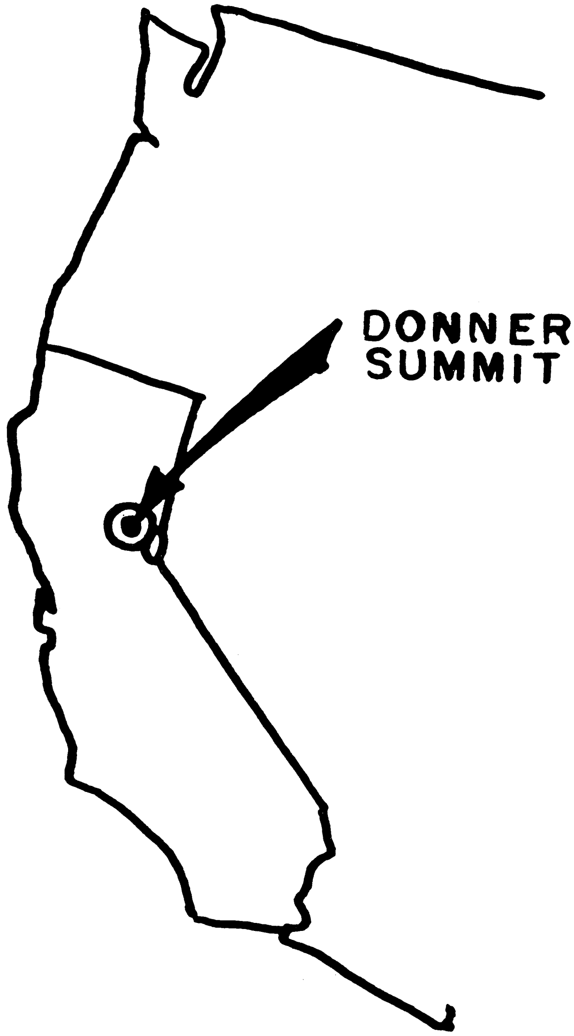


Fig. 1. Location map—Donner Summit, California.

At odd intervals, the pan was lifted from its berth and weighed at once on a triple beam balance graduated to the nearest gram. At the same time, a Weston bimetallic thermometer (0-100°F.), the long axis of whose sensitive element had been left about 3 cm below the soil surface in the pan, was read, the temperature recorded, and the pan replaced.

Also, on the ground next to the pan was placed a standard Weather Bureau instrument shelter housing a Friez USWB hygrothermograph with a weekly chart.

After 8 days of record had been taken with this setup, the shelter and instrument were moved to such a position that the hygrothermograph was 4 feet above the pan and still in a zone of almost unrestricted horizontal wind movement. A similar

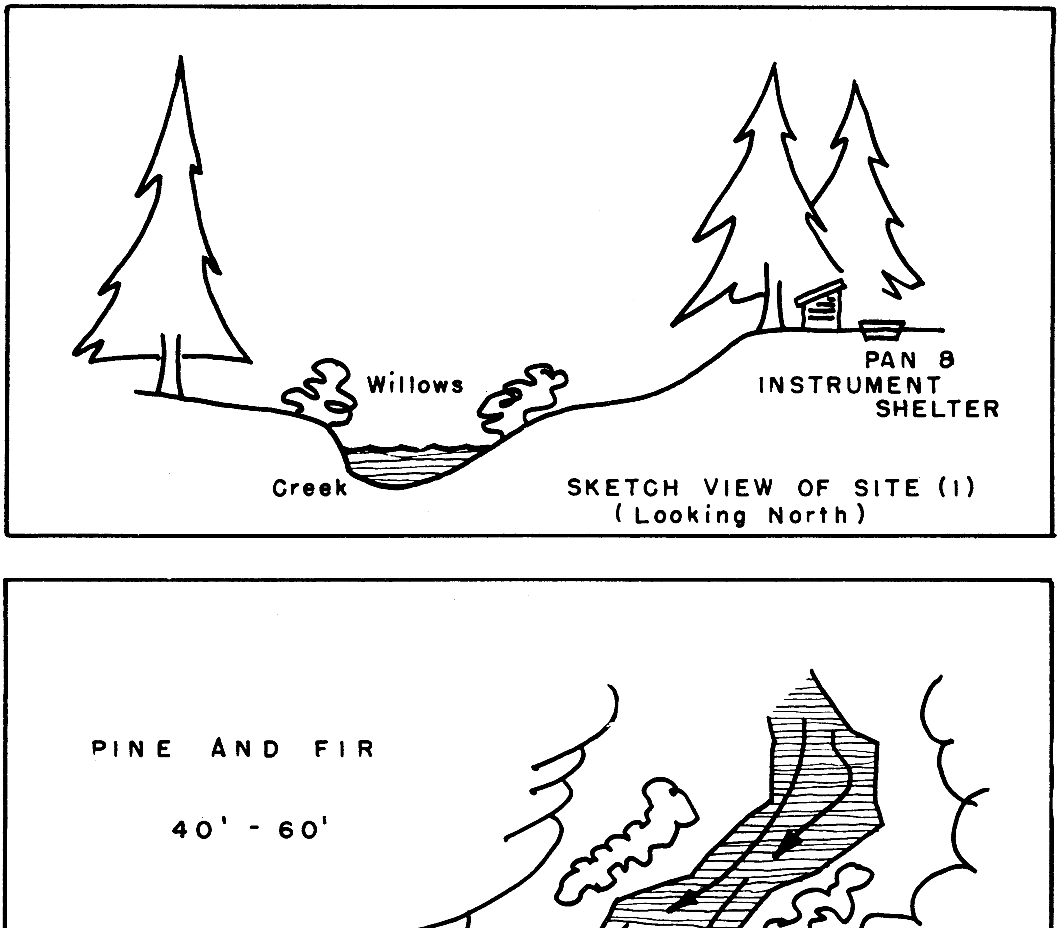


FIG. 2. Sketch of Site (1).

FIG. 3. Site (3) looking east.

length of record was taken with this arrangement, followed by several replication periods with the instrument once more on the ground.

In order to obtain comparable data from an environment having different physical attributes, a new station was established nearby in a small clearing (approximately 20 ft x 10 ft) in a dense stand of pine and fir having almost complete restriction of horizontal wind movement near the ground. (Fig. 3.) Several periods of record were taken here in a manner identical to that at the first site, but no measurements were made in the wooded site with the instrument off the ground surface.

Hereafter, the presentation of data will be grouped and designated as follows (with the dates of the periods of measurement):

Site description	*Site no.*	*Dates*
Semi-open, instrument on ground	(1)	7/1-9/52
		8/8-12/52
		8/15-20/52
		8/26-30/52
Semi-open, instrument at 4-foot level	(2)	7/9-17/52
Clearing in dense stand, instrument on ground	(3)	9/1-9/52
		9/15-22/52

The soil in the pan was not artificially watered, and no major amounts of precipitation fell during the individual periods of measurement. The few rainstorms of the summer occurred between observation periods. Since the period of the experiment was the summer following the largest winter's accumulation of snow on record in the area, the soil in and near the pan remained moist at all times.

A scheme was then devised to use these data in a formula of the form (1) as derived by Fitzgerald (1886):

$$V = (0.40 + 0.199\,u) \cdot (E_w - E_a)$$

V in inches per day
u in miles per hour
E_w, E_a in inches of mercury

In order to obtain values to use in this formula from the data collected, the procedure followed was simple, though relatively crude. First, a value for the wind speed was assumed, constant for all periods of observation. A value of 0.1 mph was taken as a general approximation in accord with extensive data measured in the immediate area by well-instrumented network of the Corps of Engineers, U. S. Army, and reported by Miller

(1952) as being typical of this height (0.5 meters) in this type of forest stand. Next, a time of day plot was made (Fig. 4) of the difference between the soil temperature and the air temperature (instrument at ground level) for each single observation made at Site (1). Through these points a smooth curve was drawn and assumed to be the invariant march of soil temperature relative to air temperature on every day of the record at that site.

For temperature and moisture data to be used in the calculations, mean temperature and relative humidity values were tabulated for each two-hour period according to the hygrothermograph charts. For each two-hour period, then, a mean saturation vapor pressure was determined by the mean temperature, and a mean ambient vapor pressure was determined by the product of mean relative humidity and mean saturation vapor pressure. A mean of the ambient vapor pressure for the observation period, with proper weighting allowance made for fractions of two-hour periods occurring in the observation period, was then taken as E_a for the period.

With no continuous record of soil temperature at hand, it was necessary to fall back on the temperature excess curve of Figure 4 for a correction to be applied to the mean air temperature. To obtain this temperature correction, the area under the excess curve (degree-hours) for the period of observation was divided by the number of hours in the period. The mean air temperature for the period plus the correction determined the value used as the mean soil temperature, which in turn determined the value of E_w used. Thus, all variables in the Fitzgerald equation were accounted for, except for the conversion of the values of V (rate of evaporation) from inches per day to total grams per cm^2 for the period, W (gm/cm^2).

The plot of calculated values against observed values for Site (1) (Fig. 5) shows the nighttime evaporation from the pan to be very well predicted by the method of calculation. True, the morning and night points (Table I) are slightly above the line of perfect correlation; but this may be accounted for by lower wind speeds than that assumed and by strong nighttime radiational cooling of the soil surface at high altitude, even under a copious canopy. The afternoon points lie on a line below perfect correlation, indicating an underestimation by the formula. Though the pan was in the shade during the day, this underestimation could be explained by the soil surface being warmer than that at a 3 cm depth and by higher wind speeds than assumed. It can be shown that the line of best fit passing through the scatter of afternoon points is that which would have resulted had a wind speed of 1.25 mph been assumed. This value (1.25 mph = 0.56 meters per second) agrees well with a value of 0.60 mps reported by Geiger (1950) for a similar pine stand. The dot-dash lines indicate the limits within which a calculated value would be within 50% of the observed value.

The plot for Site (2) (Fig. 6) shows considerable scatter and almost no stratification of data

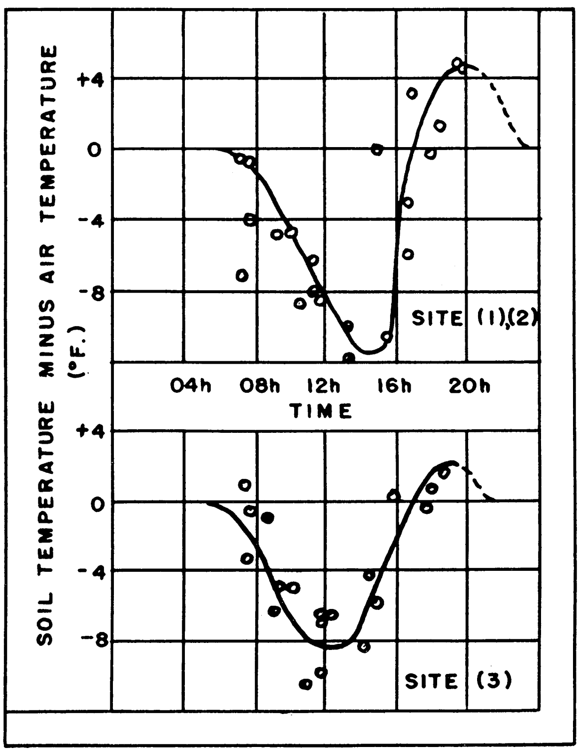


FIG. 4. Diurnal variation of (soil temperature minus air temperature).

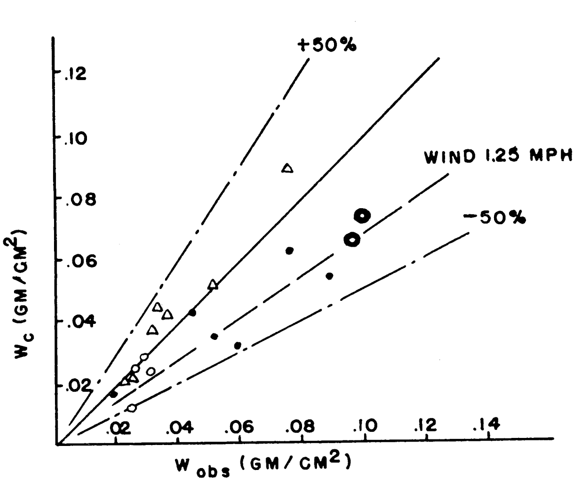


FIG. 5. Observed evaporation vs. calculated evaporation for Site (1) using Fitzgerald's formula.

TABLE I. Key to graphic symbols indicating time of day of observation period (all times Pacific Standard)

Observation period entirely within time 0600 - 1200	○
Observation period entirely within time 1200-1800	●
Observation period entirely within time 1800 - 0600	△
Observation period with at least 2 hours during 0600-1200 followed by at least 2 hours during 1200-1800	
Observation period with at least 2 hours during 1200-1800 followed by at least 2 hours during 1800-0600	
Observation period with at least 2 hours during 1800-0600 followed by at least 2 hours during 0600-1200	
Observation period longer than 12 hours, regardless of time of day.	□

according to time of day. This is probably to be expected because the data from which Fitzgerald first derived the formula were gathered with wind and temperature instruments very close to the water surface, as is the case with Site (1). However, the fact that there is no strong stratification (regardless of degree of correlation) seems to point to the idea that there is no great consistency in the relationship of the moisture gradient to the temperature gradient higher than the first foot or so above the site.

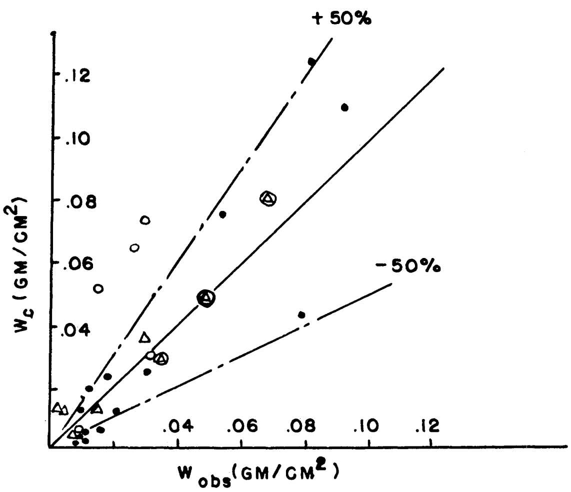


FIG. 6. Observed evaporation vs. calculated evaporation for Site (2) using Fitzgerald's formula.

The plot for Site (3) (Fig. 7) shows an immense overestimation by the formula. The curve to the left drawn by eye through the values as computed by Fitzgerald's formula suggests some sort of logarithmic function. Although no doubt not the best adjustment possible, the following equation linearizes the data sufficiently to justify saying that there is a logarithmic relation between the evaporation in a restricted site and that which one might expect at an open site under the same conditions:

Rohwer (1931) reports an empirical equation derived for use in still-air evaporation problems, but application of this equation to the data from Site (3) yields nothing in the way of a systematic relationship with the observed evaporation.

The most useful notions to come out of the use of Fitzgerald's formula might be that, 1) when the forest soil is still quite damp in the early summer, it can be expected to behave (with proper qualitative allowances for type of site) like a free water surface with respect to evaporation rates; and 2) many clues may be obtained by this comparison as to how the microclimate deviates from the microclimate of a site such as Fitzgerald used.

Using these same data in an equation of the form (3) gave results quite closely comparable to those of Kucera (*op. cit.*) (See Table II and Fig. 8). Thus, the basic concept of the vapor pressure deficit has been applied once again, this time to evaporation data from a subalpine environment with results equally as convincing as those from other environments from quite different climatic areas.

TABLE II. Correlation coefficients for various evaporation approximation methods as applied to data from Donner Summit, California

Method	Night and morning data	Afternoon data	All data
Fitzgerald's formula, Site (1)	....	....	0.85
Eq. (3), Vapor pressure deficit, Site (1)	0.88	0.38	0.92
Eq. (3), Vapor pressure deficit, Site (3)	....	....	0.75
Eq. (9), V.P.D. extension, Site (1)	....	....	0.74
Eq. (10), "P" method, Site (1)	0.88	0.67	0.88
Eq. (10), "P" method, Site (3)	....	....	0.87
Eq. (10), "P" method, Site (4)	....	....	0.97

AN EXTENSION OF THE VAPOR PRESSURE DEFICIT IDEA

Let us assume equation (3) to be correct and rewrite it slightly:

$$\frac{dW}{dt} = A\ (E_s - E) \qquad (4)$$

$W =$ evaporation in gm/cm^2

$A =$ constant $= .773$ in the case of Site (1) (Fig. 8)

$E_s =$ saturation vapor pressure of the air (mb)

$E =$ ambient vapor pressure of the air (mb)

$t =$ time

Since the relative humidity is defined as the ratio

$$r = E/E_s$$

we may rewrite the evaporation equation (4)

$$\frac{dW}{dt} = A\ (1 - r)\ E_s$$

$$V = .00873\left[\ln\left\{(0.40 + 0.199\,u)\cdot(E_w - E_a)\right\} + 5.188\right]$$

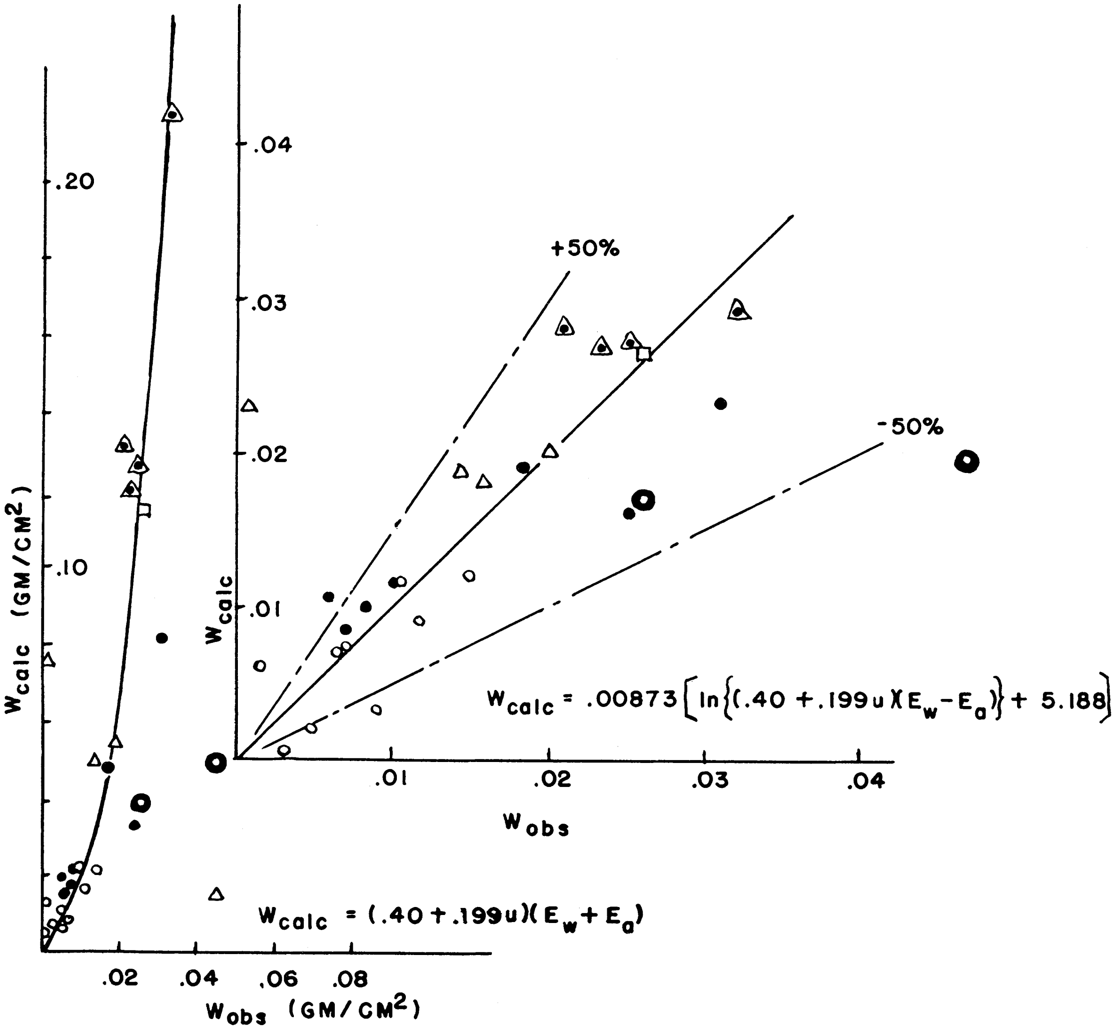


FIG. 7. Observed evaporation vs. calculated evaporation for Site (3) using Fitzgerald's formula.

and if we define $R = (1 - r)$, we have

$$\frac{dW}{dt} = ARE_s \qquad (5)$$

Now thermodynamic theory states that saturation vapor pressure over water is a function of absolute temperature alone: (in terms of natural logarithms) (Holmboe *et al.* 1945: 51)

$$E_s = e^{-(B/T) + C}$$

for example: $B = 5418$; $C = 19.336$
when: E_s in centibars
T in absolute temperature (°K).

Since the temperature and relative humidity may be expressed as certain functions of time through a diurnal cycle:

$$T = F_1(t) \qquad R = F_2(t)$$

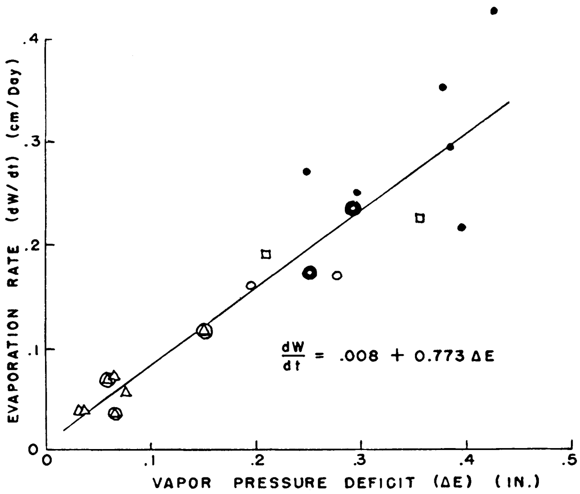
we are in a position to express evaporation as a function of time alone:

$$\frac{dW}{dt} = A \cdot F_2(t) \cdot e^{\left(\frac{-B}{F_1(t)} + c\right)} \qquad (6)$$

Equation (6) is an ordinary differential equation of W in terms of t. Perhaps if we knew F_1 and F_2 we could integrate and know W explicitly. But the first problem now is to find (or approximate) F_1 and F_2. For a day or group of days having maximum temperature (T_M) and minimum temperature (T_m), maximum relative humidity (r_M) and minimum relative humidity (r_m), F_1 and F_2 might be approximated roughly by very simple periodic functions:

$$T = \left(\frac{T_M - T_m}{2}\right) - \left(\frac{T_M - T_m}{2}\right) \cdot \text{Cos } 2\pi t \approx F_1(t) \qquad (7)$$

$$R = \left(\frac{(1 - r_m) + (1 - r_M)}{2}\right) - \left(\frac{(1 - r_m) - (1 - r_M)}{2}\right) \cdot \cos 2\pi t \approx F_2(t) \qquad (8)$$



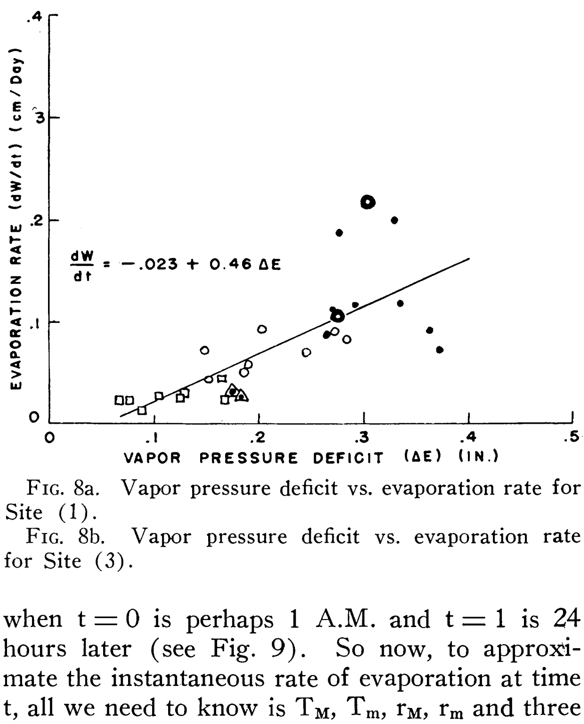


Fig. 8a. Vapor pressure deficit vs. evaporation rate for Site (1).

Fig. 8b. Vapor pressure deficit vs. evaporation rate for Site (3).

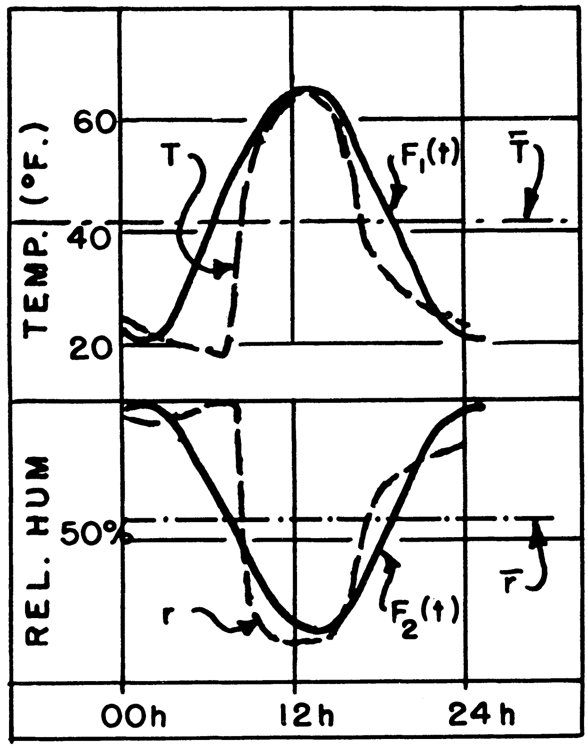


Fig. 9. Illustrating how simple periodic functions approximate R and T.

when $t = 0$ is perhaps 1 A.M. and $t = 1$ is 24 hours later (see Fig. 9). So now, to approximate the instantaneous rate of evaporation at time t, all we need to know is T_M, T_m, r_M, r_m and three constants A, B, C, according to equations (6), (7), and (8).

If the mean temperature is $\bar{T}$, the departures of T_M and T_m from $\bar{T}$ equal T′, and similarly for R and r, equation (6) becomes.

$$\frac{dW}{dt} = A\,(\bar{R} - R'\cos 2\pi t)\, e^{-[B/(\bar{T} - 2T'\cos 2\pi t)] + c} \qquad (9)$$

To solve this differential equation for total evaporation W appears quite formidable. But since there is only one independent variable, it might be possible to solve for dW/dt for various values of t. We would then have the slope of the W vs. t curve for the several values of t, and a good approximation to the integral curve may be drawn by simple geometric construction using these slopes. But the problem then arises to construct a scale of W on the graph to go with the curve and the scale of t. One value of W can be computed consistent with the preceding approximations as follows:

Using equations (7), (8), and then (9) and setting $t = \frac{1}{4}$, $dt = \Delta t = 1$ (day), we may calculate $dW = \Delta W$ for one day:

$$\Delta W = A\bar{R}e^{-(B/\bar{T}) + C}\Delta t = A\bar{R}\bar{E},$$

where $\bar{E}$ = mean daily vapor pressure, and A is evaluated from (3). Now we have two points on our scale of W: $W = 0$ for $t = 0$, and $W = \Delta W$ for $t = 1$. Making a linear scale for W to conform to these two points completes the construction of the W vs. t curve (see Figure 10). Assuming our approximations for R and T are satisfactory over a period of time, say a week, we may approximate the total amount of evaporation from the curve of equation (9) simply by the change in W from the beginning of our sample period to the end. For example, if a sample period began at 0800 on D-day and ran until 1600 on D + 3-day, we would first read the value

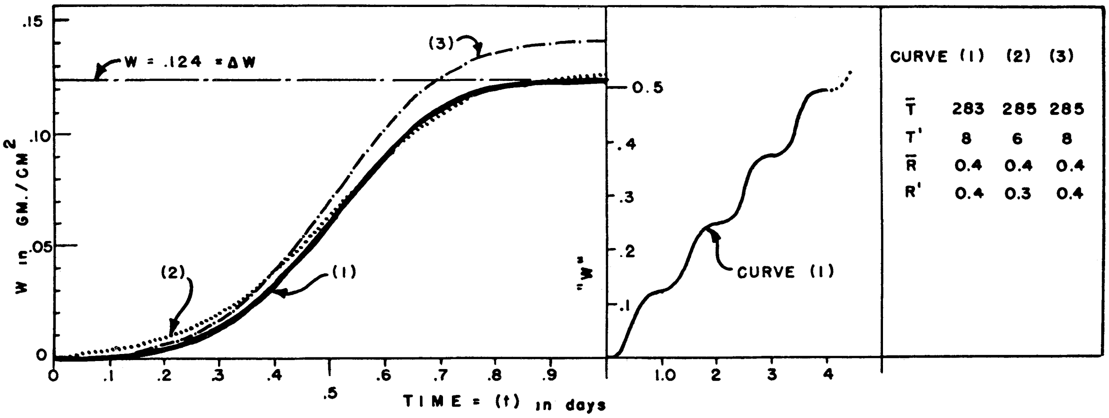


FIG. 10. Evaporation vs. time with variations in $\bar{T}$, T', $\bar{R}$, R', according to Equation (9).

of W above $t = 0.33$ $(= 8/24)$ and then subtract it from the value of W above $t = 3.67$ $(= 3 + 16/24)$ to get the total evaporation in the period. Some idea of the variation of equation (9) with variations in $\bar{T}$, T', $\bar{R}$, and R' may be gotten from the secondary plots in Figure 10. The equation is examined merely to suggest how mathematical statements of the variation of evaporation through the day may be developed.

The application of this extension of the vapor pressure deficit idea to the data from Site (1) gives results having quite acceptable reliability when compared with those relationships of the form of equation (3). Obviously, the better the mathematical approximations used in (7) and (8), the better will be the results from (9).

A FURTHER EXTENSION

A close look at equation (9) suggests a further extension of this approach. Since T is expressed in degrees Absolute (that is freezing = 273° A.), the percentage change in T through the day is relatively small: *i.e.,* $T'/\bar{T} \approx 3.5\%$ only Because of this, we may consider $\bar{T}$ to be a constant temperature through the day, with a resulting constant saturation vapor pressure, $\bar{E}$. Equation (5) then becomes:

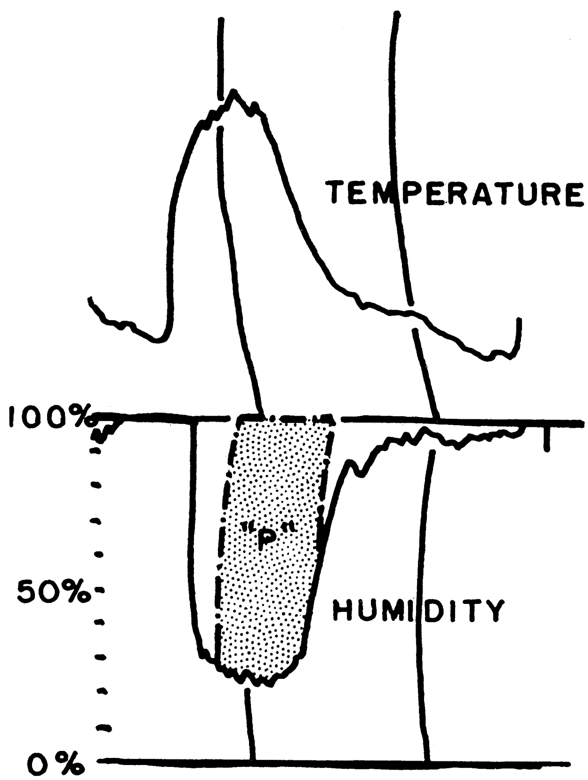


FIG. 11. Illustrating area "P" on a hygrograph chart.

$$\frac{dW}{dt} = A\bar{E}R = (A\bar{E}) \cdot F_2(t) \text{ and } dW = (A\bar{E})\, Rdt.$$

Intergrating the expression now between limits:

$$\int_0^w dW = (AE) \cdot \int_0^t Rdt \qquad (10)$$

gives us a new expression $W = A\bar{E}P$ when we define $P = \int_0^t R\, dt$. For a given observation period during which a continuous record of relative humidity (and thus, R) was obtained on a hygrograph chart, P is represented by the area on the chart between the trace of relative humidity, the 100% humidity line, and the beginning and end of the period (see Figure 11). Since $(A\bar{E})$ is very likely almost constant for a given environment, or surface, for a period of possibly a week or so, an observer may "calibrate" an area for quick approximations of evaporation.

To make this calibration, simply obtain several measurements of evaporation (*e.g.,* as described above using pan and scales) along with a humidity record. Then, planimeter, or measure the area, under the trace on the chart for each sample period. This area, P, when plotted against the

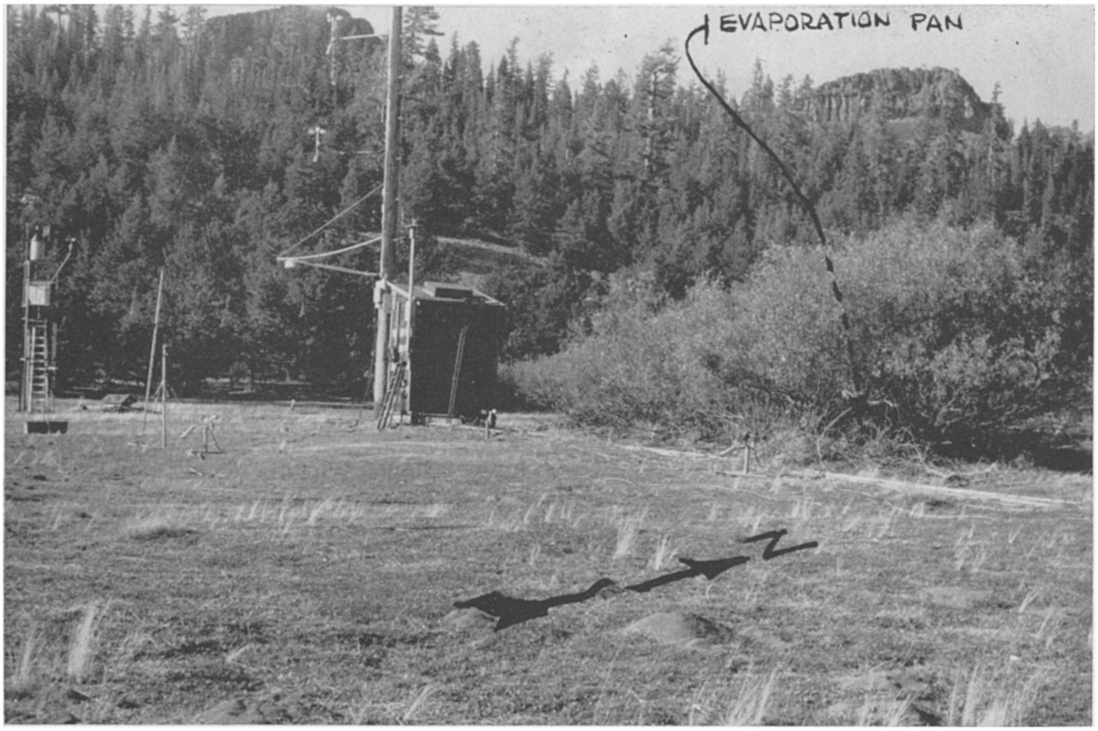


FIG. 12. Site (4) looking northwest.

observed W on log-log graph paper should give a straight line with slope 1 by the nature of equation (10).

Examples of such plots for the three sites of the Donner Summit study and an additional Site (4) in a subalpine meadow (Figure 12) appear as Figures 13, 14, 15, and 16. Of particular interest is the fact that in Sites (1) and (2), where the pan was open to vigorous wind action and strong diurnal heating nearby, the afternoon points lie along a distinctly separate line with slope greater than 1. In Sites (3) and (4) this apparently does not happen, and the slopes are very nearly 1. Values of "P" are expressed as fractions of the total area between 100%, 0%, and two time lines one day apart, *i.e.,* the maximum possible value of "P" for one day. Note the scale in the figures is 245 P, since the planimeter used measured 245 units for this maximum daily area for "P."

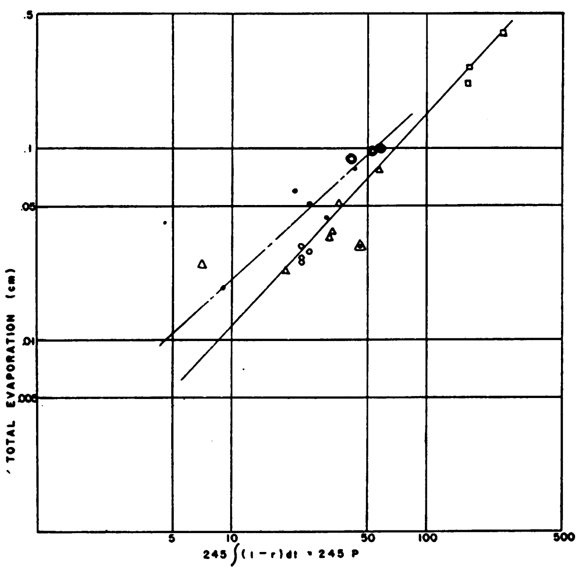


FIG. 13. Estimation of total evaporation by the "P" Method, Site (1).

Correlation analyses of these plots (Table II) show that the predictability of evaporation using this method is consistently as high as by the two standard methods mentioned, if not higher. When combined with the reduced expenditure of work in calculation and elimination of the use of tables of vapor pressure, this feature of high predictability makes the planimeter, or "P" Method, seem worthy of consideration as a field method for approximating evaporation. In addition, the method results in an estimate of evaporation directly and not of an evaporation rate for the observation period.

The principal limitations of the method appear to be:

1) the tacit assumption of a uniformly cyclic environment as regards air temperature and wind for the estimation period,

2) assumption of constant supply of soil moisture in the surface layer through the estimation period,
3) no allowance for dewfall,
4) the length of continuous estimation period during which the method is usable depends on site, climatic area, and probably season.

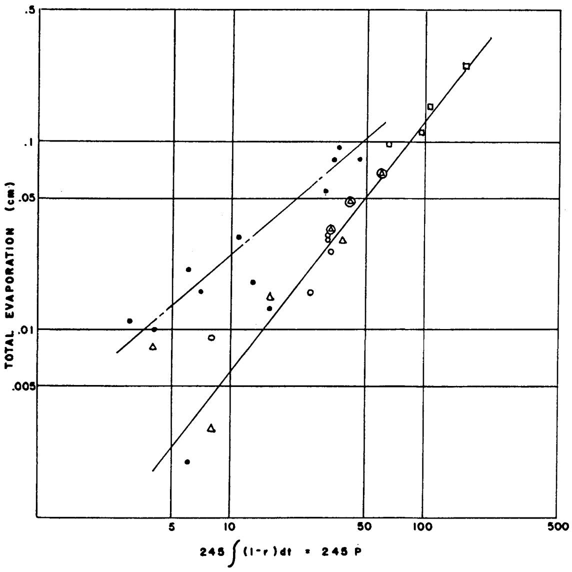


Fig. 14. Estimation of total evaporation by the "P" Method, Site (2).

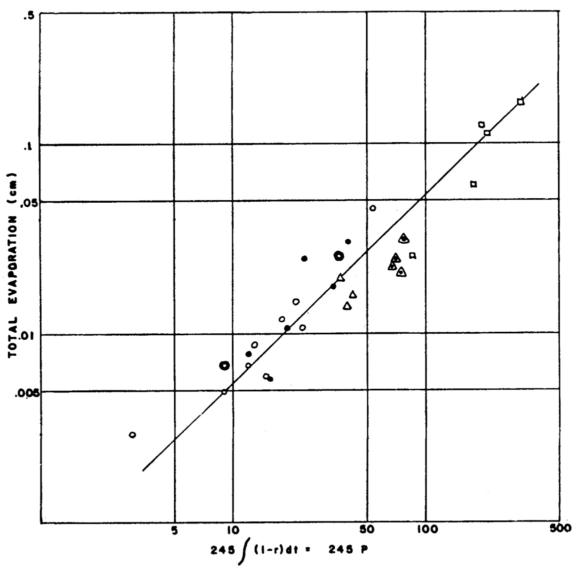


Fig. 15. Estimation of total evaporation by the "P" Method, Site (3).

Much work on the applicability of this "P" Method to widely varying environments could be done with very small investments of time and instruments. Two suggestions to further reduce the time involved in getting a field approximation by this method follow from the nature of equation (10) and the nature of the trace on the hygrograph chart:

1) Diurnal variations in evaporation rate are damped out when an observation period extends to about 3 days, as shown by the fact that the two lines converge to the right in Figures 13 and 14. Therefore, the evaluation of equation (10) could theoretically be accomplished by setting out a weighed evaporation pan and then weighing it again 3 to 5 days later. The total area P obtained and the W measured for this period would determine a single point on the log-log graph. If a line with slope 1 were then drawn through this point, the approximating curve would be complete.

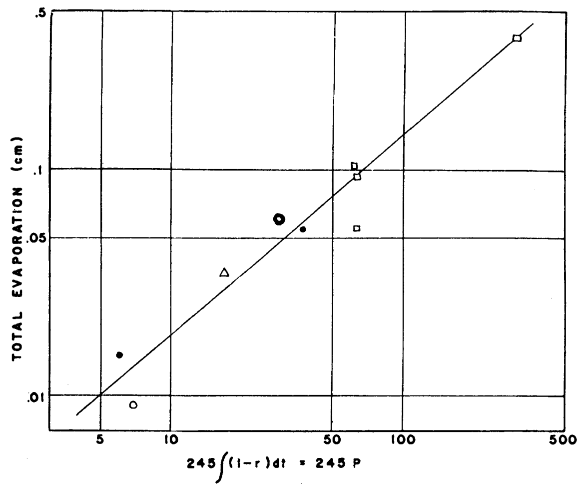


Fig. 16. Estimation of total evaporation by the "P" Method, Site (4).

2) Instead of using a mechanical planimeter to measure the area under the humidity curve, one could use an overlay with small grid or the chart itself, and just count squares (and half-squares) to get a relative measure of the area.

Summary

Two standard field methods for approximating evaporation (rates) based on the vapor pressure deficit concept have been reviewed and applied to data collected in several kinds of environments near Donner Summit, California. The reliability of the methods at high altitudes compares well with results reported by other workers in other areas.

A mathematical extension of the vapor pressure deficit equation is developed, leading to a much simplified method of making field approximations. If a soil-filled pan is placed level with the soil surface and weighed periodically to obtain a measure of evaporation, and a hygrograph giving a

continuous humidity record is placed beside the pan, it is shown that the area under the humidity trace on the chart and between the beginning and ending times of the observation period yields a straight line relationship when plotted on log-log graph paper against the evaporation measured for the same period.

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GERMINATION REGULATING MECHANISMS IN SOME DESERT SEEDS III. *CALLIGONUM COMOSUM* L'HER.[1]

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Introductory

Calligonum comosum is a summer-shedding woody shrub, reaching a height of 100-120 cm., and a crown diameter of 100-350 cm. The plant is a native of coarse sandy soils in the Sahara (Good 1947) and in the Negev (southern Israel; Eig, *et al.* 1948). Together with *Haloxylon persicum,* it forms the climax vegetation in the sandy soils of the borders between the Saharo-Sindian deserts and the Irano-Turanian steppes, where annual precipitation does not execed 150 mm. The plant is considered as a valuable perennial pasture plant for the above-mentioned regions (Boyko 1949a), and an excellent binder of shifting sands, owing to its high resistance to sanding-over (author's observations).

The dispersal unit is a brownish-red achne, covered from tip to tip with 8-16 rows of bristles. The achene itself is 10 mm long and 3-4 mm thick, but with the bristles, it reaches a length of 20-25 mm and a thickness of 15-20 mm. The bristles are soft and elastic, and break off quite easily. They do not attach themselves to wool, etc., but appear to serve in fruit dispersal by helping the fruits to roll along the ground under the influence of winds, through the springy nature of the bristles.

The fruit coat is about 1 mm thick and very tough. It was found impossible to remove the fruit coat without damaging the seed, and consequently all germination tests were carried out with intact dispersal units.

Materials and Methods

The dispersal units were collected in Nahal Timna (Wadi Menaiyeh) in the southern Negev, in May, 1951. Germination was carried out on filter paper, cotton wool, or coarse sand in Petri dishes; or imbedded in coarse sand, inside deep plastic containers. Tap water was used throughout. Counts were usually started after four or five days, and repeated at two-day intervals. Illuminated incubators at 15°, 20°, 26°, and 30°C. were used. Most experiments were run parallel in continuous light and in dark (obtained by placing the dishes or containers inside light-tight tins).

Results and Discussion

(1) Light and temperature effects

The effects of various light/temperature combinations on germination of the dispersal units

[1] Thanks are due to the Ford Foundation which supported this work. The author wishes also to express his thanks to Professor Michael Evenari for his kind interest throughout this work, and to Messrs. Moshe Negbi, Yehuda Ben-Shaul, and Dan Cohen for their assistance in the field experiments.