A PRACTICAL EVAPORIMETER

DOYLE COOK

Weather Bureau Agricultural Service Office, Lexington, Ky.

ABSTRACT

An evaporimeter is described which yields evaporation data that are probably superior to evaporation data computed from micrometer hook gage readings. The evaporimeter also gives accurate hourly rates of evaporation and provides means for arriving at reasonable amounts of evaporation during periods of precipitation.

1. INTRODUCTION

Under natural conditions, the rate of evaporation, or the amount of water turned to aqueous vapor in a given time, is a function of the following meteorological factors:

(a) solar and sky radiation,
(b) the vapor pressure deficit of the atmosphere surrounding the container,
(c) the flow of air past the evaporating surface,
(d) the air temperature which controls the temperature of the liquid and also determines the upper limit of the vapor pressure deficit.

Measurement of evaporation from a free water surface provides a value which could be used as an expression of the integrated effect of all these meteorological factors.

Evaporation has long been recognized as an important meteorological parameter. Although many means for determining evaporation amounts are available, no device has yet been developed to record this value satisfactorily.

In addition to meteorologists, scientists of various other disciplines have recognized the importance and need of a method for recording evaporation on a continuous basis. G. W. Robertson [1] indicates that an evaporimeter should:

(a) Be economical in construction;
(b) Be simple in operation and easy to care for;
(c) Measure evaporation on a daily basis at least, but operate continuously so that, at most, weekly totals could be determined;
(d) Have a sensitivity comparable with that of rainfall-measuring instruments;
(e) Be constructed of noncorrosive material;
(f) Be so constructed that rain and dew will not affect measurements;
(g) Not be accessible to birds, animals, etc.

Meyer and Anderson [2] point out that one of the commonest observations among agriculturists and gardeners is that the leaves of many species of plant often wilt on hot summer afternoons, only to regain their turgidity during the night even if the plants are not provided with additional water by rainfall or irrigation. This familiar temporary wilting results from excess stress being placed on the plant by the same meteorological factors which control the evaporation rate. It would thus prove helpful to agronomic research if an evaporimeter gave a constant recording of the evaporation rate for shorter periods than the presently accepted 24 hr. Hourly rates should prove of value.

It would be difficult to obtain hourly evaporation rates with a hook or similar gage, as expansion or contraction caused by temperature changes would probably obscure or exaggerate the readings.

2. EVAPORIMETER DEVELOPED

Evaporation measurements have been made for the past six growing seasons by personnel of the Agronomy Department, University of Kentucky, Lexington, Ky. on the University of Kentucky Agricultural Experiment Station Farm using instruments of the same type and standard as used by U.S. Weather Bureau Class A evaporation stations. A micrometer hook gage is used to measure changes in the level of water in the evaporation pan. Evaporation amounts are computed from the hook gage measurements and concurrent precipitation measurements.

In 1966, after establishment of a Weather Bureau Agricultural Service Office on the campus of the University of Kentucky, the author began construction of an evaporimeter which would satisfy Robertson's criteria. Figure 1 is a schematic diagram of the system which evolved.

A 12-in. dual traverse weighing rain gage provides sensitivity such that chart graduations of 0.05 in. are normally used. It was desired to increase the sensitivity to the point that chart graduations of 0.02 in. could be used, thus allowing readings to the nearest 0.01 in. A 12-in. gage was therefore modified so that a complete dual traverse indicated 4.8 in. This modification gave

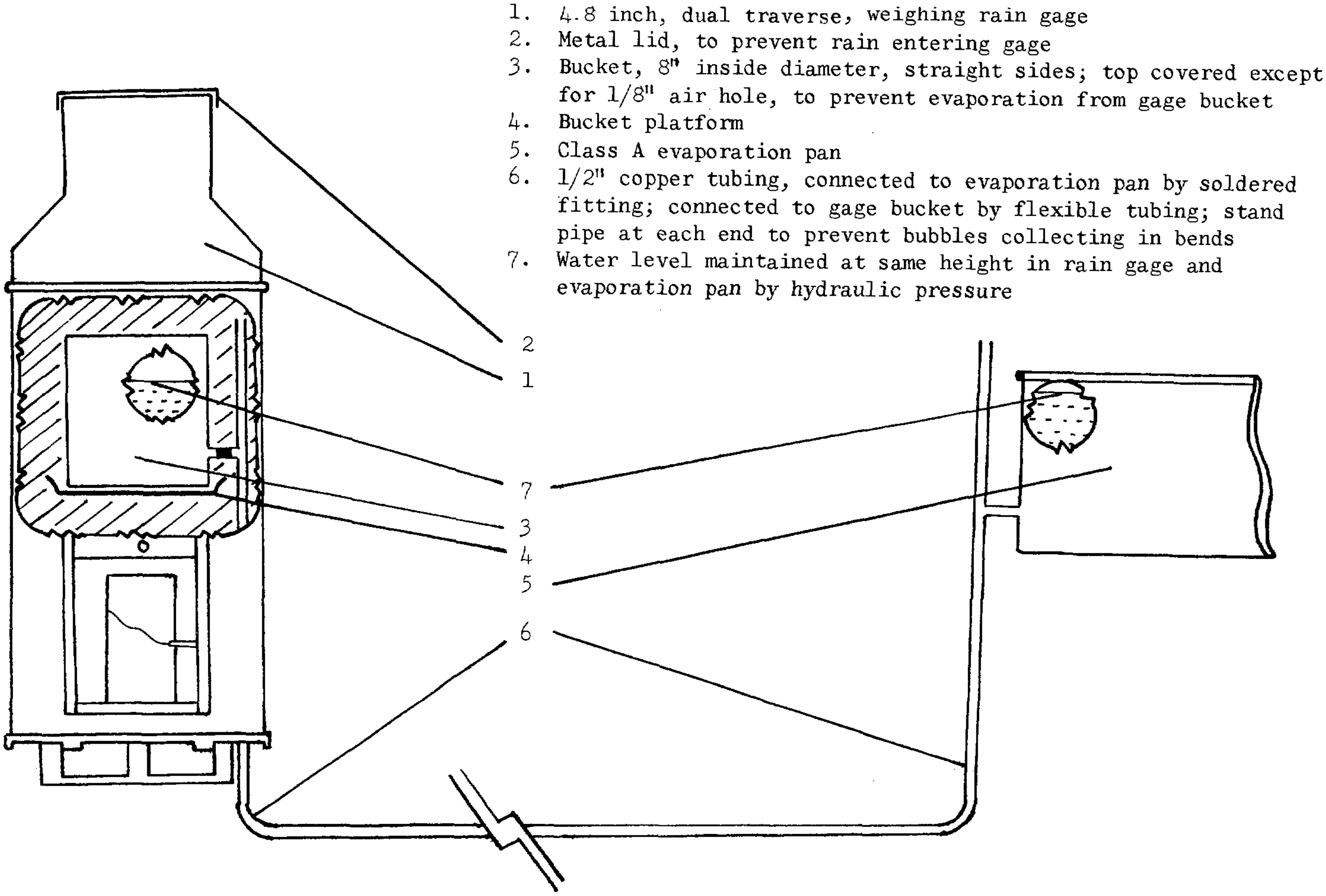

FIGURE 1.—Schematic diagram of a practical evaporimeter.

sensitivity comparable to that of rainfall measurements as well as a range of measurement satisfactory for most evaporation measurements.

This gage was originally constructed to catch water falling through an 8-in. aperture, and by weighing the water to indicate the depth of water which had fallen through the aperture. A straight-sided bucket with inside diameter of 8 in. (the bottom part of a standard 8-in. non-recording precipitation gage) was installed on the modified gage. Thus the change of depth of water within the bucket could be recorded to the nearest 0.01 in. on the recorder chart. The evaporimeter bucket was covered with an aluminum lid to eliminate evaporation within the instrument and a small hole was drilled through the lid to equalize pressure as water was removed from or added to the bucket.

The entire assembly was installed adjacent to the University of Kentucky's evaporation pan at a height such that the top of the evaporation pan fell below the 4.8-in. level of the evaporimeter bucket.

Various methods were tried to assure that the level of water in the evaporimeter would always be exactly even with the level of water in the evaporation pan. Siphoning proved unsatisfactory; air bubbles accumulated in bends of the tubing and shut off the flow of water between evaporimeter and evaporation pan.

The most satisfactory method for connecting the two containers was that shown in figure 1. Different sizes of copper tubing were tried. The general rule seems to be that the larger the tubing, the less the trouble. Evaporimeter records made when 3/16-in. diameter tubing was used for connection between evaporimeter and evaporation pan showed a large lag between pan refill and complete evaporimeter reaction. The connection depicted in figure 1 with ½-in. diameter tubing gave full-scale response within 5 min.

Accurate calibration for pen movement in both directions was performed for the entire evaporimeter scale. With this type recorder it is possible for slack to develop in the gears and cause a loss of record when the direction of pen movement changes (such as at the beginning or after the end of precipitation) or when the pen passes through the reversal point. Regular calibration should be part of any evaporimeter program.

From the Class A pan alone, evaporation of 1 in. of water converts to aqueous vapor 1772.06 in.^{3} of water. Because of hydraulic pressure from the evaporimeter bucket, and resultant addition of water to the evaporation pan, when 1 in. of water is evaporated from the evaporation pan there has actually been a loss of 1822.33 in.^{3} of water by the process of evaporation. Thus the evaporimeter actually records only 0.972 of the actual evaporation. For an evaporation pan of inside diameter 47.5 in. and an evaporimeter bucket of inside diameter 8 in., the following corrections apply to all records (evaporation and pan refill):

Amount (in.) Recorded by Evaporimeter	*Correction (in.) to Achieve Actual Evaporation or Refill*
0–0.17	0
0.18–.53	+0.01
.54–.88	+0.02
.89–1.24	+0.03
1.25–1.60	+0.04

Two methods may be used to apply this correction. The evaporimeter may be calibrated to give accurate responses to changes in pan water depth. The above corrections then may be applied arithmetically after evaluation of the recording. Or, the evaporimeter may be calibrated to give response which includes the above corrections. The latter method was used with the University of Kentucky evaporimeter system.

3. EVALUATION OF EVAPORIMETER

Table 1 lists comparative data, using as a standard of comparison evaporation computed from hook gage and precipitation observations taken at 8 a.m. EST each morning from September 18 through October 21, 1966. Figure 2 shows the distribution of evaporimeter error.

TABLE 1.—*Comparative data. Evaporation computed from hook gage measurements and recorded by evaporimeter*

Date 1966	Evaporation computed from hook gage measurements (in.)	Evaporation recorded by evaporimeter (in.)	Evaporimeter error (in.)
Sept. 18	0.10	0.09	−0.01
19	.19	.20	+.01
20	.09	.11	+.02
21	.14	.11	−.03
22	.12	.11	−.01
23	.18	.18	.0
24	.19	.22	+.03
25	.16	.15	−.01
26	.11	.10	−.01
27	.01	.01	.0
28	.05	.01	−.04
29	.06	.07	−.01
30	.57 { .44 { .27	.57 { .45 { .22	−.05
Oct. 1	.17	.23	+.06
2	.02	.04	+.02
3	.09	.10	+.01
4	.21	.22	+.01
5	.14	.16	+.02
6	.18	.18	.0
7	.10	.12	+.02
8	.13	.14	+.01
9	.09	.08	−.01
10	.11	.12	+.01
11	.42 { .26	.42 { .22	−.04
12	.16	.20	+.04
13	.17	.17	.0
14	.44 { .20	.43 { .25	+.05
15	.66 { .24	.66 { .18	−.06
16	.22	.21	−.01
17	.00	.02	+.02
18	.08	.07	−.01
19	.01	.01	.0
20	.03	.03	.0
21	.08	.07	−.01
Total	4.36	4.40	

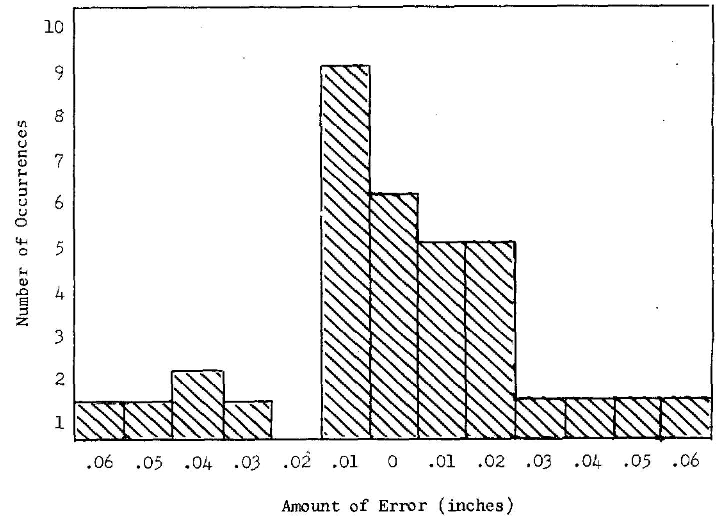

FIGURE 2.—Distribution of evaporimeter error during evaluation from September 18 through October 21, 1966.

Evaporation measurements obtained by use of fixed point gages are considered by some to be of superior quality to those obtained by use of the hook gage. As no fixed point gage was available, no comparison could be made with evaporation measurements obtained by this method.

Four separate technicians employed by the University of Kentucky made the daily hook gage evaporation observations during this period of evaluation. There were four cases of evaporimeter errors with magnitude 0.05 in. or larger. These larger errors occurred in similar instances. The error of 0.05 in. which was recorded on September 30 was followed by an error of 0.06 in. but of opposite algebraic sign on October 1. This suggests that the error resulted because the hook gage observation was taken at a time later than scheduled on September 30. A similar incident was noted October 14 and October 15. In this case the October 14 observation was apparently taken earlier than normal.

It is noteworthy that in all cases involving evaporimeter errors 0.04 in. or larger, the cumulative evaporation of the comparative systems was in essential agreement regarding total evaporation. Cumulative evaporation is shown in table 1 by the use of braces to the left of the evaporation amounts.

Average evaporimeter error for the entire period of evaluation (regardless of algebraic sign) was 0.018 in. per day. Total evaporation was in error by +0.04 in., 1 percent of the total amount. This would appear to be within the tolerance of error allowable for general meteorological use of the data.

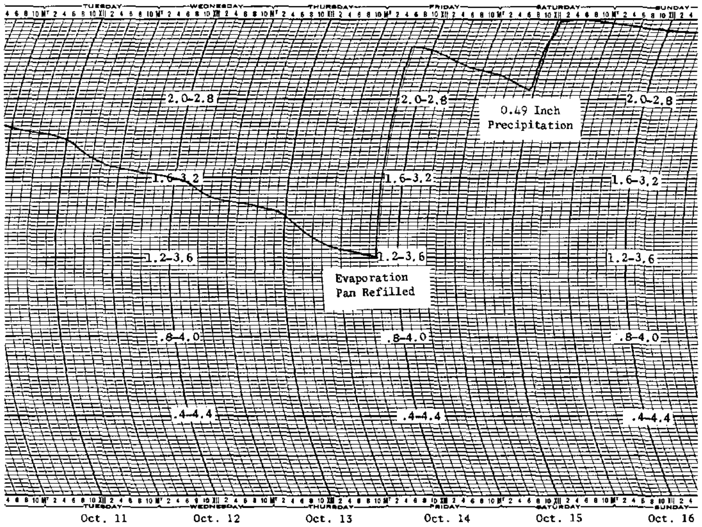

FIGURE 3.—Portion of evaporimeter chart covering period from October 11 to October 16, 1966. Vertical scale is 0.02 in. per small division.

4. DISCUSSION

Figure 3 is a portion of evaporimeter chart covering the period from October 11 to October 16, 1966. Generally fair weather occurred from October 11 through October 13. The evaporation patterns on each of these three days were very similar. Maximum hourly rates of evaporation occurred during the afternoon hours with minimum hourly rates of evaporation from approximately 9 p.m. to 10 a.m.

The method of pan refill used at this station consists of filling a large container from a faucet and pouring the water into the evaporation pan. This changes the temperature of the water in the evaporation pan, usually lowering the temperature several degrees. Sutton [3] points out that the rate of evaporation is proportional to the difference between the saturation vapor pressure at the temperature of the evaporating surface and the vapor pressure concentration in the air upward from the surface. One would thus expect that lowering the temperature of the evaporating surface would likewise lower the evaporation rate.

On October 14 (fig. 3), immediately prior to pan refill, water was evaporating from the pan at a rate of approximately 0.01 in./hr. During the hour immediately following pan refill no evaporation was recorded and a rate comparable to previous days did not become established until 10 or 11 a.m. This suggests that the evaporation amount recorded during the 24 hr. ending at 8 a.m. October 15 may be in error by 0.01 to 0.03 in. because of the method of pan refill. The Weather Bureau [4] suggests that water to be used for pan refill be stored in a container nearby only when it is necessary to transport water some distance. Evaporimeter records indicate that water should always be stored in a container on the site to allow temperature of the refill water to become equal to the temperature of the water in the evaporation pan.

To account properly for evaporation during periods of precipitation it is necessary to have a recording rain gage. This was accomplished at the University of Kentucky by installation of a 12-in. dual traverse weighing rain gage. On October 15 precipitation was recorded from approximately 11 a.m. to 12:30 p.m. Records from WBAS, Lexington, Ky. (5.4 mi. west of the evaporimeter site) showed gusty surface winds during this period of showers, reaching a maximum gust speed of 28 kt. at about noon.

The normal method of evaluating evaporation during periods of precipitation makes the assumption that the evaporation pan collects and retains all precipitation which falls up to the point of overflow. In the instance of October 15 (fig. 3) this method attributed 0.13 in. evaporation to the period during which precipitation was falling—a period of approximately 1½ hr. Prior to the onset of precipitation, the evaporation rate was approximately 0.02 in./hr. Quite obviously some of the precipitation was lost from the evaporation pan by splashing. Because of this effect, the evaporation amount recorded for the 24 hr. ending at 8 a.m. October 16 is probably in error by approximately 0.10 in.

A more satisfactory method of evaluating evaporation during periods of precipitation might be to assume an appropriate evaporation rate for the period of precipitation based on evaporation records immediately prior to the onset of precipitation. Even during periods of light wind flow, splashing could be of considerable consequence in heavy rainfall.

In evaluating evaporation for the 24 hr. ending at 8 a.m. October 16 in figure 3, the recorder pen passes through the reversal twice, once while recording the precipitation and again while recording evaporation in late afternoon, October 15.

5. CONCLUSION

An evaporimeter has been developed which satisfies all Robertson's evaporimeter criteria except (f) and (g). This evaporimeter yields data which are probably superior to the data resulting from a number of observers taking hook gage readings, as was the case at the University of Kentucky. The evaporimeter gives accurate hourly rates of evaporation and provides means for arriving at reasonable amounts of evaporation during periods of precipitation. Plans for the 1967 evaporation season include further evaluation and use of this system.

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