A COMPARISON OF BLACK POROUS DOUBLE-DISC AND BELLANI PLATE ATMOMETERS *

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INTRODUCTION

Evapotranspiration data are often used in estimating irrigation requirements by means of soil moisture budget techniques. Such techniques have been described by Ayers (1), and others as summarized by Robertson (5). Evapotranspiration data can also be utilized in various other agricultural engineering applications including the design of irrigation and drainage systems, water conservation structures and crop drying installations, and the scheduling of tillage operations. Baier (2), in reviewing the relationships between weather factors, soil moisture, and plant growth, has discussed the use of latent evaporation data in estimating actual evapotranspiration in soil moisture budget calculations.

Latent evaporation, which can be considered as an index of the drying ability of the air, is measured with an atmometer featuring a small horizontal black evaporating surface (6). The black Bellani plate atmometer, which has been widely employed in Canada in measuring latent evaporation (7), is very susceptible to frost damage. This seriously limits its usefulness since important amounts of latent evaporation may occur during the spring and fall when the risk of frost is great.

In the latter half of the 1950's, Robertson began experimenting with an atmometer of his own design at the Central Experimental Farm at Ottawa to try to overcome frost susceptibility and some other problems associated with the use of the Bellani plate (4). The instrument which he developed, known as the black porous disc atmometer, has continued to evolve and is now produced by a commercial firm in Ottawa. The manufacturer incorporates modifications and improvements after they have been tested by the Agrometeorology Section.

In 1960, Carder (3) reported that a black porous disc atmometer generally evaporated more than a "shielded burette mount" Bellani plate but less than a "shielded plastic mount" Bellani plate (sometimes known as the "Central Experimental Farm plastic mount"). These three atmometers all evaporated more than the "standard" Bellani plate (with Livingston-Thone mercury valve) and several other unshielded Bellani plate assemblies. Using data obtained at Beaverlodge, Alberta, during the summers of 1956-59, he found that the daily latent evaporation from the standard Bellani plate was highly correlated with that from the black porous disc ($r=0.988$), although the average latent evaporation from the black porous disc appeared to be about 6.2% higher than from the Bellani plate on days without rain and 5.8% higher on all days. In a test using 40 days of data, he did not find the difference between the latent evaporation from the standard Bellani plate and the black porous disc to be significant.

The present study was undertaken to find out how the version of the black porous disc atmometer in use in 1965 compared with the Bellani plate.

MATERIALS AND METHODS

At least two black porous disc atmometers are in routine use at the agrometeorological observing site at the Central Experimental Farm. In the model in use throughout the 1965 season, a metal cup held two discs (one resting on top of the other), in a horizontal position 4 feet above the ground (figure 1). The water which evaporated from the surface of the upper disc was replaced by distilled water which fed by gravity via a plastic feeder tube from a vertical cylindrical 250 cc graduated plastic reservoir above the discs, and air bubbles ascended the feeder tube to replace the water used from the reservoir.

The lower end of the feeder tube was set in a "well" formed by holes in the centres of the discs and was supported so as not to protrude below the lower surface of the bottom disc. The cup and cylinder were supported by clamps mounted on a metal stand set in the ground. Each disc was 2.9 inches in diameter, ⅛ inch thick, had a 9/16 inch centre hole, and was made of "Alundum", a black crystalline aluminous abrasive. (This instrument and its operation have been described in detail in Agroclimatological Obser-

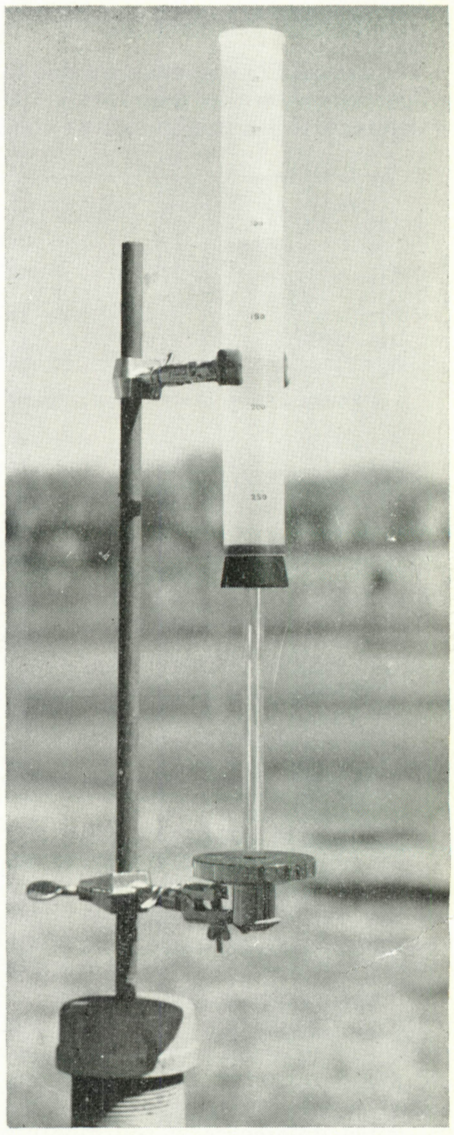

Figure 1. Black porous disc atmometer in operation.

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vations Bulletin #16, available in either English or French from the Agrometeorology Section).

This instrument and the black porous disc atmometer used in Carder's experiments in 1956-59 differed in that the earlier model had only a single disc with no centre hole, so that the end of the feeder tube rested on the upper surface of the disc. The use of the two discs with centre holes in the later model was to minimize occurrences of water loss by wind action during periods of strong gusty winds. Another difference was that in the later model, the whole apparatus was of very frost resistant material, whereas in the earlier model the feeder tube and reservoir had been of glass and therefore subject to breakage by freezing of the water.

Two black Bellani plate atmometers were operated at Ottawa, at the same site as the double-disc atmometers from July 6 to September 26, 1965. These Bellani plates were similar to the "standard" Bellani plate atmometers described by Carder (3) except that no valves were used. The purpose of such a valve is to prevent rain which falls on the plates from causing a backward movement of water through the system, thus resulting in apparently negative evaporation. In this study, it was felt that sufficient comparative data could be obtained by considering only the days without measurable rain, and this avoided the "priming" problems associated with the use of a valve which Carder mentioned.

The current procedure at Ottawa when two or more identical atmometers are in use at the same site is to arbitrarily designate them No. 1, No. 2, etc. and to use the data from No. 1 unless there is reason to believe that No. 1 has malfunctioned. For simplicity we will refer to the black porous disc atmometers used in this study as "Disc 1" and "Disc 2" and to the Bellani plate atmometers as "Plate 1" and "Plate 2". The manufacturing process for Bellani plates is such that a calibration factor is required for them. Each evaporation value from each of the Bellani plates used in this study was multiplied by 0.94, which was the coefficient for both plates. Calibration coefficients are not required for black porous disc atmometers.

Statistical analyses to compare Disc 1 with Plate 1 were performed on the latent evaporation data for 43 of the days from July 6 to September 26, 1965. Data for other days were rejected because of occurrences of measurable rain or, in one case, because of instrument malfunction.

RESULTS AND DISCUSSION

The daily latent evaporation data from Disc 1 exceeded those from Plate 1 by 2.14 cc or 5.2% on the average (table 1). This difference between the two means was significant ($t = 3.9$ for 43 pairs of observations). The two sets of data were closely correlated, however, as indicated by the high correlation coefficient ($r = 0.98$) and the goodness-of-fit to a straight line of the plotted data (figure 2).

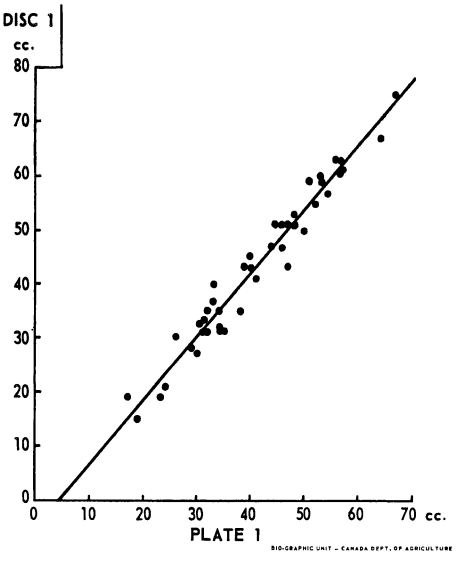

Figure 2. Comparison of daily latent evaporation from black porous disc and Bellani plate atmometers.

The high correlation coefficient between Disc 1 and Plate 1 data is similar to that found between the black porous disc and the Bellani plate in Carder's study (3). The percentage by which the evaporation from the black porous disc exceeded that from the Bellani plate is also similar in magnitude to the percentage difference found by Carder. His comment that the greater evaporation from the porous disc may be due to the fact that "the water on its surface is under no tension since it is virtually flooded at all times, while the water at the surface of the Bellani plate is under slight tension due to capillary action" seems to be the most logical explanation of the positive bias of the black porous disc in comparison to the Bellani plate data.

Contrary to Carder's results, the difference between black porous disc and Bellani plate data was found to be significant in the present study. Since this contradiction was apparently not due to any lack of similarity of mean differences or of sample size, it suggests the daily differences were more variable in Carder's experiment than in the present study. Perhaps if Carder had performed a "t" test using data from all the 230 days for which he compared the black porous disc and the standard Bellani plate, instead of using only a 40 day period, a "t" which was significant would have been obtained even if the variability of the differences was higher than in the present study.

The importance of pairing the observations in such comparisons should perhaps be stressed. In the present study, no significant difference between Disc 1 and Plate 1 would have been found if a "t" test without pairing had been employed. This is because the great day-to-day differences in latent evaporation would have obscured the differences between instruments.

The Disc 1 and Disc 2 data were highly correlated and they did not differ significantly; the average difference in their means being less than 1/10 of a cc (table 1). Their standard deviations were also quite similar. These results indicate that the procedure of arbitrarily selecting one of the two black porous disc atmometers to use

TABLE 1. STATISTICAL ANALYSIS OF DAILY LATENT EVAPORATION

Atmometer	Mean (cc)	Standard deviation (cc)	Number of days	Mean Difference (cc)	Paired "t"	Correlation coefficient "r"
Disc-1	43.26	14.35	43	2.14	3.9**	0.980**
Plate-1	41.12	11.96				
Disc-1	42.83	14.25	42	0.07	0.2	0.986**
Disc-2	42.76	14.12				
Plate-1	41.12	11.96	43	0.75	3.5**	0.994**
Plate-2	40.37	11.60				

** For $P = 0.01$, $t = \pm 2.7$, $r = \pm 0.39$

for reporting latent evaporation data and using the other only for checking purposes is justified, since the data from the two were essentially the same.

The differences between the Plate 1 and Plate 2 data, while significant, averaged less than 1 cc and the two sets of data were highly correlated. The differences were due, at least partly, to the fact that Plate 1 remained clean throughout the experiment while Plate 2 accidentally became encrusted with dirt. This did not affect the achievement of the main purpose of the experiment in view of the prior decision to use Plate 1 and Disc 1 data for the comparison of the two types of instrument. While it is strongly recommended that atmometer evaporating surfaces be kept clean at all times, the small magnitude of the differences and the high correlation in this case suggests that data even from a very dirty atmometer may be quite useful in indicating latent evaporation, if no other data are available for a particular period.

Inspection of Bellani plate and black porous disc atmometer data gathered at Ottawa in 1959 and 1960 seems to indicate that the latent evaporation may vary considerably from one Bellani plate to another, even when both are kept clean and in similar condition. While the present study suggests that Bellani plates evaporate significantly less than black porous disc atmometers, the actual quantitative relationship can be expected to vary from one pair of the two types of instrument to another.

The standard statistical tests used in this paper are based on the assumption that random independent samples from normal populations are involved. Preliminary analyses indicated that the distributions of the data used here did not differ significantly from normal distributions. The observations were not completely independent, since they were from groups of consecutive days, and evaporation on a given day would tend to be correlated somewhat with that on the previous day. The lack of independence, however, did not appear to be great enough to invalidate any of the results of the tests in Table 1. In more comprehensive studies it might be desirable to employ statistical techniques which do not require independent and normally distributed random samples.

CONCLUSIONS

This study indicates that evaporation from the black porous double-disc atmometer is about five percent higher than from the Bellani plate. This is in general agreement with Carder's findings, except that in his experiment he did not find the difference to be significant.

In research investigations involving latent evaporation, where the type of atmometer has varied from one location or time to another, the possible effect of instrumental differences on the results should be acknowledged. Such differences however can, for most practical purposes, probably be ignored.

Results of different correlation analyses between latent evaporation and some other factor would generally be comparable even though a black porous disc may have been used in one case, and a black Bellani plate in another, since the data from these two types of instruments are highly correlated with each other. If data from both types of atmometer are used together in a particular analysis to compare the evaporation with some other factor, this lack of homogeneity in the latent evaporation data will tend to reduce the correlation coefficient, but in most cases such reduction will probably be negligible.

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