Comparing Bowen Ratio-Energy Balance Systems for Measuring ET

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Abstract

Two Bowen ratio-energy balance (BREB) systems for measuring evapotranspiration (ET) under wet and dry conditions were compared. The study sites were an irrigated grass sod near Kimberly, Idaho and a sagebrush-grass range site on the Reynolds Creek Experimental Watershed near Boise, Idaho. One Bowen ratio system used positive-head, ceramic-wick, aspirated psychrometers. The other system measured the vapor gradients with a cooled-mirror, dew-point hygrometer. Differences in the amounts of ET measured by the two systems were very small and of little practical consequence. The system using a single-mirror, dew-point hygrometer was the most reliable, required the least maintenance, and was the easiest to use.

Introduction

The importance of evapotranspiration (ET) measurements is well recognized. In both rainfed and irrigated agriculture, knowledge of ET is used to evaluate management systems. In irrigated agriculture, ET is the primary input into irrigation scheduling algorithms. On arid and semiarid rangelands, ET is a major component of the water-balance equation, and accurate measurements or calculations of ET are essential to the development and application of hydrologic models.

Micrometeorological methods and lysimeters have been used extensively to measure ET in rainfed and irrigated cropping systems. On rangelands, particularly in arid and semiarid regions, water balance and, to some extent, lysimetry have been the primary method of determining ET. Only recently have micrometerlogical methods such as the BREB been used in the drier rangeland environments.

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The Bowen ratio (Bowen, 1926) and the energy balance equation are the basis for the BREB method of determining ET using micrometeorological and soil heat flow measurements (Rosenberg et al. 1983; Fritschen, 1966; Tanner, 1960). The basic energy balance model is: $Rn + G + H + LE = 0$, where Rn is net radiation, G is soil heat flux, H is sensible heat to the atmosphere, and LE is the evaporative flux. The Bowen ratio (B) is the ratio of sensible heat flux to water vapor flux (H/LE) and can be estimated from the temperature and vapor pressure gradients by $B = \gamma\ (\Delta T / \Delta e)$ where γ is the psychrometric constant, ΔT is the air temperature gradient and Δe is the vapor pressure gradient. LE is then calculated by the equation $LE = -(Rn + H) / (1 + B)$. Because temperature and/or vapor pressure gradients are often very small, the BREB method was not used extensively to measure ET until field worthy instrumentation had been developed that could measure these gradients. However, improved instrumentation that is powered by batteries and solar panels makes the application of the BREB method a viable option for measuring ET from both croplands and rangelands.

Other studies (e.g., Dugas et al. 1991) have compared BREB methods. In this study, two BREB systems that utilize different methods for measuring vapor gradients, were compared under both wet and dry conditions.

BREB Systems

A positive-head, ceramic-wick, aspirated psychrometer (PCAP) system similar to that described by Gay and Greenberg (1985) and Gay (1988) and a cooled-mirror, dew-point hygrometer (CDH) system developed by Campbell Scientific Inc., (Logan, UT)[2] were used in this study. The photograph in Fig. 1 shows the CDH system between the two towers of the PCAP system. In the PCAP system, two psychrometers were mounted on each of two towers to measure air temperature and vapor gradients. Dry- and wet-bulb temperatures were measured with small nickel-iron resistance thermometers. The upper and lower psychrometers were exchanged each 6 minutes to cancel systematic sensor errors. The sampling scheme consisted of 3 minutes for the instruments to come to equilibrium with the environment, and a 3-minute sampling period following which the psychrometers exchanged positions and continued the 12-minute cycle. The two 3-minute samples were combined to obtain a 6-minute sample for a frequency of five samples per hour. At each tower, Rn was measured by a Swissteco Type S-1[2] net radiometer and G was measured by a pair of soil heat flux disks placed at 1 cm below the soil surface and located within 2 m of each other. The entire system was controlled by a battery operated computer and data acquisition system. Solar panels were used to charge the batteries which made it possible to use the PCAP unit at remote locations.

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[2]Trade names are used in this publication solely to provide specific information. Mention of trade name does not constitute a guarantee of warranty of the product by U. S. Department of Agriculture or an indorsement over other products not mentioned.

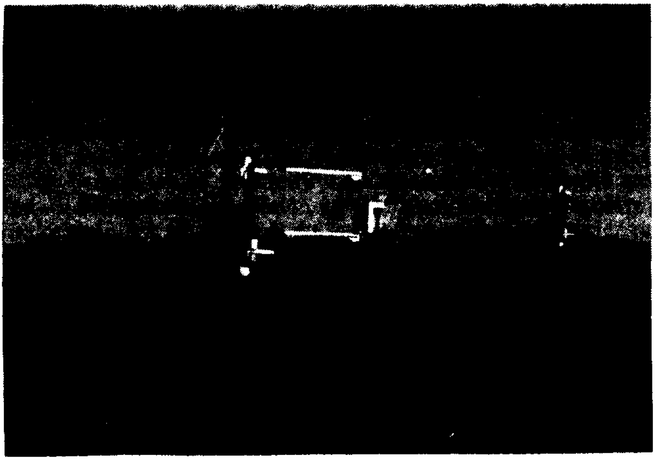

Figure 1. Photograph of the CDH system between the towers of the PCAP system on the Reynolds Creek site. 1992.

The CDH system was similar to that described by Bingham et al. (1987), Tanner et al. (1987) and Malek et al. (1990). This system measured air and dew-point temperature at the same two heights above the soil surface as the PCAP system. Air temperature was measured by unshielded, nonaspirated, 76-μm diameter, chromel-constantan thermocouples. Dew-point was measured by a single cooled-mirror dew-point hygrometer. Air was continuously pumped from both heights through 1 μm teflon filters. Air being moved across the cooled mirror was switched from one height to the other every 2 minutes with the first 40 seconds used to stabilize the new dew-point temperature and 1 minute and 20 seconds for measurements. Net radiation was measured by a REBS Q6[2] net radiometer. Soil heat flux was determined by two parallel heat flux plates each located at a depth of 8 cm and the average soil temperature above the heat flux plates as measured by four parallel thermocouples located at 2- and 6-cm depths. Mean 20-minute values from each of the sensors were used to calculate ET. This system was controlled by a battery powered datalogger. Solar panels were used to charge the batteries permitting operation of the system in remote locations.

Study Sites

One study site was in the center of a 2.6 ha rectangular field located about 1 km south of the USDA, Agricultural Research Service research facility near Kimberly, Idaho, 42° 33'N, 114° 21'W (Wright, 1991). Site elevation is about 1207 m and is surrounded by irrigated agricultural fields typical of the irrigated region. The Portneuf silt loam soil at the site was about 4 m deep and is underlain by fractured bedrock. The fescue grass was mowed regularly to maintain a height of 8 to 15 cm. The leaf area index of the grass averaged about 2.5 during the study period. The field was irrigated whenever the plant available soil water was reduced to 50 percent (about 65 kP tension at the 30-cm depth).

The second study site was located on a gravelly loam, sagebrush-grass range site on the U.S. Department of Agriculture-Agriculture Research Service's Reynolds Creek Experimental Watershed in southwestern Idaho, 43° 9'N, 116° 44'W. Site elevation is about 2100 m. The slope varies from 3 to 5 percent. Average annual precipitation is 785 mm of which most occurs as winter snow. Sagebrush is the dominant plant species accounting for about half of the vegetation cover. Native grasses and forbs accounted for about equal amounts of the remaining vegetation. The average growing season is from May 1 to October 15. During the study period, maximum leaf area index was about 0.77 and the plant available soil water was less than 50 percent.

Methods

ET was measured with two BREB systems July 18-August 8, 1991 and July 10-29, 1992 at the Kimberly and Reynolds Creek sites, respectively. The two systems were run side-by-side at each site. Dew point was measured at 53 and 153 cm above the ground at the Kimberly site and 73 and 173 cm above the ground at the Reynolds Creek site which placed the lower sensors about 10 cm above the vegetation canopy. Net radiation was measured 140 cm above the ground at each site by placing the radiometers parallel to the ground surface. Daily precipitation and pan evaporation were also measured at each site. At the Reynolds Creek site, soil water was measured periodically during the study with gravimetric samples for the 0-15 cm soil layer and by the neutron scatter method for the rooting zone. Leaf area index was measured by the point intercept method (Warren-Wilson 1959). Regression analyses were performed on the daily ET values from the two study sites. Statistical significance were determined at the $p \leq .05$ confidence level.

Results and Discussion

Both systems operated effectively at remote locations. More power was required by the PCAP system because of the psychrometer fans and motors used to exchange the position of the psychrometers at 12-minute intervals. The PCAP system required almost daily service to check water levels in the psychrometers and lubricate the psychrometer masts. The CDH system only required weekly service to clean the mirror and change air filters. In other studies, we found that cold and snowy conditions affected the performance of the PCAP system. Under such conditions, alcohol had to be added to the psychrometer water, and snow often prevented the psychrometers from exchanging positions. Insects getting into and stopping psychrometer fan motors was an occasional problem with the PCAP system. The temperature sensing unit on the CDH system is very thin and fragile and susceptible to breakage. The CDH system is more compact and easier to transport and set up than is the PCAP system. Both units have to be protected from intruding livestock.

Regression analyses of the daily ET values (Table 1) indicated that there were no significant differences in the relationship of PCAP-measured ET to CDH-measured ET between the two sites. The data from the two sites were therefore pooled and analyzed (Fig. 2). The slope of the regression equation is significantly different from 1.0 indicating a small difference in the performance of the two BREB systems when run side by side. The PCAP system tended to measure slightly more ET at the high range of measurements and less at the low range than did the CDH system. This is especially noticeable at the Kimberly site which also had the most uniform vegetation surface. From a practical perspective, these differences are probably well within instrument error and site heterogeneity.

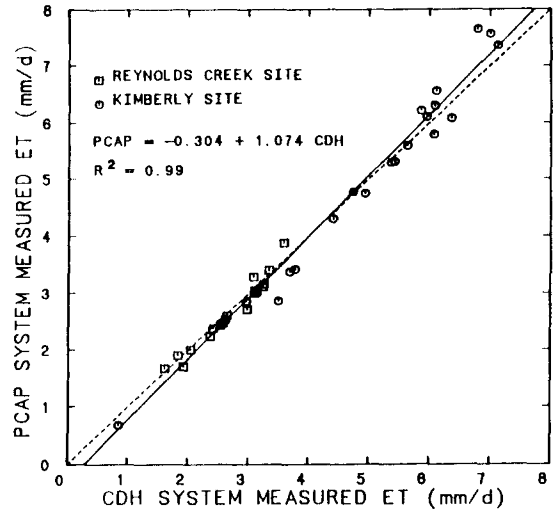

Figure 2. Daily ET measured by the PCAP and CDH systems at the Kimberly and Reynolds Creek sites. The 1:1 line is shown.

The daily energy balance plots in Fig. 3 are representative of clear days at each study site. Partitioning of the energy balance within each system was consistent from day-to-day. At the Kimberly site there was very little difference between the two systems, and ET accounted for nearly all of the Rn. At the drier Reynolds Creek site there were small differences in the way the two systems partitioned the energy balance and ET accounted for less than half the Rn. In addition to slightly higher Rn values, the CDH system recorded less ET and lower G values in the morning and more ET and higher G values in the afternoon as compared to the PCAP system. Differences between the energy balance measurements by the two systems reflect the heterogeneous nature of the vegetation and soil surfaces of this site. As would be expected, G was much more variable in the dry environment.

Table 1. Daily pan evaporation (Ep) (mm) and ET (mm) from the Kimberly (1991) and Reynolds Mountain (1992) sites as measured by two BREB Systems.

Kimberly Site				Reynolds Creek Site			
Date	Ep	CDH	PCAP	Date	Ep	CDH	PCAP
7-18	9.14	2.96	2.85	7-10	7.11	2.97	2.70
19	8.13	4.73	4.76	11	3.05	1.61	1.67
20	5.84	5.41	5.30	12	5.59	3.07	3.29
21	7.87	6.10	6.54	13	9.14	3.33	3.41
22	7.11	6.07	6.30	14	9.40	3.24	3.11
23	8.13	4.93	4.74	15	8.13	3.10	3.04
24	6.86	6.07	5.78	16	8.13	3.13	3.02
25	7.26	3.50	2.86	17	8.64	3.25	3.16
26	5.33	6.79	7.65	18	5.59	3.10	2.99
27	8.38	7.00	7.57	19	5.59	3.58	3.87
28*	—	3.77	3.43	20	5.59	2.54	2.44
29	8.89	5.85	6.21	21	4.83	1.83	1.90
30*	—	3.68	3.39	22	8.64	2.57	2.46
31*	—	0.85	0.68	23	5.84	1.92	1.70
8-1	6.86	7.12	7.36	24	5.08	2.04	2.00
2	10.41	6.08	6.29	25	6.10	2.37	2.23
3	8.64	5.36	5.29	26	9.14	2.64	2.59
4	6.60	4.40	4.30	27	7.87	2.53	2.42
5	6.35	5.95	6.10	28	9.91	2.61	2.52
6	7.11	6.35	6.08	29	8.64	2.42	2.37
7	9.90	5.63	5.59				
Total	138.81	108.60	109.07		142.01	53.85	52.89

* Part of day

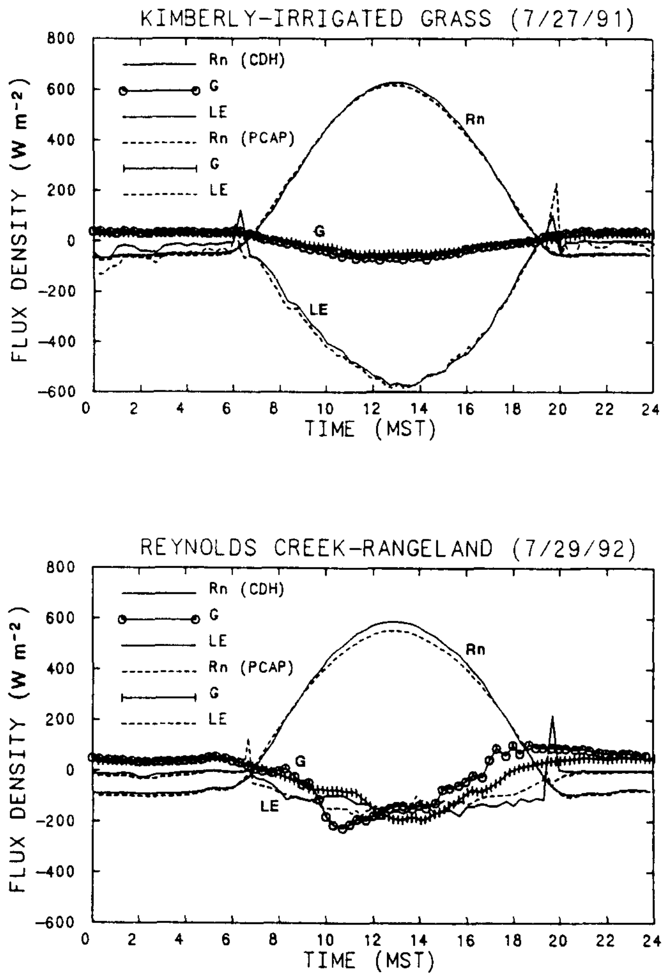

Figure 3. Energy balance comparisons of the PCAP and CDH systems on the Kimberly and Reynolds Creek sites.

In conclusion, the two systems measured ET equally well under both wet and dry conditions. It appears that the cooled-mirror, dew-point hygrometer is a viable alternative to the aspirated wet- and dry-bulb psychrometer for measuring ET with the BREB method on both cropland and rangeland.

Appendix I. References

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