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COMPARISON OF ALFALFA EVAPOTRANSPIRATION MEASURED BY A WEIGHING LYSIMETER AND A PORTABLE CHAMBER

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ABSTRACT

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Improving water use efficiency requires the development of satisfactory means to evaluate plant water use in the field. One such method is a portable chamber for measuring crop water use on field plots. The objective of our work was to compare short term alfalfa (*Medicago sativa* L.) evapotranspiration (*ET*) measured with a portable chamber (*CET*) with that measured by a weighing lysimeter (*LET*). Intensive portable chamber measurements were made and microclimate data collected between 0500—2100 h on 2 July 1980 at the meteorological station on the University of Minnesota Campus at St. Paul. The soil was a Waukegan silt loam (fine-silty over sandy or sandy-skeletal, mixed mesic Typic Hapludoll). Potential evapotranspiration (*PET*) was calculated using a modified combination equation of van Bavel. Expressed on an hourly basis, there was reasonable agreement between diurnal patterns of *CET*, *LET* and *PET*, although *CET* was as much as 0.16 mm h^{-1} lower than *LET* at 1100 h and as much as 0.09 mm h^{-1} higher than *LET* at 1800 h. Daytime *ET* values between 0500 and 2100 h were 7.97, 7.71 and 7.58 mm for *LET*, *CET* and *PET*, respectively. The reasonable agreement between the *CET* and *LET* throughout the day and the daytime *ET* suggests that the chamber is satisfactory for measurements of crop water use on field plots.

INTRODUCTION

As demand for water increases, it is essential that agriculture uses water more efficiently, particularly that applied as irrigation. Thus, the development of a portable tool for the measurement of water use is critical. Methods of measuring evapotranspiration (*ET*) have been reviewed by Tanner (1967). The weighing lysimeter, discussed by Ritchie and Burnett (1968), Hanks and Shawcroft (1965) and Pruitt and Angus (1960), is the most accurate and direct method.

Under different soil and water management practices, it is necessary to develop reliable, inexpensive and portable equipment for the measurement of *ET*. One method employs a chamber constructed of material essentially transparent to radiation, but which prevents exchange of water vapor with the atmosphere. Examples of portable chambers used in the field are those

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of Musgrave and Moss (1961), Decker et al. (1962), and Sellers and Hodges (1962). Peters et al. (1974) described an automated travel system used to measure photosynthesis and *ET* simultaneously, and Reicosky and Peters (1977) described an economical portable chamber for rapid *ET* measurements of field plots. Businger (1963) discussed the limitations and climatic alterations that can occur in the chambers.

Portable chambers similar to the one used in this study have been used for field water use studies reported by Reicosky and Deaton (1979), Reicosky et al. (1980), Reicosky et al. (1982a), Reicosky et al. (1982b). The chamber method was initially verified by calibrations against solution absorption (Reicosky and Peters, 1977). The objective of this study was to compare short term alfalfa *ET* in the field measured with a portable chamber to that measured with a precision weighing lysimeter.

METHODS AND MATERIALS

The study was conducted at the Minnesota Agricultural Experiment Station, St. Paul, Minnesota, on a Waukegan silt loam soil (fine-silty over sandy or sandy-skeletal, mixed mesic Typic Hapludoll). The water table is more than 5 m below the soil surface. The soil is characterized by approximately 0.7 m of silt loam overlying coarse sand and gravel to a depth greater than 3 m. The measurement area for the portable chamber was located within 5 m of the weighing lysimeter.

The weighing lysimeter used was part of the micrometerological station on the University of Minnesota's St. Paul campus and was patterned after that of Ritchie and Burnett (1968). The lysimeter surface area is 152 cm × 183 cm and is 122 cm deep. It was installed in early summer of 1975 and the first crop was grown the same year. Soybeans (*Glycine max* L. Merr.) were planted each year until alfalfa (*Medicago sativa* L. 'Blazer') was seeded in the spring of 1980.

Changes in weight of the lysimeter are detected by means of a strain gauge type load cell which is powered by a regulated 12-volt power supply. The output from the load cell is measured by a digital volt meter/printer system which can print output data at selected time intervals; for this experiment the output system was set at 10-minute intervals. The difference between two consecutive output values equalled the amount of evapotranspiration, hereafter referred to as lysimeter *ET* (*LET*).

The alfalfa was approximately 0.7 m tall with a dry biomass of 3,789 kg ha^{-1} obtained from 0.5 m^2 of soil area at the time of this experiment. Ground cover was complete and a full canopy had developed at the time of the *ET* measurements. There was no visible difference between the canopy stature of the alfalfa growing on the lysimeter and that on the area used for the portable chamber measurements. The lysimeter and surrounding area were irrigated with 25 mm of water on the day prior to the *ET* measurements to provide adequate soil moisture as indicated by tensiometers at 0.30, 0.50 and 0.75 m.

The portable chamber used to measure *ET*, hereafter referred to as chamber *ET* (*CET*), was similar to that described by Reicosky and Peters (1977) with a few modifications. The chamber in this study was made of 3.18 mm thick Plexiglas* instead of mylar for structural considerations and ease of operation. The Plexiglas reduced irradiance, measured by an Eppley Pyranometer*, by 8—10% inside the chamber, so that absolute values of the *ET* may be reduced slightly by the decrease in irradiance. The chamber was mounted on a hydraulic mast on the front of a farm tractor that held the chamber away from the tractor to allow a plant border around the measurement area. A portable generator and the voltage regulator were mounted on the back of the tractor to provide 120 volt (AC) power for operating the fans and the strip chart recorder.

The operation for measuring *CET* was as follows. The measurement area was premarked and plants that might be damaged with the chamber wall in place were tied back with string around the boundaries of the measurement area. The chamber was maneuvered in the up position over the measurement area until plot markers were aligned with the chamber. With the chamber in the up position, the strip chart recorder was started to record wet- and dry-bulb temperatures. After about 30 s, when the wet- and dry-bulb temperatures were constant, the chamber was lowered (which required approximately 7 s). Dry- and wet-bulb temperatures were recorded for about 1.2 minutes, after which the chamber was raised. For each measurement, the time the chamber made contact with the soil, the cloud cover and photosynthetically active radiation (*PAR*) were recorded. *PAR* was recorded using a battery operated Li-Cor* model LI-185 meter with a model LI-190S Quantum sensor. At the start of each measurement *PAR* was recorded and any substantial changes noted. The wet- and dry-bulb temperatures at the time the chamber was lowered and 30 s later were used to calculate *ET*. Knowing the volume of the chamber, and using the psychrometric equation, the rate of change in water vapor density was calculated and divided by the soil area to give *CET*. The *CET* measurements were repeated at 10-minute intervals from shortly before sunrise to near sunset on 2 July 1980. A similar data set was collected from 0500 to 1500h on 3 July 1980 with essentially the same results (data not shown).

Microclimatic data collected 1.3 m above the canopy, independent of the portable chamber data, included solar and net radiation, dry- and wet-bulb temperature and wind speed and direction. These data were logged at 10-minute intervals on an automatic data acquistion system and stored on the computer for further processing. Two hours of net radiation data were missing due to equipment failure and were estimated from a linear

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* Trade names and company names are included for the benefit of the reader and do not imply endorsement or preferential treatment by the U.S. Department of Agriculture or the University of Minnesota.

regression of hourly *PAR* measured in association with the *CET* and the remaining hourly net radiation data. The net radiation, wet- and dry-bulb temperatures, and wind speed and direction were measured at 1.3 m above the alfalfa in the lysimeter.

Potential evapotranspiration (*PET*) was calculated using the modified combination method described by van Bavel (1966) that includes Businger's (1956) modification of the transport coefficient. *PET* was calculated on an hourly basis using hourly averages of the net radiation, temperature and wind data recorded at 1.3 m height, and using a surface roughness parameter (Z_0) estimated to be 1.0 cm for alfalfa from the data of van Bavel (1966). Rosenberg (1969) has shown this method of calculating *PET* is highly sensitive to the selection of the roughness parameter, thus, any agreement of *LET* and *CET* with the calculated *PET* may be fortuitous. However, for our purposes of relative comparison, selection of $Z_0 = 1$ cm seemed to give reasonable results. Throughout the measurement period soil heat flux was assumed to be zero due to extensive canopy cover. Any error in this assumption would slightly lower the *PET* during periods of high radiation.

LET and *CET* data were collected at 10-minute intervals throughout the day. Due to the scatter in the lysimeter and the portable chamber data, a 1-2-3-2-1 weighted running average was calculated to smooth both sets of *ET* data. Hourly averages of the weighted running average were determined for both the lysimeter and portable chamber. Upon plotting the hourly values of the lysimeter data, there was still a significant amount of scatter that was later determined to be the result of inadequate filtering of the strain gauge transducer signal. The *LET* data (hourly averages) were smoothed using an eye-fitted curve based on the solar radiation data for an essentially clear day. Thus, there were two smoothing operations in the lysimeter data. The hourly averages of the portable chamber *ET* were then compared with the smoothed lysimeter data.

RESULTS AND DISCUSSION

Microclimatic data collected on 2 July 1980 are summarized in Fig. 1. Both solar and net radiation data indicated a relatively clear day. A few high thin clouds were present at approximately 1100h (CST) that were not apparent in the hourly data. The dry- and wet-bulb temperatures at 1.3 m followed a diurnal pattern that lagged behind the solar radiation. The wind speed was relatively constant at approximately 1.5 m s^{-1} during most of the measurement period. The vapor pressure deficit (VPD) data show a diurnal change from about 3 mb near sunrise to 23 mb in the afternoon. The vapor pressure deficit in conjunction with the net radiation contributed significantly to the magnitude of the calculated *PET*.

The hourly *ET* measured by the lysimeter (*LET*) and the portable chamber (*CET*) and the calculated *PET* are summarized in Fig. 2. The hourly *CET* and *LET* were the average of six readings taken at 10-min intervals.

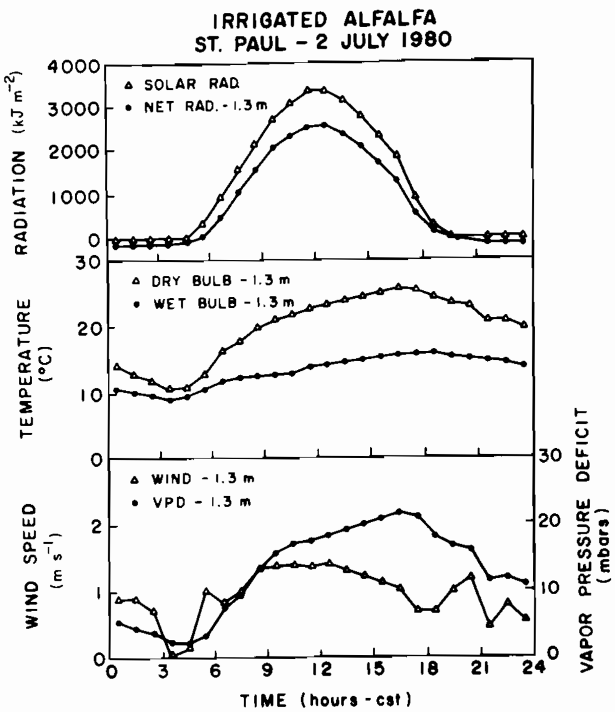

Fig. 1. Summary of the microclimatic data collected at the lysimeter site on 2 July 1980.

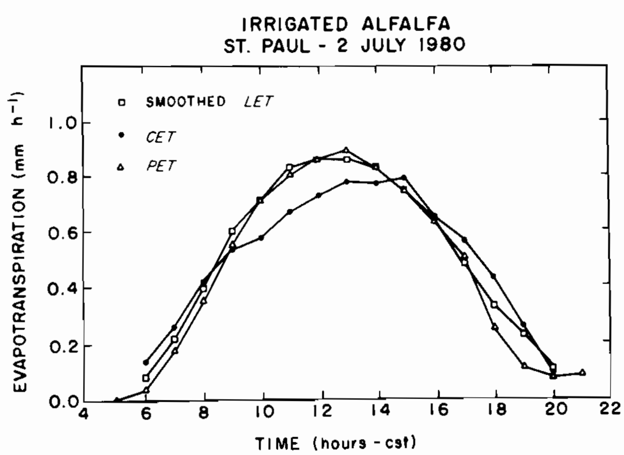

Fig. 2. Evapotranspiration measured by the portable chamber (*CET*) and by the lysimeter (*LET*) and the calculated potential evapotranspiration (*PET*) versus time on 2 July 1980.

Both *LET* and *CET* went through a typical diurnal pattern related to solar radiation with a maximum *LET* of 0.87 mm h^{-1} and a maximum *CET* of 0.80 mm h^{-1}. With the exception of a few data points between 1000 and 1400 h, both *LET* and *CET* are reasonably close. The largest difference between *CET* and *LET* occurred at 1100 h when the lysimeter data were erratic and required additional smoothing. The *PET* values were in close proximity to both *CET* and *LET* except during a few hours around solar noon. During this period the maximum *PET* was 0.90 mm h^{-1}, 0.03 mm h^{-1} higher than the corresponding *LET*. Daytime *ET* values were calculated between sunrise and sunset by summing the hourly *ET* values. Daytime *ET* values between 0500 and 2100 h were 7.97, 7.71 and 7.58 mm for *LET*, *CET* and *PET*, respectively.

The direct comparison between *CET* and *LET* using hourly data is presented in Fig. 3. On an hourly basis, *CET* was as much as 0.16 mm h^{-1} lower than *LET* at 1100 h and as much as 0.09 mm h^{-1} higher than *LET* at 1800 h. It was in much better agreement the rest of the day. While the difference between *LET* and *CET* at 1100 h was 19%, the difference between *CET* and *LET* at other times was less. Part of the difference between the *CET* and *LET* data may be explained by the presence of dew in the early morning hours. The turbulent mixing inside the chamber may have resulted in increased water vapor generation and thus higher *CET* than *LET*. Minor damage to plants around the edge of the chamber measurement area may lower *CET* compared to *LET*. A note of caution is required when drawing conclusions from a limited data set. However, the reasonable agreement

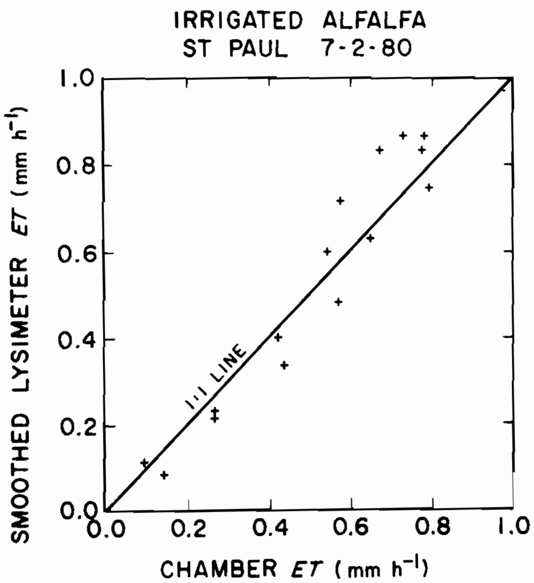

Fig. 3. Comparison of chamber evapotranspiration (*CET*) and the lysimeter evapotranspiration (*LET*) on 2 July 1980.

with *PET* as an indicator of evaporative demand suggest the chamber may yield reasonable results on other days with climatic extremes. In spite of the above possible errors and errors in *PET*, there was general agreement on this day between *CET* and *LET* that suggests the use of portable chambers in providing reasonable estimates of *ET* under field conditions. The short time required for the measurement, the relative accuracy and the flexibility in evaluating experimental treatments in remote locations suggest the portable chamber can be useful in water use studies.

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