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DIRECT EVAPORATION FROM SOIL UNDER A ROW CROP CANOPY*

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ABSTRACT

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A simplified measurement of the soil evaporation (*E*) component of evapotranspiration (*ET*) is needed to obtain independent measurements of transpiration (*T*) and to evaluate the effects of *E* and *T* on *ET*. Our objective in this study was to evaluate the use of small lysimeters placed under a crop canopy to measure the *E* component. Lysimeters were constructed of rigid PVC pipe sections, 20.3 cm in diameter and 20, 10, or 5 cm long. Water loss from the lysimeters was recorded daily. The water content of the soil surrounding the lysimeters was measured gravimetrically from composite 1-cm-increment cores sampled daily. The results reported are for two drying cycles of 16 and 13 days in July 1975 and 1976. In order for the lysimeters to behave as the surrounding soil, the water content of the lysimeters must be higher than the soil outside to compensate for changes under the natural conditions due to plant uptake, drainage and upward flow. Since the lysimeters depend on a set of compensating factors to directly measure *E*, estimates of *E* from them should be used with caution. A better use of the lysimeters would be to establish a relationship between lysimeter *E* and the surface soil water content and then use surface water content measurements to infer *E*.

INTRODUCTION

The separation of evapotranspiration (*ET*) into soil evaporation (*E*) and plant transpiration (*T*) is basic to many water management schemes. Stanhill (1973) commented about separating *ET* into *E* and *T*, and how their mutual interrelationship causes important and largely unresolved problems in agricultural water-management schemes. In much early work, *E* and *T* were assumed to be completely independent and *T* was usually separated from *ET* by measuring *E* from bare soil nearby. Denmead (1973) showed that *E* and *T* are essentially independent and, therefore, additive under conditions where *T* is not limited by water supply and the soil surface is wet. However, Stanhill (1973) cited various studies that indicated some interaction between *E* and *T*. This interaction would be more likely under conditions of partial ground cover, as in row crops. The influence of surface soil wetness on calculated *ET* in irrigation-scheduling programs can be readily demonstrated (Jensen et al., 1971). Accurate measurements of *E* under plant canopies are

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needed to refine the treatment of soil-surface wetness in irrigation-scheduling programs. Other areas where independent measurements of *E* and *T* would be useful are in developing models for water extraction by root systems, where an independent measure of *T* is need to quantify the amount of water absorbed by the roots. An independent measure of *T* is important in many models that have been developed to predict yields in relation to available water (De Wit, 1958; Hanks, 1974).

Several models have been developed that calculate *E* and *T* independently. Tanner and Jury (1976), who presented a model for evaluating *ET* for a growing crop with changing plant cover, stated that this type of modeling does not seem possible, unless *E* and *T* are considered separately. Ritchie (1972) developed a model for assessing *E* under a crop canopy where the rate of *E* is controlled by the amount of net solar radiation reaching the surface until water becomes limiting. Then *E* is controlled by the rate of water movement to the evaporating sites.

The objective of this study was to measure directly the *E* component of *ET* under a plant canopy during both the energy-limited and soil-limited phases. Our approach was to use small, shallow lysimeters strategically located under a plant canopy. We recognized that the use of lysimeters isolates the soil in the lysimeters from water uptake by plants and from direct contact with soil layers below the lysimeter, and thus eliminates drainage and upward movement of water. With these limitations in mind, we examined different depths of lysimeters to determine what size of shallow lysimeter would best overcome some of these limitations and still give reasonable values of *E* under the canopy. Al-Khafaf et al. (1978) have reported measurements of *E*, using a 30-cm-diameter and 30-cm-deep containers embedded in the soil under a cotton crop canopy. They did not clarify how they adjusted *E* for the limitations described above, but they did show reasonable agreement between cumulative loss from the containers and cumulative water content changes for 0- to 10-cm and 0- to 100-cm soil layers.

This project was part of a large field project where *ET* was measured, using energy balance and water balance techniques, and the results of the separation of *ET* into components, using the techniques developed in this paper, will be discussed in subsequent papers.

MATERIALS AND METHODS

Lysimeter construction and installation

Lysimeters 5, 10, or 20 cm deep were constructed from rigid PVC irrigation tubing with an outside diameter of 20.3 cm and a wall thickness of 0.31 cm. The lysimeters were filled by pressing them into the surface of a cultivated soil with a hydraulic soil sampler. After trimming excess soil from the lysimeters, a sheet metal bottom was attached. Soil water content measurements were made adjacent to the lysimeters at the time of filling to calculate the base dry weight of the soil in the lysimeters. The water content of the lysimeters could be adjusted for average water content by adding water, if necessary. No attempt was made to adjust the soil water distribution inside the lysimeters.

Corn (*Zea mays* L.) was planted in 76-cm rows oriented in a north-south direction. The soil was Weld silt loam (fine, montmorillonitic, mesic Aridic Paleustolls). The plots were on a solid-set sprinkler irrigation site at the U.S. Department of Agriculture, Central Great Plains Research Station, Akron, CO. A set of 4 lysimeters of each depth was placed near the center of a 2-ha field. Two lysimeters of each depth were placed midway between the rows of corn (midrow) and two lysimeters of each depth were placed in the row (row). All lysimeters were placed inside a sheet-metal retaining cylinder at the same depth as the lysimeters, but with a slightly larger diameter to facilitate lifting the lysimeter out of position for weighing. The lysimeters were positioned so the level of the soil inside them corresponded to the level of the soil outside them. The lip of the lysimeter extended from 0.5 to 1.0 cm above the soil surface to retain water or to prevent run-on of water. The retaining cylinders were located and installed shortly after emergence of the corn to ensure placement of the lysimeters in as near as uniform stand as possible.

Water loss was determined by manually lifting the lysimeter from the retaining cylinder and placing it on the balance for weighing. The balance was capable of being accurately read to the nearest gram which was equivalent to 0.03 mm of water. The lysimeters were removed from the field during irrigations. After an irrigation, water was added to the lysimeters to bring the soil water content inside of the lysimeter as close as possible to that of the soil outside of the lysimeters. The lysimeters were weighed daily at about 0700 h MST. A duplicate set of lysimeters was kept in a shelter nearby so that we could replace a lysimeter immediately in case of damage by rodents, etc. The field site was essentially level, but a small berm was constructed surrounding the site to prevent run-off or run-on of water.

Soil-water sampling

Soil-water was sampled daily, using a hand probe, at a site immediately adjacent (approximately 2 m) to the lysimeter site. A 20-cm deep soil core was taken and divided into 1-cm increments for the 0- to 10-cm depth and into 2-cm increments for the 10- to 20-cm depth. Five cores in the corn row and 5 cores midway between the rows were taken. Increments from the same depth of each of the 5 cores were composited into a single sample, and soil water content was determined gravimetrically. Bulk density measurements for the same increments and depths were also taken periodically.

Volumetric water content, θ, was calculated from gravimetric water content and bulk densities. The profiles of θ were smoothed by a simple

1-2-1 running average with depth, and then with time at each depth increment. This is similar to the smoothing technique described by Jackson et al. (1973) and Jackson (1973).

Net radiation

Net radiation and total incoming solar radiation were measured above the crop with radiometers mounted on a stationary mast. Net radiation near the soil surface was measured with radiometers mounted on a moving cart that moved parallel to the corn rows and at the same time traversed slowly between the rows. Signals were logged on a data logger and integrator located in a trailer nearby.

Field experiment

Measurements were taken throughout the summers of 1975 and 1976. The data reported are for two nearly identical drying cycles of 16 days, 8—24 July 1975 and of 13 days, 8—21 July 1976. Both of these drying cycles began immediately after irrigating and continued until a substantial rain occurred or until another irrigation was necessary. During the 1975 measuring period, 1.5 mm of rainfall occurred on 9 July and 6.3 mm on 16 July at about 1700 h MST. These dates are Days 2 and 9 of the drying cycle. In 1976, 5.6 mm of rainfall occurred on 19 July (Day 12 of the drying cycle) at about 1730 h MST. The corn crop changed from a leaf area index of near 1.0 to nearly 3.0 during the drying cycle each year.

RESULTS AND DISCUSSION

Cumulative water losses

The average cumulative daily losses from the 20- and 10-cm deep lysimeters and the cumulative daily change in water content, $\Delta\theta$, for the soil samples outside the lysimeters for the corresponding depths are shown in Fig. 1. Also included in Fig. 1 is the cumulative 'minimum potential E obtainable' or the 'equilibrium' E described by Tanner (1968) as the factor $[s/(s + \gamma)] x\ Rn_{bl}$, where s = the slope of the saturation vapor pressure as a function of temperature; γ = psychrometer constant; and Rn_{bl} = net solar radiation below the canopy. Daily water loss from the 5-cm deep lysimeter is not shown because this shallow lysimeter dried to a water content so far below the 0- to 5-cm layer outside that it became unrealistic as a measure of E. In 1975 the first 4 days of the cycle had a low evaporative demand with a mean air temperature of 20°C and 24-h average wind velocity of 4.2 km h^{-1}. Rainfall had occurred before the drying cycle so the surroundings were relatively wet. Little advection of energy from the surroundings to the corn field would have occurred. The initial daily losses

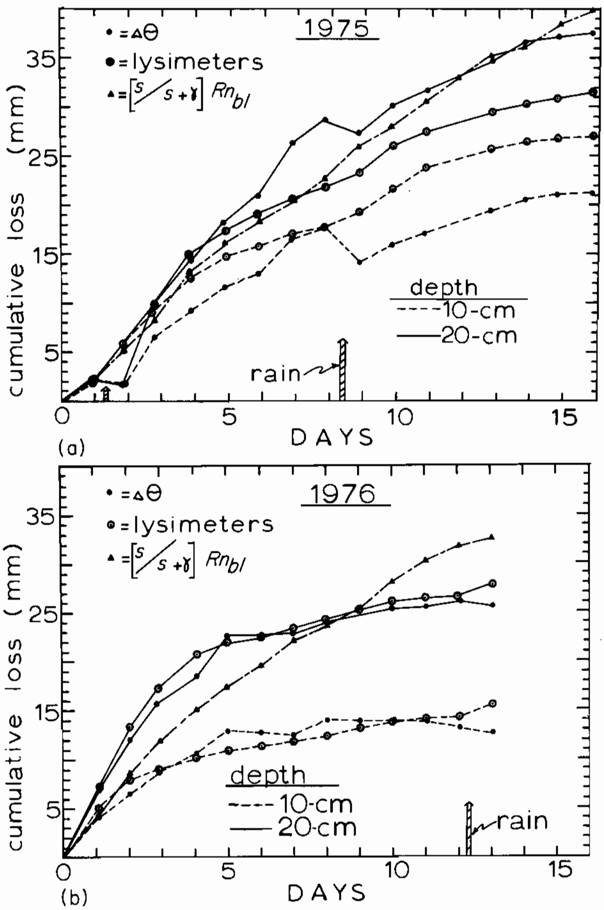

Fig. 1. Cumulative water loss from 20- and 10-cm deep lysimeters, cumulative change in water content $\Delta\theta$, for soil outside lysimeters, and cumulative equilibrium E, $[s/(s+\gamma)]Rn_{bl}$; where Rn_{bl} = net radiation below canopy; s = slope of the saturation vapor pressure as a function of temperature; γ = psychrometer constant [(see Jensen (1966) and List (1971)].

from the 20-cm deep lysimeters and the $\Delta\theta$ from the soil profile samples for the 20-cm depth follow the equilibrium E until Day 7 of the cycle. After this period the lysimeter E dropped below the equilibrium E. The 10-cm deep lysimeter began dropping below the equilibrium E after Day 4. The difference between the cumulative losses between the lysimeters and the soil samples illustrate the problem in using lysimeters for this measurement. The restricted drainage and restricted upward water flow imposed by the lysimeters makes the measurement of E under the canopy somewhat unrealistic. The $\Delta\theta$ of the soil profile samples resulted from both drainage, upward movement, E, and plant uptake whereas lysimeter losses are only from E. In order for the lysimeter to behave as the surrounding soil, the water content of the lysimeter and the water distribution must be the same as outside.

The difficulty arises in maintaining the lysimeter at this water content since the actual amount of drainage, upward flow, and/or plant uptake is not known. The lysimeter could be maintained at a slightly high water water content than the surrounding soil in order to compensate for the restricted flow, but the exact amount of the increase in water content would be difficult to maintain. An accurate measure of E under the canopy using the lysimeters would depend on a series of compensating errors in order to simulate actual conditions.

This series of compensating errors may in fact be the reason for any agreement between the $\Delta\theta$ of the soil samples and the lysimeter E. In 1976 this agreement was better than in 1975. The cumulative losses shown in Fig. 1b for 1976 exhibit the effects of higher evaporative demand and more highly advective conditions during the first few days of the cycle. The daily lysimeter E and $\Delta\theta$ for 20-cm depth both showed considerably larger values than the equilibrium E until Day 5. After Day 5 daily losses were considerably below the equilibrium E.

The problem of maintaining the θ of the lysimeter at a level large enough to compensate for the changes in θ of the soil outside the lysimeter is illustrated in the 1976 data. Even though the intent was to have θ_{lys} equal to θ_{soil}, the first soil samples following the irrigation showed $\theta_{\mathrm{soil}} = 0.28$ for the 20-cm depth, while the θ_{lys} for the 20-cm deep lysimeter averaged 0.37. The θ_{lys} remained about 0.08 above that of the outside soil for the entire cycle. The close agreement between the cumulative water losses may have been a result of the compensating factors discussed above.

A complicating factor in comparing the cumulative losses from the lysimeter and cumulative $\Delta\theta$ is the determination of the net loss on days when rainfall occurred. The $\Delta\theta$ values for the soil outside showed a net gain in water on these days. The daily lysimeter E for the days with rainfall were calculated from the ratio E to the net radiation (R_{n}) below the canopy (E/R_n) for the day immediately before the rainfall. Because corn leaves intercepted some of the rainfall, rainfall could have either been concentrated or prevented from reaching the lysimeters underneath the canopy so there was no exact measure of the gain in water from rainfall. Since rainfall occurred during the early evening, our use of the E/Rn_{bl} ratio for the day before rainfall was a more realistic estimate of E for the day rainfall occurred. Most of the E on these days would have occurred before the rain.

E below canopy versus soil water content

Ritchie and Burnett (1971) estimated E under a row crop canopy by developing a relationship between bare soil E and the water content, θ, of the 0- to 3-cm layer. This was developed by using a large lysimeter to follow E and θ over several drying cycles before and after the crop growing season. Below canopy E was then estimated from periodic sampling of the surface soil θ under the canopy. As a comparison to this method, we calculated the average θ of the 0- to 5-cm layer of the lysimeters by multiplying the overall average θ of the lysimeter by the ratio of θ for the 0—5-cm layer to θ for 0—20-cm and 0—10-cm depths for the soil outside. The assumption was made that the profile distribution of θ within the lysimeter was the same as the soil outside. The distribution of θ for the soil outside of the lysimeter is shown for several days in 1976 in Figs. 2a, b. Water was lost from the entire 20-cm profile for the first 5 days, but the maximum loss occurred from the 0- to 5-cm layer. After Day 6 of the drying cycle the change in θ below 5-cm was very small. Since the water loss from the lysimeter corresponded to the $\Delta\theta$ of the soil outside the lysimeter, the assumption about the distribution of θ inside being similar to the distribution outside has some basis. This assumption would be more valid in the layer of maximum

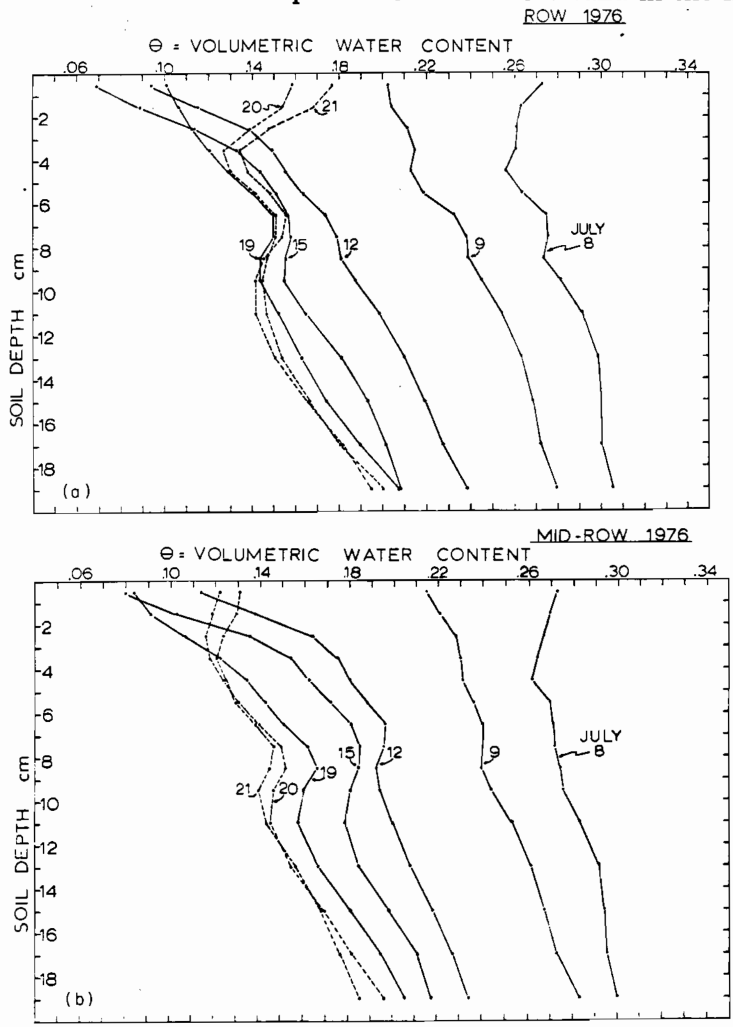

Fig. 2. Profiles of soil water content, θ, for soil samples outside of lysimeters.

loss which is the 0- to 5-cm layer. For this reason we examined the relationship between the average θ for the 0- to 5-cm layer and E rather than the average θ for the full 2-cm or 10-cm profile. The daily E from the lysimeter is plotted against the average θ for the 0- to 5-cm layer for the corresponding lysimeter in Fig. 3. Each point represents the average E and θ of 4 lysimeters. The 5-cm deep lysimeters are included in this figure in order to obtain values of E at relatively low θ. This relationship is similar to that shown by Ritchie and Burnett (1971). The scatter of points at high θ values is because at these θ's, evaporation was still in the energy-limited rather than the soil-limited phase. For this particular soil, E drops quite rapidly until θ reaches approximately 0.17, then E remains below 1.0 mm day^{-1}.

The relationship in Fig. 3 suggests a possible method for estimating E below the canopy using small lysimeters. The lysimeters can be used to develop the E vs. surface θ relationship and thereafter estimate E below the canopy from periodic sampling of surface θ. This may be particularly useful where large lysimeter installations for developing this relationship are not available.

As an additional comparison of determining E under a canopy, E values were calculated using the model presented by Ritchie (1972). Ritchie used the relationship $E = \alpha_E\,[s/(s + \gamma)]\,Rn_{bl}$ for water loss during the energy-limited phase of drying, and $E = \alpha t^{1/2}$ for soil-limited drying, where α is a soil water loss coefficient and t is the time after water loss from the soil had accumulated to some upper limit for energy-limited drying, U. Both U and α for Weld silt loam soil at Akron, CO were determined from lysimeter measurements of bare soil. The factor α_E for energy-limited phase

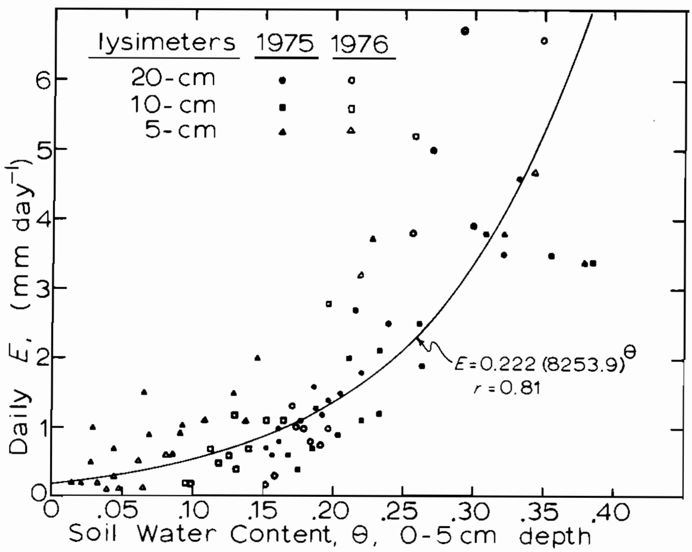

Fig. 3. Daily water loss, E, from lysimeters versus the adjusted average water content, θ, of the 0—5-cm deep layer in the lysimeter.

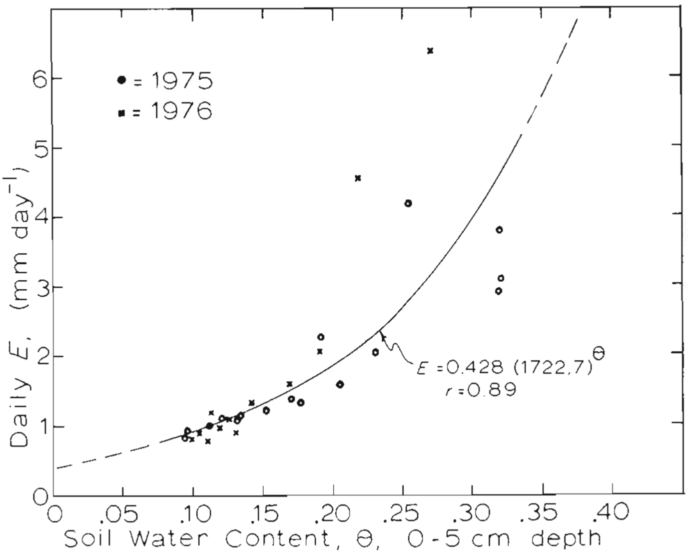

Fig. 4. Calculated daily water loss, E, using the Ritchie (1972) model with $\alpha = 4.97$ mm day$^{-1/2}$, $U = 6.00$ mm versus the average water content, θ, for the 0—5-cm soil layer outside of the lysimeters.

evaporation was adjusted for groundcover and advective conditions as described by Jury and Tanner (1975) and Tanner and Jury (1976). These calculated values of E for the two drying cycles are plotted against the average θ for the 0- to 5-cm layer of soil samples taken in the row and midrow under the corn canopy in Fig. 4. This relationship is nearly identical to that of Fig. 3. This suggests another method for obtaining estimates of E under the canopy by evaluating the inputs necessary for Ritchie's model and calibrating the calculated E to surface soil θ.

CONCLUSIONS

Our objective was to evaluate the use of small lysimeters located under a row crop canopy for obtaining direct measurements of E and to use this value in separating the components of ET into T and E. The most accurate use of the small lysimeters would be in establishing a relationship between E and surface soil θ. Once established, good estimates of E under the canopy could be made from sampling of surface θ. Extreme care should be used in estimating E from the lysimeter alone. In order to use the lysimeter E as a direct measure of the E under the canopy, several assumptions must be made as to the water content and distribution inside compared to the soil outside. Several compensating errors must be involved in order for the lysimeters to simulate conditions of the actual soil surface.

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