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RELATIONS BETWEEN EVAPORATIVITY AND EVAPORATION FROM SOILS IN CONTACT WITH A WATER TABLE

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INTRODUCTION

An evaluation of the hydrologic cycle necessarily involves computation of some of the terms in the familiar equation

$$P - E \pm \Delta S = R$$

where P = Precipitation

E = Evaporation

ΔS = Change in storage

R = Runoff

The evaporation term "E" may refer to evaporation from water surfaces, transpiration by plants, or evaporation from soils either in contact or not in contact with a water table. This paper is a presentation of experimental results on studies of the evaporation term "E" from three soil types in contact with a water table. Field conditions comparable to those simulated by these laboratory studies may be found in many areas of the irrigated West where accumulations of excess irrigation water in low-lying areas presents problem of drainage and harmful accumulations of salts.

In the case of saturated soil there is little reason to expect evaporation from soil to be different from evaporation from a free-water surface. As the soil surface dries beyond field capacity, however, the process of vapor diffusion through the soil becomes increasingly important in the evaporation process. The study reported here is concerned with the transition between moisture contents of complete saturation in which the flow is entirely in the liquid phase, and field capacity, in which the flow is largely by diffusion in the vapor phase.

EXPERIMENTAL EQUIPMENT AND PROCEDURES

Three soil types were placed on a rotating table at equal radii in a specially constructed chamber in which a constant temperature, humidity, and level of infra-red radiation could be maintained. Slide 1 shows the experimental equipment on the turntable.

Slide 1. Soil columns and related equipment in position on the turntable.

The columns were insulated to minimise radial temperature gradients. Thermocouples were placed in the columns to measure vertical temperature gradients. Radiant energy was supplied by turning on various combinations of the infra-red lamps above the turntable.

Water was supplied to the base of the column at constant pressure from Mariotte-siphon bottles. A schematic diagram of the arrangement of the column is shown in Fig. 2. The length of the column was increased by adding lucite sections. The water-table depth was fixed by the vertical position of the Mariotte-siphon bottle. Rate of evaporation was determined by periodic weighing of the bottles.

In a fourth column of fine sand on the turntable the water table was maintained at the surface. This column is hence forth termed a "free-water surface". Evaporativity, defined as the potential rate of evaporation produced by ambient conditions, was measured by the rate of evaporation from this "free-water surface".

Nine combinations of ambient factors were used to produce a variety of evaporation rates. Fig. 3 shows the rate of evaporation from the free-water surface for each of the nine sets of ambient conditions.

Additional runs were made with deeper water-table depths simulated by supplying the water to the base of the column at pressures less than atmospheric through a ceramic plate as shown in Fig. 4.

RESULTS

Evaporation rates from the soil (e_s) as a function of evaporativity as measured by the rate of evaporation from a free-water surface (e_f) are shown in Fig. 5. Examination of these figures shows that each soil type exhibits similar characteristics. For shallow water tables and low evaporativity there is nearly a one-to-one correspondence between e_s and e_f. As the water table was lowered and evaporativity increased, the relation changed so that finally an inverse relation was found between evaporativity and evaporation from the soils.

Since a major part of the increased evaporativity was caused by increased infra-red radiation on the soil surface it was first believed that the inverse relation observed was caused by the effect on vapor movement of a downward temperature gradient in the soil profile as suggested by Philip.* Additional experiments were conducted, using simulated deeper water tables with the apparatus described in Fig. 4. The results are shown in Fig. 6.

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* Philip, J. R. Evaporation, and moisture and heat field in the soil. Journal of Meteorology, 14(4):354:66, 1957.

For the series of runs shown in Fig. 6 the evaporativity was increased from the first to the second run by increasing the ambient temperature and the rate of air motion over the top of the soil columns without infra-red radiation. Evaporation from each of the soils increased with the increased evaporativity.

Evaporativity was increased for the third run by increasing the infra-red radiation on the soil surface. The net effect of this change was to decrease the rate of evaporation from each of the soils.

For the fourth run all sources of infra-red light were eliminated, but the evaporation rates from the soils did not recover to the former value. Hence it was concluded that the downward temperature gradient was not the sole cause of the observed inverse relation between evaporativity and evaporation from soils in contact with a water table.

Fig. 7 shows the results of another similar series of runs with deeper water tables (60 to 88 inches). For this series similar effects were noted, but experimental uncertainties were larger in this case than previously, and were probably of the same magnitude as the differences observed between runs.

SIGNIFICANCE

The preceding experimental evidence indicates the following characteristics concerning the inverse relation between evaporativity and evaporation from soils in contact with a water table:

1. The inverse relation can exist.
2. It does not require the presence of a downward temperature gradient in the soil.

3. Since the inverse relation can exist, measurements of evaporation rates from evaporation pan are entirely unreliable as indicators of evaporation from soils.
4. Under conditions such that the inverse relation occurs, higher evaporativity produces moisture conservation from soils.
5. The occurrence of the inverse relation is probably a function of soil properties rather than a function of the method by which evaporativity is increased.

COMMENTS REGARDING SOIL PROPERTIES

Space does not permit a detailed description of the dominant role played by soil properties in the production of the inverse relation noted, but a few of the highlights will be summarized here.

1. Any drying of the surface layer produces a condition in the soil profile such that the capability of the soil to transmit water is reduced. The soil can transmit water more rapidly through a saturated soil profile than can be imbibed upward through a partially dry surface layer.

2. The mechanism by which the soil profile rapidly loses its capability to transmit water upward as initial desaturation occurs can be explained satisfactorily in terms of a hysteresis property of the soils.* This property involves a multi-valued relation between moisture tension and moisture content that depends on whether desaturation or imbibition is occurring.

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* The Role of Hysteresis in Reducing Evaporation from Soils in Contact with a Water Table, by R. A. Schleusener and A. T. Corey. Submitted for publication in Transactions, American Geophysical Union, July, 1958.

3. Additional experiments have been performed to clarify the role of soil properties in the production of the inverse relation between evaporativity and evaporation from soils. It has been possible to duplicate this phenomenon using an oil-sand system under carefully controlled conditions with no temperature gradients. This is considered to be further experimental verification of the concept that the production of the inverse relation described in this paper is a result of soil properties and not a function of the method by which evaporativity is increased. Moreover, it is evidence that a downward temperature gradient is not required for this phenomenon.