Evaporation from soil surface in presence of shallow water tables

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ABSTRACT Field experiments were carried out to study the effect of the presence of shallow water table depth on the evaporation process from soil surfaces. Four different soils were obtained from known agricultural sites near Mosul city for investigations, with the water table at six different depths, 175, 150, 125, 100, 75 and 50 cm. The study revealed that there are two main factors affecting the evaporation process; the external meteorological conditions and/or the soil characteristics. These factors affect the soil surface evaporation individually or collectively depending upon water table location and capillary rise height of the soil. Based on the experimental work, equations for estimating the soil surface evaporation were determined for relatively deep and shallow water table depths.

INTRODUCTION

The optimum utilization of our limited supply of water and food resources in the world is becoming the central point in planning, operation and management of all irrigation and water projects. The ever growing population rate of the world and the limited sources of land and water are imposing great constraints on the food production and availability. Proper identification of storage, conservation, use and re-use of water resources are becoming more valuable and the water balance problem is taking more importance and urgency in all the countries of the world.

Upward flow from water tables subsequent to evaporation and transpiration from soils is a significant phenomenon, particularly in irrigated areas. In some areas, farmers find it advantageous to cause the water table to rise close to the root zone of crops to supply the root zone with water. In areas where soluble salts may be substantial, however, such practices have often led to unfavourable accumulation of salts within the root zone. The hydrologist, also is concerned with
upward flow from water table since such flow can have a substantial effect on the fluctuation of ground water storage.

The knowledge of the amount and rate of evapo-transpiration is useful not only for irrigation studies but also for the development of hydrological models. In many cases, the water use for some time after crop emergence and after harvest is dominated by the evaporation from the soil surface. In order to determine at what depth the water table should be maintained, the relation between depth of water table, soil properties and evaporation rate must be known. This information is also desirable when estimating water loss from soil by evaporation and estimating the amount of ground water available to plants due to upward movement of water from water table to the root zone.

Moore (1939) was one of the first to investigate upward flow from water tables as affected by measurable hydraulic properties of soils. He concluded that, at lower potentials (i.e., greater depths of the water table), the finer soils supported higher evaporation rates.

Veihmeyer & Brooks (1954) conducted experiments for measuring the evaporation rate from lysimeter in the field. They concluded that when water tables were maintained at depths between 15 - 150 cm, the evaporation loss from bare soils was not directly proportional to the depth from the soil surface to the water table.

Evaporation from shallow water tables through a homogeneous soil profile was studied theoretically by Gardner (1958). He solved the liquid flow equation for steady one-dimensional flow in a vertical upward direction.

Gardner & Fireman (1958) conducted laboratory studies on evaporation from soil columns packed in lucite cylinders. They tried to make a comparison between this method and the theoretical solution proposed by Gardner. They concluded that when the evaporativity (as measured by evaporation from a free water surface) was increased to fairly high rates, the evaporation rates from the soil columns appeared to approach a maximum as predicted by theory.

Doering (1963) introduced a method for the direct measurement of the vertical upward flow of water in the vicinity of the water table under field conditions. His results showed that the capacity of the soil to transmit water, not the surface evaporative potential, limited the flow.

Anat (1965) studied the upward flow in soil from water table. The procedure used for determining maximum upward flow rates differed from that employed by Duke in several ways. He concluded that the flow rates obtained by Duke were not unique but were affected by the particular increments by which he lowered his outflow siphon.

An experimental and theoretical study was carried out by Hadas & Hillel (1972) to examine the evaporation rate from shallow water table through a layered soil profile affected by the sequence and thickness of soil textural and structural layers. It was concluded that soil layering reduce evaporation especially when a
coarse-textured soils overlies a fine textured soil.

Shih (1983) conducted an experiment in lysimeter for studying the evaporation from soil surface in relation to water table depth and standard pan evaporation. He found that the water table depth significantly affected the soil surface evaporation.

The available literature reveals that only limited data are available on the actual rates of evaporation from soils overlying shallow water tables.

THE EXPERIMENTAL WORK

The experimental equipment consisted of four soil containers made from cylindrical metal columns with 30 cm internal diameter and 2 m height, (Fig. 1). Each container consisted of two parts, 1 m each, connected to each other by a flanged joint with six nuts and a rubber washer to prevent water leakage. The soil containers were connected to the water tanks by 25 mm pipe at a point 10 cm above the bottom of each container. A metal screen was provided at the end of the inflow pipe. Graded gravel and sand of 15 cm thickness was placed at the bottom of each soil container to act as a filter to avoid clogging of the pipe by the soil particles.

To maintain a constant water level at selected depths in each soil column, 16 metal tanks of 30 x 30 cm cross-section and 2 m height were fabricated, (Fig. 2). Each tank was provided by six floats placed at 25 cm intervals, along its height. Each float was connected to a 12.5 mm supply pipe connected to a water source located on the ground surface. The constant water level tanks were fed by ordinary tap water through 19 mm plastic tube. Water was allowed to flow until the constant water level tank was filled to a specified level, and the connection was maintained for a sufficient, predetermined, time to allow the water to rise in the soil to the maximum level by the capillarity action. Then the supply pipe of the water tank was connected to a plastic container with a known water volume. The plastic containers were kept inside wooden boxes and were surrounded by non-conductive material to protect them from the external meteorological conditions.

Two standard evaporation pans were installed adjacent to the soil containers. The evaporation pans had the same diameter and elevation as that of the soil container. A point gauge, with accuracy of 0.1 mm was fixed at the top edge of the evaporation pan.

Four soils from known agricultural sites were selected to be used in this study. All pertinent information concerning the soils were determined. Standard mechanical analysis were performed and textural classifications were determined. In addition the height of the capillary for the soils were determined experimentally. The data are shown in table 1.

A 2 m deep pit was excavated in the experimental field at desired location. The floats were checked and tested in each tank and connected properly to the supply pipes.
Fig. 1 General layout of the experimental equipment.

Fig. 2 Soil container and variable water tank.
The soil containers and water tanks were lowered into the pit and fixed in an up-right position. The soil containers and water tanks were connected in the pit. The proper operation of all the components were checked and tested.

After the completion of the equipment installation, the excavated soil was refilled to the pit to a depth of 1 m. The upper part of the soil container was removed, and the soil sample was placed in each container by the use of plastic funnel to avoid soil segregation. The soil was compacted to its average bulk density in layers of 5 cm thickness. The desired bulk density of each soil was achieved by compacting a known weight of soil to a calculated volume. To assure the continuity and preventing layering of the soil profile after compaction, the soil surface of the completed soil layer was disturbed before placing a new layer. The process was continued until the lower part of the soil container was filled, then the upper part of the soil container was jointed to the lower one. The pit was filled and levelled with ground surface. The same procedure for the soil compaction was followed to fill the soil container to the desired depth of 2 m. The evaporation from soil surfaces were recorded.

The evaporation rates from soils in presence of shallow water tables were computed, for soils 1, 2, 3 and 4 for six different depths. The depths were 175, 150, 125, 100, 75 and 50 cm respectively. Six runs were performed for each water table level for duration of 17 days. Typical evaporation for data from the soil surfaces for water table depth of 75 cm are shown in table 2. The evaporation rates in relation to water table depth are shown in Fig. 3.

RESULTS AND DISCUSSIONS

Analysis of the results of the experimental work reveals the following:-

(a) The free water surface evaporation (PPE) which represents the external evaporativity conditions closely correlates to the soil surface evaporation when the water table depth is near the soil surface; i.e. the meteorological conditions are the influential factor in the evaporation process. However, as the water table depth increased the correlations between soil surface evaporation changed and no consistent relations were observed.
Table 2  Typical Evaporation from the Soils for Water Table Depth at 75 cm

<table>
<thead>
<tr>
<th>Date</th>
<th>Avg. Temp. °C</th>
<th>Mean Relat. Humidity %</th>
<th>Radia- mm/day</th>
<th>Wind Speed km/day</th>
<th>PPE Evaporation rate from (mm/day) Soil 1</th>
<th>Soil 2</th>
<th>Soil 3</th>
<th>Soil 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 July</td>
<td>33.5</td>
<td>26.0</td>
<td>9.8</td>
<td>93.1</td>
<td>14.3</td>
<td>6.8</td>
<td>7.8</td>
<td>11.3</td>
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<td>22</td>
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<td>6.7</td>
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<td>6.9</td>
<td>11.1</td>
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<td>9.1</td>
<td>160.4</td>
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<td>6.5</td>
<td>6.9</td>
<td>10.0</td>
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<td>16.3</td>
<td>7.6</td>
<td>7.7</td>
<td>11.7</td>
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</table>

SUM 46.0 527.0 126.7 2255.9 216.4 93.9 102.5 159.7 115.2

AVG 32.9 37.6 9.1 161.1 15.5 6.7 7.3 11.4 8.2

Fig. 3 Average evaporation as related to water table depths.
(b) The soil surface evaporation, (SSE), value approaches the free water surface evaporation, when the capillary rise heights of the soils are more than the water table depths.

(c) Unfortunately, no clear relationship between the variables, water table depth, soil surface evaporation and pan evaporation, is possible for direct application. This is due to the fact that the soil surface is influenced by the meteorological conditions and soil properties. These factors influence the soil surface evaporation individually or collectively depending upon the location of water table.

(d) Generally when the water table is close to the soil surface; i.e., the meteorological factors are in control of the evaporation process, the evaporation rates from the soils are higher for the coarse textured soils and decrease as the soil becomes finer.

(e) The soil surface evaporation decreases as the water table depth increases. When the water table is deepest, the variation in the values of soil surface evaporation is minimal and does not correspond to the free water surface evaporation fluctuation.

(f) The evaporation from soil surface is controlled either by climatological factors or by the soil characteristics depending upon the relation between the water table depth, \( d \) and capillary rise height in the soil, \( C_r \). Figure 4 shows the relations between the dimensionless parameters \( \frac{\text{SSE}}{\text{PPE}} \) and \( \frac{d-C_r}{d} \), for the soils investigated. The results are presented in two categories.

\[ \text{Fig. 4 Soil surface evaporation/pan evaporation related to water table depth and capillary heights.} \]
(i) Category one, when $C_r < d$; i.e. soil properties are the influential factor in soil surface evaporation. The following general equation is suggested for estimations of soil surface evaporation based on linear regression model:

$$\frac{SSE}{PPE} = C + F \frac{(d-C_r)}{d} \quad 1$$

$(C)$ and $(F)$ are coefficient estimated from experimental data shown in (Table 3) for the soils studied.

Table 3 The Coefficients of Soils studied

<table>
<thead>
<tr>
<th>Soil No.</th>
<th>$C$</th>
<th>$F$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.76</td>
<td>1.02</td>
</tr>
<tr>
<td>2</td>
<td>0.59</td>
<td>0.86</td>
</tr>
<tr>
<td>3</td>
<td>0.71</td>
<td>1.21</td>
</tr>
<tr>
<td>4</td>
<td>0.63</td>
<td>0.88</td>
</tr>
</tbody>
</table>

(ii) Category two, when $C_r > d$; i.e. when the meteorological factors are in control of evaporation process. The following equation is suggested for estimating the soil surface evaporation.

$$\frac{SSE}{PPE} = \frac{C}{\phi} \quad 2$$

$(\phi)$ is a coefficient estimated from experimental data obtained for the tested soils. In the present study $(\phi)$ was found to be (0.8) for all the soils with water table depth at 50 cm.

REFERENCES


Measurements of cumulative evaporation from bare soil.