Effect of shallow saline-groundwater depth in evaporation rate

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Abstract: Shallow water table conditions may be found quite extensively in arid and semi-arid environments. When the evaporative demand is greater than the ability of the soil to conduct water in the liquid phase, the soil profile above a water table exhibits a liquid-vapour discontinuity, known as the evaporation front, that affects the rate of evaporation. This is influenced by climate, soil type, crop, irrigation water quality and management practice and depth to water table. The objective of this study was to assessment of the magnitude, extent of evaporation due to capillary upward flow in bare soil with shallow water table depths by saline groundwater. In this study we were controlled and observed profiles of soil water over periods of experiment. This experiment conducted on summer of 2010. The experiments shown that rates of evaporation in the end of period were 3.17, 1.42, and 0.2 mm/day for water table depths of 300, 500, and 800 mm, respectively.

Keyword: Evaporation, Water Table, Shallow Ground Water

1. Introduction

Assessment of evaporation from a bare soil surface is also very important (Mehmet et al., 2005). Researchers investigated and discussed in detail the effects of quality of irrigation water, irrigation strategy, soil type, ground water quality and depth on evaporation and salinisation of soils (Ali et al., 2000).

results obtained from study of Zhu Xue and Takeo Akae (2010), showed that the evaporation from salt affected soil was less than that of non-saline soil under the same climate condition, the main reasons may be due to the effect salt accumulating on soil surface reducing the soil evaporation. Salinity problems caused by the presence of saline groundwater at shallow depths are widely acknowledged to adversely affect production from the world's irrigated land, especially in arid and semi-arid regions. Elrick et al. (1994) successfully modeled the upward movement of solutes from shallow water tables under the low evaporative demand (3-4 mm/day) of summer in northern Europe using the convection-dispersion equation, but the surface of their soil always remained moist. Hassan and Ghaibeh (1977), Chen (1992), and Shimojima et al. (1996) investigated experimentally the movement of water and salts above saline water tables in controled condition. further experimental and theoretical work is needed on the upward movement of water and salt from a shallow saline water table in field condition evaporation. In arid and semi-arid regions, the evaporative demand is usually greater than the ability of the soil to conduct water in the liquid phase and a liquid–vapour phase discontinuity, known as the evaporation front (EF), occurs at an intermediate depth between the soil surface and the water table (Menenti, 1984; Bastiaanssenet al., 1989; Gowing and Asghar, 1996; Rose et al., 2006).

Upward flow from shallow water table

The following theoretical considerations have been well understood for the past four decades. The principle of mass conservation combined with the Darcy equation leads to the following nonlinear partial differential equation for one-dimensional vertical flow systems under isothermal conditions:

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}K(h)\frac{\partial h}{\partial A} + \frac{\partial K(h)}{\partial z} \quad (1)$$

Where h= h (z, t) is the pressure head of the soil water, z the position positive upwards and t is the water-holding capacity dθ/dA, K(h) the hydraulic conductivity function. The medium is assumed uniform so that the water-holding capacity and conductivity function are independent of position (Gardner, 1958).

To predict the behavior flow system, equation 1 must be solved for appropriate boundary and initial conditions. If the boundary conditions are kept constant the follow system will eventually reach a steady state. The partial derivative with respect to time vanishes and equation 1 is reduced to the ordinary differential equation:

$$\frac{\partial}{\partial z}\left[K(h)\frac{\partial h}{\partial z}\right] + \frac{\partial K(h)}{\partial z} = 0$$

this upon integration leads to

$$K(h)\frac{\partial h}{\partial z} + K(h) = -A$$

(2)

Equation 2 is simply Darcy`s equation so that the constant of integration, A, is volumetric flux, Q, of the soil solution. Hence,

$$Q = -K(h)\frac{\partial h}{\partial z} - K(h)$$

(3)

If one is interested in the steady state flux and salt accumulation, the flow system is shown schematically in figure 1. Flow is upward in the z direction which represents the depth from the soil surface to the water table and C is the salt concentration in the groundwater which enters the bottom of the soil column. The rate at which salt enters the profile from below, dF / dt, is given by:

$$\frac{dF}{dt} = Cq_i$$

(4)

Where q_i is the volume rates of inflow of water from water table. since the salt remain in the soil when the water evaporates from the surface, there is an accumulation of salt in the profile.

Furthermore, the continuity principle requires that inflow minus outflow must equal storage. This applies for both salt and water. For water:

$$V_i = V_E + V_S$$

Where V is expressed in units of volume per unit area, and the subscripts I, E and S denote inflow, outflow by evaporation, and storage, respectively. But

$$V = \int_{t_1}^{t_2} qdt$$

(5)

And if θ is the average water content of the soil column in milliliters per unit volume, then we will have

$$q_E = \frac{1}{C}\frac{dF}{dt} - Z\frac{d\theta}{dt}$$

(6)

Where q_E is the volume rate of evaporation per unit cross-sectional area.

Although man, through miss use of water and soil resources, is quit often the creator of the shallow water table, natural seepage and artesian flows are also sometimes involved. All this factors should be considered in monitoring and predicting salinity due to the shallow groundwater. In this regard, the term 'critical water table depth" is often mentioned and considered as the level above which water rising by capillarity will cause salinization of the arable soil horizons.

Also many researchers have investigated experimentally the movement of water and salts above saline water tables in controled condition. further experimental and theoretical work is needed on the upward movement of water and salt from a shallow saline water table in field condition evaporation.

Rose et al.(2005) measured the rate of evaporation as a function of the water table depth and the evaporability. The experiment was conducted in constant temperature and no radiation. They discarded the salt effect as an explanation and promoted the idea that the gradual drying of the soil surface zone in effect created a two-layer condition.

Most workers tested the theory experimentally by means of evaporation studies. Some introductory remarks seem warranted before presenting the results reported in literature. The pressure head at soil surface was neither measured nor controlled directly in most evaporation studies. The pressure head was the resultant of the combined effects of the water table depth, the soil conductivity function and evaporation conditions. The evaporative conditions were expressed quantitatively as the potential evaporability which was defined as the integrated effects of the relative humidity, the air temperature, the air circulation, and the incident radiation on the evaporation rate from a free water surface. The evaporability was then used as convenient reference with which the actual evaporation rates from soil columns with a water table at a given depth were compared.

Hadass and Hillel (1968) measured the rate of evaporation as a function of the water table depth and the evaporability. The air circulation over the top of the soil columns was varied to obtain different evaporability condition. The experiment was conducted in constant temperature and no radiation. Furthermore evaporation was measured for different water table depth under conditions of increasing evaporability. His experiments shown that, for the loess-derived soil, an inverse relation exists between the evaporation and evaporability. He discarded the salt effect as an explanation and promoted the idea that the gradual drying of the soil surface zone in effect created a two-layer condition. Water movement across the dry surface layer would then be in the vapor phase only.

This study was designed to assessment the effect of water table depth and its salinity on salinization of soil from evaporation (bair soil as follow soil) of saline solutions. This experiment conducts in field condition in a semi-arid region- Ahwaz, Iran,- with simulating by lysimeters.

2. Material and methods

This research concluded three experiments. Some Lysimeters contained, from the base upwards, 5 cm of gravel and 5 cm of sand (to allow unrestricted

exchange with the supply of groundwater), then soil to rim. Topsoil of the research field of Chamran University of Ahvaz was sieved through a 2 mm mesh. The soil was packed as uniformly as possible in 10-cm layers to bulk density of 1.35 g/cm^3. Selected properties of the soils are given in Table 1. The field was excavated in order to place the lysimeters at a certain depth so that their top was on level with the ground surface. The excavated soil was then placed back into the lysimeters and the surrounding space. The experiments with saline ([3 g NaCl/L + 3.5 g CaCl$_2$/l]), and three Water table depths (300, 500, and 800 mm) were conducted under field conditions. The soil columns were cylindrical PVC tubes of 120 mm inside diameter. The base of each column was closed by a plastic disc.

To saturate the soil, tape water was introduced from the bottom to avoid trapping air. Water was then allowed to drain while keeping the soil surface covered and allowed to stand for one day in order to deplete the detention storages by gravitational force. The soil columns were weighed and then placed in excavated places and left for evaporation in field condition. The Marriot tank systems were installed to conduct constant water table depth in experiment period. The lysimeters were weighed and sectioned, (10 cm layers) after 5, 15, 30,45, 60 days and at the end of experiment to determine gravimetric water content. Salt contents (EC$_e$) determined in end of period. The experiments started on April, 10, 2010.

The rate of capillary rise was taken as the volume of water supplied by the Mariotte tank. This volume was monitored periodically. Potential Evaporation was monitored with a Class-A evaporation pan that located at 10 m from the lysimeters.

Table 1. The selected chemical and physical properteis of original soil

Soil properties	Amount	
Ca^{+2}	10	meq/lit
Mg^{+2}	3	meq/lit
Na$^+$	24.8	meq/lit
K$^+$	1.41	meq/lit
Cation Exchange Capacity	31.34	meq/100g soil
pH	7.7	
EC$_e$	2.55	
Organic Material	0.74 %	
Texture	Clay Loam	

3. Result and Discussion

In the steady-state, the rate of water loss from the Mariotte siphon is equal to the rate of evaporation from the soil surface. However, in a non-steady-state, the rate of evaporation equals the sum of the rates of water loss from the Mariotte siphon and the water depleted from the soil profile which may be calculated from successive water-content profiles over a given time period.

In Figures 1 and 2 were showed the accumulated evaporation rate from pan evaporation and soil surface respectively. As be shown, under the same atmospheric demand, evaporation from the soil surface was significantly affected by the depth of the water table (Figure 2). In this period the rate of potential evaporation, E$_p$, (pan evaporation) was 8 mm/day, in first day, and 16 mm/day, in last days.

In experiment I(D = 300 mm), the soil was sufficiently wet that the flow of water to the surface as liquid was unrestricted so that the flux from the groundwater remained constant. Since the evaporative demand of the atmosphere was greater than the ability of the soil to conduct water, the soil surface, rather than first of experiment, dried and the hydraulic conductivity also decreased. After 5 days, the average rate of evaporation from the profile was 7 mm/day. Its rate decreased slightly during the period of research and was 5.23 and 3 mm/day in 15 and 80 days after start of experiment, respectively. Chen (1992) also observed that a very thin (2 mm) crust diminished the evaporation to about 2% of that from a freshwater surface, even though the soil underlying the crust remained almost saturated. When he added distilled water to the salt crust, the evaporation rate increased nearly 20-fold for a short time, then returned to the previous low value.

The rate of evaporation from the soil surface showed similar patterns with deeper watertables. However there were differences. In experiment II(D =500 mm), the rate of evaporation was about 6.62 mm/day within 5 days, followed by a slower continuous drop until day 60 to a steady rate of 1.74 mm/day and 1.4 mm/day, in last days. In the 800-mm water table (experiment III), the evaporation rate of 6.5 mm/day, in 5 first days, decreased rapidly to about 2.7 mm/day within 10 days. It then fell steadily to 0.61 mm/day during the following 30 days, and finally decreased slowly to a steady rate of 0.2 mm/day by

day 80. The deeper the water table, the later was the steady-state achieved.

Result of this study showed that under the same atmospheric demand, evaporation from the soil surface was significantly affected by the depth of the watertable. A similar initial rate of evaporation was observed for all water table depths, close to that for open water. However, the progress of the relative rate of evaporation, E/E_p, with time differed; the deeper the watertable, the steeper was the falling rate of evaporation. When the water table depth increased from 300 to 500 and 800 mm, the final evaporation rate fell from 3 to 1.4 and 0.2 mm/day, and E/E_p from 0.22 to 0.1 and 0.01, respectively (Table 2). These values are comparable to those from salt-encrusted surfaces reported by Chen (1992).

Table 2 summarizes the effect of water table depth on evaporation. The results for open water, E_p,

and final evaporation, E, rates are the average values over the relevant periods. A comparison of final cumulative Ep and cumulative E, confirms that, under our experimental conditions, the actual evaporation from the soil surface was severely restricted. Table 3 shows the effect of increasing water table depth on the magnitude of the changes in Epaccumulated/ Eaccumulated. The quantity of water lost from the surface and decreased with increasing water table depth. For example, under the same evaporative demand, when the water table depth was increased from 300 to 500 mm, the final relative evaporation and the amounts of water lost from the soil surface decreased by only 36.7 and 38%, respectively. However, when the water table depth was increased from 500 to 800 mm, the relative evaporation and the amounts of water lost from the soil surface decreased by about 48.6 and 47.6%, respectively.
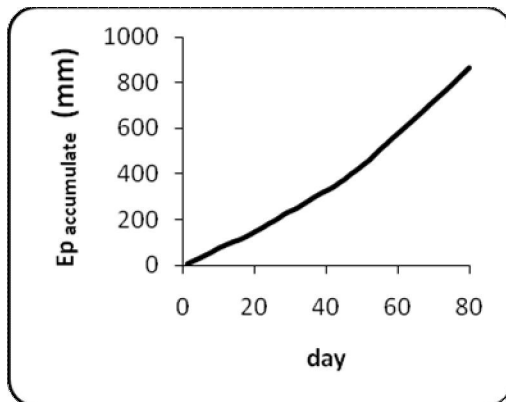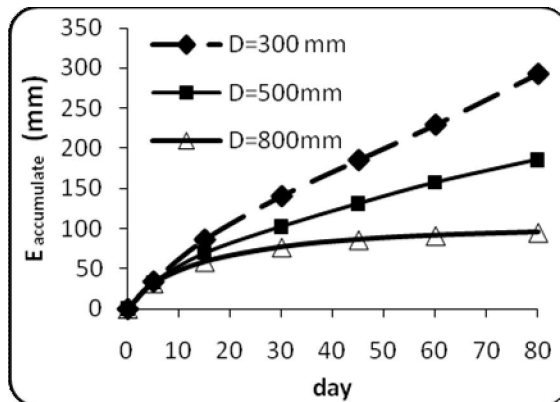

Figure 1. Accumulated Pan Evaporation rate

Figure 2. Accumulated Evaporation rate

Table 2. Effect of water table depth on water fluxes

Period (day)	1-5			5-15			15-30		
Water table depth (mm)	E_p (mm/d)	E (mm/d)	E/E_p	E_p (mm/d)	E (mm/d)	E/E_p	E_p (mm/d)	E (mm/d)	E/E_p
300	7.52	6.84	0.9	7.09	5.23	0.73	8.7	3.61	0.41
500	7.52	6.62	0.88	7.09	3.64	0.51	8.7	2.2	0.25
800	7.52	6.4	0.85	7.09	2.66	0.37	8.7	1.22	0.14
Period (day)	30-45			45-60			60-80		
Water table depth(mm)	E_p (mm/d)	E (mm/d)	E/E_p	E_p (mm/d)	E (mm/d)	E/E_p	E_p (mm/d)	E (mm/d)	E/E_p
300	9.6	3	0.31	13.5	2.94	0.22	14.5	3.17	0.22
500	9.6	1.88	0.2	13.5	1.75	0.13	14.5	1.42	0.1
800	9.6	0.61	0.06	13.5	0.34	0.02	14.5	0.2	0.01

*E= actual Evaporation, E_p= Pan Evaporation
Rate Ep accumulated

Table 3. Effect of water table depth in $E_{accumulated}$

Water table depth(mm)	Day					
	5	15	30	45	60	80
300	0.92	0.78	0.59	0.49	0.4	0.34
500	0.89	0.63	0.43	0.35	0.27	0.21
800	0.86	0.53	0.32	0.23	0.16	0.11

Moreover the profiles of salt content in days 80, showed in Figure 3 the lower the lysimeter, had most salt accumulation in top layers, because of that had most evaporation rate from soil surface in same condition. Figure3 explained the profiles of salt content at end of experiment. The ECe of the soil increased with evaporation at soil surface. As be shown in Figure 3, the salt concentration increased with high slope between 200 and 10 mm, in D=300 treatment and the concentration remained at or closes to the 10.55 dS/m below the depth of 200 mm.

In the treatment of D=500, the salt concentration profile increased from 9.57 dS/m to 56.88dS/m between 200 mm and 10 mm and in the end of experiment. This values rose more slightly than that D300 column. Below 200 mm, the concentration of salt changed from 9.55 dS/m to 10.55 dS/m.

The salt concentration between 200 mm and 10 mm, increased with low slope, and increased from 9.95 dS/m to 24.01dS/m below the depth of 200 mm, In treatment D=800. Below the depth of 200 mm, the concentration did not change noticeably and remained about 10.55 dS/m.

4. Conclusion

In this paper, we conducted experiments on a clay loam soil, with shallow saline water tables under natural evaporative demand in ahvaz, monitoring amount of evaporation from bare soil, and observing profiles of soil water and salinity over periods of up to 80 days. The experiments shown that, Salts mainly accumulated in the soil surface and transition zone. Furthermore, it be shown that, the volume of evaporation from bare soil in lower water table depth (D=300mm), is greater than other lysimeters (D=500 mm and D=800 mm), that result in higher salt accumulation in this lysimeters. We used a disturbed and repacked homogeneous soil profile, whereas a field soil is likely to be structured and have vertical and horizontal differences in texture, bulk density, and hydraulic properties.
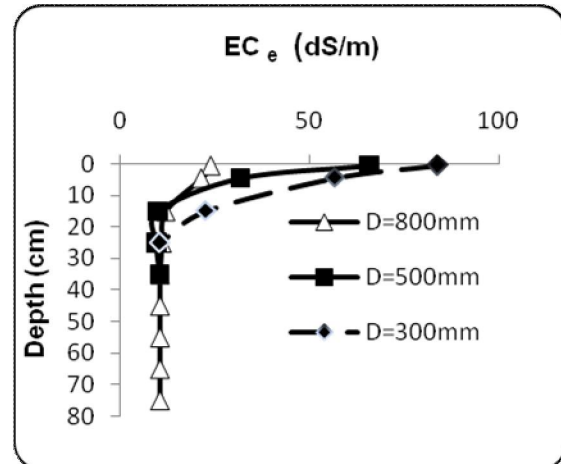

Figure 3. Salt profile in the end of experiment

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