

92

EVAPORATION and TRANSPIRATION:

THEIR EFFECTS

on

SALT ACCUMULATION

RACERASE BOND

SOUTHWORTH CO. U.S.A.

25% COTTON FIBER

Dan Munk
SSC-122
Fall 1986

Salt accumulation in soils occurs when the supply of soluble salts is greater than the removal of those salts within the soil profile. Because solutes are continually supplied to the soil profile through a variety of sources, an adequate leaching regime is required in order to keep salt accumulation at a minimum. In semi-arid and arid regions this is not often an easy task to accomplish. Plant water uptake is a discriminating process in which the water is taken up at a much higher rate than the solutes that accompany it. Similarly, evaporation exclusively removes water while leaving all solutes behind. The study of evaporation, transpiration, and solute interactions can provide information relating to salt accumulation in soils. Let us then look more closely at the energy consuming processes of evaporation.

Evaporation in the field can take place at plant surfaces, at the soil surface, or at free water surfaces. On plant surfaces, water often is guttated or condensed due to low morning temperatures making it available to diffusion into the atmosphere. Another form of evaporation from plant surfaces is that called transpiration which results from the transfer of soil-water to the plant and ultimately into the atmosphere. ^{as vapor?} Of great use to scientists studying the transfer of water from the soil or plant, is the combined processes of evaporation and transpiration known as evapotranspiration. Evapotranspiration(ET) is hence, the process by which soil and plant water is transferred into the atmosphere.

In order for water to be transferred from liquid to gaseous state, three conditions are necessary. The heat of vaporization must be supplied in order to break H-bonds of liquid water. About 590 calories are required ^{Reference?} to vaporize 1 gram of water at 15 °C. The vapor pressure of the atmosphere must be lower than that of the liquid surface so that a gradient of water

vapor can allow vapor transfer from the evaporating surface. Finally, a continual supply of readily available water is needed to maintain an unimpeded flux of vapor from the water surface. ^{Are these the same?} The content or potential of water on a plant or soil surface must then be considered as well as the conductive properties of such media. Evaporation and transpiration are thus a function of radiant energy, vapor pressure gradient and the conductive properties of the soil or plant water. It will be useful here to first consider the less complex case of evaporation from a bare field.

Consider a recent rainfall or irrigation over a uniform bare plot of soil which has been deeply wetted. If atmospheric evaporativity is held constant, the soil drying process can be explained in terms of three separate stages (Pearce et al., 1949).

During the initial stage, the soil surface gradually dries out and moisture is drawn up by capillary action. At this stage, the rate of evaporation is controlled by the ^{mostly?} atmosphere conditions as previously discussed. ^{Some effects from water potential in the soil?} In a hot, dry climate this condition may only last a couple of hours depending on the soil water retention characteristics. As the soil continues to dry out, the decrease in soil surface moisture yields a smaller value of soil water conductivity, limiting upward capillary transfer and a second stage of evaporation rate is entered.

In terms of Darcy's law in which:

$$q = K (\partial \psi / \partial z)$$

q = Flux

K = Conductivity

$\partial \psi / \partial z$ = Driving force for water transport ^{ie potential distance = head}

We can imagine decreased water contents giving rise to smaller capillary pores within the soil, thereby decreasing its ability to conduct water.

Therefore, K is reduced. As the soil dries however, $\partial \psi / \partial z$ is increased, compensating for the decrease in K , ~~as the soil dries, / increases suf-~~

Does this describe only the 2nd stage? →

non-linearity of K vs. θ

efficiently during Stage I. During Stage II, however, the reduction in K is greater than the increase in the driving force and the flux(q) is reduced. ~~Surface~~ In the final stage the surface soil has dried further, bringing K closer to zero. Although the driving force for water transport is extremely large, the soil's ability to conduct water through capillary pores is minimal. The process of vapor diffusion is now the most important governing water flux. The rate of vapor flux is affected by the vapor diffusivity of the surface zone and by the absorptive properties of water on particle surfaces. Such a process is slow since its mechanism of transport through surface soil is diffusion rather than mass flow.

Figure 1b shows the three different stages of evaporation rates as they vary over time. Again, it is important to keep in mind that the length of time for each stage is dependent upon soil type and atmospheric conditions. High rates of evaporation yield short time increments for Stage I and Stage II as seen in figure 1b.

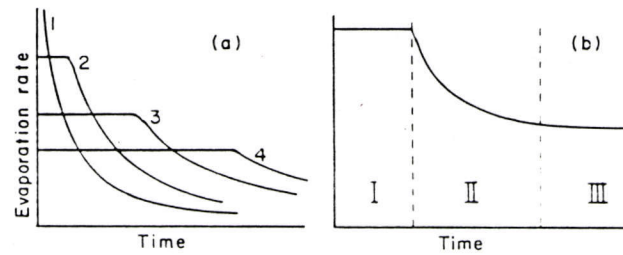
A closer examination of constant rate evaporation (Stage I) has been studied by Gardner and Hillel. They found that this constant rate evaporation could be described mathematically using the flow equation (Gardner and Hillel, 1962):

$$\frac{e}{L} = \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left(D \frac{\partial \theta}{\partial z} \right)$$

Where e = rate of water loss per unit soil volume
 L = depth of uniformly wetted soil
 θ = volumetric water content
 t = time, z = height above the bottom of the profile
 D = diffusivity (a function of potential and water content)

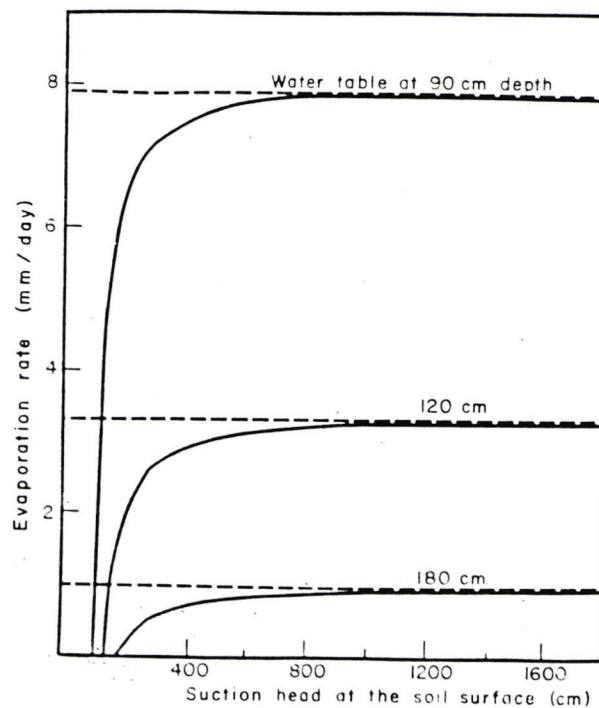
A flow equation was also developed for the falling rate (Stage II) stage of evaporation by these two researchers. During the decreasing-rate stage of drying:

$$e = - dw / dt = D(\theta) w \pi / 4 L^2$$



(a) Relation of evaporation rate (flux) to time under different evaporativities (curves 1-4 are in order of decreasing initial evaporation rate). (b) Relation of relative evaporation rate (actual rate as a fraction of the potential rate) to time, indicating the three stages of the drying process.

Figure 1.



Steady rate of upward flow and evaporation from a water table as function of suction head at the soil surface. The soil is a fine sandy loam, with $n = 3$. (After Ga 1958.)

Figure 2.

Where Θ is the average volumetric wetness obtained by dividing the total of the soil W by the depth of wetting L and $D(\Theta)$ is the diffusivity function.

The steady flux of water upward from a water table to the soil surface was described by Gardner (1958). A semi-empirical formula for the evaporation rate under these conditions is:

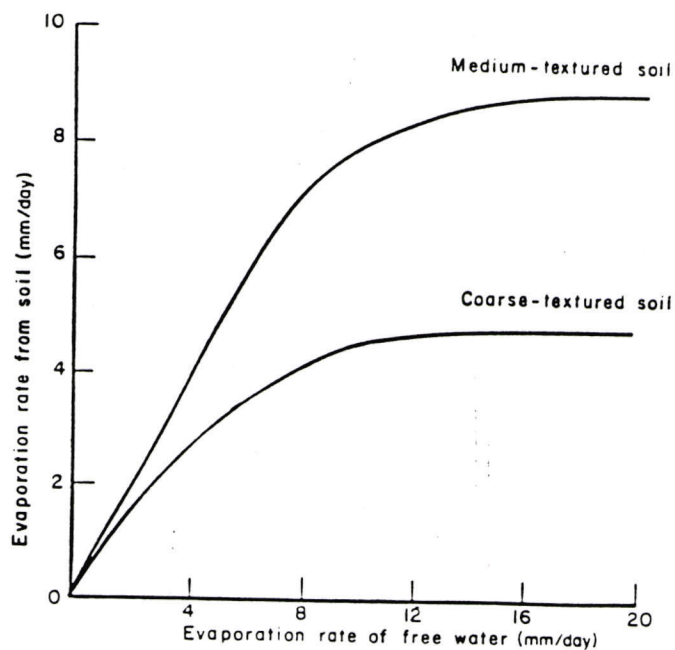
$$e = \frac{a}{\psi^n + b} \left(\frac{d\psi}{dz} - 1 \right)$$

Where e is the evaporation rate; a , b and n are constants that are determined for the individual soil.

The curves in figure 2 show that the steady rate of capillary rise and evaporation depend on the depth of the water table and on the suction head at the soil surface. This suction head is in turn dependent upon the atmospheric conditions and the soil type. For coarse textured soils, n would be greater and is seen from the above equation that evaporation would decrease. This is not surprising since the water holding capacity of a coarse soil is much lower than that of a fine soil. Figure 3 confirms the fact that small pores connect the lower horizons with the soil surface reducing the capillary transport upward.

Also that med. text. soils have more fine pores that contain water at lower potentials so evap. rate is higher than coarse text. soils.

The accumulation of soluble salts in bare soils is generally not significant unless accompanied by a high water table. The rise of capillary water can yield much higher evaporation rates allowing the concentration of solutes particularly if the ground water initially contains high amounts of soluble constituents. Unless adequate leaching practices are implemented, the buildup of salts can impair vegetative survival or growth due to solute and specific ion effects. Evaporation from bare surface soils is only important for special conditions such as fallow agricultural lands or saline basins. Of even greater importance is the loss of water through transpiration.



Theoretical relation between the rate of evaporation from coarse- and medium-textured soils (water table depth, 60 cm) and the rate of evaporation from a free-water surface. (After Gardner, 1958.)

Figure 3

Approximate water potential values for a transpiring corn plant^a

Component	Water potential (MPa)
Soil	-0.01
Roots	-0.15
Leaves	-0.80
Air	-80.0

^a Soil water is at field capacity, relative humidity is 50%, and air temperature is 30°C. Data are from Neumann et al. (1974) and Leyton (1978).

Table 1

Plants require substantial amounts of water. For example, 1 Kg. of wheat requires about 1000 Kg. of water (Krogman and Hobbs, 1976). An actively growing plant uses 5 to 10 times as much water as it can hold at one time. Water availability is thus seen as a primary factor in plant survival, development and ultimate productivity. Particularly at the early stages of growth, water availability is of importance to the expansive growth of leaves and stems as well as the root system. Once a mature root system is developed, the plant can extract soil moisture more readily, thus keeping up with the transpiration demands of the canopy.

to produce 1 kg of grain?
or 1 kg of total plant?

Plants function like conducting elements moving water from the root zone into the plant and eventually into the atmosphere. The water move in response to water potential gradients i.e. from high to low water potentials. The water potential in the soil water is often highest, decreasing through the plant and eventually in the atmosphere.

If we divide the water potential gradient into its component parts and account for its resistance to flow, we can estimate the flux as in Darcy's equation to obtain:

$$\text{Flow Rate} = \frac{\Psi_g - \Psi_r}{r_g} = \frac{\Psi_r - \Psi_L}{r_r + r_x} = \frac{\Psi_L - \Psi_a}{r_s + r_a}$$

Where Ψ_g , Ψ_r , Ψ_L and Ψ_a are water potentials of the soil, root, leaf and air respectively, r_g , r_x , r_s and r_a are the resistances through the soil and to the root surface, across the root, through the xylem, the stomates and the aerial boundary layer, respectively. Table 1 shows some typical values of water potential for a transpiring corn plant. The large gradient between the air and the leaves is needed due to the large resistance to flow in the vapor phase. This compensation allows substantial quantities of water to be transpired by the leaf surfaces.

Because plants are able to make use of soil water, limited only by the

physical or chemical constraints imposed on their rooting systems, much larger volumes of water can be extracted compared to the condition of no vegetation. Plants have varying abilities to extract water at different levels within the soil profile corresponding to their root density profiles. Many grasses, for example, are very shallow rooted and utilize surface soil moisture while many tree and shrub species "mine" water at deeper depths. Since soil waters transport solutes, it is likely that solute accumulation will be most concentrated in those zones that remove the highest quantities of soil water. The situation is made more complex by other interacting factors.

The water balance in the root zone can be reduced to the simple equation:

$$\Delta W = W_{in} - W_{out}$$

Where ΔW is the change in soil water content. The water balance here can be expanded into its components where W_{in} may include water from precipitation (P) or irrigation (I) of a water table (W). W_{out} can be seen as water that runs off (R_o), is deep percolated (D_p) or is expelled through evapotranspiration (E_T). This yields:

$$\Delta W = PI + W - R_o - D_p - E_T$$

Can this be incorporated into a salt balance eqn?

The water balance method provides a useful way in which to look at the balance of salts in soil profile because it considers water fluxes which result from most any kind of change in the system. If several short term, low intensity rainfall events occurs over any given time-step, this method can account for soil-water that has been transpired or evaporated between the rainfalls and any water that may leach through the profile completely.

When modeling either a natural system or a man-made system, the only

constraints using such a method are the parameters used to construct the individual terms. Widespread knowledge of soil-water fluxes, water holding capacity and root density are needed. Good approximations for evaporation and transpiration are also vital to the validity of such a model. If one component in the water balance method is unknown, it can be estimated from the difference of the other components. The only problem with this is that the errors are summed with the individual components.

Recently, many models of solute and water transport have been constructed with such principles in mind (Wilcox and Sly, Weeks and Sorey, Addicott and Wagenet). (With proper construction, purposes including the estimation of salt loading in soils.)? *(notes)*

Not in
Sources
cited?

The water balance in soil systems is critical to the understanding of the accumulation processes occurring within the soil profile. Whether there is a flux of solutes downward as a result of surface waters infiltrating or an upward flux of subsurface waters rising (or a combination of the two) solute transport is dramatically effected in the long run by evaporation and transpiration. It is only when there is substantial quantities of water percolating through the soil profile that salt accumulation need not be significant to plant growth or soil property changes.

Good discussion of evaporation processes & transpiration
A bit thin on the link between these & salt accumulation
eg, how solutes reduce vapor pressure & change pot.
gradients.
Also, how water balance equations can be used
to develop salt balance models for leaching of
or accumulation of salts.

SOURCES CITED

- Addiscott, D.M. 1985. "Concepts of Solute Leaching in Soils: A Review of Modeling Approaches." Soil Science: 36, 441-424.
- Bohn, H.L., McNeal, B.L. Soil Chemistry. 1979. John Wiley & Sons
- Gardner, W.R. and Hillel, D. "The Relation of External Evaporative Conditions to the Drying of Soils" 1962. Geophys. Res. 87, 4219-4325.
- Gardner, W.R. 1958. "Some Steady State Solutions of the Unsaturated Moisture Flow Equation with Application to Evaporation From a Water Table", Soil Sci.: 85, 4.
- Hillel, Daniel. Introduction to Soil Physics. 1982. Academic Press.
- Krogman, K.K., and Hobbs, E.H. "Scheduling irrigation to Meet Crop Demands", 1950, Agriculture Canada: 18.
- Neumann, H.H. Thurtell, G.W. and Stevenson, K.R. "In Site Measurements of Leaf Water Potential and Resistance to Water Flow in Corn, Soybean and Sunflower at Several Transpiration Rates", Canada Plant Sci. 54:175-184.
- Nielsen, Jackson, Cary, Evans. Soil Water. 1972. American Society of Agronomy.
- Pearce, J.F., Oliver, T.R. "The Mechanism of the Drying of Solids" Trans. Inst. Chem. Eng. London, 27, 1-8.
- Rosenberg, N.J. The Biological Environment. 1983. John Wiley and Sons.