MOISTURE LOSS FROM CLAY SOILS SUBJECTED TO HIGH WATER TABLE CONDITIONS - A DISCUSSION BASED ON A PRELIMINARY DRUM EXPERIMENT

A. VAN DER LELIJ, W.R.C., GRIFFITH

Introduction

In some N.S.W. irrigated areas pressure levels in shallow aquifers at 6 - 14 metres depth have risen close to the surface. This rise has been rapid, mainly because of recent increases in the area of rice grown on eac holding. Watertables are now maintained at levels close to the surface beneath much of the irrigated land, and some salinisation is occurring.

The study of capillary rise in clay soils of the M.I.A. has resulted in the concept of "critical depth" (12). This is the water table depth at which capillary rise would be 1 mm/day, which is less than the average evaporation rates during the winter months. If capillary rise is less than the evaporation, a dry surface mulch would form and the upward movement would be negligible.

Observations at locations away from rice fields during summer showed that water tables dropped, even though the soil surface was dry and cracke the water tables were deeper than 1 metre and there was a lateral groundwater supply to these locations from the nearby rice fields.

Evidently the moisture loss from the profile during summer from greater than critical depth was still significant (13). The rate of capillary rise from the watertable when it is deep enough otherwise to allow a dry soil surface is of relevance to the rate of salting of such land.

Theoretical considerations:

Smiles(10), reviewing air-water-heat relationships found that the evaporation rate (E) from a bare soil surface is either equal to the rate applying for a saturated soil exposed to atmospheric conditions (Es), or some lesser value, determined by the transmissive properties of the soil.

With a steady evaporation from a water table there is a maximum evaporation rate (Emax) that can be sustained by capillary rise. If Es is less than Emax, then E will be Es. If Es exceeds Emax however, the rate of evaporation will be limited by the capacity of the soil to transmit moisture. In the latter instance Ecum, the cumulative evaporatio over a period, increases with the square root of time. This was observed for cases without a water table at various depths (8, 9).

On further drying, the soil moisture movement is dominated by vapour flux, affected by temperature and moisture content gradient. Vapour flux is described by the termal water vapour diffusivity and the thermal liquid diffusivity. These two together, for Yolo light clay, total about 1.7×10^{-2} $cm^2/day/^oC$ for moisture content between 3 and 50% by volume (4,7,8,10).

These diffusion co-efficients are to be compared with other co-efficients, applicable for isothermal conditions. The liquid water transfer diffusivity caused by gradients in moisture content is several orders of magnitude higher than the values quoted above, if the moisture content is above 15% (Yolo light clay). The isothermal water vapour diffusivity is only significant at low moisture levels, less than 10% (4, 10).

It is concluded that under isothermal conditions in dry surface soils the vapour transport is significant but that deeper down, towards the water table, liquid flow due to moisture gradients dominates.

Other models to describe moisture flux have been proposed (3,4) but the principles remain similar. With higher temperatures at the soil surface, water will move downwards into the profile and that when the soil is warmer than the atmosphere, moisture flow is towards the atmosphere.

Some measurements with constant "evaporativity" are available(2, 4,11). The bare soil moisture loss depends on the depth of the water table, and on the external evaporation rate. Soil layering is also important. Sand or gravel at the surface reduces the bare soil evaporation greatly (1, 2, 11). Measurements and theory are available for diurnal temperature fluctuations (7,9) but no such measurements exist for situations in which there is further seasonal fluctuations superimposed on the diurnal one. Spring and summer conditions involves gradual warming up over a 6-10 day period, followed by a rapid cooling, as a recurring cycle.

The drum experiment described below shows preliminary results of such an effect.

Experimental Design

Four 200 Litre drums of diameter 0.59 m were filled with soil materials to the rim after placement of a 0.10 m sand layer at the base. The drums were buried so that the tops were level with the land surface. The surface 0.10 m of soil in the drums was a clay loam. The drums were duplicated for soil type and depth to water level in a 2 x 2 design.

Plastic tubes from each of the four drums led to a pit one metre away. These were used to measure pressure levels of the water in the sand layer at the bottom of the drum. Aluminium tubes (40 mm diameter) were buried in the drums to allow adjustment to water levels by addition of water to the sand base.

Regional soil materials used, were the upper horizons of a self-mulching clay soil, and a heavy clay of a B horizon of a duplex soil.

Tensiometers were inserted in two of the drums. Temperature was measured at 0.05 - 0.20 m and 0.40 - 0.55 m in the other two drums, using mercury in steel probes connected to a Cambridge recorder. Moisture loss from a drum through evaporation was measured by recording the quantity of (tap) water necessary to keep the pressure level/water table at the same level over a period of time. Measurements were carried out each weekday morning, from 1st September to 19th December, 1980.

Results

The pattern of pressure level behaviour proved to be fairly complex when related to the thermal conditions in the environment. The pressure level read was not necessarily the same as the water table or the average for the day since it took time for added water to dissipate and equilibrate into the soil.

The tensiometer readings fluctuated little and showed very low suction at all times at depths greater than about 20 cm. The soil was very wet below that level even though the surface was dry and slightly cracked.

Moisture loss from the drums at all times was less than the rate of evaporation, except after a couple of light showers, which did not immediately affect the pressure level.

Four periods were observed during which pressure level conditions were approximately constant. With two drums for each soil, this gives eight sets of data of average class A pan evaporation (A), depth of pressure level below soil surface (h) and moisture added to the drum in mm/day. The results are summarised in table 1, which also shows the results of regression analysis

Table 1 Summary of results of bare soil moisture loss from two soils subject to a high water table condition in 200 Litre drums.

A Transitional Red Brown Earth

Period	drum	A* mm/day	h* m	E* mm/day
1.9-2.10	3	4.2	0.34	Nil
	4	4.2	0.28	0.03
11.10-21.10	3	5.5	0.32	Nil
	4	5.5	0.14	0.15
22.10-11.11	3	6.4	0.40	0.16
	4	6.4	0.16	0.36
17.11-9.12	3	7.6	0.50	0.35
	4	7.6	0.34	0.44

B Self Mulching Soil

Period	drum	A* mm/day	h* m	E* mm/day
1.9-26.9	1	3.8	0.36	0.41
	2	3.8	0.56	0.27
1.10-21.10	1	5.6	0.34	0.36
	2	5.6	0.56	0.32
22.10-11.11	1	6.4	0.36	0.71
	2	6.4	0.58	0.47
13.11-8.12	1	8.3	0.28	1.38
	2	8.3	0.70	0.31

* averages for period.

C Regressions (n= 8)

(1) Self mulching soil $E = 0.46 - 0.016\,h + 0.13\,A$ mm/day ($r^2 = 0.61$)
(h and A equally well correlated to E($r = 0.64$)

(2) Transitional Red Brown Earth $E = -0.50 + 0.116\,A$ ($r^2 = 0.87$)
(h has no significant effect)

The measurements with the temperature recorder were from 4 to 19 December, 1980 and these are shown at Figure 1.

Discussion

For the self-mulching soil it was found that the moisture loss from the drum was positively related to class A pan evaporation and negatively related to depth of the pressure level (range 0.2 - 0.6 m). Both factors contributed about equally to the correlation, see Table 1.

In the duplex soil the moisture loss appeared to be nil during early spring but became significant as the weather warmed up. There was very little correlation with deptn to pressure level but a positive relationship with Class A pan evaporation was found. There seemed to be a relationship with the cycle of increasing heat each day followed by a cool change, which is typical for the weather pattern in South Eastern Australia. Such a cycle was closely monitored between the 4th and 19th December, 1980, as shown at Figure 1.

The downward temperature gradient from 5 th to 12th December, about 8° in magnitude between 0.15 to 0.50 metres, coincided with an increase in pressure level from 0.55 to 0.30 metres from the soil surface. Although this was partly caused by the addition of 200 mL on 5th December, most of the rise would have been caused by downward moisture flux. Considering the very low matrix soil water potential below 0.15 metres depth, very little water movement is needed to bring about the effect. For instance, with an effective porosity of 1%, downward moisture flux would have been 2.5 mm.

At higher moisture levels the thermal liquid water diffusivity is in the order of 1.7×10^{-2} cm^2/day/°C for Yolo light clay and $10 cm^2$/day/°C for Palouse silt (4,10), which is a considerable variation. A simple calculation for the drum experiment shows that to shift 2.5 mm of water under a 8°C temperature gradient over an average 0.20 metres distance requires a diffusivity of 0.625 cm^2/day/°C. This is within the range of the soils referred to.

During the cool change, temperature gradients were reversed and it is likely thatseveral mm's of moisture were lost from the water table to the soil above and to the atmosphere. For instance at 0.5 metres depth the temperature dropped from 29.5°C on 12th December to 17.5°C (average for day) on 17th December, 1980. If the 0.5 metres of soil involved had the heat capacity of 3,000 KJ/m^3, this would represent an evaporation of 7 mm. Actually about 3.8 mm (1,000 mL) was added from 15th to 19th December, to prevent the pressure level dropping below about 0.55 metres.

There are other explanations for a fluctuation in the water tables due to temperature changes. Peck (5,6) describes some of these in detail. Heatwave conditions coincide with high barometric pressure, which may compress air below the water table. These air pockets may be as much as 10% by volume. The increased temperature below the water table will tend to expand these air pockets but on the other hand the solubility of gases becomes less.

Conclusions:

These latter effects cannot be separated but the experiment discussed demonstrates the significant effect of the heat wave/cool change cycle on moisture losses from soil profiles. On average over the period of investigations the duplex soil lost 0.19 mm/day and the self mulching soil 0.55 mm/day, with water tables varying between 0.16 and 0.70 metres depth.

Upward movement in the self-mulching soil was observed to occur during a range of conditions of evaporation. For the duplex soils, this movement may only be significant during the heat wave/cool change cycle conditions described.

Salt transport is by liquid flow only and where moisture is lost as vapour flux, salts will not move to the soil surface. This may be a partial explanation for the phenomenon usually observed in most parts of the irrigated landscape, viz low salinity near the soil surface but relatively high salinity in the subsoil.