EVAPORATION FROM A DRYING SOIL

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ABSTRACT

Soil evaporation from a Manawatu fine sandy loam, before and during crop establishment in late spring, was measured using the energy balance method. Predicted soil evaporation agreed reasonably with field measurements. The predictive model used, assumed cumulative soil evaporation at any stage to be proportional to the square root of time following heavy rainfall.

The predicted evaporation from a fallow soil was compared with the estimated actual evapotranspiration of a paspalum pasture. Under the fallow system approximately 69 mm and 35 mm soil water were conserved during November 1971 and March 1972, respectively.

The effect of rainfall frequency on total soil evaporation was examined for the months of November and March.

INTRODUCTION

The seasonal consumptive water use of a perennial forage typically exceeds that of an annual crop or forage. Pruitt **et al.** (1972) in their comparative studies of perennial grasses with several annual crops, all grown under non-limiting soil water conditions, found savings of 10-30% in the annual crops' water requirements. Similarly, Kerr **et al.** (1973) report estimated savings of 35% under maize relative to the perennial forages, lucerne and paspalum.

Soil water is conserved by annual crops primarily during the fallow and early crop establishment phases. As the leaf canopy develops the evapotranspiration rates of annual crops can approach or exceed those of the perennial forages thereby utilising the soil water conserved earlier. An understanding of the factors which determine the quantities of water which could be conserved in this manner may assist the development of forage-production strategies for water-short situations.

The development and use of suitable methods for separately measuring transpiration and soil evaporation is necessary for crop evapotranspiration studies. This paper examines some of the factors responsible for loss of water from the soil by evaporation. The physical process of evaporation from a drying soil is discussed, and a model describing cumulative soil evaporation following rain is assessed. The cumulative soil evaporation is compared with evapotranspiration from a crop, for a period of one month. The effect of rainfall frequency on soil evaporation is examined.

PHYSICAL CONDITIONS NECESSARY FOR EVAPORATION

Three physical conditions have to be met in order that soil evaporation may proceed, viz.:

1. There must be a continual supply of energy to the soil evaporating sites. This energy can originate from both radiant and advective sources.
2. There must be a vapour pressure gradient away from the surface so that water vapour will in fact be transported away from the soil.
3. The water must move through the soil to the evaporating sites. Soil water movement is a complex process which depends on several soil physical properties such as water content, water potential gradients and hydraulic conductivity.

The actual rate of evaporation from the soil is determined either by the evaporative capacity of atmospheric environment (conditions 1 and 2), or by the ability of the bulk soil to deliver water to the surface evaporating sites — whichever is the lesser.

EVAPORATION FROM A DRYING SOIL

The evaporation rate from a soil proceeds in two stages. Firstly, the initial rate of evaporation from a wet soil is constant and depends upon the atmospheric evaporative conditions. During the second stage, the drying rate continuously decreases with time and with decreasing water content of the soil. The rate depends upon flux of water or vapour from the bulk mass of soil to the evaporating sites at the surface.

EXPERIMENTAL DATA

The two drying stages can be illustrated with data obtained at Palmerston North for a Manawatu fine sandy loam.

Soil evaporation was measured in a 1 ha field of seedling maize throughout an 8-day drying cycle immediately following rain on 7 December, 1971. Comparative evapotranspiration measurements were made on an adjacent 1 ha paspalum pasture. Diurnal curves of soil evaporation (F_s) and evapotranspiration (ET_a) are presented in Figure 1 for several days at the beginning and end of the drying period. The energy balance method was used to measure E_s and ET_a (Tanner, 1960).

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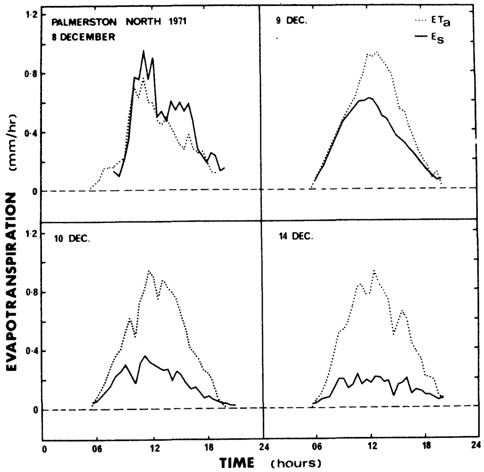

Figure 1. Daily patterns of soil evaporation (E_s) from a field of seedling maize and evapotranspiration (ET_a) from a paspalum pasture.

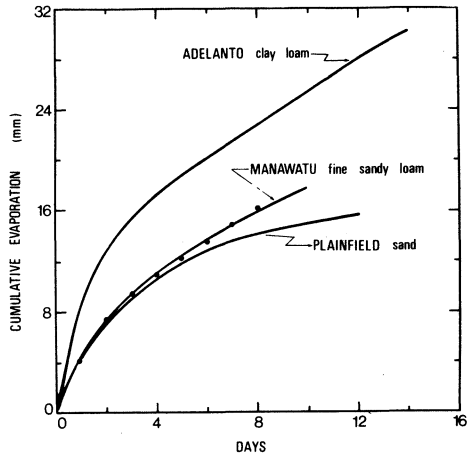

Figure 2. Cumulative soil evaporation from a Manawatu fine sandy loam, Adelanto clay loam and a Plainfield sand.

The maize was planted on 11 November and at the time of the measurements the plants had an estimated LAI <0.2. Consequently, the transpiration of the seedling maize plants was negligible and it can be reasonably assumed that $E_s = ET_a$ on the maize field.

The soil is a Manawatu fine sandy loam on medium sands which overlie coarser sands. Gravels occur at a mean depth of 1.3 m (Cowie, pers. comm., 1971).

Approximately 46 mm water was stored in the 30 cm topsoil at soil water potentials between -0.2 bars and -15 bars (Gradwell, pers. comm., 1973). Soil water drainage from the 1.0 m profile was measured with a drainage lysimeter. No drainage occured during the 8-day drying cycle.

Soil evaporation declined from 4.1 mm/day to 1.2 mm/day during the drying cycle, whereas paspalum evapotranspiration averaged 4.4 $\pm$0.5 mm/day. On 8 December E_s was unrestricted and actually exceeded ET_a. However, on 9 December the onset of stage II drying in the afternoon is apparent, when E_s became limited by the hydraulic properties of the soil. Data for 14 December are typical of the later stage of the drying period when E_s was continuously limited by unavailability of water at the soil surface. For the 8-day period ΣE_s =19.2 mm and ΣET_a = 55.1 mm.

The cumulative soil evaporation after 7 December rain has been plotted in Figure 2 as a function of time. Data for an Adelanto clay loam (van Bavel and Reginato, 1965) and a Plainfield sand (Black **et al.**, 1969) are presented for comparison.

Black **et al.** (1969) showed that the cumulative evaporation from an initially wet deep soil can be expressed by the equation,

$$\Sigma E_s = C t^{\frac{1}{2}} \quad (1)$$

The constant C in equation (1) is defined as follows:

$$C = 2(\theta_i - \theta_o)(D/\pi)^{\frac{1}{2}} \quad (2)$$

where θ_i is the initial water content, assumed constant for t = O and x $\geqslant$ O, θ_o is the water content at the boundary (x = O), assumed content for $t > O$. D is the weighted-mean diffusivity. C is related to the hydraulic properties of the soil and to the soil water content.

Their prediction of ΣE_s used the solution of the unsaturated flow equation and assumed one dimensional flow, under isothermal conditions, in an homogenous soil profile wet initially to an infinite depth. Previously, Gardner (1959) concluded that a soil profile wet to a finite depth may be treated as semi-infinite at least in the initial stages of drying or until about 50% of the water in the profile is evaporated.

The constant C was determined for the Manawatu fine sandy loam by plotting the cumulative E_s data against $t^{\frac{1}{2}}$ for the drying cycle beginning 8 December (Figure 3). A straight line was fitted to the points and the slope C was found to be 5.53 mm/day$^{\frac{1}{2}}$. The comparative data for other soils show the better water conduction properties of the clay loam, and the slightly poorer properties of the sand, relative to the fine sandy loam.

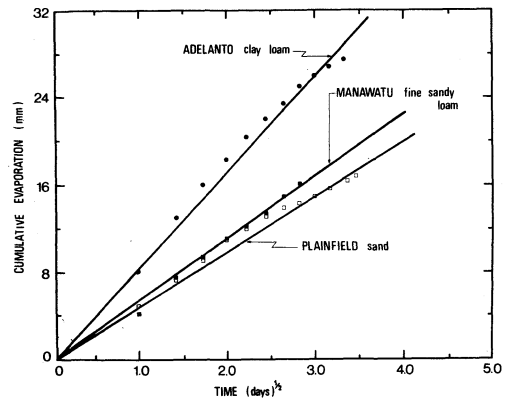

Figure 3. Cumulative soil evaporation as a function of $t^{1/2}$.

PREDICTION OF SOIL EVAPORATION

A simple model was used to predict soil evaporation (Figure 4). This model assumes that on rain days (or irrigation) $E_s = ET_a$ provided daily rainfall (or irrigation) exceeds 3 mm. On days following rain the soil evaporation is calculated as follows:

$$E_s = C\left\{t^{1/2} - (t-1)^{1/2}\right\} \quad (3)$$

where t is the number of days since the last significant rainfall. The model requires that E_s does not exceed ET_a and if this condition is not met, the model assumes $E_s = ET_a$.

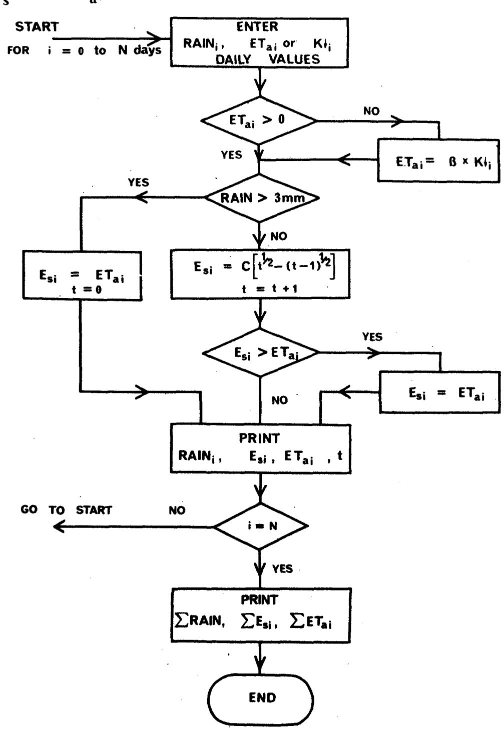

Figure 4. Flow diagram of the soil evaporation model, where $K\downarrow$ is solar radiation, β is a constant and t is time in days.

The model was used to compare ΣE_s from a fallow soil with ΣET_a from a growing crop for the period 27 October - 30 November, 1971. ET_a from a paspalum pasture (LAI > 3.0) was either measured directly, or estimated from solar radiation data. Results are presented in Figure 5.

The predicted E_s values agreed reasonably with the early November measurements on a fallow soil which had been cultivated in preparation for sowing during the previous week.

During this period $\Sigma ET_a = 144$ mm and $\Sigma E_s = 75$ mm and therefore 69 mm soil water was conserved under the fallow-summer crop regime compared with the actively growing perennial paspalum pasture. Drainage losses during November were 7.5 mm under the fallow. The net soil water conserved under fallow was 61.5 mm, assuming no runoff losses.

The model was run using rainfall and ET_a data for March 1972. In this case $\Sigma ET_a = 76$ mm and $\Sigma E_s = 41$ mm, giving an estimated 35 mm soil water conserved under the hypothetical fallow-winter crop regime compared with an actively growing crop.

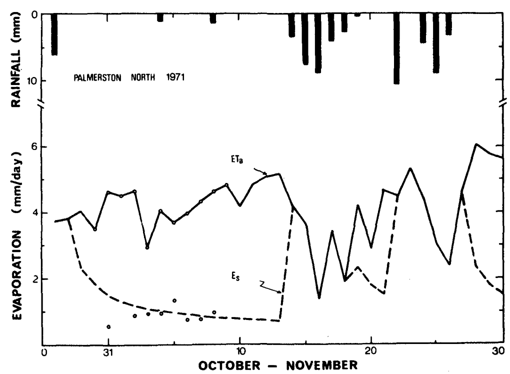

Figure 5. Rainfall, soil evaporation (E_s) and paspalum evapotranspiration (ET_a) for 27 October - 30 October, 1971. Experimental points (o).

EFFECT OF RAINFALL FREQUENCY ON SOIL EVAPORATION

ΣE_s is largely determined by the frequency of rainfalls rather than by the total rainfall received. The model was used to assess the effect of rainfall frequency on ΣE_s, with the November 1971 and March 1972 ET_a data as input. The curves were generated by increasing the interval between successive rains from 1 to 30 days; with the initial rain always falling on the first day of the month. Results are presented in Figure 6.

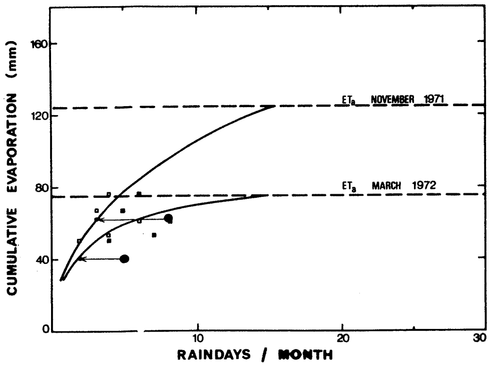

Figure 6. Cumulative soil evaporation (solid line) as a function of rain days/month for November 1971 and March 1972. Estimates based on random days (■), actual rain days (●) and rain periods (□, o).

Under frequent rains ΣE_s approximates ΣET_a, but as rainfall frequency decreases ΣE_s falls below ΣET_a. For a given rainfall frequency of 5 rain days/month, predicted ΣE_s equalled 0.62 ΣET_a and 0.78ΣET_a for November and March, respectively.

The field situation can be simulated better by programming rain days to occur at random intervals throughout the month. The estimates of ΣE_s produced using either random rain days or actual rain days do not lie on the curve generated by using systematic rain days. However, if we define a rain period as a period of successive rain days each with a rainfall greater than 3 mm and plot the ΣE_s as a function of rain periods, all points are moved closer to the predicted curve. In November eight rain days exceeded 3 mm, but there were only three rain periods.

CONCLUSIONS

Evaporation from fallow soils, during stage II drying, can be predicted using the model $\Sigma E_s = C\ t^{1/2}$, provided soil data are available from which C can be estimated.

This model has been used to provide an estimate of ΣE_s under a fallow regime compared with ΣET_a of an actively growing perennial forage. Soil water is conserved under the fallow, particularly at times when mean daily ET_a is high and rain frequency is less than five periods/month.

These conditions are typical of the late spring, early summer period when high producing annual summer crops are often grown for forage conservation. Therefore, soil water can be conserved during the establishment phase of a summer crop. In many seasons, particularly those with low rainfall, soil water conserved during the establishment of a crop is retained in the soil for later consumption. The ability of a summer crop to transfer water reserves from the seedling establishment phase into the active crop growth phase may be a significant contributing factor to the crop's ultimate yield, and will provide a measure of drought insurance to the crop. Under high rainfall situations much of the water conserved through reduced surface evaporation will be lost through increased drainage from the root zone.

The model shows how variation in water use is caused by differences in rainfall patterns.

The model may have an application in predicting the soil evaporation beneath a crop, provided the net radiation flux density at the soil surface can be determined and values of C are known. Ritchie (1972) has used a similar model to predict E_s beneath a grain sorghum canopy.

ABBREVIATIONS

$\sum E_s$	Cumulative soil evaporation	mm
$\sum ET_a$	Cumulative evapotranspiration	mm

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