

Estimation of basic irrigation requirements

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Summary

Calculations of the irrigation frequencies in arid zones from available moisture in the root zone and the evaporation of the crop with good water supply give too high values. Availing ourselves of what is already known about the decrease of the evaporation due to higher diffusion resistances when the pF of the soil becomes higher than appr. 2,7 to 3,0, a first attempt has been made to give a relationship between the moisture content of the soil and the time after the irrigation. A nomograph is given and the differences with the old method are discussed.

1. Introduction

In order to determine irrigation requirements it is usual to start with the calculation of the evaporation of a kind of hypothetical surface, for instance an extensive wet surface without heat capacity, the radiation properties of a green crop and the aerodynamic roughness of a short grass cover. This evaporation we shall call E_0 . In literature descriptions of calculation methods of E_0 can be found (among others BUDYKO; SCHOLTE UBING, 1959, 1961).

The evaporation of a crop has an evaporation which is not the same as E_0 . In cases where the soil is approximately at field capacity and the light intensity is high, the most stomata are opened (DE ALVIM, GAASTRA).

In this case the evaporation is different from E_0 , and will be expressed as $E^* = f \cdot E_0$. The factor f differs for different crops. The main reason is that even with fully opened stomata there is still a diffusion resistance which is lacking in the calculations for E_0 (mm day⁻¹). For short grass and high light intensities f has been determined by various investigators (Proceedings; SCHOLTE UBING, 1959). For other crops this factor is of course not the same, principally due to the fact that the aerodynamical roughness is not the same for each crop and the stomatal diffusion resistance may also be different.

In this paper, however, this problem will not be a point of discussion. The only reason for this introduction is to point out that there are possibilities of estimating E^* (mm day⁻¹), based on meteorological data, but that certainly important lacks in our knowledge (i.a. aerodynamical roughness, diffusion resistances and the state of opening of the stomata under natural circumstances) make the result somewhat uncertain.

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2. The "old" method

To make it possible to determine irrigation intervals it is always necessary to calculate the volume of water available in the root zone. This is the amount of water B mm which is found by multiplying the mean root depth by the volume percentage of water between field capacity and wilting point, assuming a low water table which is common in irrigated areas. Now in most cases it is agriculturally undesirable to let the soil dry out till wilting point. Let us say for the crop in question the point at which it must be irrigated is reached when $(100-V)\%$ of B is used. A widely used method for determining the time T between two irrigations is now by using the formula

$$T = \frac{(100-V)B}{100E^*} \text{ days} \quad (1)$$

The capacity of the irrigation system covering an area A is simple based on a net requirement of AE^* mm day⁻¹.

In practice however it is evident that the figures found are, in general, too high.

3. Evaporation in connection with soil moisture content

Many investigators found that the stomatal opening depends on the soil moisture content. Lower contents result in closing of the stomata and thus a rising of the stomatal diffusion resistance (DE ALVIM; GAASTRA, 1959) which results in a lower evaporation. The difficulty is to know the relationship between the soil moisture and the evaporation. Up till now it has not yet been possible to derive this formula from the relationships between stomatal opening and soil moisture content. This is due to the fact that the light intensity is not the same for each leaf, even for the leaves at the top of the crop the light intensity may be different for the stomata on both sides of the leaf and therefore it is possible that their openings are not the same. As the problem is of great practical importance it is nevertheless worth trying to make a first rough approximation based on an empirical relationship. VISSER gave a graphical relationship based on extensive American investigations.

More recent experiments gave curves of the same shape (BIERHUIZEN, 1959). Of course the shape also depends on the type of the pF curve. The connection between moisture content and the pF curve is being studied at the moment at the I.C.W. (Institute for Land and Water Management Research) at Wageningen. This gives a future possibility of a better approximation of the curve. For a first attempt a rectilinear curve seems justified. Especially for silty soils and clay soils, for as far as our experience goes, this must be possible.

A glance at the graphs in the literature mentioned makes it clear that the straight line cannot be drawn from the moisture content at field capacity to that at wilting point. By field capacity we mean the point at which the moisture content decreases so slowly, due to vertical water movement by earth acceleration that changes in pF by other factors such as evaporation are more important. It is clear that field capacity has not necessarily the same pF for different soils. When now a soil dries out from field capacity to $pF = 2,7$ to $3,0$ varying for different crops, the evaporation does not decrease. This is theoretically clear. This will be pointed out in the I.C.W.

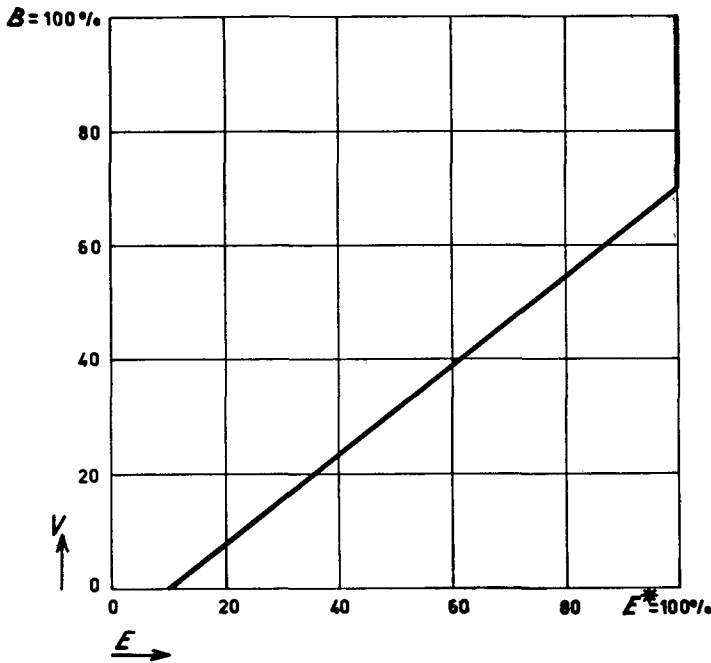
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publication mentioned above. Between these two points the mean available moisture is near 30 %. From this point the evaporation decreases rectilinearly to the wilting point ($pF = 4,2$), at which the evaporation is not zero, but due to leaks in the stomata and the cuticular evaporation, can be taken to be $0,1 E^*$ (DE ALVIM). Let V be the percentage of the maximum available moisture content B , we get the following formulae

$$\begin{aligned}
 E &= E^* & \text{for } V > 70 \% \\
 E &= E^* \left(\frac{0,9}{70} V \right) \text{ mm day}^{-1} & \text{for } V \leq 70 \%
 \end{aligned}
 \tag{2}$$

These formulae are graphically presented in FIG. 1.

Figure 1



In order to find the relationship between V and the time T after the irrigation, it is convenient to use again two different formulae for $V > 70 \%$ and for $V \leq 70 \%$. For $V > 70 \%$ yields

$$t' = \frac{0,3 B}{E^*} \text{ days}
 \tag{3}$$

and

$$V = 100 \left(1 - \frac{E^* T}{B} \right)
 \tag{4}$$

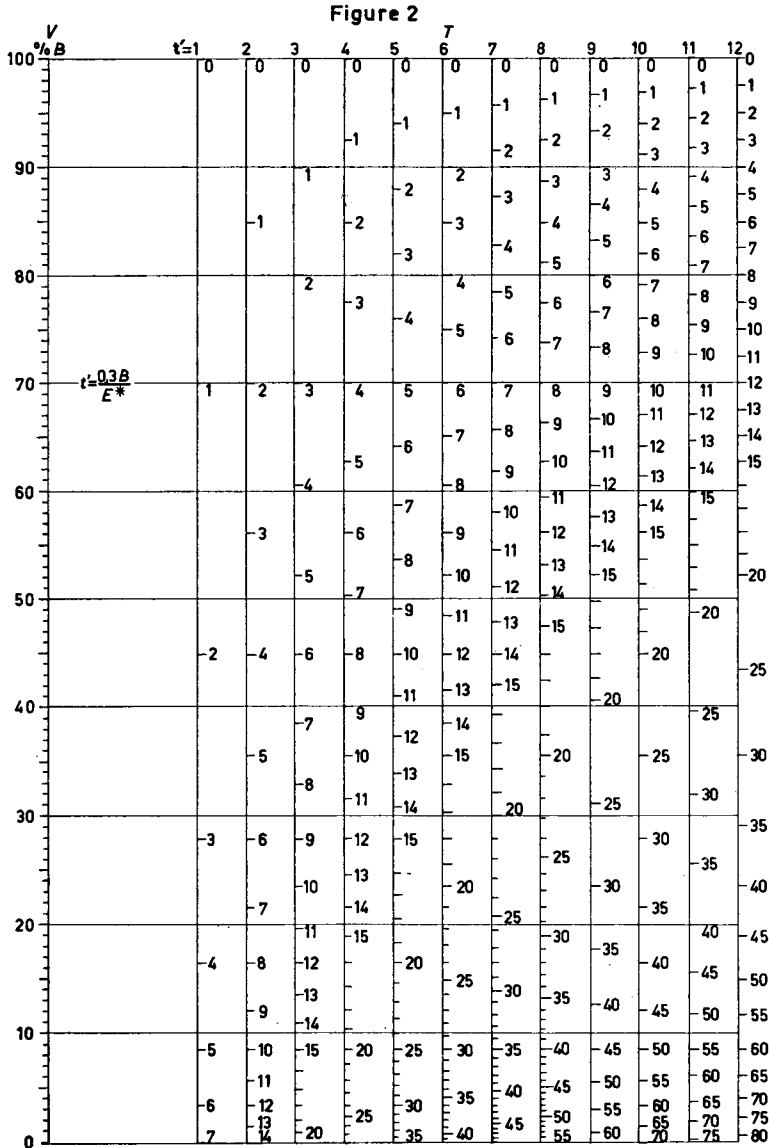
For $V \leq 70\%$ thus $T \geq t'$ can be found

$$V = \{77,7 \exp(-1,3 E^* T/B + 0,39) - 7,7\} \%$$

for $V \leq 70\%$

(5)

The formulae (4) and (5) can be found in a nomogram in FIG. 2.



4. The use of the nomograph

The use of the nomograph can be explained by an example.

Let $E^* = 3 \text{ mm day}^{-1}$

$B = 30 \text{ mm}$

Thus from (3) it follows that $t' = \frac{0,3 B}{E^*} = 3 \text{ days}$.

This means that in the nomograph the scale must be used with $t' = 3$ on top.

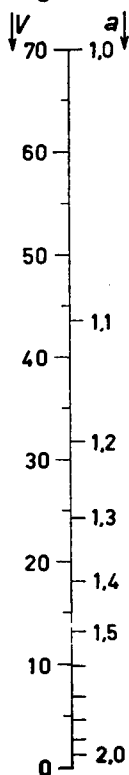
If one wants to know after how many days 80 % of the available water is used, thus $V = 20$, this can be found by going from the left scale horizontally to the right to the scale $t' = 3$, so that it is the case after 11 days.

The water used was $\frac{80}{100} \times 30 \text{ mm} = 24 \text{ mm}$.

By the "old" method using formula (1) one would have found that the irrigation interval must be $T_{\text{old}} = \frac{24}{3} \text{ days} = 8 \text{ days}$, instead of 11 days, which difference

in frequency is considerable, and is for instance of great importance in the case of overhead irrigation.

Figure 3



5. Discussion

It appears to be possible as a first approximation to use the relationship between the relative moisture content of the soil and the evaporation of a crop for a better estimation of the irrigation frequency in arid zones. The conditions are that the agricultural engineer must give the point to which the soil may be dry before a new irrigation is required, the mean depth of the root zone and the difference in volume percentage moisture between field capacity and wilting point.

It is of interest to know how great the differences are. This can be done by comparing the frequencies according to the old and the new method.

Elimination of $\frac{B}{E^*}$ between formulae (1) and (5) gives

$$a = \frac{T \text{ (form. 5)}}{T \text{ (form. 1)}} = \frac{0,39 + \ln 77,7 - \ln (V + 7,7)}{1,3 - 0,013 V} \quad (6)$$

for $V \leq 70 \%$,
which is represented in FIG. 3.

It is obvious that especially in cases where V is very low, the differences in time are important (for instance cotton).

In cases of high values of B (and for low values of E^* , but this does not so frequently occur in practice) the differences in time can also be of interest, although the ratio a here is 1.

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