CALCULATING CROP EVAPOTRANSPIRATION USING A DUAL CROP COEFFICIENT – PART 1

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INTRODUCTION

Water is essential in every biological process within a plant and makes up between 75% and 90% of a plant's mass by weight. The role of water in the plant includes involvement in all biological reactions, being a structural component in the proteins and nucleic acids in the plant cells, and being a regulator of plant temperature. In addition, water also acts as an environmental regulator of the climate around the plant. All annual and deciduous crops have a similar growth and development pattern which entails new growth starting at the beginning of the season with new foliage developing, and very little ground cover.

As the crop develops, foliage size increases until the soil surface is mostly or fully covered. Plants then usually go into a reproductive phase where seed and fruit are developed. These ripen towards the end of the season, the foliage dies off and at the end of the season the soil surface is bare again. A similarity to this pattern is also found in perennial crops, and even in evergreen crops grown in non-tropical areas, where although the foliage stays active, a slow-down in growth activities usually occurs during the cooler season.

The complex physiology and phenology that can be observed in the plant's behaviour as described above and affects the crop water requirement, is best introduced into the irrigation planning process through the four-stage crop growth cycle as described by Allen et al (1998) in FAO publication nr 56:

Table 1: Definition of the four stages of the crop growth cycle

STAGE NAME	DESCRIPTION
Initial stage	Germination and early growth, when the ground surface is barely covered by foliage (ground cover less than 10%)
Crop development stage	From the end of the initial stage to effective full ground cover (when ground cover rea ches 70% – 80%)
Mid-season stage	From reaching full effective ground cover until the reaching of maturity, as indicated by colour change of leaves and leaf drop
Late season stage	From the end of the mid-season stage to full maturity or harvest

CROP EVAPOTRANSPIRATION

As discussed in a previous article, the water used by a crop, or crop evapotranspiration (ET_c) is determined by multiplying the short grass reference evapotranspiration (ETo) with a growth stage-specific crop coefficient (K_c), which serves as an aggregation of the physical and physiological differences between crops and the reference condition.

Location: Roodeplaat, Pretoria; Season: summer 1996/97; Soil: clay loam:

Figure 1: Initial stage
Fractional interception of radiation (canopy cover) = 0.11; Crop height = 0.3 m

Figure 2: Crop development stage
Fractional interception of radiation (canopy cover) = 0.58; Crop height = 1.1 m

Figure 3: Mid-season stage
Fractional interception of radiation (canopy cover) = 0.89; Crop height = 2.0 m

Figure 4: Late season stage
Fractional interception of radiation (canopy cover) = 0.78; Crop height = 2.1 m

The relationship can be expressed by Equation 1:

$$ET_c = K_c \times ET_o$$

ET_o is a climatic parameter, expressing the evaporation power of the atmosphere at a specific location and time of year, not considering the crop characteristics and soil factors, but in terms of "a hypothetical crop with an assumed height 0.12 m, having a surface resistance of 70 s/m and an albedo of 0.23, closely resembling the evaporation of an extensive surface of green grass of uniform height, actively growing and adequately watered" (Allen et al, 1998).

ET_c is the evapotranspiration from a specific disease-free, well-fertilised crop grown in large fields, under optimum soil water conditions and achieving full production under the given climatic conditions. It consists of an evaporation component (E) and a transpiration component (T).

Kc is therefore the ratio between ET_c and ET_o for the specific crop calculated on a daily basis. If crops are grown under management and /or environmental conditions that differ from the ideal conditions described above (due to pest or disease, high salinity, low soil fertility, water shortages or other problems often encountered in the field), a lower degree of ground cover may result, reducing the evapotranspiration rate below ET_c. A correction then has to be made when calculating ET_c by using a water stress coefficient Ks and/or by adjusting K_c, otherwise over-estimation of the ET_c will take place, which can, in the case of irrigation management, lead to over-irrigation of the crop.

The adjusted ET_c can then be defined as in Equation 2:

$$ET_{c\ adj} = K_s \times K_{c\ adj} \times ET_o$$

DUAL CROP COEFFICIENTS

Modern ET_c calculation methods as described in FAO 56 recognise that wetting events (such as rainfall or irrigation) has an effect on K_c, a fact that has been ignored in the earlier days of irrigation science. The number of wetting events as well as the percentage of wetted soil surface area influence the ET_c and this needs to be taken into account when determining K_c. This is done by splitting K_c into two separate coefficients, one for crop transpiration, known as the basal crop coefficient (K_{cb}), and one for soil evaporation (K_e). The calculation of ET_c now becomes:

$$ET_c = (K_{cb} + K_e) \times ET_o$$

Equation 3a

Or

$$ET_c = (K_{cb} \times ET_o) + (K_e \times ET_o)$$

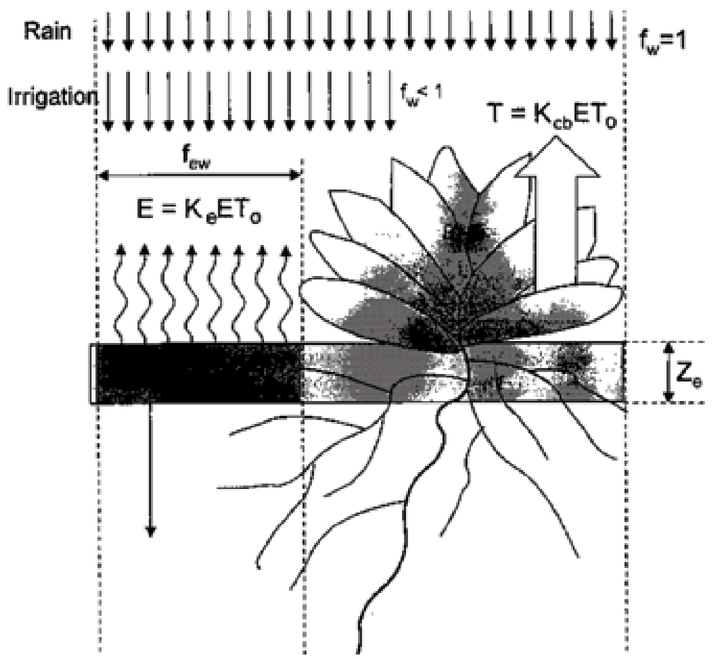
Equation 3b

The first component of Equation 3b (K_{cb} x ET_o) represents primarily the transpiration component (T) of ET_c – a crop will transpire at the potential rate as long as water in the root zone is not a limiting factor (and therefore even when the soil surface is dry).

The second component of the equation (K_e x ET_o) represents the evaporation component (E) of ET_c. Where the topsoil is wet following rain or irrigation, this component will be at a maximum. As the soil surface dries, the component will decrease until no practically measureable evaporation is taking place. The evaporation depends on few as shown in Figure 5 - the fraction of the surface area wetted by either rain or irrigation (f_w) as well as the fraction of soil exposed to sunlight and ventilation(f_c) - and will therefore vary for different crops (eg orchards vs field crops), different irrigation systems (eg sprinkler irrigation vs drip irrigation) and the canopy cover of that growth stage.

In the next article, we will look at how to determine the basal crop coefficients (K_{cb}) for different crop growth stage lengths and how to construct the basal crop coefficient curve.

Figure 5: Evaporation (E) and Transpiration (T) components of ET_c (Allen et al, 1998)



REFERENCE:

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper nr 56. FAO, Rome, Italy.

The information provided here was partially abstracted from the recently released Water Research Commission (WRC) report entitled "Integrating and Upgrading SAPWAT and PLANWAT to create a powerful and user-friendly irrigation water planning tool" (WRC report nr TT391/08) in collaboration with report main author Pieter van Heerden. Copies of the report which include a copy of the SAPWAT3 program are available from the WRC at 012 3300340 or www.wrc.org.za.