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Evapotranspiration Crop Coefficients for a Hot and Arid Climate

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ABSTRACT. The evapotranspiration of crops is often determined from the reference evapotranspiration, *ET* (of alfalfa or grass) by using suitable crop coefficients. This technique can easily be adopted for computerized irrigation scheduling. To obtain crop coefficients under hot and arid conditions, some of the crops were grown in lysimeters and their *ET* was obtained. The ET measurements for a uniform and well watered stand of alfalfa, grown in lysimeters, were also made and the reference *ET* for 20 cm tall alfalfa was obtained from the record.

For most of the crops, the *ET* and hence the crop coefficients fall into phases in accordance with the growth stage, namely: initial, flowering and fruiting stages. The crop coefficients were found to change considerably from one stage to another, in some cases. Hence a single value of a crop coefficient is usually not suitable for the entire crop season.

Values of the *ET* crop coefficients are given for some crops, for better estimates of *ET* under hot and arid climates in general and Saudi Arabia in particular.

Determination of the evapotranspiration or water requirements of agricultural crops is essential for economic utilization of water in irrigation practice. Crop coefficients are used, together with potential evapotranspiration of some reference crop, for the estimation of irrigation requirements and for irrigation scheduling. An equation for actual crop evapotranspiration or $(ET)_a$ can be written as:

$$(ET)_a = K_c \, PET \quad \text{..............(Hargreaves 1974).}$$

where K_c = Crop coefficient and *PET* is the potential evapotranspiration of the reference crop. For most crops, the K_c (crop coefficient) value increases from a low value at the time of crop emergence to a maximum value during the period when the crop reaches full development and declines as the crop matures (Johl 1980).

The potential evapotranspiration of a reference crop may either be determined by actual measurement or be estimated by using the available *ET* formulae. The reference crop may be 8 to 15 cm tall green grass cover, actively growing, completely shading the ground and not short of water, or alfalfa (15 or 20 cm high) under the same conditions as the grass (Cuenca and Nicholson 1982). Alfalfa has relatively high evapotranspiration rates in arid areas with considerable advective sensible heat input from the air (Wright 1982) and hence can advantageously be used as a reference crop.

Most of the formulae available for the determination of evapotranspiration involve a large number of variables and a high degree of accuracy may be expected only within the range of the formulae, if corresponding coefficients are properly evaluated (Johl 1980). Since data on these coefficients under arid conditions are lacking, it is difficult to obtain accurate reference values of evapotranspiration from meteorological data by using these equations. Thus, in order to arrive at a reliable estimate of the reference *ET*, one would need to test and calibrate existing formulae under the anticipated hot and arid conditions.

The testing or calibration of *ET* formulae requires long term measurements of the actual evapotranspiration from a reference crop, actively growing, adequately watered and completely shading the ground. The climatological data during this period of observation is used to arrive at the estimated values of the evapotranspiration by using the formula/formulae under consideration. The comparison of the actual and estimated values of evapotranspiration would result in some coefficient which could subsequently be used with the formula for a more reliable estimate of the reference evapotranspiration.

Another technique for arriving at a reliable estimate of reference evapotranspiration would be to correlate directly the observed long term evapotranspiration from the reference crop to the meteorological data.

The formulae most commonly used for the estimation of reference evapotranspiration are the modified Penman, Jensen & Haise, Thornthwaite, and modified Blaney-Criddle ...etc. Their calibration has been carried out under hot and arid climates and hence can be used for arriving at a reliable estimate of reference evapotranspiration for alfalfa 20 cm high (Abdel-Aziz and Saeed 1984).

Knowing the reference evapotranspiration, the consumptive use of a crop can easily be determined if the crop coefficient is properly selected. For accuracy, it is necessary to adopt a value which has been obtained under similar conditions.

This work was carried out to obtain coefficients for some crops or crop coefficients under hot and arid conditions. The results obtained could be used in field and research work for most efficient use of irrigation water. The results could also be used in computerized irrigation scheduling programs with ET_{20} values obtained from meteorological data during any period. Such a technique has been used by the USDA Agricultural Research Service and described by Jensen *et al.* (1971).

Material and Methods

The crops were grown in lysimeters (2m × 2m × 1.25m) at the Agricultural Research Station of the Agricultural College, King Saud University, in Dirab. At least two lysimeters were used in each study. The irrigation water was applied through calibrated flow meters. The drainage water was obtained through an underground passage and measured with a calibrated can. Soil moisture samples were taken for changes in soil water stored from the middle of each lysimeter. Two tensiometers were installed in each lysimeter in the root zone of the crops at depths of 15 and 30 cms. The soil tension was kept below 25 centibars, so that the available water within the root zone was not limiting the plant growth or transpiration. The necessary weather data was taken from the adjacent meteorological station.

Evapotranspiration for a crop was determined by balancing the inputs and outputs to the lysimeters. The average value was used as its evapotranspiration (ET). The reference ET for 20 cm tall alfalfa was obtained from ET measured continuously on stands of alfalfa in two lysimeters over a period of 5-10 days.

Results and Discussions

The variation of the ratio ET/ET_{20} (evapotranspiration from a crop to that from alfalfa, 20 cm in height or reference ET) is shown in Figure 1, for three crops: wheat, tomatoes and lettuce. The Figure shows that the ratio does not remain constant during the crop season. Therefore, a single value for the crop coefficient cannot be used for accurate determination of consumptive use by a crop throughout its growth season. However, for convenience, the variation could be approximated by a straight line in these cases as shown in Figure 1. The equations of the straight lines give us the crop coefficients in terms of ET_{20} and day of growth as follows:

$k_w = ET/ET_{20} = 0.009\,D - 0.10$ .... for wheat

for values of D greater than 25, but less than 75.

$K_l = ET/ET_{20} = 0.012\,D - 0.22$ .... for lettuce

and $K_t = ET/ET_{20} = 0.011\,D - 0.09$ .... for tomatoes.

where D is the number of days from sowing.

The variation of the ratio ET/ET_{20} during the entire season for two more crops (corn and soyabean) is shown separately in Figure 2.

Figures 1 and 2 demonstrate that the evapotranspiration of crops during their life cycle is divided into three distinct phases. In the first phase, the crop is in its initial stages of growth, there is a gradual increase in the water requirements with growth and hence the ratio ET/ET_{20} rises slowly. In the second phase, which corresponds to the flowering, heading or silking stage, the ratio (ET/ET_{20}) rises

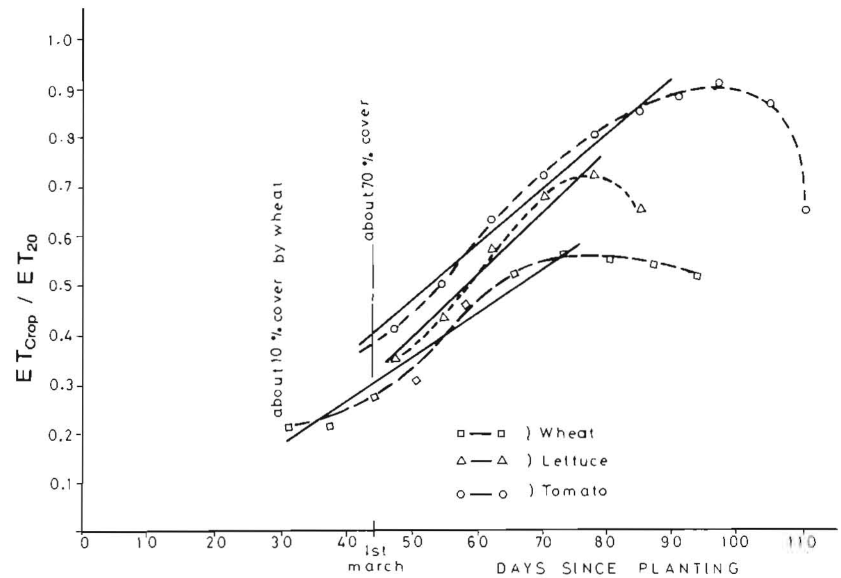

Fig. 1. Time variation of $(ET_{Crop})/ET_{20}$ (*i.e. ET* of the Crop to reference *ET* from 20 Cm tall alfalfa)

abruptly and reaches its peak at the beginning of the third phase, namely the fruiting period. There is a maximum demand for water during the fruiting period and is followed by a sharp decrease in water needs as the crop matures further and the fall in physiological activity commences.

Figure 2 shows the comparison of the ET/ET_{20} ratios obtained for two crops of corn, one sown in spring (March 22*nd*) and the other in late summer (September 4). Obviously, the former faces hot and dry conditions as it grows, while the later confronts comparatively colder and humid conditions with an advance in growth. The Figure shows that, in spite of the great differences in meteorological conditions, there is a little change in the variation of the ET/ET_{20} values. Hence for any crop the ratio seems to be independent of the meteorological conditions which does not seem unexpected. Hence the coefficient derived for a crop in one season could be used for consumptive use estimation even if the crop is grown in a different season.

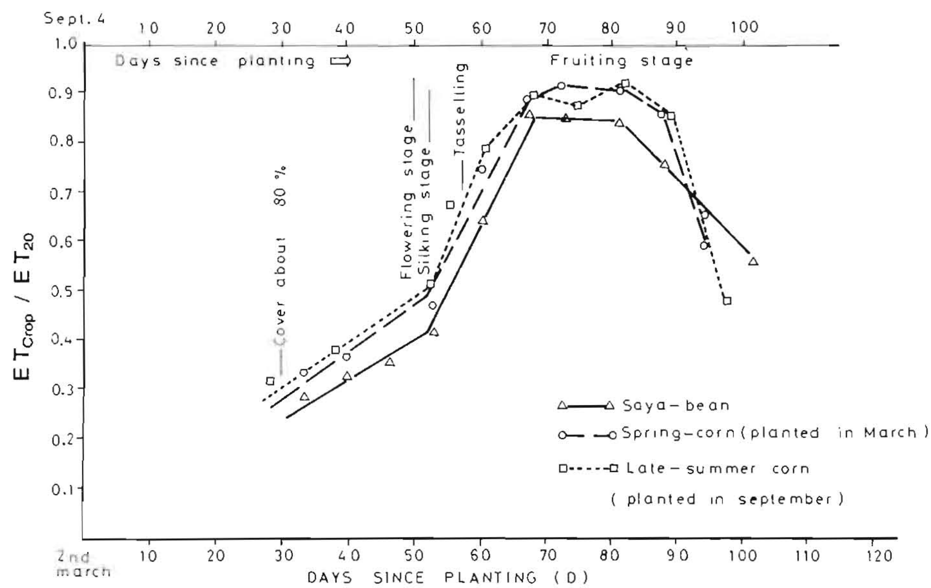

Fig. 2. The variation of crop coefficient during various stages of growth.

Figure 2, however, does not show certain important observations made during the experiment, such as the total quantities of water consumed and the yield and quality of corn in both cases. A look at the cumulative water consumed with time is shown in Figure 3 for both cases. The Figure shows that initially when the weather conditions are mild, the water needs do not differ much, but as time advances, the spring corn experiences higher temperatures, as it matures, and hence the total water consumed considerably exceeds that of the late summer corn with lower growing temperatures during its maturity (*i.e.* 520 mm depth and 210 mm respectively). Concerning the yield and quality of corn, although, the weight of the vegetative matter obtained was about the same, the yield of corn was considerably more and of better quality for late summer than that for spring corn. This is due to the fact that the fruiting period in spring corn occurs in June and the crop is subjected to a very high rate of *ET*, *i.e.* on average 12.3 mm/day. Such a high rate cannot be maintained without having an effect on production. High *ET* rates or high temperatures with low humidity are not favourable to maize or corn especially during the fruiting period. Hence, a crop of corn with better yield and quality can be produced during late summer with less water applied during the season.

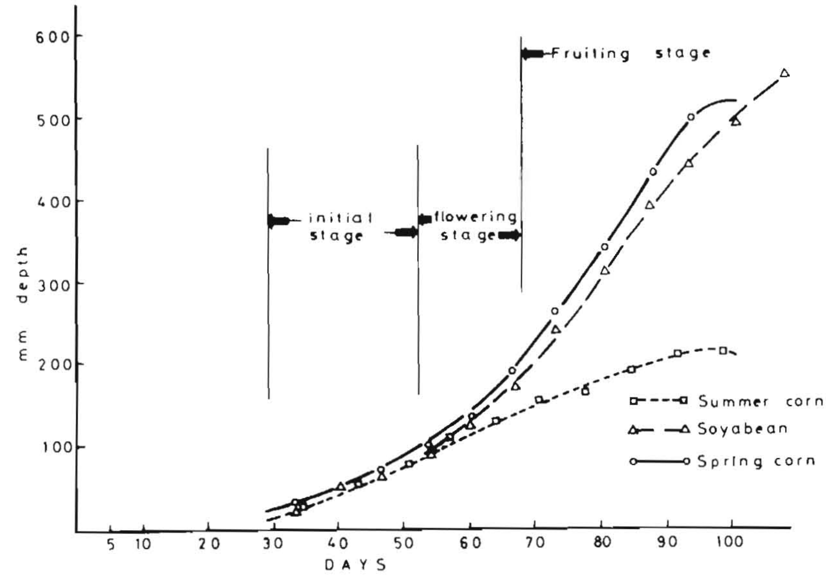

Fig. 3. Total water consumed since planting by spring and summer corn and soyabean.

To approximate the evaportranspiration, the crop coefficients given by the equations of the straight lines at different stages of growth can be used. These are:

1. Corn:

i. Initial Stage	$ET = 0.0095\ D\ (ET_{20})$	$30 < D < 50$
ii. Silking-Tasselling Stage	$ET = (0.025D - 0.81)ET_{20}$	$50 < D < 70$
iii. Fruiting Stage (Maximum ET)	$ET_{max} = 0.9ET_{20}$	$70 < D < 85$

where D is number of days since planting.

2. Soyabean:

i. Initial Stage	$ET = 0.008\ D.\ (ET_{20})$	$30 < D < 50$
ii. Flowering Stage	$ET = (0.025D - 0.875)ET_{20}$	$50 < D < 70$
iii. Fruiting Stage	$ET = ET_{max} = 0.84\ ET_{20}$	$70 < D < 80$

Briefly, the ET values of these crops range from 0.28 ET_{20} to 0.49 ET_{20} during the initial stage, 0.48 ET_{20} to 0.9 ET_{20} during the flowering stage for corn and from 0.23 ET_{20} to 0.41 ET_{20} during the initial stage and 0.41 ET_{20} to 0.84 ET_{20} during the flowering stage for soyabean.

A straight line relationship can be fitted between the cumulative water demand and the day of growth for the late summer corn as seen from Figure 3. The equation of the straight line enables us to determine the water needs of the crop at any stage. The equation is:

$$S = 3D - 62.5 \quad \ldots\ldots\ldots\ldots\ldots \quad \text{for } D > 25$$

where S = cumulative water demand, mm depth and

D = no of days since planting.

A single equation for crop coefficient of corn and soyabean crops, applicable during the entire crop season, cannot be suggested. For these crops, a simple method would be to use the crop coefficient during the initial stage as a basic value and determine the ratio of the crop coefficient during other stages relative to this value. Using the ratio in conjunction with the crop coefficient during the initial stage, crop coefficients at other stages can be arrived at. Then:

$$ET = ET_{20} \cdot K_i \cdot r$$

where K_i = Crop coefficient during the initial stage

and r = stage factor.

For hot summer months, stage factor may be taken as 1.9 and 2.4 (for corn) and 2 and 2.6 (for soyabean) during the flowering/silking and fruiting stages respectively.

Crop coefficients are also available from Doorenbos and Pruitt (1977), for arid conditions, with reference to grass, 15 cm in height. The peak ET coefficients for alfalfa are given to vary from 1.05 to 1.25, under light to strong wind conditions. However, the ratio of peak ET from alfalfa to the reference ET from Doorenbos and Pruitt, under hot and arid conditions here, is of the order 1.4 to 1.7 during the months March to October (Abdel-Aziz and Saeed 1984). Hence the ET for alfalfa is underestimated by more than 30%. Similar results are obtained for most of the crops. The values suggested here will result in better estimates of ET, under hot and arid conditions in general and Saudi Arabia in particular.

References

Abdel Aziz, M.H. and **Saeed, M.** (1984) Estimation of consumptive use of alfalfa in hot and arid regions of Riyadh, Saudi Arabia. AMA Agricultural Mechanization in Asia, Africa and Latin America), Abs. Farm Machinery Research Corporation. Tokyo, **XV**(2): 70-71.

Cuenca, R.H. and **Nicholson, M.T.** (1982) Application of Penman equation wind function, *Journal of Irrigation and Drainage Division,* ASCE **108** (IR 1): 13-21.

Doorenbos, J. and **Pruitt, W.O.** (1977) *Guidelines for predicting crop water requirements.* FAO Irrigation and Drainage, Paper 24. FAO Rome.

Hargreaves, G.H. (1974) Estimation of potential and crop evapotranspiration, *Transactions of ASAE* **17**: 701-704.

Jensen, M.E., Wright, J.L. and **Pratt, B.J.** (1971) Estimating soil moisture deplection from climate, crop and soil data, *Transactions of ASAE* **14**: 954-959.

Johl, S.S. (1980) *Irrigation and Agricultural Development,* Pergamon Press, Oxford.

Wright, J.L. (1982) New ET crop coefficients, *Journal of Irrigation and Drainage Division,* ASCE **108** (IR 1): 57-71.

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معاملات الاستهلاك المائي لبعض المحاصيل تحت ظروف المناطق الحارة الجافة

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يقدر الاستهلاك المائي للمحاصيل الزراعية في كثير من الأحيان باستعمال معامل خاص للمحصول دون اعتبار للتغير في طبيعة مناخ المناطق المختلفة أو مواعيد الزراعة أو مراحل النمو المختلفة التي يمر بها النبات من الإنبات إلى الحصاد.

ولقد أجريت هذه الدراسة تحت ظروف منطقة الرياض (منطقة جافة حارة) لعدة محاصيل لإيجاد معاملات الاستهلاك المائي في ليسومترات خاصة.

وقد وجد أن معامل الاستهلاك المائي يتغير تغيراً كبيراً تبعاً لمراحل النمو المختلفة لكل محصول مما يستتبع إيجاد هذا المعامل لكل مرحلة على حدة عند تقدير الاستهلاك المائي للمحاصيل.