Crop Coefficients for Wheat Crop at AL-Hassa Oasis

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ABSTRACT

The reference crop evapotranspiration based on FAO modified Penman formula was calculated. The actual wheat water use was determined from the lysimeters at adequate soil moisture availability. The crop coefficient (Kc) for the four growth stages of wheat was estimated.

The seasonal actual wheat water use estimated at adequate soil moisture availability was 485.3 mm under Al-Hassa conditions. The initial growth stage consumed was 43.32 mm where the crop development stage of growth required was 86.43 mm. The mid-season stage demanded was 291.5 mm and the late season needed was 64.05 mm. The crop coefficient (Kc) for the above growth stages was 0.57, 0.67, 1.10 and 0.35 respectively. Moreover, the Kc_{ini}, Kc_{mid} and Kc_{end} for wheat crop were 0.6, 1.15 and 0.3 respectively.

Key words : Saudi Arabia, wheat crop, evapotranspiration, crop coefficient, Penman equation, lysimeters.

INTRODUCTION

Wheat is the most important grain crop in the world. It is also the main food crop in Saudi Arabia, and due to its strategic nature, it has been receiving considerable support from the Government of Saudi Arabia. Wheat is moderately tolerant to soil salinity (Doorenbos et al.,1979).

To account for the effect of the crop characteristics on crop water requirements, crop coefficients (K_C) are determined to relate reference crop evapotranspiration (ETo) to actual crop evapotranspiration (ET_c). The effect of crop characteristics on the above relationships is associated with the resistance to transpiration, such as closed stomata during the day, waxing leaves, crop height, roughness, reflection, and ground cover (Doorenbos and Pruitt, 1984). It is necessary to collect local data on growing season and rate of irrigated crop development in order to draw a crop coefficient curve. Four stages of crop development were described. Stress during the early stages reduced the total number of heads and number of seeds per head. Stress at the latter stage of yield formation resulted in incomplete grain filling and in a reduced yield.

Ohlemyer and Von Hoyningen-Huene (1976) working under the arid conditions of Al-Hassa oasis with alfalfa crop as a reference to water consumption; compared actual to potential consumptive water use with the empirical equations of Blaney-Criddle and Penman. They also reported that the consumptive use coefficients of Al-Hassa Oasis were found higher than the other arid regions in K.S.A.

The review of literature indicates that very little work has been done on the water requirements of wheat especially under arid conditions in the eastern province. The first work reported on the water requirements of wheat in Hofuf was carried out by Hussain (1978). Field investigations were carried out on wheat to determine crop water requirement, with different irrigation rates of 80%, 100% and 120% of the soil water available. Consumptive water use of wheat differed significantly with different irrigation rates The average water consumption for a growing season of 140 days was 377mm . The highest protein yield achieved was 477kg /ha when soil moisture depletion was refilled to field capacity .

The second work on water requirements of wheat was carried out at King Faisal University Training and Research Station by Assed *et al.* (1982). The work included field measurements as well as predictions using 5 methods; modified Blaney-Criddle, Jensen-Haise, Turc, Thornthwaite, and Penman method. A comparison was also made between the field measurement and those obtained through predictions to find out the most suitable method for estimating crop water requirements of wheat crop. The measurements of the actual evapotranspiration was carried out with three different irrigation treatments (low moisture stress, moderate moisture stress, and high moisture stress) ranging from 3.8 to 5.4 mm /day, 3.7 to 4.6 mm/day and 3.6 to 4 mm/day. The depths of water consumed during the growing season of wheat were 53.7, 48.5 and 45.4 cm for low, moderate and high moisture stress treatments, respectively. The average Kc values or the ETc/ETo of the growth season were 1.25, 1.05, 1.29 1.35 and 1.12 for modified Blaney-Criddle, Jensen-Haise, Penman, Turc and Thornthwaite respectively. It was concluded that modified Blaney-Criddle, Jensen-Haise, and Penman equations gave close estimation of the reasonable crop evapotranspiration in the area when the proper crop coefficient was used.

A model for determining the potential and actual evapotranspiration for agricultural crops has been done by Hansen (1984). The model required only a limited number of meteorological variables i.e. global radiation, air temperature and precipitation. The vegetation is characterized by the crop surface area and effective root depth. The soil is characterized by the root zone capacity. The model estimated evaporation of intercepted water, evaporation from the soil surface and transpiration from plants. The potential evapotranspiration is partitioned between crop and soil by the use of Beer's law.

The actual water requirements for wheat under center pivot irrigation was determined by Shammary, (1986). As a first step for determining crop evaporation which is an essential factor for calculating the water requirements data for the climatic condition in that region (temperature, RH %, EPAN, Wind speed, etc.) were collected. A pan evaporation method was used to determine the rate of water evaporation. He concluded that the water requirement for wheat is about 7946 m^3/ha without the soil leaching requirements.

Abdelaziz and Saeed (1986) used crop coefficients together with potential evapotranspiration (ET) of some reference crops for the estimation of irrigation requirement and irrigation scheduling. They indicated that this technique is generally adopted for computerized irrigation scheduling. With a view to obtain crop coefficients under hot and arid conditions, some crops were grown in lysimeters and their ET were determined. Alfalfa was used for this purpose. Values for crop coefficients fall into three phases in accordance with the initial, flowering and fruiting growth stages. The values were reported to change from one stage to another. Hence a single value of crop coefficient is usually not suitable for the entire crop season. Values of ET crop coefficients were given for some crops under arid and hot climate in general and for Saudi Arabia in particular.

Saeed (1988) in his study developed simple equations based on easily available climatic data for estimating the reference evapotranspiration in an arid climate of Saudi Arabia taking 20 cm tall alfalfa as a reference crop . The crop was frequently irrigated and the evapotranspiration was obtained by balancing the water inputs and outputs to the lysimeters. Equations based on the most important climatic variables were then fitted to the data.

Alajaji and Helweg (1988) have used the modified penman model to determine the timing and amount of irrigation for wheat at Hail Agricultural Development Company Farm. California Irrigation Management information system was modified to make it usable for center pivot irrigation scheduling. The program was used to estimate daily reference evapotranspiration and monitor the soil moisture profile. The new system issued an irrigation recommendation, containing date of irrigation and speed at which the center pivot should be run, depending on the soil moisture condition.Results showed a possible water saving of 25%.

Al-Amoud and Mohammed (1992) conducted an irrigation scheduling experiment on wheat crop using climatic data collected continuously from an automatic weather station previously installed and tested at the site. Irrigation scheduling was based on the estimation of reference evapotranspiration using modified penman and Jensen Haise methods. The result of this experiment indicated that Penman method was more realistic than Jensen Haise method in estimating the actual crop water need. The use of automatic weather station for scheduling have demonstrated that, not only water could be saved but crop yield could also be increased.

Stegman and Soderland (1992) indicated that irrigation scheduling for spring wheat requires information on different irrigation timing methods. Irrigation timing based on allowable root zone available water depletion and selected crop water stress index thresholds were evaluated in terms of their effect on spring wheat yield.

Mohammad (1997) compared different methods for estimating the reference evapotranspiration equations for alfalfa under arid climatic conditions. He found that the Penman method gave the best performance of all methods as it had the highest correlation with the observed ETo during the two years period.

Smith (1992) developed a computer program (CROPWAT) for irrigation planning and management. This program calculates crop water requirements and irrigation requirements from climatic and crop data. The procedures for calculations crop water requirements and irrigation requirements are mainly based on methodologies presented in FAO Irrigation and Drainage Papers No. 24 ' Crop water requirements ' and No. 33 ' Yields response to water '

Allen *et al* (1998) presented an updated procedure for calculating reference and crop evapotranspiration from meteorological data and crop coefficients. They used Penman-Monteith combination method. Moreover, they introduced three values of crop coefficients for the different growth stages; (1) crop coefficient for the initial stage (Kc_{ini}); (2) crop coefficient for the mid-season stage (Kc_{mid}) and (3) crop coefficient for the end of the late season stage (Kc_{end}) instead of four crop coefficients used by Doorenbos and Pruitt (1984).

The aim of this work is to estimate the crop factor (Kc) and the actual wheat water use for four different growth stages at adequate soil moisture availability.

MATERIALS AND METHODS

Calculation of reference crop evapotranspiration (ETo) :

Reference crop evapotranspiration (ETo) is the amount of water potentially demanded by the atmosphere and predicted via certain weather parameters. The FAO modified Penman equation published by Doorenbos and Pruitt (1984) was used in this study.

The derivative equation is :

$$ETo = \frac{\Delta Q_n + \gamma E_a}{\Delta + \gamma}$$

Where

ETo = Reference crop evapotranspiration (mm/day).

Δ = slope of the saturation vapor pressure versus temperature curve at air temperature T_a (mbar/^oC). It can be calculated from the following formula :

$$\Delta = \frac{4098 e_{sa}}{(T_a + 237.3)^2}$$

e_{sa} = saturation vapor pressure at air temperature T_a (mbar);

$$e_{sa} = \exp\left(\frac{19.08\,T_a + 429.4}{T_a + 237.3}\right)$$

T_a = temperature of the air (^oC)

γ = psychometric constant (mbar/^oC);

$$\gamma = \frac{1615 P_a}{2.49(10)^6 - 2.13(10)^3 T_a}$$

P_a = air pressure (mbar);

$P_a = 1013 - 0.1152h + 5.44(10^{-6})h^2$

h = elevation above mean sea level (m).

E_a = aerodynamic term = $f(e_{sa}, e_a, u_1)$(mm/day);

$E_a = (0.27 + 0.233u)(e_{sa} - e_a)$

Q_n = net radiation (mm/day);

$$Q_n = 0.75R_s - 2.00(10)^{-9}(T_a+273.16)^4(0.34\ 0.044\sqrt{e_a})\left(-0.35+1.8\frac{R_s}{R_a}\right)$$

R_s = solar radiation in equivalent depth of evaporation (mm).

e_a = actual vapor pressure of the air (mbar);

$e_a = e_{sa}\,.RH/100$

RH= relative humidity (%)

R_a = extraterrestrial radiation (mm/day);

$$R_a = 1.26714(h_{do}/r^2_{ve})\left[h_s \frac{\pi}{180}\sin(\Phi)\sin(\delta) + \cos(\Phi)\cos(\delta)\sin(h_s)\right]$$

h_{do} = daytime hours at zero declination (h);

$h_{do} = 12.126 - 1.85191(10)^{-3}\ ABS(\Phi) + 7.61048(10)^{-5}\ (\Phi)^2$

r_{ve} = radius vector of earth;

$r_{ve} = 0.98387 - 1.11406(10)^{-4}\ (J) + 5.2774(10)^{-6}\ (J)^2 - 2.68286(10)^{-8}\ (J)^3 + 3.61634(10)^{-11}\ (J)^4$

h_s = sunrise to sunset hour angle (degrees);

$h_s = \cos^{-1}(-\tan\Phi \tan \delta)$

δ = declination of the sun (degrees);

$$\delta = \frac{180}{\pi}(0.006918\ 0.399912 \cos\theta + 0.070257 \sin\theta - 0.006758 \cos 2\theta + 0.000907 \sin 2\theta - 0.002697 \cos 3\theta - 0.001480 \sin\theta)$$

Φ = location latitude (degrees) (Φ is positive for north latitudes and negative for south latitudes);

J = days from Jan.1 (e.g., J = 1 for Jan.1, J = 2 for Jan.2,..., J = 365 for Dec.31).

θ = day of year expressed in degrees (i.e., $\theta = 0^o$ is Jan.1, $\theta = 90^o$ is Apr.2, $\theta = 180^o$ is July 2,.....).

$\theta = 0.986(J-1)$

A computer program was developed in QUICK BASIC to estimate the reference crop evapotranspiration (using the FAO modified Penman equation discussed previously). The program read an input file which contains a meteorological data for one year (i.e. the month, maximum temperature (^oC),minimum temperature (^oC), average relative humidity (%), duration of sun hours (hrs), wind speed (km/hr), rainfall (mm/month)), altitude and longitude of the desired location. Then the program stores the results in another file. The program has been tested manually and it gave accurate results. The list of the program can be seen in Appendix A.

Actual crop evapotranspiration (ETc)

In order to fulfill the objectives of this paper, two growing seasons of wheat crop were conducted using center pivot irrigation. The experiments were in a random block design with four replications. The experiments were carried out at the Experiments Station for Research and Training at King Faisal University.

Before hand, the site was irrigated to restore soil to field capacity. Two days later the site were ploughed, where a disc harrow plough was used. This operation was conducted twice to ensure the disposal of weeds as well as having good seed bed for planting. The plots received all cultural practices used by the local farmers. The physical and chemical properties of soil can be seen in Table (2) and Table (3) respectively.

An evapotranspirometer (weighing lysimeter) was used to measure the actual water use of the wheat crop (ETc). The lysimeter in its simplest form involves the water balance measurements of all the incoming and outgoing water of a container which enclose an isolated soil mass with vegetative surfaces. A container (71x 71x 40cm) made of galvanized metal sheets was manufactured and filled with soil mass. Special care was taken to restore soil layers to their original packing density as far as it was possible.

The lysimeter was installed **in situ** in the middle of a wheat field and was thus become part of the field in order to minimize the advection effects. A mechanical platform balance (300kg ± 100g) was installed to weigh the soil container periodically. Initially, after the soil container was placed on the platform, the field capacity was determined immediately by adding enough water and allowed to stay for 24 hours to drain the free water. It was again re-weighed in order to apply the amount of water needed to obtain full water treatment required at field capacity. The change in the soil moisture was then monitored from the change in weight as recorded from the balance scale. In this type of weighing lysimeter, the change of weight provides a direct measurement of the change of water content between the two intervals of waterings; the amount of water lost and needed to maintain field capacity.

Crop coefficient (Kc)

The crop coefficient (Kc) is the relation between the measured actual crop evapotranspiration (ETc) to the calculated reference crop evapotranspiration (ETo) as :

$$Kc = \frac{ETc}{ETo}$$

Where :

Kc = crop coefficient.
ETc = measured actual crop evapotranspiration (mm/day).
ETo = calculated reference crop evapotranspiration (mm/day).

The crop coefficient (Kc) for wheat crop was determined based on data acquire from lysimeter measurement as well as predicated ETo values based on FAO modified Penman equation stated above following the procedure described by Doorenbos and Pruitt (1984).

RESULTS AND DISCUSSIONS

Table (1) shows the ETo demanded by the atmospheric factors, the ETc resulted from lysimeter readings and the crop coefficient (Kc) calculated for different growth stages of wheat growth. Also the Kc* obtained by Doorenbos *et al*. (1979) and the Kc** obtained by Al-Zeid *et al*. (1988) were included in table (1) for comparison.

Table (1) : Comparison of total ETo, total ETc measured from lysimeter, Kc calculated, Kc* obtained by Doorenbos *et al.* (1979) and the Kc obtained by Al-Zeid *et al.* (1988) for different growth stages of wheat growth.**

Growth period	Total ETo mm	Total ETc mm	Kc	Kc*	Kc**
Initial(20 days)	76.0	43.3	0.57	0.35	0.55
Crop development (30 days)	129.0	86.4	0.67	0.75	0.65
Mid-season (50 days)	265.0	291.5	1.10	1.12	1.15
Late season (30 days)	183.0	64.1	0.35	0.65	0.30
Seasonal total	653.0	485.3	0.74	-	-

From the Table (1), it can be noticed that there was a close agreement between the Kc calculated and the Kc** obtained by AL-Zeid *et al*. (1988) in all growth stages. Whereas there were differences between the Kc calculated and the Kc* obtained by Doorenbos *et al*. (1979) in the initial and late stages.

In addition the results obtained for Kc were in line with that acquired by Hussain (1978). The grain yield of wheat obtained from this study was 6.14 ton/ha.

To simplify the comparison, the same ETo calculated in this study was used to calculate the ETc* for Doorenbos *et al*. (1979) and ETc** for AL-Zeid *et al*. (1988) using their crop coefficients. These comparisons can be shown in Figure (1) .

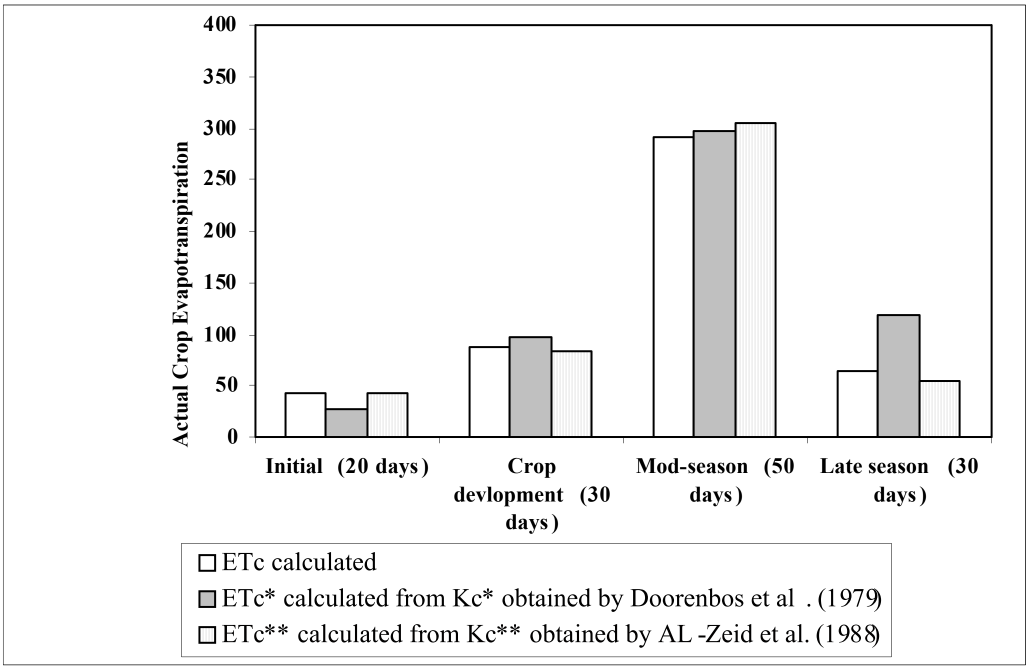

Figure (1) : Comparison between the measured ETc, ETc* and ETc**

From the figure, it can be noticed that there were no differences between the measured ETc and ETc** calculated. In addition, the total ETc measured for all season were almost the same with the total ETc** calculated. Whereas, there were small differences between measured ETc and ETc* calculated in initial and late stages. And the total measured ETc for all seasons was less by 53.9mm than the total ETc * calculated by Doorenbos *et al* (1979).

By using the procedure used by Allen *et al* (1998) , the Kc_{ini}, Kc_{mid} and Kc_{end} for wheat crop are 0.6, 1.15 and 0.3 respect ively. These results were in line with that acquired by Allen *et al* (1998). Figure (2) shows the coefficient curve for different growth stage for the wheat crop.

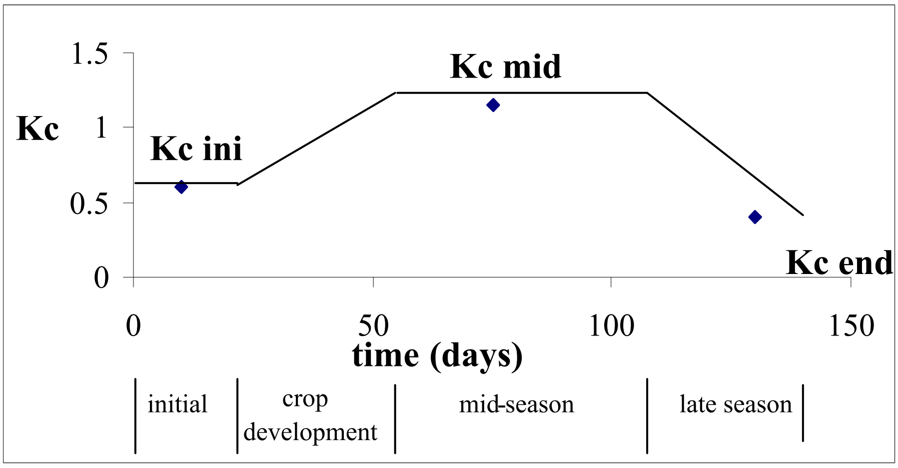

Figure (2) : Crop coefficient curve for the wheat crop.

Table (2) : Physical and chemical properties of soil

Depth (cm)	Mechanical analysis			Soil texture*	S.P. %	F.C. %	P.W.P %	A.W %.	Bulk density gm/cm^3	$CaCO_3$ %
	Sand %	Silt %	Clay %							
0-30	92	8	0	S	24	12	6	6	1.487	8.81
30-70	54	42	4	SL	62	31	15.5	15.5	1.432	12.13

Table (3) : Chemical properties of the (1 : 2.5) soil : water ratio extract for the soil

Depth	PH	EC	Soluble cations and anions, meq/L								SAR**
(cm)		mS/cm	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO^{2-}_{3}	HCO^{-}_{3}	SO^{2-}_{4}	Cl^{-}	
0-30	7.53	0.469	1.76	0.27	1.21	0.35	0	1.15	3.1	1	1.19
30-70	7.52	2.79	22.8	0	3.87	1.42	0	1	2641	11	1

* S = Sand
SL = Sandy loam

$$**SAR\ \text{Sodium adsorption ratio} = \frac{Na^{+}}{\sqrt{\frac{ca^{2+} + Mg^{2+}}{2}}}$$

CONCLUSIONS:

Whereas, there are many factors affecting the value of the crop coefficient (Kc) mainly the crop characteristics, crop planting or sowing date, rate of crop development, length of growing season and climatic conditions (Doorenbos and Pruitt, 1984). Thus the approach which has been used in calculating the wheat crop coefficient (Kc) in AL-Hassa is appropriate and could be used to estimate the actual crop consumptive use if the prediction of the weather factors are accurate.

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حساب معامل محصول القمح في واحة الأحساء

مشاري بن عبد اللطيف النعيم

قسم الهندسة الزراعية-كلية العلوم الزراعية والأغذية-جامعة الملك فيصل

ص.ب ٤٢٠-الأحساء ٣١٩٨٢ المملكة العربية السعودية

الملخص :

تم حساب التبخر النتحي المقارن باستخدام طريقة بنمان المعدلة. وتم حساب الاستهلاك المائي الفعلي لمحصول القمح باستخدام الليزوميتر وذلك تحت ظروف مثلى من رطوبة التربة. ومن ثم تم حساب معامل المحصول (Kc) لمراحل نمو المحصول الأربعة.

وكان الاستهلاك المائي الفعلي الموسمي لمحصول القمح تحت الظروف المثلى من رطوبة التربة في واحة الأحساء ٤٨٥,٣ مم . تم استهلاك ٤٣,٣٢ مم في مرحلة النمو البدائية و ٨٦,٤٣ مم في مرحلة تطور المحصول. وتم استهلاك ٢٩٤,٥ مم في مرحلة وسط الموسم بينما كان الاستهلاك المائي ٦٤,٠٥ مم في مرحلة أخر الموسم. وكان معامل المحصول (Kc) للمراحل النمو الأربعة بالترتيب هي ٠,٥٧ و ٠,٦٧ و ١,١٠ و ٠,٣٥ . وإن معامل المحصول Kc_{ini} و Kc_{mid} و Kc_{end} هي ٠,٦ و ١,١٥ و ٠,٣ على التوالي.