*Arab Gulf J. Scient. Res.*, 11(1), pp. 57-67 (1993)

# Development of Irrigation Crop Coefficients for Wheat in Al-Qassim Region

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ABSTRACT. A method for estimating crop coefficients using tensiometer and neutron probe data was used. Data for a wheat field site were analyzed using this method to calculate wheat crop coefficients. Crop coefficients were developed for the Class A Pan, Radiation, Jensen-Haise, and Penman methods. The estimated crop coefficients were compared to those of Doorenbos and Pruitt (1977). The crop coefficient polynomial equations produced in this study are useful in estimating crop water requirements in Al-Qassim region.

Improved estimates of crop water requirements based upon weather data can be used for the efficient management of irrigation water. Crop evapotranspiration ($ET_c$) is generally estimated by multiplying the reference evapotranspiration (ET) by an empirically derived crop coefficient ($K_c$). A crop coefficient is determined empirically as the ratio of the actual evapotranspiration of the crop to the evapotranspiration of a reference crop which is usually alfalfa ($ET_r$) or grass ($ET_0$). The concept of crop coefficients for estimating ET of field crops was first proposed by Wijk and de Varies (1954) and later developed by others (Jensen 1968-1973, Wright 1982). These coefficients represent an average situation in the field between a wet and a dry soil surface and without soil water limitations in the crop root zone. Crop coefficients vary depending on location, climate and especially the method used to compute the reference evapotranspiration. As long as lysimeter date are not available, irrigators need crop coefficients developed for their own area to calculate the consumptive use of crops.

Salih and Sendil (1984) compared several methods for estimating $ET_0$ and evaluated them using ET data from alfalfa at two sites in the Al-Hassa region of Saudi Arabia. At one site a lysimeter was used and at the other a field plot technique. After statistical evaluation of the results they ranked Jensen-Haise and the Class A Pan methods in first place, Hargreaves methods consistently next and then Penman and Modified Penman.

The main objective of this study was to develop crop coefficients for wheat using tensiometer and neutron probe field data and four standard methods for calculating reference evapotranspiration in Qassim, Saudi Arabia.

## Meterials and Methods

***Field site***

The field research site was located at the college of Agriculture farm in Buraidah, Qassim (latitude 26° N; elevation 625m). Eight plots, each 8m by 4m, were used for ET measurements. The spacing between plots was 0.5m. The plots were irrigated by fixed sprinkler irrigation system with average net application rate of 15.8 mm/hr received at the catch cans. The coefficient of uniformity for the irrigation system calculated from catch cans test was 91.6% using catch cans grid spacing of 2x2 m. Irrigation was carried out during calm wind conditions. The plots were irrigated with enough water to bring the soil moisture content to field capacity. The soil type was sandy soil (43.15% coarse sand, 47.28% fine sand, 3.19% silt and 6.38% clay) with an available water holding capacity of 8.6-9.8% by weight. The soil salinity was 2.72% dS/m and the pH was 8.5. The irrigation water salinity was 1.3 dS/m. The plots were planted with wheat (Yecora Rojo) in mid-December 1989, 1990 and 1991 at a row spacing of 17cm using the seed drill. The seed drill was calibrated to give a 160 kg seeding rate per hectar. Fertilizer was applied uniformly in all plots, with 300 kg of triple super phosphate ($P_2O_5$ 45-47%) applied per hectar at planting and subsequent fertilizations totalling 300 kg per hectar of 46% urea-N applied between January and March. A heavy irrigation before planting was applied to leach the accumulatd salts during the previous growing season and to bring the soil profile to field capacity and to germinate the existing weed seeds in order to get rid of it before planting. After planting, the irrigation system was managed to keep the 10 cm soil surface layer wet enough to obtain good germination.

***Determining Crop Evapotranspiration***

One access tube was installed in each plot and neutron readings were taken at 15, 30, 45 and 60 cm. The moisture profiles indicated that the wheat rooting depths ranged between 20 and 30 cm and negligible moisture change occured at 60 cm depths. The equation used to estimate soil moisture in the wheat root zone was:

$$d = wc_{15} \times 225 + wc_{30} \times 150 \times wc_{45} \times 150 \qquad (1)$$

where

d is the total depth of water in the root zone, mm

$wc_{15}$, $wc_{30}$, and $wc_{45}$ are the average fractional moisture contents on volume basis at 15, 30 and 45 cm soil depths, respectively.

The values 225, 150 and 150 are weighing factors for depths in mm for neutron probe readings at 15, 30 and 45 cm, respectvely.

The following soil water balance equation was used for estimating $ET_c$.

$$p + I = RO + \Delta d + ET_c \, \Delta t + DP \quad (2)$$

where

$\Delta d$ = change of the water depth in the field plot root zone

$p$ = precipitation depth, mm

$I$ = irrigation depth, mm

$RO$ = runoff depth, mm

$DP$ = deep percolation depth, mm

$ET_c$ = crop evapotranspiration, mm/day

$\Delta t$ = time interval, days

Neutron probe readings were used to determine the decrease in soil moisture profile and adjust the calculated amount of applied water to the depth required to refill the soil profile to field capacity. Deep percolation DP was therefore minimized and assumed to be negligible. When rainfall exceeds the depletion value, leaching can result since the soil water storage in the root zone has been exceeded. The amount of rainfall (R) was measured with a rain gauge. Runoff was negligible because the water application rate did not exceed the infiltration rate. The amount of water applied (I) was measured with catchment cans 100 mm in diameter, which were placed at each plot.

Putting RO = 0 and DP = 0 and solving eq. 2 for ETc, the following equation can be obtained:

$$ET_c = (P + I - \Delta d) / \Delta t \quad (3)$$

Soil matric potential was measured with jet fill tensiometers placed at 15, 30, 45 and 60 cm depth. The tensiometers were used to manage the irrigation system to maintain the soil matric potential at a minimum of –20 kPa. The soil water measurements were read for 2-7 day periods during each growing season. However, the measurements used to determine reference evapotranspiration were taken daily.

***Estimating Reference Evapotranspiration***

The FAO procedures (Doorenbos and Pruitt (1977) for estimating grass reference evapotranspiration $ET_0$, by class A-pan, radiation, Jensen-Haise and Penman methods were followed. The FAO procedures were programmed in BASIC language and run using a personal computer. The input data for the computer program were the weather data of the period December 15 to April 30 for the 1989, 1990 and 1991 seasons collected from the agrometriological station located at the College of Agriculture farm, Bureidah, Qassim.

***Estimating Crop Coefficients***

The crop coefficients for wheat were generated for a 7-day intervals during the growing season of 1989, 1990 and 1991 for the four methods of estimating $ET_0$ as follows:

$$K_c = ET_c / ET_0 \quad (4)$$

## Results and Discussion

The crop coefficient versus time since planting relationships are shown in Figs. 1, 2, 3 and 4 for the four methods of estimating $ET_0$. Time since planting was used for the abscissa of the crop coefficient curve to describe the rate of crop development. Each point on Figs. 1, 2, 3 and 4 represents an average of a crop coefficient calculated from data taken during a 7-day period during one growing season. Reference ET was calculated for each day of this period and then summed to take the average value.

Short grass $ET_0$ is less than alfalfa $ET_r$. Thus when $ET_0$ is used in place of $ET_r$ in Eq. 4, the resulting crop coefficients are larger than when $ET_r$ is used.

The data for the three seasons were averaged and fitted to a ploynomial model for each reference ET method and plotted in the same figure as a predicted $K_c$ as shown in Figs. 1, 2, 3 and 4. The four $K_c$ curves generated using the third-degree polynomial equations were plotted in Fig. 5 for comparison.

The general equation for the third-degree ploynomial model was:

$$K = a + bX + cX^2 + dX^3 \quad (5)$$

where

K = mean crop coefficient

X = days from planting

a, b, c, d = regression coefficients.

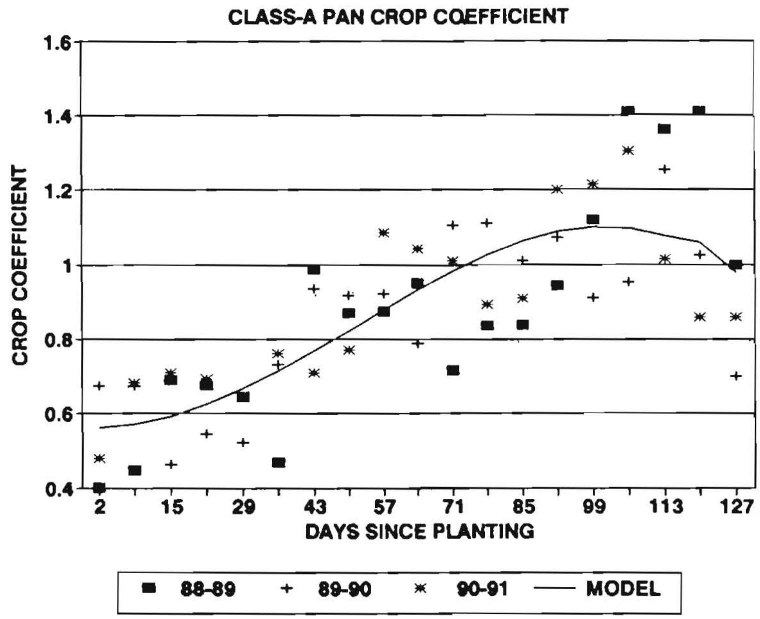


**Fig. 1.** Class A-Pan crop coefficients.

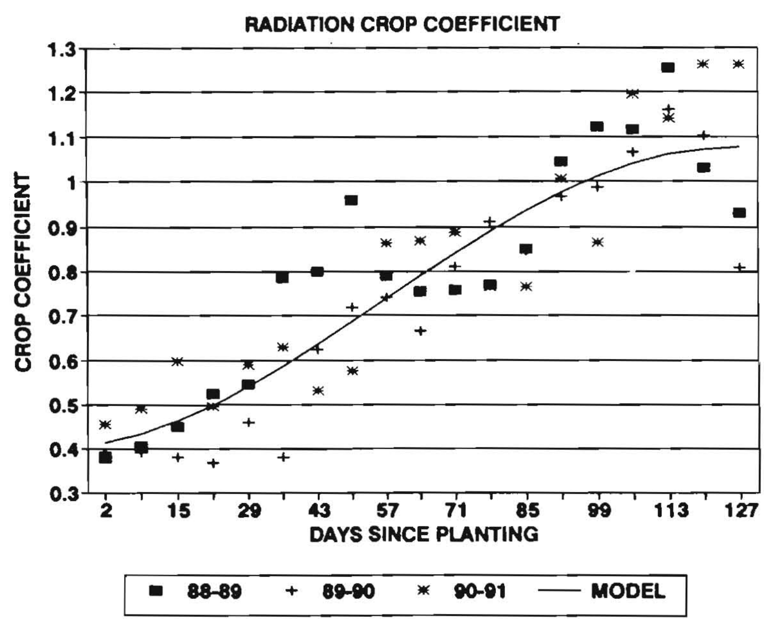


**Fig. 2.** Radiation method crop coefficients.

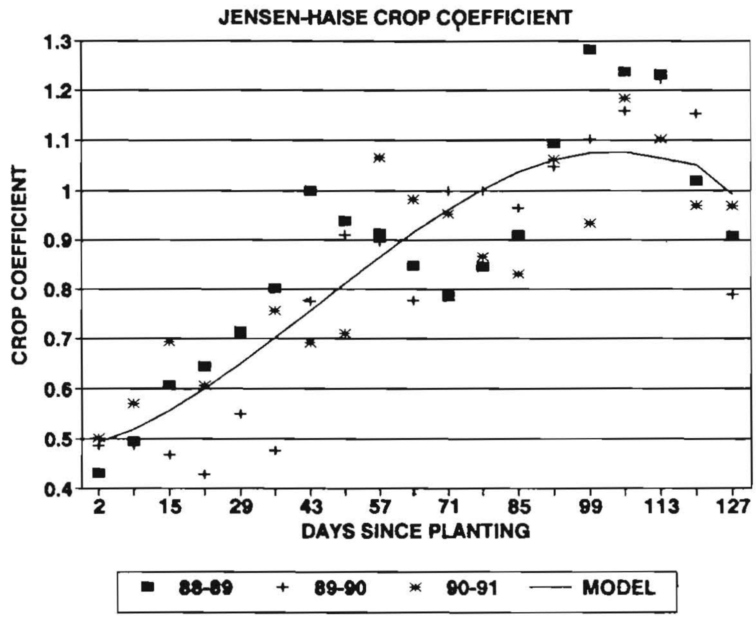


Fig. 3. Jensen-Haise method crop coefficients.

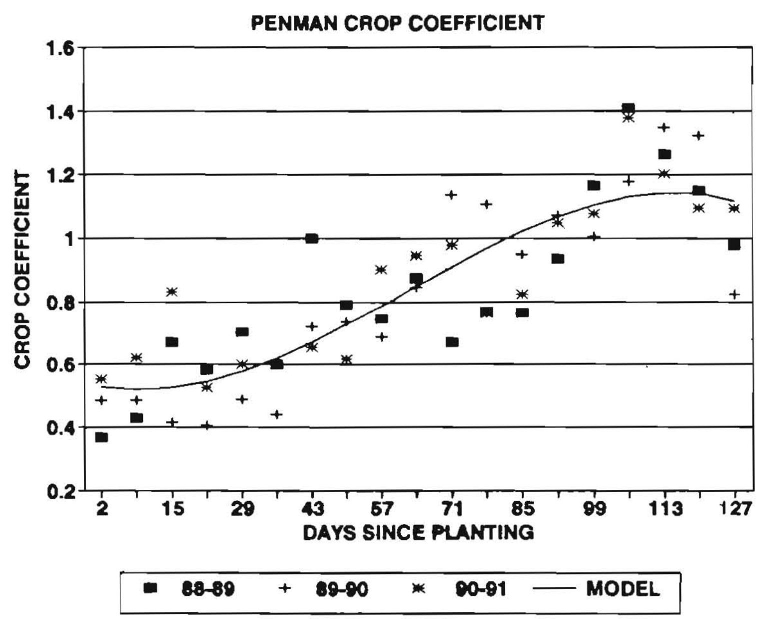


Fig. 4. Penman method crop coefficients.

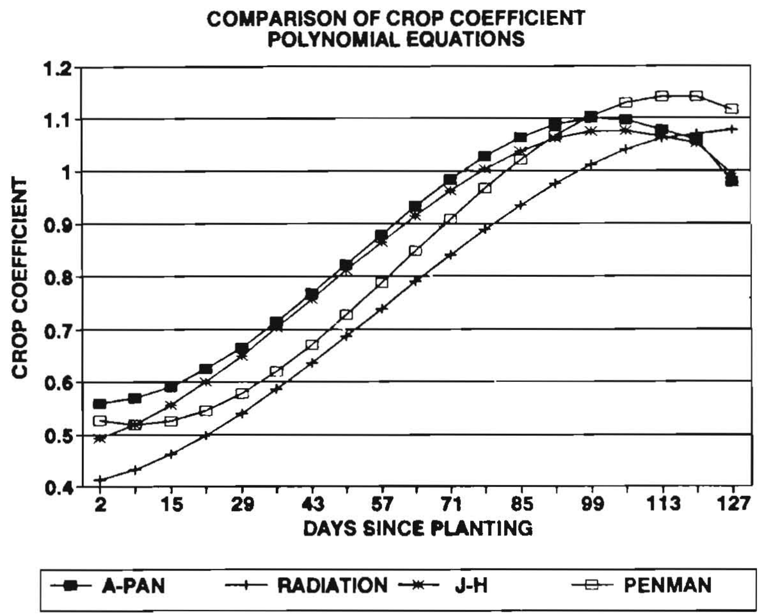


**Fig. 5.** Comparison of crop coefficients curves generated using the third-degree polynomial model.

The statistical parameters for the ploynomial model together with the correlation coefficient (R) are shown in Table 1. The model coefficient of variation, C.V, for the class A-pan, Radiation, Jensen-Haise, and Penman are 0.1395, 0.1167, 0.1072 and 0.1382 respectively.

The crop coefficient equations produced in this study are useful in estimated crop water requirements using computer programming.

**Table 1.** Regression coefficients for the average ploynomial wheat crop coefficient model

| Reference grass ET | Regression Coefficients | | | | R |
|---|---|---|---|---|---|
| | a | b | c | d | |
| Class A-pan | .5601 | −1.0339E-4 | 1.5969E-4 | −1.0467E-6 | 0.9314 |
| Radiation | .4069 | 2.4824E-3 | 8.8197E-5 | −5.2107E-7 | 0.9717 |
| Jensen-Haise | .4856 | 3.3478E-3 | 1.01110E-4 | −7.5576E-7 | 0.9464 |
| Penman | .5334 | −3.2056E-3 | 1.9367E-4 | −1.0417E-6 | 0.9318 |

Fig. 5 shows that the value of $K_c$ exceeded 1.0 from 70 to 120 days after planting which is the flowering and grain filling stage. The demand for water is critical in this period of wheat growth. The information on the critical stages is useful in areas with limited water resources where maximum production per unit water is aimed at.

The crop coefficients in relation to crop growth stages as compared to FAO values (Doorenhos and Pruitt, 1977) are presented in Table 2. It can be seen that the FAO values during the late season are the lowest due to the hot dry weather conditions of the area during the month of April.

Al-Zeid (1988) calculated crop coefficient values at different growing times for each month for the growing season of various crops grown in the Kingdom. They followed the FAO method for estimating the crop coefficient values based on the planting date and the length of the growing season. For wheat planted on December 15 and a growing season of 120 days, they reported crop coefficient values of 0.58, 0.82, 1.14, 1.08 and 0.54 for Dec., Jan., Feb., Mar., and April.

It can be seen from Fig. 5 that the $K_c$ peak of about 1.1 was reached at 99 days from planting for class A-pan and Jensen-Haise methods and at about 113 days for Radiation method. However, the $K_c$ peak of 1.15 was reached at about 113 days from planting for Penman method. The estimated peak $K_c$ values for wheat agreed well with those found in FAO data.

It can be concluded that the developed crop coefficient models can be used in calculating the wheat water requirement in Al-Qassim region based on days after planting.

**Table 2.** Crop coefficient values in relation to crop growth stages as compared to FAO values

| Growth stage | Days from Planting | FAO Kc | Pan Kc | Rad. Kc | J-H Kc | Penman Kc |
|---|---|---|---|---|---|---|
| Initial | 0-15 | .3-.4 | .51-61 | .4-.47 | .47-.58 | .46-.64 |
| Crop development | 15-55 | .7-.8 | .61-.85 | .47-.79 | .58-.85 | .64-77 |
| Mid season | 55-115 | 1.05-1.2 | .85-1.2 | .79-.1.18 | .85-1.18 | .78-1.2 |
| Late season | 115-135 | .65-.75 | 1.2-.85 | 1.18-1.0 | 1.18-.88 | 1.2-.96 |

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*(Received 10/12/1991;*
*in revised form 29/06/1992)*

# تقدير معامل محصول القمح للري في منطقة القصيم

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تمّ اتباع طريقة حقليّة لتقدير معامل المحصول للقمح باستعمال التنسيومتر وجهاز النيترون لقياس رطوبة التربة. وأجريت التجربة على ٨ قطع مساحة القطعة ٨ × ٤ متر مربّع زرعت بالقمح (يوكورا روجو) في تربة رمليّة لثلاثة مواسم متتالية في ١٩٨٩ - ١٩٩٠ - ١٩٩١ م في الفترة من ١٥ كانون الأول (ديسمبر) الى ٣٠ نيسان (أبريل) باستخدام الري بارش الثابت وكانت مسافات الزراعة ١٧ سم ومعدل التقاوي ١٦٠ كجم للهكتار ومعدل السماد المستخدم ٣٠٠ كجم ثلاثي سوبر فوسفات للهكتار بالاضافة الى ٣٠٠ كجم يوريا للهكتار على دفعات، وقدّرت الرطوبة دورياً بجهاز النيترون على أعماق ١٥ - ٣٠ - ٤٥ - ٦٠ سم أثناء التجربة علاوة على تقدير الشد الرطوبي بواسطة التنسيومترات على نفس الأعماق بهدف تقدير الاستهلاك المائي الفعلي للمحصول وجدولة عملية الري. وقد استخدمت معادلة الاتزان المائي لحساب الاستهلاك المائي الفعلي للمحصول عن طريق معرفة التغيّر في رطوبة قطاع التربة ومعرفة كمية مياه الري المضافة والأمطار. وقد تمّ تصميم وتشغيل نظام الري بالرش بحيث يمكن اهمال التسرّب العميق والفائض السطحي.

وتمّ عمل برنامج بلغة البيسك لتقدير البخر نتح المطلق المنسوب للأعشاب الخضراء باستخدام بيانات الارصاد الجوية وذلك لأربع طرق هي وعاء البخر القياسي - الأشعّة - جنس هيز - بنمان، وبذلك تمّ استنتاج منحنى معامل المحصول للأربع طرق كمتوسّط للثلاث سنوات من خارج قسمة الاستهلاك المائي الفعلي والبخر نتح المطلق وتمّ أيضاً ايجاد معادلة كثيرة حدود من الدرجة الثالثة لكل طريقة يمكن عن طريقها تعيين معامل المحصول

عند أي فترة من فترات نمو المحصول وهذه المعادلات مفيدة عند استخدام برامج الكمبيوتر في تقدير الاحتياجات المائية وجدولة عملية الري لمحصول القمح بهدف الحصول على أعلى انتاج من وحدة المياه وخاصّة في المناطق التي تتّصف فيها المياه بالندرة. وتمّ مقارنة قيم معامل المحصول المتحصّل عليها بالقيم المنشورة من قبل منظمة الأمم المتحدة لأغذية والزراعة.