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The Crop Coefficient of Barley (*Hordium vulgare)* Under Gezira Conditions

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Abstract: The development of regionally based and growth-stage-specific crop coefficient Kc helps in estimation of the crop water requirements (CWR) and irrigation planning. In this regard the Kc of barley is needed for the estimation of CWR in the Gezira and similar regions in the Sudan. An experiment was conducted for three consecutive seasons 2003/04, 2004/05 and 2005/06, at Gezira Research Station to determine the Kc of barley. The crop evapotranspiration (ETc), reference crop evapotranspiration (ET_0) and the crop coefficient values as ratios of ETc to ET0 were calculated. The results showed that the Kc values of 0.48, 0.96, 1.04 and 0.48 were appropriate for the initial stage, crop development, and mid-season and late season stages, respectively. These Kc values could be used for estimation of CWR as a product of Kc * ET_0 in the Gezira as well as other similar regions of the Sudan.

Key word: Crop coefficient; evapotranspiration; barley

INTRODUCTION

Winter suited field crops in the Gezira are limited and wheat regardless of its production problems stands as the most ideal choice. The production of wheat, however, is generally faced by skepticism from the farmers due to the high cost of production, low yields and uncertain marketability. Barley

(Hordium vulgare) stands as a possible alternative option as a forage crop (Salih *et al.* 2006). A prerequisite for the adoption of barley in the Gezira, under the current and the expected water shortage, is the knowledge of its water requirement, which, in turn necessitates the calculation of the Kc.

The crop coefficient is the ratio of crop evapotranspiration (ETc) to a reference crop evapotranspiration (ET_0). The $ET_{0,}$ in turn, is the evapotranspiration of a reference grass with standard height and fully covering the ground with sufficient water supply. Most of the effects of the various weather conditions are incorporated in the ET_0 estimate (FAO, 2009). The Kc varies predominately with specific crop characteristics and, to a, limited extent, with climate. Conditions affecting soil evaporation will also have effects on kc such as the crop type, climate and growth stages (Allen *et al.* 1997).

Crop growth period can be divided into four distinct growth stages: initial, development, mid-season and late season (Allen *et al.* 1998). The initial stage refers to crop germination and / or transplanting when the crop canopy covers < 10% of the soil surface. The crop development stage denotes the vegetative period of the crop which extends from 10% to 70% up to 80% canopy cover. The mid-season stage represents the period between full ground cover to the time of start of maturity (leaf yellowing). Late season stage stands for the crop period from end of mid- season stage to full maturity.

For annual crops, during the crop's germination and establishment, most of the ETc occurs as evaporation from the soil surface. As the foliage develops, evaporation from the soil surface decreases and transpiration increases. Maximum ET occurs when the canopy cover is about 60% to 70% for tree crops and 70% to 80% for field and row crops (Allen *et al.* 1997).

In Sudan, Farbrother in the early 1970_s used the Penman equation for the estimation of the evaporation from free water surface in the calculation of crop factors. FAO Penman-Montieth (Allen *et al.* 1997) method was developed, instead to estimate ET_0 values from a hypothetical reference crop that was more consistent with actual CWR and has been recommended by FAO as the standard method for CWR calculation (Allen *et al*. 1994). In the case of ET_0, grass is used as the reference. However, other crops may not use the same amount of water as grass due to changes in crop height, crop growth stages and plant cover. The Kc takes into account the crop type and crop development to adjust the ET_0 for that specific crop. The kc of barley in the four above-mentioned growth stages is pressingly needed to calculate its crop water requirement.

The objective of this study, therefore, was to determine the kc of barley under Gezira condition and the calculation of the crop water requirement for determining CWR at different growth stages.

MATERIALS AND METHODS

An experiment was conducted for three consecutive winter seasons viz, 2004, 2005 and 2006 at the Gezira Research Station Farm, (GRSF), (latitude$14^0 24^,$ N, longitude $33^0 31^,$ E, and altitude 407m a.s.l), Wad Medani, Sudan to calculate the kc of a local variety of barley sown in the 3rd week of November and irrigated every 10 days to avoid any water stress (Mohamed 2008). The meteorological data (every 10 days) for the relative humidity, minimum and maximum temperature, wind speed and sunshine hours were obtained from Wad Medani weather station (Table 1). The reference evapotranspiration (ET_o) was computed based on the full data set, using FAO-Penman-Monteith equation (FAO 2009) and ET_o software program.

The gravimetric soil moisture measurement for the calculation of the ETc was monitored before (pre) and after (post) each irrigation. The pre irrigation soil samples were taken just before each irrigation, whereas the post irrigation soil samples were taken 2 to 3 days after each irrigation. Five soil samples were taken from three randomly selected sites in each subplot using an auger. In each site the five samples were taken successfully at 20 cm intervals depth to one meter. The samples were mixed thoroughly to form a composite sample, which were then taken in pre-weighed and labeled moisture cans in a cool box to the laboratory for moisture determination according to Blake and Hartge (1986). The volumetric values were then obtained by multiplying the gravimetric soil moisture by the corresponding bulk density (Farbrother 1996). The actual crop evapotranspiration (ETc) was calculated by using the water balance equation (Allen *et al*. 1998) from the direct soil moisture depletion, where the runoff, deep percolation and capillary rise are negligible in Gezira vertisols

The water balance equation:-

$$ETc = I + P - D - RO \pm \Delta S \qquad (1)$$

where, ΔS: is the change in soil moisture storage between volumetric soil moisture measurements (mm), I: is irrigation (mm); P is rainfall (mm); D: is drainage (mm); RO: is runoff (mm). The Kc was calculated according to the method described by Dooronbos and Pruitt (1977), as the ratio of actual crop evapotranspiration (ETc) to reference crop evapotranspiration (ET_o) according to the following equation:-

$$Kc = \frac{ETc}{ET_0} \qquad (2)$$

The crop water requirement (CWR) of barley was calculated from the calculated Kc and ETo values according to equation 3. This special characteristic of Gezira cracking clay soil, which is gently sloping, allowed surface irrigation to be carried out by gravity with very high efficiency, (Adam 2005).

$$CWR = Kc \times ET_0 \qquad (3)$$

RESULTS AND DISCUSSION

The reference evapotranspiration (ET_0) every 10 days was calculated for the three seasons using Penman - Monteith equation (Table 2). The results revealed that the ET_0 for February - March in season 2004/05 was higher than ET_0 for the same period in either 2003/04 or 2005/06. This increase in ET_0 value is attributed mainly to the relative increase in the mean maximum temperature during February and March 2004/05 (Table 1). Quadratic regression equations were obtained for crop evapotranspiration (ETc), Kc and CWR in each year by the regression on the crop age as days after sowing (DAS). The correlation values obtained were highly significant, the coefficient of determination (R^2) was high to very high indicating high accountability of the independent variable DAS for the dependent variables ETc, Kc and CWR (Table 3).

Table: 1 Meteorological data every 10 days during the years 2003/04, 2004/05

Month	Dekad	Tmax (^0C)	Tmin (^0C)	RH (%)	Sun shine hours/day	Wind speed m/s
			2003/04			
Nov	3	34.3	16.4	35	9.8	1.1
Dec	1	32.8	13.4	36	10.7	0.9
Dec	2	37.2	14	37	10.3	0.8
Dec	3	35.8	13	37	10.2	0.8
Jan	1	32.8	18	37	10.4	0.9
Jan	2	37.2	14.2	36	10.3	1
Jan	3	35.8	14.9	35	10.2	1
Feb	1	36.2	12.4	28	10	1.1
Feb	2	32	16.9	28	10	1.1
Feb	3	33.7	15	30	9	1.1
Marc	1	31.2	20.9	28	8.8	0.8
			2004/05			
Nov	3	40.3	16.7	30	9.6	0.9
Dec	1	39.3	19	41	10.3	1
Dec	2	39.5	16.1	41	10.3	1
Dec	3	32.2	14.9	41	10.1	1
Jan	1	31.5	14.6	32	10.3	1.4
Jan	2	30.9	11.5	31	8.1	1.5
Jan	3	34.4	15.1	31	10.2	1.6
Feb	1	37	19.5	30	10.3	1.6
Feb	2	38.3	18.8	29	10.7	1.6
Feb	3	41.8	24	28	10.5	1.7
Marc	1	40.4	19.7	24	10.6	0.9

Table 1.continued

Month	Decade	Tmax (^{0}C)	Tmin (^{0}C)	RH (%)	Sun shine hours/day	Wind speed m/s
			2005/06			
Nov	3	38.4	21.4	48.5	10.3	1.7
Dec	1	37.6	18.6	47.1	10	1.4
Dec	2	37.6	20	48.5	10.3	1.9
Dec	3	35.4	18.2	49	9.9	2.1
Jan	1	37.6	19.6	44.8	10.2	1.7
Jan	2	32.3	15.6	38.3	10.2	2.3
Jan	3	37.5	20.2	46.6	10.4	2.3
Feb	1	38.0	19.5	38.1	10.1	2.0
Feb	2	35.1	16.1	33.2	10.4	2.7
Feb	3	38.5	20.6	35.8	10.4	2.0
Marc	1	38.6	22.1	33.4	9.9	2.3

Table 2. Reference evapotranspiration (ET_0) in mm day^{-1}every 10 days for the three seasons

Month	Decade	2003/04	2004/05	2005/06
Nov	3	5.1	5.3	5.1
Dec	1	4.7	5.3	5.1
Dec	2	4.9	5.2	5.1
Dec	3	4.7	4.6	4.9
Jan	1	4.8	5.3	5.1
Jan	2	5.2	5.0	4.8
Jan	3	5.3	6.0	5.4
Feb	1	5.5	6.5	5.6
Feb	2	5.4	6.9	6.2
Feb	3	5.5	7.6	6.1
March	1	5.2	6.5	6.1

Table 3. Regression equations of ETc, Kc and CWR on the crop age (days after sowing) of barley in each growing season

Variables	Season	Regression equation [1]	R^2
	2003/04	$y = -0.001x^2 + 0.165X + 0.221$	0.999
ETc	2004/05	$y = -0.0016x^2 + 0.1969X - 0.1929$	0.999
	2005/06	$y = -0.0011x^2 + 0.137X - 0.9071$	0.999
	2003/04	$y = -0.0003x^2 + 0.0309X +0.1059$	0.931
Kc	2004/05	$y = -0.0003x^2 + 0.0311X +- 0.093$	0.985
	2005/06	$y = -0.0002x^2 + 0.02854X - 0.5213$	0.923
	2003/04	$y = -0.1301x^2 + 16.262X +- 21.903$	0.957
CWR	2004/05	$y = -0.1601x^2 + 19.614X – 22.42$	0.936
	2005/06	$y = -0.1147x^2 + 14.05X +- 85.42$	0.973

Table 4 shows the crop evapotranspiration (ETc) for each irrigation interval throughout the three seasons. The ETc increased with plant age, reached its maximum values at 60 DAS, and decreased towards maturity. Season 2004/05 had higher ETc values compared to the other two seasons and this was likely due to the higher average monthly temperature (Table 1). The total ETc of barley as a mean over three seasons was 389 mm (Table 4) which was little higher than in north Ethiopia (Araya *et al*. 2011) and southern Tunisia (Nagaz *et al*. 2008). The estimated seasonal ETc of barley was about 375 and 340 mm, respectively. The differences could be attributed to differences in climate and cultivar characteristics.

Table 4. Crop Evapotranspiration ETc mm of barley as affected by DAS For the three seasons

DAS	2003/04	2004/05	2005/06	Means
20	3.0	3.5	3.2	3.2
30	4.0	4.6	4.1	4.2
40	4.7	5.5	4.7	5.0
50	5.2	6.0	5.1	5.4
60	5.4	6.2	5.3	5.6
70	5.3	6.0	5.3	5.6
80	5.0	5.6	5.1	5.2
Mean	4.6	5.3	4.7	
Total per season	368	424	376	389*

*ETc average of the three seasons

The crop coefficient was calculated every 10 days crossponding to specific growth stages as a function of DAS (Table 5). Those stages were the initial, developmental, mid and the late season stages corresponding respectively to 15, 30, 60 and 75 DAS (Fig. 1). The Kc increased steadily with the advancement of crop age until they reached their peak at the mid stage (60 DAS) and then, started to decline.

The quadratic regression equation ($R^2 = 0.9908$) was obtained for the Kcs of barley as the function of DAS *i.e.* the crop age. In fact, the mean Kcs for the initial, development, mid and late season stages were 0.48, 0.95, 1.04 and 0.47, respectively. This finding agrees with those of Araya *et al.* (2011) who found that the Kc values for barley started to increase from the development (vegetative) stage up to the mid-season stage and later declined during the late season stage (Kc started to decline at 66 days after planting).

Table 5. The crop coefficient and crop water requirement of barley (m^3/ha) as affected by DAS for the three seasons

DAS	Kc			CWR		
	2003/04	2004/05	2005/06	2003/04	2004/05	2005/06
10	0.42	0.38	0.41	214	201	209
20	0.54	0.53	0.59	254	276	301
30	0.82	0.83	0.82	402	382	418
40	0.91	0.98	0.97	428	519	475
50	1.03	1.02	1.04	494	510	530
60	1.05	1.04	1.08	546	624	518
70	1.01	0.92	0.92	535	598	497
80	0.94	0.77	0.81	517	531	454
90	0.82	0.61	0.65	443	464	403
100	0.63	0.42	0.55	347	273	336
110	0.42	0.34	0.44	218	221	268
Total				4398	4599	4409

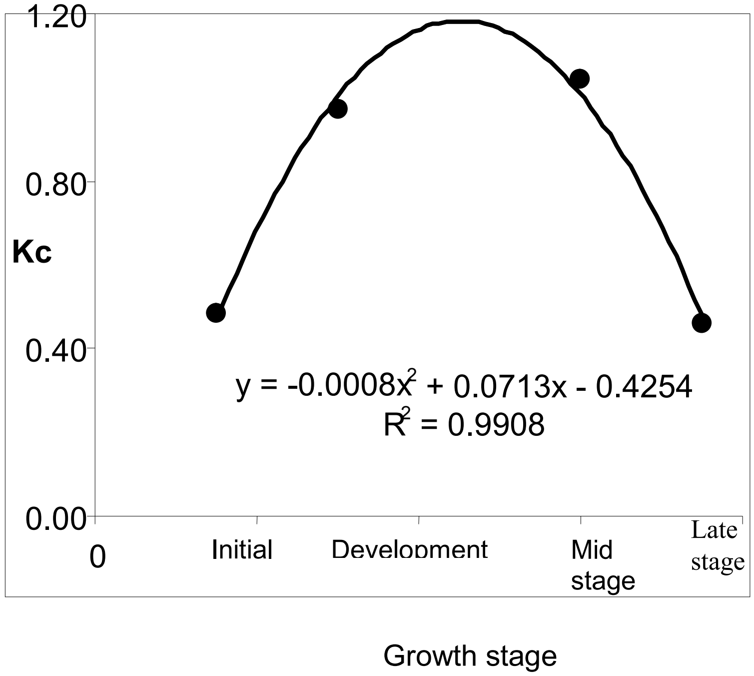

Fig 1. Crop coefficient of barley for different growth stages

The CWR of barley was calculated from the calculated Kc and ET_0 values (Table 2) according to equation 3. Table 5 shows the CWR for barley in the three seasons viz; 2003/04 (4398 m^3/ha), 2004/05 (4599 m^3/ha) and 2005/06 (4410 m^3/ha). The seasonal effect on the CWR was clear. Season 2004/05 consumed more quantities of water (4599 m^3/ha) compared to the other two seasons. The CWR in 2004/05 exceeded that of 2003/04 and 2005/06 by 4.6 % and 4.3 %, respectively (Table 5). Season 2004/05, however, was associated with high forage yield (Mohamed 2008) which necessarily reflects higher rate of evapotranspiration. This result agreed with that of Angas *et al*. (2005), who found that in the Ebro Valley in northeast Spain in three different locations, the total water used by barley ranged between 2750 and 4750 m^3/ha depending on year and location, whereas Araya *et al*. (2011) in north Ethiopia and Nagaz *et al*. (2008) in southern Tunisia estimated the seasonal ETc of barley as 3750 and 3400 m^3/ha, respectively. The difference could be attributed to differences in climate and cultivar characteristics.

CONCLUSIONS

This study determines the Kc of barley in central Gezira clay soil and similar regions in Sudan as 0.48, 0.95, 1.04 and 0.47 for the initial, development, mid and late stages, respectively.

The CWR of barley as a mean over the three seasons is 4469 m^3/ha, which indicates that barley is water saving winter crop in Sudan compared with other winter forage crops.

Therefore barley can be a possible forage crop option for farmers during winter in the Gezira.

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معامل نمو المحصول للشعير (*Hordium vulgare*) في الجزيرة

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المستخلص: يساعد تحديد معامل نمو المحصول Kc لمراحل النمو المختلفة في التخطيط للري ولتقدير الإحتياجات المائية للمحصول CWR . وفي هذا الصدد، هناك حاجة إلى تحديد معامل نمو المحصول Kc للشعير لتقدير الإحتياجات المائية للمحصول CWR في الجزيرة والمناطق المماثلة في السودان. أجريت تجربة خلال ثلاثة مواسم متتالية 2003/04، 2004/05 و2005/06 في محطة بحوث الجزيرة لتحديد معامل نمو محصول الشعير. وقد تم حساب البخرنتح للمحصول ETc ، البخرنتح المرجعي ET_0 ومعامل نمو المحصول Kc كنسبة بين البخرنتح للمحصول ETc والبخرنتح المرجعي ET_0 . أظهرت النتائج أن قيم معامل نمو المحصول Kc للشعير 0.48 و 0.96 و 1.04 و 0.48 كانت مناسبة للمرحلة الأولية ومرحلة تطور النبات وعند نصف الموسم وعند نهاية الموسم، على التوالي. ويمكن استخدام هذه القيم لمعدل نمو الحصول Kc لتقدير الإحتياج المائي CWR كناتج من معدل نمو المحصول Kc والبخرنتح المرجعي ET_0 في الجزيرة وكذلك في مناطق أخرى مماثلة في السودان.