Gezira of agric. 14(2): 100-112(2016)

Determination of crop coefficients, water requirements and water productivity for maize (*Zea mays* L.) under central Gezira clay soil conditions, Sudan

Hisham M.Mohammed[I], Hussien, S. Adam[2] , Siddig. E. Idris[I] and Osama A.Muhieldeen[I]

[I]*Faculty of Agricultural Science, University of Gezira, Wad Medani, Sudan.*
[2]*Water Management and Irrigation Institute, University of Gezira, Wad Medani, Sudan*

ABSTRACT

Development of site specific crop coefficients (K_c) helps tremendously in irrigation management and furthermore provides precise water application in the region. This study was conducted at the Experimental Farm, University of Gezira, during seasons 2014/15 (first season) and 2015/16 (second season) to estimate crop coefficients (K_c), crop water requirements (CWR) and water productivity (WP) of maize cultivar Hudaiba2. The reference evapotranspiration (ET_o) was calculated using the FAO computer program (CROPWAT). Actual crop evapotranspiration (ET_c) was estimated by the gravimetric method. Crop coefficients were derived from the relationship between reference evapotranspiration and actual crop evapotranspiration. The results showed that crop coefficients values for maize were 0.51 and 0.47 for initial stages, 1.26, and 1.15 for the mid stages and then decreased gradually to 0.53 and 0.42 for the late stages, in the first and second season; respectively. The peak K_c occurred during the period 60 to 70 days after sowing (DAS), coinciding with the maximum ET_c of 6.75 mm/day at the mid-season stage for maize. The crop consumptive water use of maize were 491 mm (4910 m^3/ha) for the total growing period. The mean yield of maize was 4285kg/ha and the crop water productivity was 0.58 kg/m^3.

INTRODUCTION

Maize (*Zea mays* L.) ranks as one of the most important cereal crops after sorghum, wheat and millet. In the Sudan, maize is considered as a minor crop and it is normally grown as a rain- fed crop in Kordofan, Darfur and in small irrigated areas in the Northern, Sennar and Blue Nile States, with average production of 0.697 ton/ha (Idris and Ibrahim, 2012). Crop coefficients vary for the different crops, as well as for the crops grown in the same location. In addition, crop coefficient change based on the growing stage of the crop. Allen, *et al.* (1998), determined the K_c of maize as 0.3, 0.5, 1.2 and 0.5 for the $K_{c\ ini}$, $K_{c\ dev,}$ $K_{c\ mid}$ and $K_{c\ end,}$ respectively. In India, Bandyopadhyay and Mallick (2003) reported that the estimated values of K_c for winter maize at initial crop development, mid-season, late season and maturity were 0.56, 0.93, 1.21, 0.85 and 0.52, respectively. Reference evapotranspiration (ET_o) depends on the climate and varies with location. Meteorogical stations are used to collect the climatic data for calculating ET_o, including temperature (maximum and minimum), dew relative humidity, wind speed, sunshine hours and solar radiation.

Crop water requirement (CWR) is the quantity of water utilized by a crop, irrespective of its source, for obtaining maximum yield in a particular area without adverse effects on soil properties. The total ET_c of maize were 273 - 470 mm (Abdul Salam and Suad, 2006) and 611.5 mm (Zhao and Nan, 2004) while it exceeded 500 mm as reported by Tariq and Usman (2002). For maximum production, a medium maturity grain crop requires between 500 and 800 mm of water depending on climate. Yield of maize under irrigation is 6 to 9 ton/ha FAO (2002). The water productivity for grain yield was 0.8 to 1.0 kg/m^3. The present work was undertaken to estimate crop coefficients (K_c), water requirements and water productivity of maize.

MATERIALS AND METHODS

Experiments were carried out during the winter seasons of 2014/15 (first season) and 2015/16 (second season) at the Experimental Farm, University of Gezira. It lies north of Wad Medani town, Lat. 14.4° N, Long. 33.5° E and altitude of 405masl. The soil in the farm is Vertisol, with a high CEC, and a pH of 7.5 (Alhilo, 1996). It is characterized by its alkaline reaction with low permeability.

The land was prepared by disc plow followed by harrowing and leveling. Maize (Hudaiba2) cultivar was sown on ridges 80 cm apart by placing 2-3seeds per hole and 25 cm between holes. The plot area was 100 m^2, each plot was separated from the other by 2 m. Three weeks later, plants were thinned to one plant per hole. Urea was applied of the rate of 86 kg N ha^{-1} as recommended by the Agricultural Research Corporation.

Reference evapotranspiration (ET_o)

The climatic data for reference evapotranspiration were collected from the Wad Medani Meteorological Station during the period from 20th November to 10th March for the two seasons (2014/15 and 2015/16). The CROPWAT software was used to estimate reference evapotranspiration.

Crop evapotranspiration (ET_c)

Crop evapotranspiration (ET_c) was calculated from soil moisture depletion measured by the gravimetric method. Three soil samples were taken from each plot using an auger every 20 cm down to 100 cm depth. The gravimetric moisture samples were collected one to two days after each irrigation and one hour before the next irrigation throughout the growing season and samples were taken eleven times every season. The samples were labeled and weighed immediately and the wet weight (W_w) was determined and then oven dried at 105 ºC for 24 hours and re-weighed for the dry weight (D_w).

$\theta_g = 100 (W_w - D_w)/ D_w$ …….. (1)

The values of gravimetric moisture content (θ_g) were converted to volumetric values (θ_v) by multiplying by dry soil bulk density of the profile (ρ), using the following formula.

$\theta_v = \theta_g \rho$……(2)

The change in soil moisture (ω) was obtained from:

$\omega = (\theta_2 - \theta_1) R$ ……. (3)

Where:

R = Sampling depth (cm),

θ_1 = Initial moisture content,

θ_2 = Final moisture content.

Determination of crop coefficients (K_c)

Crop coefficients (K_c) for maize were estimated according to the method described by Doorenbos and Pruitt (1975), where the ratios of actual crop evapotranspiration (ET_c) measured gravimetrically to the reference evapotranspiration (ET_o) calculated as averages from the Penman-Monteith on decadal basis:

$K_c = ET_c / ET_o$ ……..... (4)

Measurement of applied water

Water flow into each plot was measured from a small calibrated diesel water pump (Honda GX160, 1100 L/minute).

Water productivity (kg/m^3)

Water requirement (consumptive water use) and crop water productivity (WP) of crops are two important factors that are normally considered when assessing the feasibility of growing crops in any region.

CWP (kg/m^3) = Yield (kg) / applied water (m^3) ……. (5)

RESULTS AND DISCUSSION

Reference evapotranspiration (ET_o)

The average climatic data and the calculated ET_o in mm/day are presented in Table1. The average ET_o during the growing season ranged between 4.87 to 7.20 mm/day. The lowest value of ET_o coincided with the lowest mean air temperature (21.5 C^o), while the highest value of ET_o was associated with the highest mean of minimum and maximum air temperature (22.03 and 41.28 C^o, respectively. Allen *et al.* (1998) reported that under arid conditions, small variations in wind speed might result in larger variations in the evapotranspiration rate.

Table 1. Climatic data and reference evapotranspiration (ET_o) for maize during the first and second seasons.

DAS 20 Nov.	Min. temp. (C°)	Max. temp. (C°)	R.H (%)	Wind speed (m/s)	Sunshine (hours)	Radiation ($Mj/m^2/day$)	ET_o (mm/day)
10	17.20	38.55	33.40	1.60	10.40	21.05	5.30
20	17.05	34.75	38.20	1.75	10.75	21.20	5.23
30	15.15	33.90	38.70	1.75	10.25	20.35	5.06
40	13.65	32.75	38.45	1.90	10.55	20.75	5.09
50	12.90	33.10	33.55	2.15	10.35	20.80	5.53
60	11.85	31.10	36.85	1.75	10.15	20.90	4.87
70	14.80	33.20	39.20	1.85	10.15	21.45	5.27
80	15.95	36.90	37.10	1.80	10.65	22.80	5.92
90	18.30	37.10	32.10	1.95	10.90	23.80	6.46
100	16.65	38.05	30.40	2.05	10.80	24.30	6.82
110	22.03	41.28	31.67	1.99	10.30	24.05	7.20
Mean	15.96	35.51	35.42	1.87	10.48	21.95	5.71

Crop evapotranspiration (ET_c):

Table 2 shows the actual measured crop evapotranspiration, which was calculated from the soil moisture depletion for each irrigation throughout the seasons 2014/15 and 2015/16. Crop evapotranspiration was expressed in mm/day. The results indicated that the actual measured values of ET_c for the first season and second season started with low values of 1.95 and 2.13 mm/day, respectively, during the initial stage, then increased to a peak of consumptive water use of 6.53 and 6.98 mm/day, respectively, during the mid-stage, and then ET_c decreased during the late stage to a value of 3.21 and 3.35 mm/day, respectively. The average seasonal measured value of ET_c was 4.47mm/day. The highest water requirements were recorded at the mid-season stage, while the lowest values were observed at the initial growth stage. The low crop water requirement at the initial stage was mainly due to the low crop leaf area development. On the other hand, the rapid reduction in ET_c in the late season stage was due to the physiological senescence of leaves.

The period of maturity coincides with the period of less water demand because of drying of leaves and minimum leaf area available for transpiration. The calculated total consumptive water used was 491.5mm. Elzubeir and Alamin (2009) reported that maize consumptive water used was 612 mm in Sudan. This finding matched closely with that of Doorenbos and Pruitt (1975) and Piccinni *et al.* (2009) who stated that, to obtain high yields, water requirements of 430 to 490 mm and 441 to 641 mm were needed depending on climate and length of growing period.

Table 2. Crop evapotranspiration (ET_c) in mm /day for maize for the first and second seasons.

Irrigation number	Maize ET_C (mm/day)		
	Season (2014/15)	(2015/16)	Mean
1	1.95	2.13	2.04
2	2.30	2.87	2.59
3	3.72	3.52	3.62
4	4.12	4.10	4.11
5	5.11	4.95	5.03
6	5.06	5.87	5.46
7	6.53	6.98	6.75
8	5.63	6.52	6.08
9	6.25	4.78	5.52
10	4.64	4.70	4.67
11	3.21	3.35	3.28
Total	485.2	497.7	591.5
Mean	4.41	4.52	4.47

Crop coefficients (K_c):

The K_c values which were calculated using equation 4 are shown in Table 3. There was a gradual increase in K_c as plant development continued until the K_c reached its maximum values of 1.26 and 1.30 at the full growth period and the K_c decreased to 0.44 and 0.47 at the end of the growing season for the first and second season, respectively.

The peak K_c values of 1.26 and 1.30 were obtained at 70 DAS and coincided with the maximum ET_c of 6.53 and 6.98 mm/day for the first and second season, respectively. The K_c values for the initial, mid-season, and late stages were 0.36 – 0.41, 1.26 –1.30, and 0.44 – 0.47, in the first and second season, respectively. The measured K_c values were different from FAO (2002) reported values; the cause might be that FAO K_c values were generalized ones and recommended for a wide range of climatic conditions. This finding of K_c values was within the range of Abdul Salam and Suad (2006) who reported that K_c values were 0.30, 1.20 and 0.50 for the $K_{c\ ini}$, $K_{c\ mid}$ and $K_{c\ end}$, respectively. Results were in line with those of Piccinni *et al*. (2009), who reported that maize K_c varied from 0.1 to 1.3 in India. Also, Attarod *et al*. (2009) reported that daily average K_c for the winter season was between 0.2 and 1.20. Abedinpour (2015) reported that K_c values for the initial, crop development, mid-season, and late stages were 0.40 – 0.60, 0.70 – 0.80, 1.1–1.21, and 0.50 – 0.65, respectively. The K_c was within the range of previous reports of Shankar *et al.* (2012)who reported that K_c values for the initial, development, mid and late stages were 0.55, 1.08, 1.25 and 0.75, respectively. The length of periods for the initial, development, mid and late stages were 25, 30, 30 and 25 days, respectively.

Table 3 Reference evapotranspiration (ET_0), actual evapotranspiration (ET_c), and crop coefficients (K_c) for maize for the first and second season.

	seasons						
	2014/15			2015/16			
Irrigation Number	ET_o (mm/day)	ET_c (mm/day)	K_c	ET_o (mm/day)	ET_c (mm/day)	K_c	Mean
1	5.41	1.95	0.36	5.19	2.13	0.41	0.38
2	4.70	2.30	0.49	5.75	2.87	0.50	0.49
3	5.10	3.72	0.73	5.03	3.52	0.70	0.71
4	5.07	4.12	0.81	5.12	4.10	0.80	0.80
5	5.68	5.11	0.90	5.38	4.95	0.92	0.91
6	4.60	5.06	1.10	5.15	5.87	1.14	1.12
7	5.18	6.53	1.26	5.37	6.98	1.30	1.28
8	5.91	5.63	1.00	5.93	6.52	1.10	1.05
9	6.79	6.25	0.83	6.13	4.78	0.78	0.80
10	6.73	4.64	0.69	6.91	4.70	0.68	0.68
11	7.29	3.21	0.44	7.12	3.35	0.47	0.45
Mean	5.68	4.41	0.78	5.73	4.52	0.80	0.79

Measurement of applied water (m^3/ha)

Total amount of applied irrigation water was presented in Table 4. Total water applied by irrigation (7355m^3/ha) was more than the estimated consumptive water use (4915 m^3/ha). Also, the amount of irrigation water applied during the first irrigation was high (1169 m^3/ha) which was due to the heavy cracking clay soils. The variation in water amount applied in each irrigation was attributed to the variations of the climatic conditions of the month.

Table 4. Irrigation water applied to maize (m^3/ha), for both seasons.

Irrigation number	Applied water (m^3/ha)		
	First season	Second season	Mean
1	1165	1173	1169
2	620	637	628.5
3	606	617	611.5
4	626	620	623
5	632	640	636
6	638	633	635.5
7	677	681	679
8	664	658	661
9	651	655	653
10	583	589	586
11	478	467	472.5
Total	7340	7370	7355
mean	667.3	670	668.6

Crop water productivity (CWP)

Crop water productivity was calculated according to equation 5. There were significant differences in seed yield between the two seasons. Seed yield was 4650 and 3920 kg/ha in the first and second season, respectively. It was within the range of previous reports of Radma and Dagash (2013) who reported that seed yield ranged between 3870 and 4180 kg/ha. Results in Table 5 showed that the average water productivity was 0.58 kg/m^3 which was in line with those of Elzubeir *et al.* (2009) who reported that maize water productivity in the Sudan varied from 0.60 to 0.78. On the other hand, this finding was low compared to that reported by FAO (2002) who showed that water productivity varied between 0.8 and 1.6 kg/m^3. Al-Kaisi and Broner (2009) reported that crop water use was influenced by prevailing weather conditions, available water in the soil, crop species and growth stage.

Table 5. Water productivity (kg/ m^3) for first and second season

Season	Yield (kg/ha)	AW (m^3/ha)	WP (kg/ m^3)
2014/15	4650	7340	0.633
2015/16	3920	7370	0.532
Mean	4285	7355	0.582

AW= Applied water (m^3/ha), WP= Water productivity (kg/ m^3)

CONCLUSION

Crop coefficients increased from early stage to its maximum measured value at the middle of the growth period and thereafter k_c decreased to the lower value at the end of the growing season. The total average water consumptive use of maize was 491 mm (4910 m^3/ha) for the growing period. Across the seasons, the daily average of ET_c values were 4.5 mm/day and the maximum ET_c reached 6.75 mm/day which was recorded for mid-season stage. Development of site specific K_c helps tremendously in irrigation management and furthermore provides precise water application in the region.

REFERENCES

Abdul Salam. M and M. Suad. 2006. Crop water and irrigation water requirements of maize (*Zea mays* L.) in the Entisols of Kuwait. Tenth International Water Technology Conference, Alexandria, Egypt.

Abedinpour, M. 2015. Evaluation of growth-stage-specific crop coefficients of maize using weighing lysimeter. Soil and Water Research 10 (2): 99–104.

Alhilo. A.S 1996. Water management in the University of Gezira Farm. M.Sc. Thesis, University of Gezira, Sudan.

Al-Kaisi. M.M and I. Broner. 2009. Crop water use and growth stages. Colorado State University Extension, Fort Collins, Colorado, USA.

Allen, R. G, L. S. Raes and M. Smith. 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper No 56, FAO, Rome.

Attarod. P., M. Aoki and V. Bayramzadeh. 2009. Measurements of the actual evapotranspiration and crop coefficients of summer and winter season crops in Japan. Plant Soil Environment 55 (3): 121–127.

Bandyopadhyay, P. K. and S. Mallick .2003. Effect of soil moisture levels on root distribution, water uptake and crop coefficients of winter maize in a humid tropic region. Food, Agriculture and Environment 1, (3 and 4) : 141-147.

Doorenbos. J and W. O. Pruitt. 1975. Guidelines for predicting crop water requirements. Irrigation and Drainage. FAO, Rome.

Elzubeir , A. O and M. A Elamin. 2011. Response of maize (*Zea mays* L.) growth and yield to irrigation regimes and different tillage systems in arid area of Sudan. Agriculture and Biology Journal of North America 2(6): 1015-1021

FAO. 2002. Crop water management, water management group. Rome, Italy.

Idris, A. E and M. H. Ibrahim. 2012. Screening maize (*Zea mays* L.) genotypes by genetic variability of vegetative and yield traits using compromise programming technique. British Biotechnology Journal 2 (2): 102-114.

Piccinni, G., J. Ko., J. Marek and H. Terry. 2009. Determination of growth-stage-specific crop coefficients (K_c) of maize and sorghum. Agricultural Water Management 96: 1698–1704.

Radma, I. A.M and Y. M.I. Dagash.2013. Effect of different nitrogen and weeding levels on yield of five maize cultivars under irrigation. Universal Journal of Agricultural Research 1(4): 119-125.

Shankar. V., C.S.P. Ojha and K.S. Hari Prasad .2012. Irrigation scheduling for maize and Indian-mustard based on daily crop water requirements in a semi-arid region. World Academy of Science, Engineering and Technology 6: 03-20.

Tariq, J.A. and K. Usman. 2009. Regulated deficit irrigation scheduling of maize crop. Sarhad Journal of Agriculture. 25(3): 441- 450.

Zhao. C and Z. Nan. 2004. Estimating water needs of maize *(Zea mays* L.) using the dual crop coefficient method in the arid region of northwestern China African Journal of Agricultural Research 2(7): 325-333.

حساب معامل المحصول والاحتياج المائى وكفاءة استخدام مياه الرى لمحصول الذرة الشامى فى التربة الطينية – بولاية الجزيرة ، السودان

هشام موسى محمد احمد[1] و حسين سليمان ادم[2] و صديق عيسى ادريس[1] و اسامة عباس محى الدين[1]

[1]كلية العلوم الزراعية ، جامعة الجزيرة ، ودمدنى السودان.
[2]معهد ادارة المياه والرى ، جامعة الجزيرة، ود مدني، السودان

الخلاصة

إنّ حساب معامل المحصول (K_c) يساعد بشكل كبير فى إدارة مياه الرى وتطبيق دقيق للماء المضاف فى المنطقة. أجريت هذه الدراسة بمزرعة جامعة الجزيرة – كلية العلوم الزراعية بولاية الجزيرة في موسمين 2015/2014م و2016/2015م. بهدف حساب معامل المحصول (K_c) والاحتياج المائى (CWR) وكفاءة استخدام المياه (WP) لمحصول الذرة الشامي (صنف حديبة 2) . تم حساب البخرنتح المرجعي (ET_o) باستخدام برنامج CROPWAT كما تم حساب البخر نتح للمحصول(ET_c) باستخدام الطريقة الوزنية ومن ثم تم تقدير معامل المحصول (K_c) من العلاقة بين البخرنتح المرجعى والبخرنتح للمحصول. أوضحت النتائج أن معامل المحصول يبدأ من 0.36 و 0,41 فى المراحل الأولية من عمر المحصول حتى يصل إلى أعلى قيمة له 1,26 و 1,30 ومن ثم يتناقص تدريجيا إلى أن يصل أدنى قيمة له 0,44 و 0,47 فى الطور النهائي لمحصول الذرة الشامى للموسم الاول والثانى على التوالي. أعلى قيمة لمعامل محصول الذرة الشامى كانت بعد مرور 60 و 70 يوم من تاريخ الزراعة وهى 6.53 و 6.98 ملم/يوم. الاستهلاك المائي خلال الموسم بلغ 448 و 380 ملم و كانت الإنتاجية 4650 و 3920 كجم/هكتار على التوالى أما متوسط كفاءة استخدام المحصول لمياه الري فكانت 0.58 كجم/م^3. لهذا فان قيم معامل المحصول يجب أنّ تستخدم لحساب كمية الماء المضاف لزيادة الانتاجية وكفاءة استخدام المياه.