African Crop Science Journal, Vol. 23, No. 3, pp. 239 - 247 ISSN 1021-9730/2015 $4.00

EVAPOTRANSPIRATION AND CROP COEFFICIENTS OF GRAIN LEGUMES IN SEMI-DESERT CLIMATIC CONDITIONS

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(Received 4 June, 2015; accepted 18 August, 2015)

ABSTRACT

Crop evapotranspiration (ETc) is a very important parameter in irrigation management. It can be either directly measured using water balance approach or estimated. A field experiment was carried out at Hudeiba Research Station farm in Sudan to determine crop evapotranspiration (ETc) and coefficients (kc) for faba bean (*Vicia faba* L.), common bean (*Phaseolus vulgaris* L.) and chickpea (*Cicer arietinum* L.). The total ETc values of faba bean, chickpea and common bean were 403, 337 and 280 mm, respectively, with maximum daily values of 5.4, 4.9 and 4.7 mm day^{-1}. The estimated crop coefficients during the initial, mid-season and late -season stages for faba bean were 0.33, 1.22 and 0.60, respectively. The corresponding values for chickpea were 0.26, 1.08 and 0.52, respectively; and for common bean, 0.20, 1.07 and 0.52.

Key Words: *Cicer arietinum*, *Phaseolus vulgaris*, *Vicia faba*

RÉSUMÉ

L'évapotranspiration des cultures (ETc) est un paramètre très important dans la gestion de l'irrigation des cultures. Ce paramètre peut être mesuré directement en se servant du bilan hydrique ou soit estimé. Une expérimentation en plein champs a été conduite à la station de recherche de Hudeiba au Sudan afin de déterminer l'évapotranspiration des cultures (ETc) et les coefficients culturaux (kc) pour la fève (*Vicia faba* L.), le haricot commun (*Phaseolus vulgaris* L.) et le pois chiche (*Cicer arietinum* L.). Les valeurs totales d'ETc de fève, pois chiche et haricot commun étaient respectivement de 403, 337 et 280 mm, avec un maximum de valeur journalière d'ETc équivalente à 5,4 ; 4,9 et 4,7 mm par jour. Les coefficients culturaux estimés durant les stades de développement initial, stade moyen et stade final pour la fève étaient respectivement de 0,33; 1,22 et 0,60. Les valeurs correspondantes pour le pois chiche étaient respectivement de 0,26; 1,08 et 0,52; et de 0,20 ; 1,07 et 0,52 pour le haricot commun.

Mots Clés: *Cicer arietinum*, *Phaseolus vulgaris*, *Vicia faba*

INTRODUCTION

Faba bean (*Vicia faba* L.), common bean (*Phaseolus vulgaris* L.) and chickpea (*Cicer arietinum* L.) contribute substantially to the daily diets in sub-Saharan Africa. In addition, they play an important role in sustaining the productivity of arable soils because of their role of atmospheric nitrogen fixation (Pala *et al.*, 2000; Maiti, 2001; Duc *et al.*, 2010). In Sudan, they are grown mainly in the northern parts (Northern and River Nile states), where environmental conditions suit their production better than in other parts of the country. Their growing season is restricted to the short period of time, due to high temperatures prevailing at the beginning and end of winter (Salih *et al*., 1996). Faba bean is produced exclusively under irrigation; while chickpea and common bean are grown under flood (residual soil moisture) and irrigation conditions.

Crop evapotranspiration is a very important parameter (Shaozhong *et al*., 2000; Irmak *et al*., 2008; Payero *et al*., 2008) in water management, for better irrigation scheduling and efficient water use. Crop evapotranspiration (ETc) can be either directly measured using a Lysimeters or water balance approaches; or estimated using climatological data (Allen *et al*., 1998). In the climatological data method, the crop evapotranspiration is calculated by multiplying the reference evapotranspiration (ETo) by a crop coefficient (kc) (Doorenbos and Pruitt, 1977; Allen *et al*., 1998). ETo reflects local climatic conditions; whereas Kc reflects the crop characteristics such as growth stage since sowing date, leaf area, plant height, crop development, canopy cover and canopy resistance. It also reflects soil and climate conditions. Among all methods, the Penman-Monteith equation has been recommended by the Food and Agriculture Organisation (FAO) as the standard method for the computation of ETo from climatological data, especially under arid conditions (Allen *et al*., 1998), where the FAO Paper No. 24 method was proven unsuitable (Allen *et al*., 1994).

For irrigation scheduling purposes, daily values of crop ETc can be estimated from crop coefficient curves (Benli *et al*., 2006), which reflect the changing rates of crop water use over a growing season, if the values of daily ETo are available. Crop coefficient values for a number of crops grown under different climatic conditions have been suggested by Doorenbos and Pruitt (1977). These values are commonly used in places where the local data are not available. However, there is strong need to develop crop coefficients under given climatic conditions.

The objective of this research was to determine the crop evapotranspiration (ETc) and crop coefficients (kc) of faba bean, chickpea and common bean under semi-desert climatic conditions of northern Sudan.

MATERIALS AND METHODS

A field experiment was conducted under irrigation, for two consecutive seasons (2011/2012 and 2012/2013), at the Hudeiba Research Station Farm, Ed-Damer, Sudan, located at latitude (17.57°) N, Longitude (33.93°) E, and altitude 350 m above sea level. The local climate is semi-desert (Adam, 2005), very hot and dry in summer and relatively cool in winter. According to soil profile (Table 1) the soil of the study site is clay in texture and is classified as VerticTorrifluvent, fine Smectitic, Calcaleous, hyperthermic, Bergieg series (USA, Soil Taxonomy); with very low permeability, field capacity of 46% by volume and a permanent wilting point of 25% by volume. In general, the soil is non-saline and non-sodic, with alkaline reaction; and low in both organic carbon and nitrogen content.

Faba bean and common bean crops were sown during the first week of November; whereas chickpea was sown during the third week of November in each of the two crop seasons. All crops were planted in holes on top of 60 cm ridges (ridge width), with intra-row spacing of 0.1 m between holes and at the rates of 2 seeds per hole. Nitrogen at the rate of 86 and 43 kg N ha^{-1} in form of urea, was applied uniformly, to all experimental plots of common bean and chickpea, respectively. However, no fertiliser was added to faba bean plots since in an earlier study in Northern Sudan, there was no response to nitrogen addition.

Ground cover was estimated visually at 5-day intervals, starting from germination. From the observations on canopy cover, crop developmental stages as defined by Doorenbos and Pruitt (1977) were determined. Data of maximum, minimum temperature, relative humidity, sunshine hours and wind speed, at 2 m height, were obtained from Hudeiba Meteorological Station. This was done to calculate ETo using Penman-Monteith Equation. The daily weather data were averaged for each 10 days along the growing season as presented in Table 2. It is well known that crop water requirement must be determined when the crop enjoys sufficient soil moisture for maximum evapotranspiration; so the crops were irrigated every ten days to provide enough soil water. The

TABLE 1. Selected physical and chemical properties of the soil at the experimental site in northern Sudan

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	H.C (cm/hr)	1/3 bar (%)	15 bar (%)	Bulk density (g/cm^3)	pH	EC (dS/m)	$CaCO_3$ (%)	N (%)	O.C (%)	CEC	SAR
0-23	4	47	49	0.32	38	21	1.77	7.8	0.3	6.0	0.045	0.499	48	1
23-44	3	42	55	0.10	43	23	1.66	8.0	2.4	4.6	0.040	0.312	54	7
44-87	3	39	58	0.10	47	26	1.85	7.9	3.6	5.4	0.045	0.203	53	10
87-120	3	37	60	0.11	44	24	1.74	7.7	3.5	6.0	0.030	0.265	52	12
120-157	4	40	56	0.07	50	27	1.71	8.0	3.6	5.2	0.035	0.187	53	7
157-203	3	37	60	0.07	54	29	1.83	7.9	4.9	5.4	0.035	0.218	58	7

H.C = Hydraulic conductivity, EC = Electrical conductivity, $CaCO_3$ = Calcium carbonate, N = total nitrogen, O.C = Organic carbon, CEC = cation exchange capacity, SAR = Sodium absorption ratio, RH = Relative humidity, Max Temp. = Maximum air temperature, Min Temp. = Minimum air temperature, ETo = Reference evapotranspiration

amount of irrigation water (m^3) for each plot in each irrigation event was measured directly in the field, using a current meter, using the following equation:

$$I = A \times T \times V \quad \text{.................................. Equation 1}$$

Where, I = irrigation water (m^3), A = cross section area (m^2), T = total time (s) and V = velocity (m s^{-1})

ETc was determined using a standard water balance equation (Equation 2).

$$ETc = I + P + W - R - D \pm \Delta S \quad \text{.................... Equation 2}$$

Where: I = irrigation, P = rainfall, W = capillary rise, R = runoff, D = deep drainage, and S = soil moisture.

For the period after irrigation and before the next irrigation, I = 0 as no irrigation water is added. During winter (November-February), the rainfall (P) is zero. The water table is deep so the capillary rise (W) is zero. The runoff (R) is negligible as the land is flat with a very gentle slope (Adam 2005). The soil is impermeable so the deep drainage (D) is almost zero. Therefore the evapotranspiration is equal to the change in soil moisture ("S")

Soil water depletion "S" was calculated from soil water profile, measured in one replication for a depth of 60 cm with 20 cm intervals, 2-3 days after irrigation and immediately before each irrigation event. This was done from planting to harvesting, through gravimetric method. Soil samples were oven-dried at 105 °C for 24 hours. Then, the calculated gravimetric moisture contents were converted into volumetric values, through multiplication with dry soil bulk density, *viz:*

$$\Delta S = \frac{\sum_{i=1}^{n} (\theta 1 - \theta 2) d}{\Delta t} \quad \text{............... Equation 3}$$

Where: n = number of soil layers sampled in the effective root zone which is = 3 (0-20, 20-40, 40-60); θ1 volumetric moisture content within 2-3

TABLE 2. The average 10 days of climatic data of Hudeiba Meteorological Station

Period	RH (%)	Max Temp (°C)	Min Temp (°C)	Wind (m s^{-1})	Sunshine (hr)	ET_0 (mm)
			2011/2012			
05 November	31	34.3	18.1	1.7	10.5	5.4
15 November	32	34.0	19.3	2.5	10.3	6.1
25 November	40	28.7	14.5	2.5	10.2	5.0
05 December	48	29.7	15.2	2.3	10.0	4.6
15 December	52	31.2	16.5	1.7	09.8	4.2
25 December	52	33.0	17.2	1.8	09.6	4.5
05 January	38	29.8	13.9	2.7	09.5	5.2
15 January	37	26.5	11.4	3.0	09.5	5.1
25 January	48	30.1	12.2	2.0	10.2	4.6
05 February	53	33.7	16.3	2.4	08.1	5.0
15 February	51	33.3	17.8	2.7	07.6	5.5
25 February	46	32.2	15.6	2.5	08.1	5.5
			2012/2013			
05 November	40	37.9	21.7	1.2	09.4	4.9
15 November	37	35.0	19.9	1.7	10.2	5.2
25 November	42	32.4	16.9	1.7	10.2	4.8
05 December	53	33.3	18.8	1.5	10.0	4.3
15 December	44	30.1	16.1	2.1	09.7	4.6
25 December	45	27.5	13.4	1.9	09.9	4.2
05 January	45	27.9	16.0	2.3	09.5	4.5
15 January	55	31.0	14.5	2.0	09.5	4.3
25 January	50	33.2	17.9	2.3	08.2	4.9
05 February	47	32.2	15.8	2.0	08.9	4.9
15 February	42	34.0	17.6	2.4	10.0	6.0
25 February	30	36.6	18.2	1.8	09.1	6.0

RH = Relative humidity, Temp. = Temperature, ETo = Reference evapotranspiration

days after irrigation; θ2 = volumetric moisture content before the next irrigation in the i-th layer; d = the thickness of i-th layer (mm), which is = 200 mm; and Δt = the time interval between two consecutive measurements (days).

The kc values were calculated at ten-day intervals as the ratio between ETc and ETo values (Allen *et al*., 1998):

$$kc = \frac{ETc}{ETo} \quad \text{..................................... Equation 4}$$

Doorenbos and Pruitt (1977) divided the kc curve into four stages: initial, crop development, mid and late-season stages. The Initial growth stage occurs from sowing to about 10% ground cover. Crop development stage occurs from about 10 to 70% ground cover. The mid-season stage includes flowering and yield formation, while the late-season, includes ripening and harvesting.

Table 3 shows the length of the four crop development stages for faba bean, chickpea and common bean.In this study, crop coefficients (kc) for faba bean, chickpea and common bean were calculated on ten-day intervals, then the data were plotted in a graph to obtain smooth kc values for each growth stage.

RESULTS AND DISCUSSION

Crop evapotranspiration (ETc). The trend of average crop evapotranspiration (ETc) values for faba bean, chickpea and common bean are

TABLE 3. Length of crop development stage (days) for faba and common bean and chickpea in Northern Sudan

Crop	Total growing season (days)	Crop growth stages			
		Initial	Development	Mid-season	Late-season
Faba bean	102	18	27	35	22
Chick pea	99	19	20	35	25
Common bean	88	16	21	30	21

illustrated in Figure 1. Crop evapotranspiration for faba bean increased up to 65 days after sowing (DAS), reaching a maximum of 5.4 mm day^{-1}, and thereafter decreasing. Low ETc rates occurred during the first 20 DAS, when only few leaves contributed to the evapotranspiration. Thus, most of ETc was evaporation from the soil. ETc is affected by climate, management, crop type and stage of growth (Doorenbos and Pruitt, 1977). ETc increased during flowering and pod setting stages (65 DAS), because the crop had attained high canopy cover and maximum rooting depth (maximum water requirements) (Doorenbos and Pruitt, 1977). During the ripening stage of the crop (80 DAS), ETc declined rapidly because leaves turned chlorotic eventually necrotic, and ultimately transpiration stopped. The trend is in agreement with reports for various crops documented in the past (Doorenbos and Pruitt, 1977; Allen *et al*., 1998). The seasonal ETc during the cropping season was 403 mm. Neutron probe studies at Hudeiba Research Station (HRS) showed that faba bean requires about 430 mm of water (Ahmed 1996). De Costa *et al.* (1997) found that faba bean grown for seed production used 302-472 mm of water under well irrigated conditions. Hashim *et al.* (2012) found that seasonal crop water consumption of broad beans in Saudi Arabia was 303 mm with mean daily ET of 3.6. Krogman *et al.* (1980) reported that growing season ET in the highest yield of faba bean in southern Alberta averaged 544 mm.

For chickpea, ETc ranged from 1.8 to 4.9 mm day^{-1} during the growing season, with the lowest and highest corresponding to crop establishment and flowering, respectively (Fig. 1). ETc increased up to 60 DAS and peaked at 4.9 mm day^{-1}, then declined to 2.9 mm day^{-1} at the end of the season.The average seasonal ETc was about 337. Neutron probe studies at HRS showed that chickpea requires about 380 mm of water (Ahmed 1996). Desta *et al.* (2015) found that crop water demand of chickpea in Ethiopia was 437 mm.

For common bean, daily ETc crop varied from 2.4 mm day^{-1} at crop establishment to 4.0 mm day^{-1} at vegetative stage (up to first flower).The peak ETc of 4.7 mm day^{-1}occured at flowering and pod setting (Fig. 1).

Results from this study indicated that total crop water consumption (ET) for the three investigated crops was highest in faba bean (403mm), followed by chickpea (337 mm) and common bean (280 mm) (Fig. 1). This may be attributed to faba bean has higher daily water needs (faba bean grows upright and with taller canopy height, while chickpea and common bean have prostrate growth habit), longer growing period and greatest root system. The rooting depth was estimated at 22 cm for faba bean, 21 cm for chickpea and 19 cm for common bean.

Crop water consumption and crop water productivity (CWP) of crops are two important factors that should be considered when assessing the feasibility of growing crops in any region (Hashim *et al*., 2012). CWP is defined in this text as the yield production (kg ha^{-1}) per unit of crop water use (m^3 ha^{-1}). In this study, the average obtainable yields of faba bean, chickpea and common bean were 2232, 1165 and 740 kg ha^{-1}, respectively. On the other hand, crop water productivity was estimated to be 0.554, 0.346 and 0.264 kg m^{-3} for faba bean, chickpea and common bean, respectively.

Crop coefficients. Crop coefficient for faba bean, chickpea and common bean are presented in Figure 2. The kc values increased from initial to mid-season stages, and decreased during the

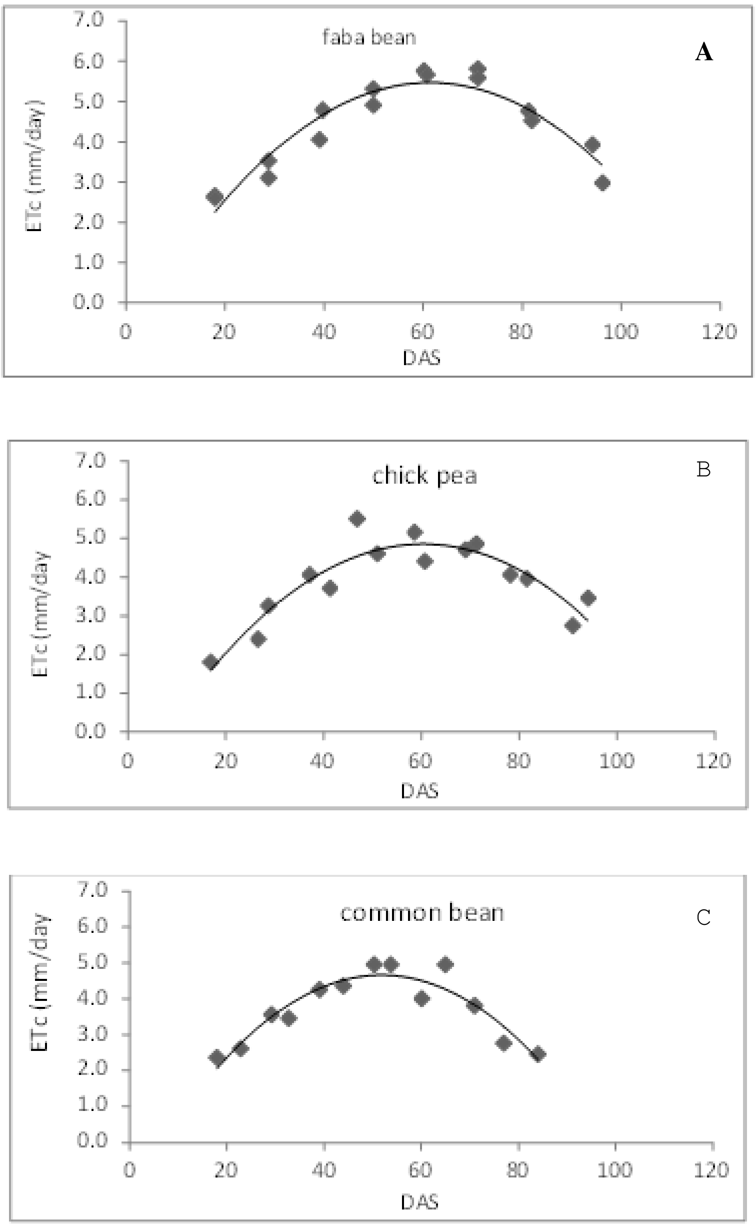

Figure 1. Values of daily ETc during the cropping period of (A) Faba bean, (B) chickpea and (C) common bean under optimal conditions in Hudeiba in Sudan.

later-season of the crop, with crop coefficients of 0.33, 1.22 and 0.60, respectively. The corresponding values for chickpea, were 0.26, 1.08 and 0.52, respectively; and for common bean were 0.20, 1.07 and 0.52.

These Kc values could be used in calculation of crop water requirements under similar soil, climatic, and crop management conditions by only knowing the average weather data, hence, facilitating irrigation scheduling of these crops in Northern Sudan.

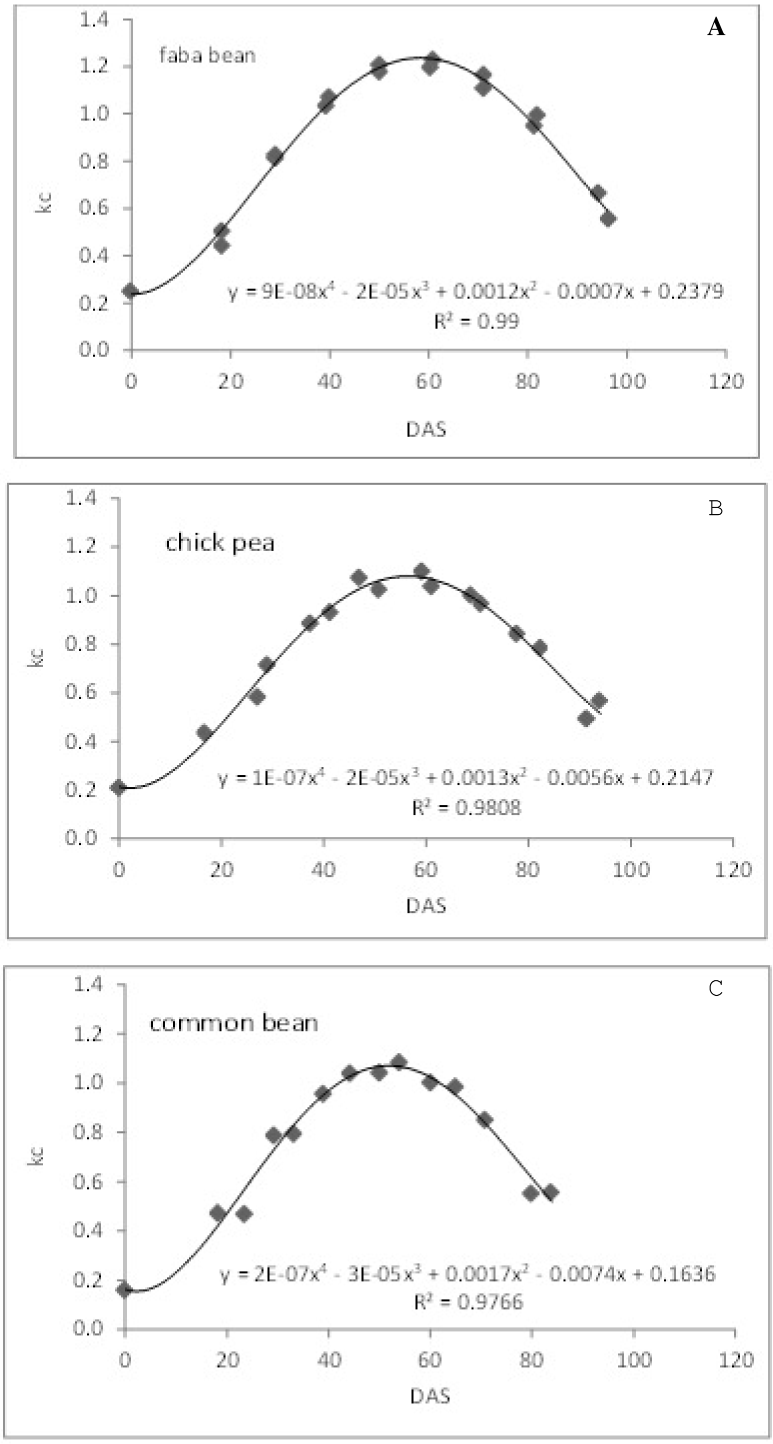

Figure 2. (A) Faba bean, (B) chickpea and (C) common bean crop coefficients (kc) with its fitting for ETc study in northern Sudan.

CONCLUSION

The estimated values of crop coefficients during the initial, mid -season and late-season stages for faba bean are 0.33, 1.22 and 0.60, respectively. The corresponding values for chickpea are 0.26, 1.08 and 0.52; and for common bean are 0.20, 1.07 and 0.52, respectively. These Kc values could be used in calculation of crop water requirements under similar soil, climatic, and crop management conditions and only knowing the average weather data, hence, facilitating irrigation scheduling of these crops in Northern Sudan.

ACKNOWLEDGEMENT

The authors thank the Land and Water Research Centre, Wad Medani, Sudan; the EU-IFAD PROJECT- ICARDA International Center for Agricultural Research in the Dry Areas for supporting and funding this work.

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