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Crop Coefficient of Haricot Bean at Melkassa, Central Rift Valley of Ethiopia

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Abstract

Crop coefficient (K_c), the ratio of potential crop evapotranspiration to reference evapotranspiration, is an important parameter in irrigation planning and management. However, this information is not available for many important crops. A study was carried out at the experimental farm of Melkassa Agricultural Research Center of Ethiopian Agricultural Research Organization, which is located in a semi arid climate. Four drainage type lysimeters were used to measure the daily evapotranspiration of haricot bean, *Awash Melka* variety on a clay loam soil. Crop coefficient was developed from measured crop evapotranspiration and reference evapotranspiration calculated using weather data. The measured values of crop coefficient for the crop were 0.34, 0.70, 1.01 and 0.68 during initial, development, mid-season and late-season stages. These locally determined values can be used by irrigation planners and mangers at Melkassa and other areas with similar agroecological conditions.

Keywords: crop coefficient, Ethiopia, haricot bean, lysimeter

1 Introduction

Decisions related to agricultural water management such as irrigation scheduling, water resources allocation and planning require the information about the water loss for a given crop. This water loss from a given cropped plot of land can be determined from the knowledge of reference evapotranspiration (ET_o), potential evapotranspiration (ET_c), and crop coefficient (K_c).

Most methods of estimating evapotranspiration involve two steps; first, evapotranspiration for a well watered reference crop (grass or alfalfa) with standard canopy characteristics (ET_o) is estimated (Burman *et al.*, 1980; Doorenbos and Pruitt, 1977). Currently, the FAO Penman-Monteith method is recommended to estimate ET_o (Allen *et al.*, 1998). Then evapotranspiration for the crop being considered (ET_c) is obtained by multiplying ET_o by a crop coefficient (K_c) which varies by growth stage for each crop.

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Crop coefficient represents crop specific water use and is essential for accurate estimation of irrigation requirement of different crops in the command area. It serves as an aggregation of the physical and physiological differences between crops and the reference definition. The variation of the crop coefficient during a growing season is obtained experimentally (BURMAN *et al.*, 1980; DOORENBOS and PRUITT, 1977; JENSEN, 1974; PRUITT *et al.*, 1972, 1987; WRIGHT, 1982). Although there are published K_c values for different crops, these values are commonly used in places where local data are not available. As these values vary from place to place and from season to season, there is a strong need for local calibration of crop coefficients under given climatic conditions (TYAGI *et al.*, 2000). There is, therefore, a pressing need to experimentally measure crop coefficients locally, so that project managers can correctly be advised.

Haricot bean (*Phaseolus vulgaris*), the subject crop of this research, is a well-established component of Ethiopian agriculture. From the export of white seeded beans, Ethiopia on average obtains about 16 million USD, out of which Awash Melka, the famous exportable variety used in this study, contributes the major portion (MARC, 2001). The middle rift valley of Ethiopia contributes about 60% of haricot bean production in the country. However, unreliable and poor distribution of rain is one of the major causes for low yield of haricot bean in this area (IAR, 1990). At present, farmers are opting for the production of this crop under irrigation. However, the water requirement data and crop coefficient of this crop is not locally available. Hence, knowledge of experimentally determined K_c value is important for proper irrigation scheduling and efficient water management of the selected crop variety. Therefore, this study was undertaken with the objective of developing crop coefficient for different growth stages of haricot bean.

2 Materials and Methods

2.1 General description of the study area and experimental lysimeters

This research was conducted on four lysimeters at Melkassa Agricultural Research Center, Central Rift Valley of Ethiopia. The center is located at an elevation of 1550 m above sea level with latitude of 8°24' N and longitude of 39°21' E. The average annual rainfall in the area is 768 mm, which is erratic and uneven in distribution. The site has a mean maximum temperature of 28.5°C and mean minimum temperature of 12.6°C. Loam and clay loam soil textures are the dominant soils of the area.

The experimental lysimeters are located near the agrometeorological station of the research center. The lysimeters were of non-weighing type each having an access chamber for aeration and underground steel pipes for disposal of drainage water from the lysimeters. These pipes are connected to water collecting tank mid way between the four lysimeters. Rim of each lysimeter protrued 10 cm above the soil surface so that no surface water runon or runoff may occur. One access tube for each lysimeter was installed at the center down to 90 cm depth.

2.2 Crop detail

The well known haricot bean variety in the area, *Awash Melka*, was sown on November 21, 2004 in and out of the lysimeters in all directions to have similar environment as in normal fields and decrease advective effects. Before sowing, all the four lysimeters were made to have the same moisture content. The crop was harvested on March 7, 2005.

The row spacing and plant spacing were 40 cm and 10 cm respectively. Recommended doses of fertilizers of 100 kg/ha Urea and 100 kg/ha DAP were added to increase yield and obtain reasonable K_c value. Plant height was measured at each growth stage by taking representative 5 plants from each plot and measuring from the bottom at soil surface to the tip. Leaf area index (LAI) was monitored. The leaf area index (LAI) was determined as a ratio of leaf area per unit area of soil below it by taking representative 5 plants from each plot at different times during the growing season.

2.3 Measurement of soil moisture and irrigation application

Soil samples were collected at interval of 30 cm up to 90 cm depth for determination of some soil physical properties like field capacity, permanent wilting point, bulk density and texture. The average field capacity and permanent wilting points of the root zone profile were 31.6% and 15.0% respectively. The bulk density was 1.1 g/cm^3. Neutron probe was used to monitor the soil moisture content. The probe was calibrated following standard procedure for neutron probe calibration by plotting the results of neutron probe reading and gravimetric sampling around the access tube. The moisture content was monitored at intervals of 30 cm up to 90 cm soil depth at different times during the growing season.

Irrigation water was applied to the crop when there was 30% depletion of the available soil moisture within the crop root zone (DOORENBOS and KASSAM, 1979). Similar irrigation amount at this depletion level was given to the crop in and out side the lysimeter to ensure uniform plant growth. The application of irrigation was carried out in known volume of buckets by converting the 30% depletion in terms of volume. Irrigation was terminated at crop maturity.

2.4 Determination of crop coefficient

Ideally, ET_o of the reference crop should be experimentally measured with a lysimeter. However, the alternative procedure is to determine ET_o from climatic data using the FAO Penman-Monteith method once the necessary variables specific to the location are determined. In this study, ET_o was calculated using FAO Penman-Monteith Equation (ALLEN et al. 1998) using weather data of the Melkassa weather station. The crop evapotranspiration for each growth stage of the crop was calculated by using water balance equation as:

$$ET_c = I + R - D + S \tag{1}$$

where ET_c: crop evapotranspiration (mm); I: irrigation (mm), R: rain fall (mm), D: drainage collected (mm), and S: decrease in storage of soil moisture (mm).

The crop coefficient value over a given period, such as decade, physiological growth stage or whole season, was then calculated as:

$$K_c = \frac{ET_c}{ET_o} \tag{2}$$

where K_c: crop coefficient; ET_c: crop evapotranspiration, and ET_o: reference crop evapotranspiration.

3 Results and Discussion

Crop evapotranspiration in 10 day intervals (decades) was calculated for each lysimeter using the water balance equation, Eq. (1). The result of the average of the four lysimeters is presented in Table 1. It can be observed from the Table that the peak water demand occurred almost three months after planting and only two weeks before harvest.

Table 1: Average potential crop eavpotranspiration, reference crop evapotarnpiration and crop coefficient values on 10-day interval basis.

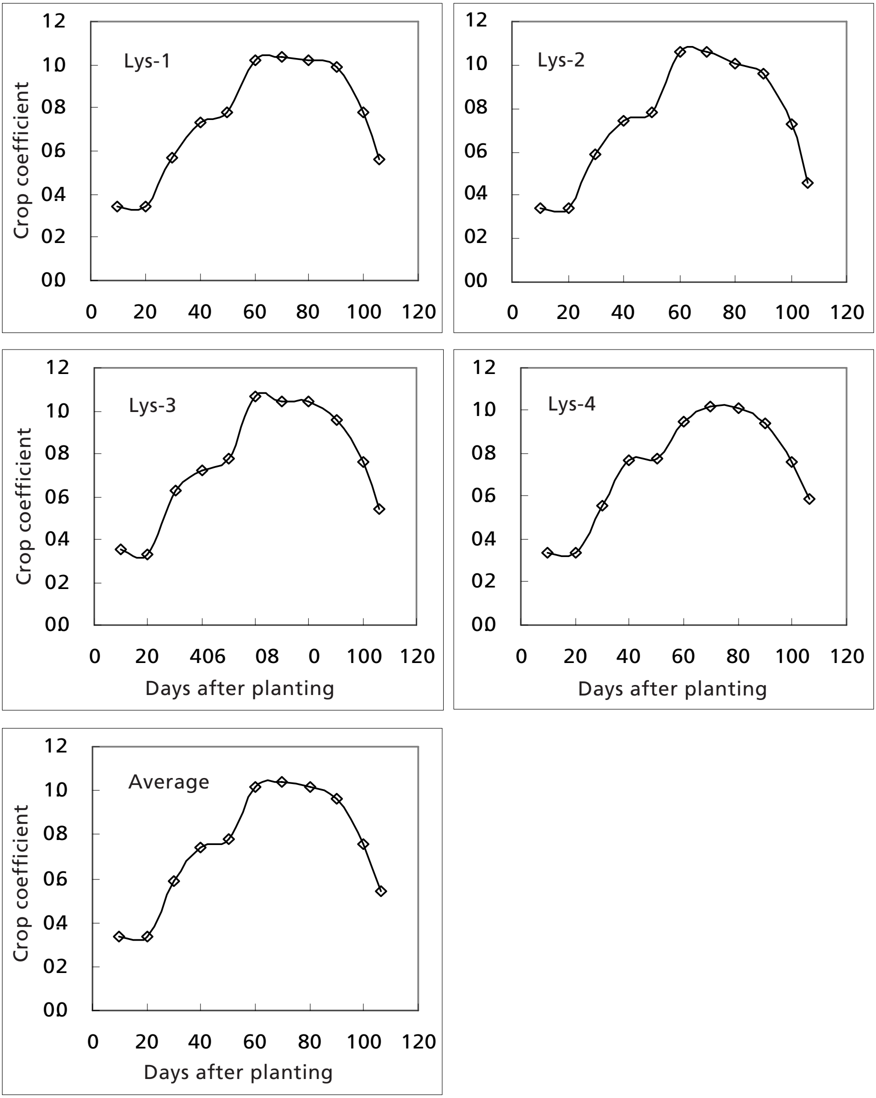
Days after planting	*Crop evapotranspiration* ET_c *(mm)*	*Reference evapotranspiration* ET_o *(mm)*	*Crop coefficient* K_c
10	17.87	51.72	0.34
20	17.83	52.38	0.34
30	34.12	57.85	0.59
40	36.79	49.71	0.74
50	40.04	51.30	0.78
60	47.76	46.62	1.02
70	53.91	51.90	1.04
80	64.49	63.06	1.02
90	68.57	71.17	0.96
100	46.63	61.46	0.76
106*	19.15	35.37	0.54

* row was calculated for 6 days period.

Crop coefficient values of haricot bean were obtained by dividing crop evapotranspiration measured by lysimeter with reference evapotarnspiration, Eq. (2). Fig. 1 presents the seasonal evolution of crop coefficient values in each lysimeters calculated for decades (ten-day period). There is a general trend of K_c increment from initial stage to end of development stage and in the midseason stage the curves show almost constant values. As the results of water balance analysis showed no stress periods, the scatter of points can be assumed to be normal for an experimental data.

The evolution of K_c values reflected the effects of crop development and physiology on ET_c. Fig. 2. shows the general trend of ET_c and ET_o values of haricot bean calculated as average value of the four lysimeters.

Figure 1: Ten-day period K_c curves of haricot bean at Melkassa (Lys-1, Lys-2, Lys-3, and Lys-4 and refer to lysimeters 1, 2, 3, and 4 reservedly).



The observed growth stages of haricot bean at Melkassa were 20, 30, 40, and 16 days during initial, crop development, midseason and late season growth stages. The total growth cycle is 106 days. The values of crop coefficients calculated for each growth stage of haricot bean are presented in Table 2.

Figure 2: Average evapotranspiration values at Melkassa.

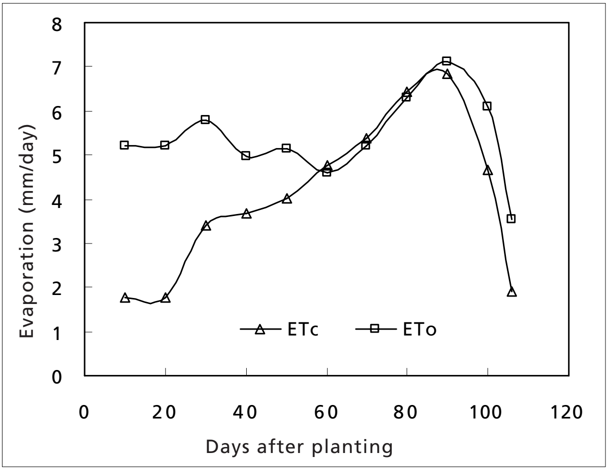


Table 2: Growth stage-wise K_c values of haricot bean at Melkassa.

	Initial stage	*Development stage*	*Mid season stage*	*Late season stage*
Duration (day)	20	30	40	16
ET_c (mm)	35.61	110.96	234.74	65.78
ET_o (mm)	104.10	158.86	232.75	96.83
K_c	0.34	0.70	1.01	0.68

The increase in K_c value from initial stage up to midseason stage is due to increase in ground cover of the crop, which has impact on evapotranspiration. During this stage, leaf area is small and evapotranspiration is mainly in the form of soil evaporation. This stage is terminated when 10% of the ground is covered (ALLEN *et al.*, 1998). As the crop develops and shades the ground to effective full cover and reach full size with increasing LAI, plant height and root depth, the amount of water abstraction increased which in turn increased the evapotranspiration. The evolution of ET_c indicated that maximum crop water requirement occurred at the end of the midseason stage, when evaporative demand was high. From the midseason stage to late season stage, there was a general decline in K_c. This decline is attributed to leaf senescence and to completion for assimilates between leaves and seed. Senescence is usually associated with less efficient stomatal conductance of leaf surfaces due to the effects of ageing, thereby restricting transpiration and causing a reduction in crop coefficient. Crop coefficient value at late season stage reflects crop and water management practices hence the crop at this stage need not get frequent irrigation as evaporation becomes restricted.

It can be observed that there is a slight variation in K_c values between the lysimeters observed during the crop development, midseason and late season stages. The computed overall average K_c values during initial, crop development; midseason and late season stages were 0.34, 0.70, 1.01 and 0.68 respectively. K_c value at the end of the growing season (harvest) was found to be 0.54. The K_c values for this crop given by WRIGHT (1982) at Kimberly, Idaho for initial, midseason and end of season stage were 0.15, 1.19 and 0.35. The K_c values suggested by ALLEN *et al.* (1998) for dry bean were 0.40, 1.15, and 0.35 for the initial, midseason and end of season. The differences of K_c values of the crop at different stages in different areas emphasize the need for local calibration of K_c values.

Some of the observed agronomic parameters (yield, LAI and plant height) of the crop are presented in Table 3. From the table, it can be observed that LAI and plant height increased as the crop passes through the different growth stages and reached maximum at the beginning of the midseason stage. Then after it decreased due to maturity of the crop associated with leaf ageing, senescence of leaves and leaf drop.

The recommended yield of this crop is 2500 kg/ha which is quite close to the observed average yield in this study. There is not as such significant difference in yield between the lysimeters indicating that the crop in each lysimeter has got the same amount of irrigation water at its depletion and the same amount of recommended doses of fertilizer.

Table 3: Agronomic parameters of haricot bean at Awash Melkassa.

Experimental Lysimeter	*Agronomic parameter*	*Initial stage*	*Development stage*	*Mid season stage*	*Late season stage*
Lys-1	Plant height (cm)	12.0	25.2	65.0	65.0
	LAI	0.70	2.00	3.50	1.50
	Yield (kg/ha)				2500.0
Lys-2	Plant height (cm)	12.20	25.8	65.5	66.0
	LAI	0.71	2.20	3.70	1.60
	Yield (kg/ha)				2520.0
Lys-3	Plant height (cm)	11.8	24.6	63.0	63.5
	LAI	0.70	2.10	3.40	1.30
	Yield (kg/ha)				2503.0
Lys-4	Plant height (cm)	12.2	25.5	64.0	64.0
	LAI	0.70	2.30	3.60	1.40
	Yield (kg/ha)				2510.0
Average	Plant height (cm)	12.1	25.4	64.4	64.6
	LAI	0.70	2.15	3.55	1.45
	Yield (kg/ha)				2508.3

4 Conclusion

From the study, it has been shown that estimates of crop water requirement made with locally determined crop coefficients slightly differ from estimates published in literature (e.g. ALLEN *et al.* (1998)). This emphasizes the strong need for local calibration of K_c for each variety. The fact that ET_c was measured locally makes the K_c values locally calibrated. Although the values may not be exactly the same as would be obtained with measured ET_o, they should be accurate enough for the purpose of estimating crop water requirements in the climatic region. ET_c and K_c are some what dependent on water management, i.e., operational criteria of irrigation system/method and amount of water supplied, variety, climate, location and other cultural differences. Thus, the K_c values obtained at in this study at Melkassa can be beneficial to areas with similar agroclimatic condition as that of Melkassa.

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