Determination of Crop Water Requirement and Crop Coefficient of Wheat (*Triticum aestivum L.*) at Melkassa, Central Rift Valley of Ethiopia

Ketema Tezera, Gobena Dirirsa and Tilahun Hordofa
Melkassa Agricultural Research Centre, Ethiopian Institute of Agricultural Research
PO Box 2003, Addis Ababa, Ethiopia, Email: ketematezera29@gmail.com

Abstract

Accurate estimation of crop water requirement is essential for water resource and irrigation project planning and operation that include optimal irrigation scheduling. Field experiment was carried out at Melkassa agricultural research center during the wet growing season using lysimeter. The aim of the study was to estimate the seasonal water demand and crop coefficient of wheat under climatic condition of Melkassa, central rift valley of Ethiopia. Two non-weighing type lysimeters with dimension of 1 m × 2 m area and 1 m depth was used to estimate the daily ETc of wheat crop. The Kc was determined for each crop growth stages as the ratio of ETc to ETo. The ETc determined by soil water balance equation and ETo computed by CROPWAT version 8.0 using the FAO Penman-Monteith equation. The seasonal ETc was found to be 52.2 mm, 97.1 mm, 191.5 mm and 73.2 mm of water during initial, crop development, mid-season, and late-season stages, respectively. The estimated Kc values were 0.54, 1.15 and 0.67 for the initial, mid and late stages, respectively. The Kc value in the initial crop growth stage differed from the FAO value. This indicates that there is a need to develop Kc values for given local climate conditions and crop. The average plant height and spike length obtained were 86.6 and 8.2 cm, respectively. The average grain yield and the above-ground biomass yield were 4559.1 and 10897.1 kg/ha, respectively. Also, the maximum number of tillers per square meter of 559.0 and number of grains per spike of 42.0 were obtained.

Keywords: Crop coefficient, crop water requirement, lysimeter, wheat

Introduction

Water is vital for crop production and its shortage and excess has an influence on crop yields and quality. The natural resources like land and water are limited and even decreasing due to over exploitation, pollution and climate change (FAO, 2011). The rapidly increasing population growth worldwide in general and in developing countries in particular is forcing to produce more food per drop of water and enhance economic development of the country.

Wheat (*Triticum aestivum* L.) is regarded as the world's king of cereals standing globally as the most valuable staple food and produced worldwide with larger area of cultivation than any other crop covering 217 million hectares with average yield of 3.0 t/ha. The crop is the largest shortfall crop in the developing countries. Between 1970 and 2010, more than half of the increment in wheat consumption was met by increased wheat imports, and several countries became totally dependent on imports for wheat (FAO, 2013).

In Ethiopia, wheat is the fourth most important crop in area coverage following tef, maize and sorghum with land holding of 13.25% of the total area covered with grain crops. It is commonly grown in the highlands at altitudes ranging from 1500 to 3400 masl and produced solely under rain fed conditions predominantly by smallholder farmers (Bekele *et al*., 2000). The rainfall distribution in these areas is bimodal and ranges between 600 and 2000 mm per annum. The country could not able to meet its large food deficit through rain-fed farming. One of the most important considerations in increasing and stabilizing agricultural production is through irrigation development.

In the country there was a limited wheat production under irrigation although there is huge potential to produce wheat under irrigation. In arid and semi-arid part of the country there was vast tract of land suitable for irrigation. In the central rift valley (CRV) of Ethiopia, wheat is grown by smallholder farmers during wet season (June - September) and by private farmers during cool season of the year (October - January) under irrigation.

Accurate estimate of crop water requirement is essential for proper water resource and irrigation project planning that include proper irrigation scheduling for efficient water management and sustainable use of land resources and environment. The crop water requirement is the depth of water needed to compensate the combined process of evaporation from soil surface and transpiration through the plant from the cropped field. The water requirement varies widely from crop to crop and also during the crop growth period of individual crops. Estimation of crop water requirement requires to determination of reference evapotranspiration (ETo) from climatic parameters. Once the ETo has been identified, a crop coefficient (Kc) must be applied to adjust the ETo-value for local conditions and the type of crop being irrigated. The Kc is simply a ratio of crop evapotranspiration (ETc) from a crop or soil surface to ETo.

The Kc varies during the growing season as: the plants develop, the fraction of ground covered by vegetation changes, and the plants age and mature. It also varies according to the wetness of the soil surface. Under bare soil conditions, Kc has a high value when soil is wet and its value steadily decreases as the soil dries (Allen *et al.* 1998).

The Kc are normally determined under highly controlled conditions of adequate soil moisture, good plant health, and cultural practices. Locally determined Kc-values were not available for many crops in Ethiopia and rather the Kc-values from reference books were used. Doorenbos and Pruitt (1977) emphasized the strong need for local calibration of crop coefficients under given climatic conditions. Hence, this study was initiated to determine the seasonal crop water requirement and crop coefficient for wheat cultivar *Kekeba* at different growth stage under climatic condition of Melkassa.

Materials and Methods

Study area

The study was conducted at Melkassa Agricultural Research Center that located in the Central Rift Valley of Ethiopia ($8^0$24' to $8^0$26 'N; $39^0$19' to $39^0$19' E with mean altitude of 1550 m.a.s.l.) The climate of the area is characterized as semi-arid with low and erratic rainfall pattern. The long-term climatic data (1977 – 2018) indicate annual average of 825 mm and about 67% of the total rainfall of the area occurs from June to September. The mean maximum temperature varied from 26.3 to 31.0 ^{0}C while the mean minimum temperature varied from 10.4 to 16.4 ^{0}C.

The average FC and PWP of the soil depth profile were 31.8% and 15.3%, respectively. Thus TAW at wheat root depth was 111.9 mm. The obtained bulk density was 1.13 g/cm^3.

Experimental setup

Two non-weighing lysimeters that were located near to Meteorological Station of the MARC were used for the study. Lysimeter is a tank buried in the soil and water balance within the tank is monitored. The lysimeters were connected to underground steel pipes for disposal of drainage water from the lysimeters and these pipes are connected to drainage water collecting tank. The lysimeters used was rectangular in shape with 1 m x 2 m dimension. Its effective soil depth was 100 cm. The lysimeter rims were maintained near the ground level to minimize the boundary layer effect in and around it. However, the rims of lysimeters protruded 20 cm above the soil surface so that no surface run-on or runoff could occur into or out of the lysimeters, respectively. One access tube for each lysimeter was installed at the center of the lysimeter down to 105 cm depth to monitor the soil moisture inside the lysimeter.

Crop management practices

Wheat cultivar *Kekeba* was sown on plot size of 3m by 3m including 1 m x 2 m lysimeter area in mid-June for three consecutive years (2016, 2017 and 2018). The seed was sown by drilling manually in both sides of a ridge spaced at 60 cm with row spacing of 20 cm in well prepared and pre-irrigated in and around the field of lysimeters. Recommended fertilizers rates of 100 kg/ha DAP at planting and 100 kg/ha urea in split application, half at planting and half 30 days of sowing were applied. The crop was harvested in the last week of October.

The moisture content was monitored using calibrated neutron probe at intervals of 15 cm for lower depth 15 to 105 cm soil depth of wheat root depth at different times during the growing season. The upper soil moisture content (0 – 15cm soil depth) was monitored gravimetrically as the radius of influence of the neutron is 30 cm. Irrigation water was applied to the crop when there was 50% depletion of the total available soil moisture within the crop root zone (Doorenbos and Kassam, 1979). Similar irrigation amount was given to the crop in and outside the lysimeter to ensure uniform plant growth and create same environment around cropped area. The application of irrigation was carried out with known volume of watering cans by converting the 50% depletion in terms of volume. All other cultural practices for the buffer and lysimeter area were same recommended for the area. Irrigation was terminated when the crop show sign of maturity.

Determination of wheat water requirement and crop coefficient

Crop water requirement is determined through 'Kc ETo' approach, whereby the effect of the climate on crop water requirements is given by the reference evapotranspiration ETo and the effect of the crop by the crop coefficient Kc. However, in this study ETc for wheat during the growth period was obtained by measuring the various components of the soil water balance in the lysimeter for each growth stage.

$$ETc = I + R - D - \Delta S$$

where, ETc in mm/ day; I is depth of irrigation water applied in mm; R is rainfall in mm/ day; D is drainage water collected from drainage water collecting tank and ΔS is change in soil profile.

Daily metrological data (minimum and maximum temperatures, sunshine hours, and wind speed, and average relative humidity) were obtained from MARC weather station and the reference crop evapotranspiration, ETo was computed using FAO Penman-Monteith method the with the help of Cropwat version 8.0 model (Allen et al. 1998).

The crop coefficient values for each growth stage were then obtained from the following relationship:

$$Kc = ETc/ ETo$$

where, Kc is crop coefficient in fraction; ETc is crop evapotranspiration in mm/ day and ETo is reference crop evapotranspiration in mm/ day.

Data Collection

Plant height, spike length, grain yield and yield components were collected from lysimeters for further evaluation.

Results and Discussion

Crop Evapotranspiration

Crop evapotranspiration (ETc) of wheat in decades (10 day intervals) basis was obtained from lysimeters following the soil water balance inside the lysimeter. The result of the average of the three years is presented in Table 1. The ETc of wheat showed an increasing from the 20 day after sowing (DAS) to the 45 DAS and started to decline from 80 DAS to 100 DAS period (Figure 1). This implies that there was lesser and similar ET of the crop at the initial stage. In the development stage, there was an increase in ETc. During mid-season stage the ETc was almost constant as compared to the other stages. Finally, at the late-season stage the crop ET showed a decreasing trend, which resulted from leaf senescence and to the completion of grain formation and filling thereby limiting transpiration (Figure 1). The result in line with Allen *et al.*, 1998, that reported the crop water use declined in the late season stage, which was due to the cessation of leaf growth.

Table 1: Average ETc, ETo and Kc-values on decadal basis

Days after planting	ETc, mm/day	ETo, mm/day	Kc
10	26.1	48.3	0.54
20	26.1	48.3	0.54
30	38.8	45.1	0.67
40	38.8	45.1	0.90
50	46.8	46.3	1.12
60	54.7	47.6	1.15
70	54.7	47.6	1.15
80	54.7	47.6	1.15
90	36.6	54.6	0.94
100	36.6	54.6	0.67

The maximum water use was 191.5 mm at the mid-season stage followed by development stage was 97.1 mm. The minimum water use obtained from initial stage of 52.2 mm. Late-season of 73.2 mm hold the third in water use (Table 2). The ETc for the whole growth period of wheat varied from a minimum value of 390.8 mm to a maximum of 427.3 mm.

Naturally, crops need sufficient moisture for different physiological activities like metabolism of food. Over-watering severely limits (or even cuts off) the supply of oxygen that roots depends on to function properly, meaning that plants do not get adequate oxygen to survive. Furthermore, too much water can also lead to root rotting and the irreversible decay of roots. Though under watering leads to moisture stress in which the amount of water applied is not sufficient for potential grain yield production since food synthesis is reduced. Different crops display a

variety of physiological and biochemical responses to existing drought stress making complex phenomenon like reduced CO_2 assimilation mainly by stomata closure, membrane damage and disturbed activity of various enzymes, especially those of CO_2 fixation and adenosine triphosphate synthesis (Farooq *et al*., 2009).
Due to absence of actual data on wheat seasonal water requirement in the study area; FAO result was frequently used as representatives in the design and planning of irrigation systems. This leads to erroneous application of water use. Efficient use of water for irrigated agriculture is fundamental for agricultural production in arid and semi-arid areas that improves crop water productivity. In general, as water is scarce and becomes a critical resource for agriculture, supplying the right amount is essential for healthy plants and optimum productivity (Johnson *et al.*, 2005) and also important for effective irrigation water planning and management.

Table 2: Stage-wise average ETc, ETo, estimated and FAO Kc values of wheat

	Growth stage			
Parameters	Initial stage	Development stage	Mid-season	Late season
Growing length, day	20	25	35	20
ETc, mm	52.2	97.1	191.5	73.
ETo, mm/day	4.83	4.51	4.76	5.46
Estimated Kc	0.54	-	1.15	0.67
FAO (1986) Kc	0.3-0.4	-	1.05-1.2	0.65-0.75

Reference Evapotranspiration

The reference evapotranspiration values computed during the growing seasons of wheat for study area and are shown in Figure 1. The result of ETo during initial stage was higher than ETc and lower at mid stage, this implies that the ground cover of leaf shadow has a role in reducing the amount of water that evaporates from a bare soil. Similarly, Allen *et al.*, (1998) has also indicated that at initial stage nearly 100% of ET comes from evaporation, while crop full cover at the mid-season stage more than 90% of ET comes from transpiration.

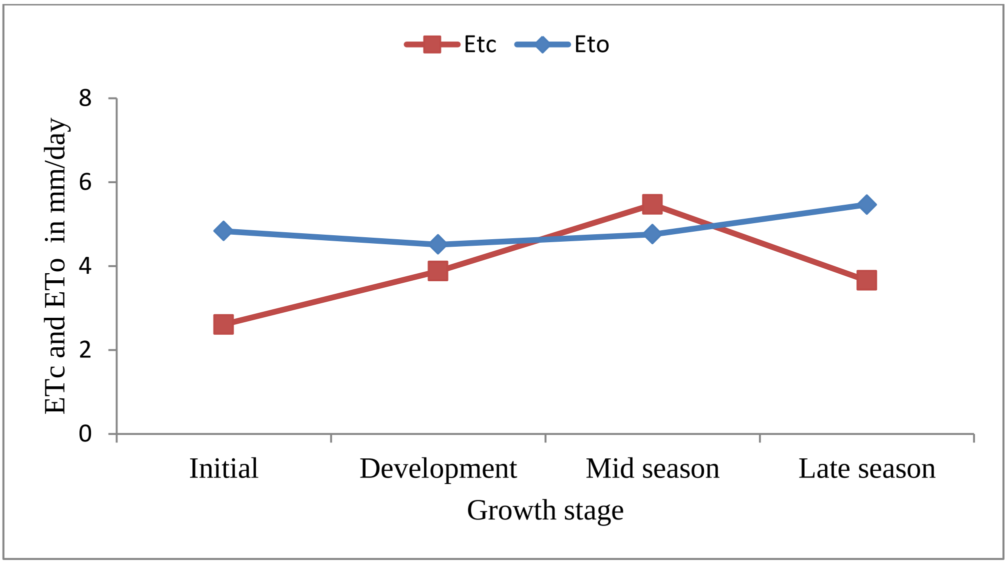

Figure 1: Water balance during the experiment

Seasonal Kc for Wheat

After determining ETo and ETc, Kc was obtained from the ratio ETc to ETo. The results of three year data show that there was a high variation in Kc values among growth stages. The Kc values changed from one stage to the other stage rapidly with the changes in crop development (Table 3). The Kc value ranged from 0.54 at the initial growth stage to 1.15 at the mid-season stage (Table 2).

Table 3: yearly CWR and Kc of wheat

Trial years	CWR and Kc	Growth stage			
		Initial stage	Development stage	Mid-season	Late season
year I (2016)	CWR	2.64	3.9	5.69	3.89
	Kc	0.49	-	1.16	0.66
Year II (2017)	CWR	2.73	3.9	4.98	3.22
	Kc	0.6	-	1.14	0.67
Year III (2018)	CWR	2.45	3.85	5.73	3.86
	Kc	0.54	-	1.16	0.68

The Kc value increased from the initial to the development stages while it reached its highest and relatively remained constant at the mid-season stage (Figure 2). The Kc declined rapidly during the late season stage. A higher Kc value was recorded from 45-80 days after planting as compared to the values at the beginning and end of the crop life cycle. The overall average Kc of wheat values for the initial, mid-season and late season growth stages were 0.54, 1.15 and 0.67 respectively. The initial value of Kc started to increase after 10% ground cover, reached a maximum during the mid-season stage and thereafter gradually declined. This could be explained by foliage senescence that restricted transpiration and caused a reduction in the crop coefficient.

Table 4: Agronomic and yield components of wheat recorded during experiment

Growth parameters	Plant Height (cm)	Spike Length (cm)	Number of tillers per square meter	Above ground biomass (kg/ha)	Grain yield (kg/ha)	Number of grains per spike
Obtained results	86.6	8.2	559.0	10897.1	4559.1	42.0

As indicated in Table 4, different crop data were observed from the study. The average plant and spike length obtained were 86.6 and 8.2 cm, respectively. The average obtained grain yield and above ground biomass yield from the study were 4559.1 and 10897.1 kg/ha, respectively. Also, the maximum number of tillers per square meter of 559.0 and number of grains per spike of 42.0 were obtained. Therefore, it could be concluded that supplying the right amount of crop water requirement is essential for healthy plants and potential production of wheat.

References

Allen R, Pereira L, Raes D, and Smith M. 1998. Crop evapotranspiration; guidelines for computing crop water requirements. Irrigation and Drainage Paper No. 56, FAO, Rome, Italy.

Bekele Hundie Kotu, Verkuijl H, Mwangi W and Tanner D. 2000. Adoption of improved wheat technologies in Adaba and Dodola Woredas of the Bale Highlands, Ethiopia. International Maize and Wheat Improvement Center (CIMMYT) and Ethiopian Agricultural Research Organization (EARO). Mexico.

Doorenbos J and Kassam AH. 1979. Yield Response to Water Irrigation and Drainage No. 33., FAO Rome, Italy.

Doorenbos J, and Pruitt WO. 1977. Crop water requirements. Irrigation and drainage paper No. 24. FAO, Rome, Italy.

FAO (Food and Agriculture Organization). 2011. The State of the world's land and water resources for food and agriculture. Managing systems at risk. FAO, Rome, Italy.

FAO (Food and Agricultural Organization). 2013. World food and agriculture statistical year book. FAO, Rome, Italy.

Farooq M, Wahid A, Kobayashi N, Fujita D and Basra SMA. 2009. Plant drought stress: effects, mechanisms and management. Agron. Sustain. Dev. 29: 185-212.

Johnson RS, Williams LE, Ayars JE and Trout TJ. 2005. Weighing lysimeters aid study of water relations in tree and vine crops. California Agriculture, v.59, p.133-136.