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Determination of Wheat (*Triticum Aestivum* L) Seasonal Water Demand and Crop Coefficient for Effective Irrigation Water Planning and Management in Semi-Arid, Central Rift Valley of Ethiopia

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Abstract

Estimating right amount of crop water requirement is the need for designing, establishing and managing irrigation projects, and scheduling irrigation. The objective of this study was to estimate the seasonal water demand and crop coefficient of wheat for effective irrigation water planning and management. Field experiment was carried out at Melkassa Agricultural Research Center, Ethiopia during wet growing season under lysimeter. Two non-weighing type lysimeters with the dimension of 1m × 2m area and 1m depth were used to determine the daily ETc of wheat crop. Crop coefficient (Kc) was determined for each growth stages as the ratio of ETc to ETo. The ETc was determined by soil water balance equation and ETo was computed by CROPWAT version 8.0 using the FAO Penman-Monteith equation. The seasonal ETc was found to be 52.2mm, 97.1mm, 191.5mm and 73.2mm of water calculated for initial, crop development, mid-season, and late-season stages, respectively. The measured crop coefficient (Kc) values were 0.54, 1.15 and 0.67 for the initial, mid and late stages, respectively. Some of the Kc values found in this experiment differed slightly from the average of FAO estimation. This indicates that there is a need to develop Kc values for given local climate conditions and cultivars. The maximum plant height and spike length obtained were 86.6 and 8.2cm, respectively. The maximum obtained grain yield and the above- ground biomass yield were 4559.1 and 10897.1kg/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 a finite resource used in different sectors like agriculture, domestic and industry. The competition for both quality and quantity of water is alarmingly increasing from time to time [1]. The rapid exponential increment of population growth worldwide in general and in developing countries is forcing the environment to produce more food and cash crop to feed and enhance economic development of the people. The main reason for increasing pressure on water resources are human activity like population growth, urbanization, increased living standards, growing competition for water, and pollution. These are aggravated by climate change and variations in natural conditions. However, the environmental resources like land and water are limited and even decreasing due to over exploitation, pollution and climate change [2].

Water is vital for crop production which its shortage has an influence on crop yields. Therefore, farmers have a tendency to over-irrigate than irrigating with some tolerable stress without due consideration for scarce water resources. These problems need optimization of water allocation based on water use efficiency (WUE) and enhancement of water productivity is essential similar to the aim of increasing crop yield.

In arid and semi-arid areas where moisture stress is the main challenge for crop production, the spatial and temporal variations exacerbate the problem. Different physical and biological measures are adopted to conserve moisture in the farm level. Moreover, design of irrigation schemes does not address the situation of moisture availability for crop and the competition between different sectors for these reason determinations of the right amount of crop water requirement and crop coefficient is needed.

Wheat (*Triticum aestivum* L.) is one of the important grain crops produced worldwide with larger area of cultivation than any other crop covering 217 million hectares with average yield of 3.00t/ha. Wheat is the largest deficit item in the developing country food basket. 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 [3].

Wheat is one of the major cereal food crops grown highly in Ethiopia, which ranks the country in second place from sub-Saharan Africa in terms of the total wheat area and production. Among cereals, wheat is the fourth most important crop in area coverage following teff, maize and sorghum holding 13.25% out of the total grain crops cultivation area in the country. Moreover, in amount of production volume, next to maize, teff and sorghum, wheat is the higher production volume from cereals production in the country with total production of 3,434,706 tons, which accounts around 14.85% from the total grain production during 2012/2013 production season [4]. The yield and production of wheat in Ethiopia also is increasing [5]. It is commonly grown in the highlands at altitudes ranging from 1500 to 3000masl. Major wheat production areas in the country are Arsi, Bale, Shewa, Ilubabor, Western Harerghe, Sidama, Tigray, Northern Gonder, and Gojam regions [6].

In Ethiopia due to improvements in seed supply, greater fertilizer applications and increase in extension support, wheat production is slightly increasing. However, only during 2012/13 marketing year, 984,000 metric tons of wheat imported from India, USA and Italy. Moreover, during 2013/14 marketing year, the Ethiopia Grain Trade Enterprise (EGTE), the government owned enterprise that controls all commercial wheat imports, planned to import 400,000 metric tons of wheat [7]. For these reason, expansion of irrigated wheat production area needed especially in arid and semiarid. Ethiopian wheat production for 2019/20 will reach a projected 4.6 million metric tons. This increase is in part due to a new governmental initiative to make the country wheat self-sufficient through supplying required inputs, development of irrigation schemes, promoting mechanization and extension support in semi-arid areas of the country. The wheat production estimate for 2018/19 reached 4.5 million metric tons, which is like the official USDA estimate. This is mainly due to good weather conditions, improved input supply, few pests and lower disease pressure. Most of the farmers in wheat growing belts started using mechanized farming systems, especially during harvest. In the past the country has usually imported 30 to 35 percent of the domestic wheat demand with no significant volumes of grain exports due to official export restriction on grains.

Therefore, determination of the crop water requirement and crop coefficient of wheat is important to utilize the limited water resources for agricultural water management, design of scheme and planning of different crop production with available water. The purpose of this study is to explore the amount of wheat seasonal water demand and crop coefficient in the rift valley area.

Materials and Methods

General description of the study area

The study was conducted at Melkassa Agricultural Research Center, Central Rift Valley of Ethiopia. It is geographically located between latitude of $8^0$24’ to $8^0$26’ N, longitude of $39^0$19’ to $39^0$19’ E and the mean altitude of the area is 1550m.a.s.l. The climate of the area is characterized as semi-arid with uni-modal low and erratic rainfall pattern with annual average of 824.9 mm. About 67.4% of the total rainfall of the area occurs from June to September. The mean maximum temperature varies from 26.3 to 31.0 ^{0}C while the mean minimum temperature varies from 10.4 to 16.4 ^{0}C.

Experimental setup

Two non-weighing lysimeters were located 100m away from the Meteorological Station of the Melkassa Agricultural Research Center was used for the study. The lysimeters used was rectangular in shape with 1m x 2m dimension. Its effective soil depth was 100cm with additional 100cm layers, 20cm rock, 20cm gravel and 20cm sand pack beneath which excess water from the upper soil was collected and discharged into the drainage collector placed in the working chamber through a drainage pipe. The lysimeters have chambers for aeration and drainage pipes connected to a water collecting tank and were placed in the working area beneath the lysimeter. The heights of 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 20cm above the soil surface so that no surface runoff water entered the lysimeters. One access tube for each lysimeter was installed at the center down to 100cm depth.

Test crop wheat

Kekeba, a bread wheat variety is a semi-dwarf, early maturing and widely cultivated in various parts of the country. It can grow in wide agro-ecology, ranging from altitude of 1500 to 2200masl. It was released by KARC of EIAR in 2010 and it is among the few wheat varieties grown in lowland area, as it is drought tolerant [8]. The seed of wheat Kekeba variety was sown by drilling manually in row after land is prepared well and pre irrigated, with seeding rate of 125kg/ha at mid-June of the three consecutive years

(2016, 2017 and 2018) in and out of the lysimeters in all directions to have identical and uniform environment as in normal fields and decrease adverse effects. Plots size of 1m x 2m with ridges spaced at 60cm. Seed was sown in double row on both side of the ridge with spacing of 20cm. The plots were fertilized with rate of 100kg/ha for both DAP and UREA but UREA was applied in split. The crop was harvested at the end of October.

Measurement of soil moisture and irrigation application

Soil samples were collected at interval of 15cm up to 100cm depth for determination of some soil physical properties like field capacity, permanent wilting point, bulk density and texture. Par-

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ticle size distribution was determined using the Bouyoucos hydrometer method. The water content at FC and PWP were determined by the pressure plate apparatus technique, whereas total available water (TAW) was obtained by subtracting PWP from FC. Bulk density was determined by taking undisturbed soil sample from the site using the core method [9]. The average FC and PWP of the soil depth profile were 31.8% and 15.3%, respectively. Thus, TAW at wheat root depth was 111.9mm. The obtained bulk density was 1.13g/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 15cm up to 60m soil depth of wheat root depth at different times during the growing season. Irrigation water was applied to the crop when there was 55% depletion of the available soil moisture within the crop root zone [10]. Similar irrigation amount at this depletion level was given to the crop in and outside the lysimeter to ensure uniform plant growth. The application of irrigation was carried out in known volume of water cans by converting the 55% depletion in terms of volume. Irrigation was terminated at crop maturity.

Determination of wheat water requirement and crop coefficient

Crop water requirement (ETc) and crop coefficient (Kc) for wheat was accurately determined using the lysimeters. Drainage (non-weighing) type lysimeters were installed near to meteorological station in the center. They were constructed of reinforced concrete and the inside was lined with a plastic sheet to avoid leakage or lateral inflow and outflow of water. The actual wheat ETc was determined using the water balance from lysimeters for the growth stage of the crop. The ETo was calculated using the daily weather data of the study area using CROPWATT version 8.0. However, the alternative procedure is to determine ETo from climatic data using the FAO Penman-monteith method once the necessary variables specific to the location are determined. In this study, daily ETo was calculated using FAO Penman-Monteith Equation [11] based on the actual daily climatic data collected at MARC, Agro-meteorological Service Department. The CROPWAT model calculates ETo based on the formula of FAO Penman-Monteith using equation 1.

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \text{......................}(1)$$

Where: ETo -reference evapotranspiration (mm/day), Rn -net radiation at the crop surface (MJ/m^2/day), G - soil heat flux density (MJ/m^2/day), T -mean daily air temperature at 2m height (^{0}C), u_2 -wind speed at 2m height (m/s), e_s -saturation vapour pressure (kPa), e_a -actual vapour pressure (kPa), e_s - e_a -saturation vapour pressure deficit (kPa), Δ -slope vapour pressure curve (kPa/^{0}C) and γ -psychrometric constant (kPa/^{0}C).

The crop evapotranspiration for each growth stage of the crop was calculated by using water balance equation 2

$$ETc = I + R - D + \Delta S \quad \text{....................} \quad (2)$$

Where ETc: crop evapotranspiration (mm), I: irrigation (mm), R: rain fall (mm), D: drainage collected (mm),

and ΔS: change in storage of soil moisture (mm). The crop coefficient value over a given period, such as physiological growth stage or whole season, was then calculated using equation 3

$$Kc = ETc / ETo \quad \text{................................}(3)$$

Where Kc: crop coefficient; ETc: crop evapotranspiration, and ETo: reference crop evapotranspiration.

Results and Discussion

Water is necessary for proper crop nourishment, when this water is not naturally available; irrigation makes it possible to compensate for water deficits. Even when the amount of rainfall is sufficient, its spatial and temporal distribution may not be as required. Both under watering and as well as over-watering leads to soil problems of root and turf diseases, nutritional deficiencies and reduced plant yields. To ensure success of the wheat production and the irrigation system monitoring, managing and maintaining the study was conducted.

Crop evapotranspiration (ETc)

The detailed crop water requirement (ETc) of wheat from water balance components obtained from lysimeter, values are presented in Table 1. Crop evapotranspiration (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. [11], that reported the crop water use declined in the late season stage, which was due to the cessation of leaf growth.

Table 1: Stage-wise average ETc, ETo, estimated and FAO Kc values of wheat kekeba variety.

Parameters	Growth stage			
	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

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Estimated Kc	0.54	-	1.15	0.67
FAO Kc	0.3	-	1.15	0.4

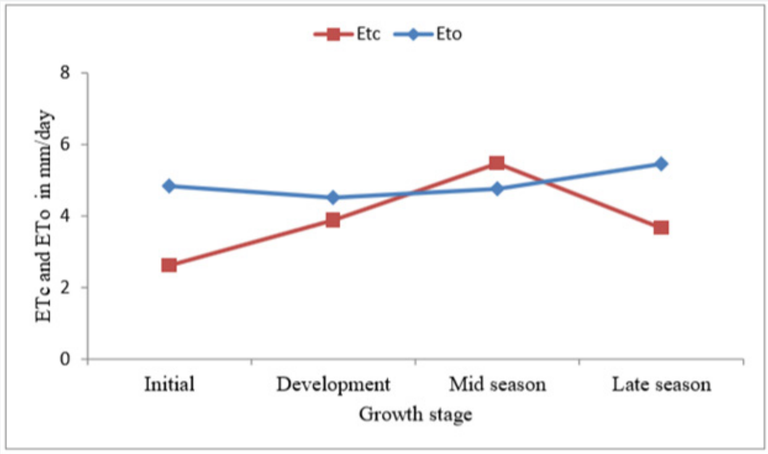

Figure 1: Water balance during the experiment.

The maximum water use was 191.5mm at the mid-season stage followed by development stage was 97.1mm. The minimum water use obtained from initial stage of 52.2mm. Late-season of 73.2mm hold the third in water use (Table 1). The ETc for the whole growth period of wheat varied from a minimum value of 390.8mm to a maximum of 427.3mm. The overall average was 413.7mm. Similarly, Charles [12] obtained that 427mm for wheat in central Arizona, but the result is significantly different from value obtained by FOA, which is reported as 550mm ETc.

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 [13].

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 [14] and also important for effective irrigation water planning and management.

Reference evapotranspiration

The meteorological data temperature, relative humidity, sunshine and wind speed were recorded from weather stations during growing seasons and using FAO Penman-Monteith equation 1, the reference evapotranspiration values calculated during the growing seasons of wheat for studied area and is 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. [11] 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.

Seasonal crop coefficient (Kc) for wheat

After determining ETo and ETc, Kc can be calculated using the appropriate crop coefficient formula by equation (3). 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 2). The Kc value ranged from 0.54 at the initial growth stage to 1.15 at the mid-season stage (Table 1). The curve presented in Figure 2 represents the changes in the Kc values over the length of the growing season of wheat. The shape of the curve represents the changes in the vegetation and ground cover during plant development and maturation that affect the ratio of ETc to ETo.

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 begin-

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ning 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% cover of the ground, 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 2: yearly CWR and Kc of wheat kekeba variety.

Trial Years	Growth stage				
	CWR and Kc	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

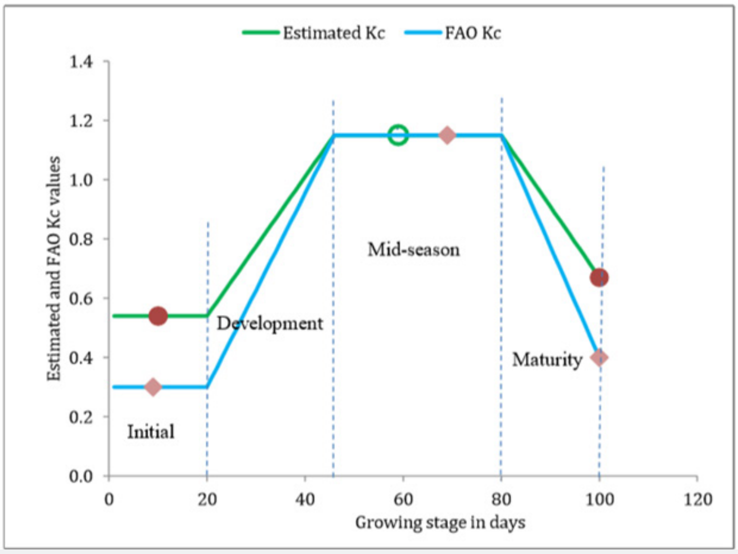

Figure 2: Estimated and FAO crop coefficient value for different growth stage of wheat.

Crop coefficient was collected from FAO Irrigation and Drainage Paper 56 [15] for wheat (spring wheat). The crop coefficient values for respective growth stages are 0.3, 1.15 and 0.4 for initial, mid and end, respectively. This result is different from the estimated Kc values of study area. Determining ETc and Kc of agricultural crops for at the location helps to have wise management of irrigation water, designing and managing irrigated projects and also helps researchers to appropriate irrigation scheduling, by using meteorological data ETo and local crop Kc value of the area.

As indicated in table different agronomic and yield data were observed from the study. The maximum plant and spike length obtained were 86.6 and 8.2cm, respectively. The maximum obtained grain yield and above ground biomass yield from the study were 4559.1 and 10897.1kg/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.

Conclusion

The ETc and Kc of wheat kekeba variety was evaluated for each growth stage under climatic condition of Melkassa and areas which have similar climatic conditions and soil characteristics. The finding showed that estimates of crop water requirement made with locally determined crop coefficients differ from estimates of FAO publications and others. This emphasizes a strong need for local calibration of Kc for each crop variety. The results of ETc and Kc reflected on crop variety, climate, location, and growing seasons. The Kc values obtained at the study site (Melkassa) could be applicable to areas with similar soil type, climate, growing seasons, and other agro-ecological conditions.

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References

1. Mexico. Biswas KA (1997) Water development and environment. In: Biswas AK (Ed.), Water resources: environmental planning, management, and development. Tata McGraw-Hill. New Delhi, India.
2. FAO (Food and Agriculture Organization) (2011) The State of the world's land and water resources for food and agriculture. Managing systems at risk.
3. FAO (Food and Agricultural Organization) (2013) World food and agriculture statistical yearbook. FAO, Rome, Italy.
4. CSA (Central Statistical Agency) (2013) Agricultural sample survey 2012/2013 (2005 E.C.) Report on area and production of major crops. Volume I.
5. Bezabeh E, Haregewoin T, Hailegiorgis D, Daniel F, Belay B (2015) Change and growth rate analysis in area, yield and production of wheat in Ethiopia. Research Journal of Agriculture and Environmental Management 4(4): 189-191.
6. Kotu BH, Verkuijl H, Mwangi W, 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).
7. Tefera A, Tefera T (2014) Ethiopia grain and feed annual report. In: Quintin G (Ed.), Global agricultural Information Network. USDA Foreign Agricultural Service.
8. ICARDA (International Center for Agricultural Research in the Dry Areas) (2010) Ethiopia and ICARDA. Ties that bind. No. 29. ICARDA, Aleppo, Syria.
9. Ryan J, Estefan G, Rashid A (2001) Soil and Plant Analysis Laboratory Manual. (2nd ed), International Center for Agricultural Research in the Dry Areas (ICARDA) and the National Agricultural Research Center (NARC), Aleppo, Syria.
10. Doorenbos J, Kassam AH (1979) FAO (Food and Agriculture Organization) Irrigation and Drainage No. 33. Yield Response to Water, Rome, Italy.
11. Allen R, Pereira L, Raes D, Smith M (1998) Crop evapotranspiration; guidelines for computing crop water requirements. Food and Agricultural Organization, Irrigation and Drainage Paper No. 56, Rome, Italy.
12. Charles AS, Paul B (2009) Determination of Evapotranspiration ET for Desert Durum Wheat using Weighing Lysimeters in the Lower Colorado River, Region Yuma Agricultural Center. Department of Soil Water and Environmental Sciences. The University of Arizona. Tucson. AZ.
13. Farooq M, Wahid A, Kobayashi N, Fujita D, Basra SMA (2009) Plant drought stress: effects, mechanisms and management. Agron Sustain Dev 29(1): 185-212.
14. Johnson RS, Williams LE, Ayars JE, Trout TJ (2005) Weighing lysimeters aid study of water relations in tree and vine crops. California Agriculture 59(2): 133-136.
15. FAO (Food and Agriculture Organization of the United Nations) (1998) Crop evapotranspiration guidelines for computing crop water requirements. Irrigation and Drainage Paper 56. FAO, Rome.

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