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Determination of wheat (*Triticum aestivum* L.) seasonal water demand and crop coefficient for effective irrigation water planning and management at Harrai village in Prayagraj

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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 Harrai village, Prayagraj during wet growing season. Crop coefficient (Kc) was determined for each growth stages as the ratio of ETc to ETo. The ETc and ETo were computed by CROPWAT version 8.0 using the FAO Penman-Monteith equation. The seasonal ETc was found to be 14.1 mm, 48.3 mm, 136.8 mm, and 77.5 mm of water calculated for initial, crop development, mid-season, and late-season stages, respectively. The measured crop coefficient (Kc) values were 0.3, 0.52, 1.14 and 0.68 for the initial, development, 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 97.3 cm and 7.9 cm, respectively. The maximum obtained grain yield and the above- ground biomass yield were 5487.61 and 8780.18 kg/ha, respectively.

Keywords: Crop coefficient, crop water requirement, cropwat, evapotranspiration, 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 (Mexico. Biswas KA 1997) [13]. 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 (FAO, 2011) [8].

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 (FAO, 2013) [6].

Wheat is one of the major cereal food crops grown highly in India, which ranks the Country in second place in terms of the total wheat area and production. Among cereals, wheat is the second most important crop in area coverage following Rice, Wheat, Millets, Maize and Pulses. Moreover, in amount of production volume, next to Rice, wheat is the higher production volume from cereals production in the country with total production of 99.70 million tons, rice 112.91 million tonnes and pulses at 25.23 million tonnes for the 2017-18 crop year production season (CSA, 2013) [4]. The yield and production of wheat in India also is increasing (Bezabeh E. *et al*. 2015) [2]. Major wheat production areas in the country are Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan, Bihar and Gujarat regions.

In India due to improvements in seed supply, greater fertilizer applications and increase in extension support, wheat production is slightly increasing. However, only during 2017/18 marketing year, 42.8 million metric tons of wheat imported from India, USA and Italy. For this reason, expansion of irrigated wheat production area needed especially in arid and semiarid. Indian wheat production for 2018-19 will reach a projected 103.60 million tonnes. 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 3.73 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 25 to 28 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 Harrai watershed, Prayagraj, Uttar Pradesh, India. It is geographically located between latitude of 81.96241 to 81.98128 N, longitude of 25.28055 to 25.2876 E and the mean altitude of the area is 261 ft to 290 ft. above M.S.L. The climate of the area is characterized as semi-arid with erratic rainfall pattern with annual average of 896 mm. About 14% in June and September receive 21% of south west monsoon rainfall, respectively. The mean maximum temperature varies from 28.7 to 47.5 ^{0}C while the mean minimum temperature varies from 7.4 to 18.3 ^{0}C.

Determination of wheat water requirement and crop coefficient

Crop water requirement (ETc), Reference Evapotranspiration (ETo) and crop coefficient (Kc) for wheat was accurately determined using the CROPWAT by the daily weather data of the study area. 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 (Allen R. *et al*.1998) [1] based on the actual daily climatic data collected at Meteorological Department SHUATS, Prayagraj, The CROPWAT model calculates ETo based on the formula of FAO Penman-Monteith using equation 1.

$$ETo = \frac{0.408 \, x \, \Delta \, x \, (R_n - G) + \gamma \, x \left(\frac{900}{T+273}\right) x \, U_2 \, (e_s - e_a)}{\Delta + \gamma \, (1 + 0.34 U_2)} \quad (1)$$

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), es -saturation vapour pressure (kPa), ea -actual vapour pressure (kPa), es - ea -saturation vapour pressure deficit (kPa), Δ -slope vapour pressure curve (kPa/^{0}C) and γ - psychrometric constant (kPa/^{0}C).

The crop coefficient value over a given period, such as physiological growth stage or whole season, was then calculated using equation 2.

$$Kc = \frac{ETc}{ETo} \quad (2)$$

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 Cropwat, values are presented in Table 1. Crop evapotranspiration (ETc) of wheat showed an increasing from the 45 days after sowing (DAS) to the 116 DAS and started to decline from 120 DAS to 130 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*., 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.

Parameters	Growth stage			
	Initial Stage	Development Stage	Mid-Season	Late Season
Growing length, day	20	25	35	20
ETc, mm	14.1	48.3	136.8	77.5
ETo, mm	45.71	63.03	120.13	116.46
Estimated Kc	0.3	0.52	1.14	0.68
FAO Kc	0.3	-	1.15	0.4

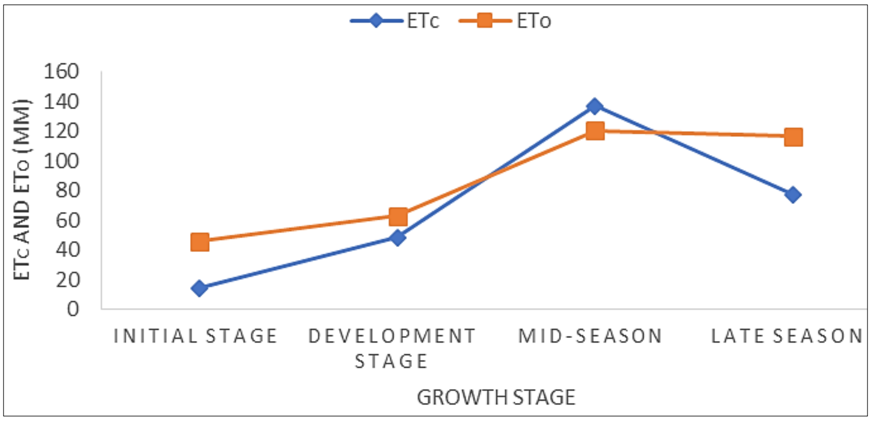

Fig 1: Water balance during the experiment.

The maximum water use was 136.8 mm at the mid-season stage followed by development stage was 48.3 mm. The minimum water use obtained from initial stage of 14.1 mm. Late-season of 77.5 mm hold the second in water use (Table 1). The ETc for the whole growth period of wheat to 276.4 mm. The overall average was 18.42 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 depend 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 M. *et al*.2009) [9].

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 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 R.S. *et al*. 2005) [11] 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*. 1998) [1] 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 0.3 at the initial growth stage to 1.14 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 71-115 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, development, mid-season and late season growth stages were 0.3, 0.52, 1.14 and 0.68 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: Seasonally CWR and Kc of wheat variety.

Trial Years	Growth stage				
	CWR and Kc	Initial Stage	Development Stage	Mid-Season	Late Season
Year I (2017-18)	CWR	14.1	48.3	136.8	77.5
	Kc	0.3	0.52	1.14	0.68
Year II (2018-19)	CWR	14.9	46.8	133	76.3
	Kc	0.3	0.52	1.13	0.38

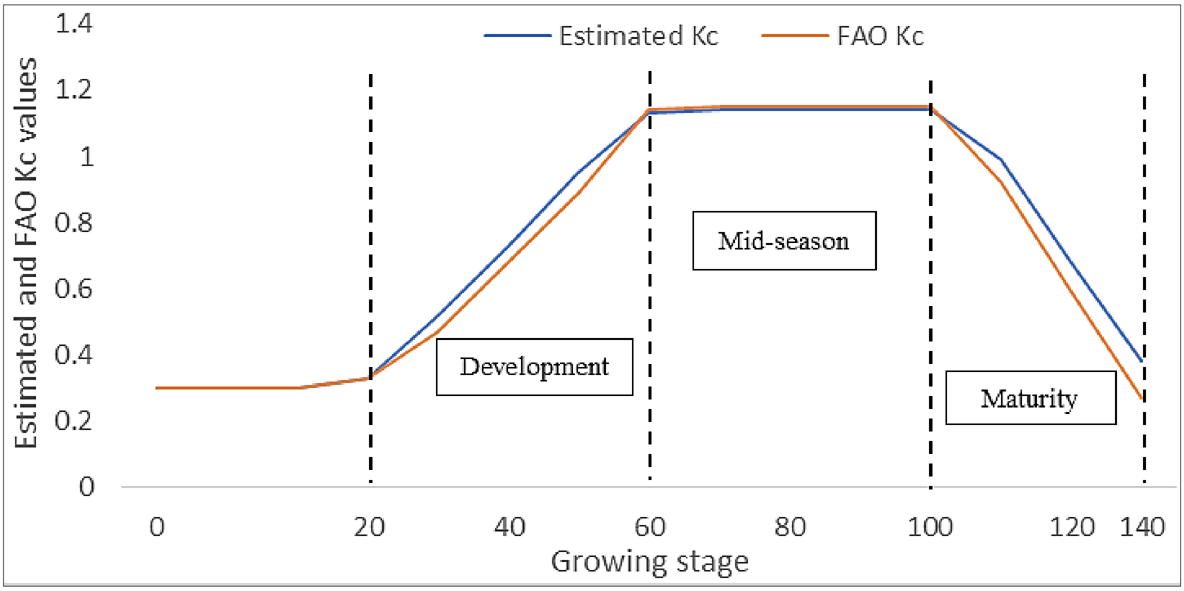

Fig 2: Estimated and FAO crop coefficient value for different growth stage of wheat.

Crop coefficient was collected from FAO Irrigation and Drainage Paper 56 (FAO.1998) [7] 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 an agronomic and yield data were observed from the study. The maximum plant and spike length obtained were 97.3 and 7.9 cm, respectively. The maximum obtained grain yield and above ground biomass yield from the study were 5487.61 and 8780.18 kg/ha, respectively. Also, the maximum number of tillers per square meter of 467.0 and number of grains per spike of 63.0 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 was evaluated for each growth stage under climatic condition of Allahabad 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 wheat crop. The results of ETc and Kc reflected on crop, climate, location, and growing seasons. The Kc values obtained at the study site (Allahabad) could be applicable to areas with similar soil type, climate, growing seasons, and other Agro-ecological conditions.

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