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Crop Water Requirement using Single and Dual Crop Coefficient Approach

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Abstract: The determination of crop coefficients and reference crop evapotranspiration are important for estimating irrigation water requirements of any crop in order to have better irrigation scheduling and water management. The purpose of this study is to determine the crop water requirement of cauliflower, using single and dual crop coefficient approach using FAO-56 Penman–Monteith Method. Meteorological data like maximum temperature, minimum temperature, relative humidity, sunshine hours and wind speed for Vadodara region are used to determine Reference crop evapotranspiration. Crop Coefficient (Kc) can be utilized as single Kc which is influenced by moderate effect of evaporation and transpiration together. Dual Kc is expressed by soil evaporation coefficient (Ke) and basal crop coefficient (Kcb), separately. Kc values for all growth stages are determined using both approaches. Micro irrigation systems are used to irrigate the fields. Cauliflower water requirements (ETc) are 256 mm and 237 mm for single and dual crop coefficient approach, respectively during the growing season. The study reveals that maximum differences between ETc of single and dual Kc values were observed at initial stage. The dual crop coefficient approach is more precise and it is best for real time irrigation scheduling, for soil water balance computations, and for research studies where effects of every day variations in soil surface wetness and the resulting impacts on daily ETc and the soil water profile are important. Dual crop coefficient approach is best suited for high frequency irrigation systems like micro irrigation systems. These results can be useful for agricultural planning and efficient management of irrigation for cultivation of cauliflower.

Keywords: Crop Water Requirement, Cauliflower, Dual crop coefficient, Irrigation Scheduling, Single Crop Coefficient

I. INTRODUCTION

Determination of crop evapotranspiration by direct methods are expensive and difficult, and almost all direct methods are impractical for permanent use on a large scale, so evapotranspiration is commonly estimated by developed empirical methods. Food and Agriculture Organization proposed Penman–Monteith method to determine reference evapotranspiration (ETo) for irrigation scheduling. Compared with other common methods, Penman–Monteith method has been widely used because it gives satisfactory results under many climate conditions across the world.

Actual crop evapotranspiration (ETc) is calculated by multiplying the reference evapotranspiration by a crop coefficient. Single and/or dual crop coefficient approaches are used to estimate crop evapotranspiration. Single crop coefficient is used for irrigation planning and design, irrigation management, basic and real-time irrigation scheduling of less frequent water applications whereas dual crop coefficient is mainly used in research and for real time irrigation scheduling, irrigation scheduling of high frequent water application such as daily irrigation, supplementary irrigation and detailed soil and hydrologic water balance studies, Doorenbos and Kassam (1979) and Jensen et al. (1990) have reported crop coefficients for many crops. These values are commonly used in places where the local data are not available. Allen et al. (1998) have suggested that the crop coefficient values should be derived empirically for each crop based on lysimeteric data and local climatic conditions because the crop coefficients depend on climate conditions, soil properties, the particular crop and its varieties, irrigation methods and so on.

Kc can be utilized as single Kc which is influenced by moderate effect of evaporation and transpiration together (Allen, 2000). Dual Kc is expressed by soil evaporation coefficient (Ke) and crop base coefficient (Kcb), separately (FAO-56). According to Allen (2000), using single crop coefficient is simpler. Furthermore, Suleiman et al. (2007) reported that using single Kc for cotton crop estimation in humid regions is reasonable. These researchers suggested Kc can be used in all weather conditions where no experimental data are available. According to Allen et al. (2005) nonconformity of crop and climate characteristics are engendered to inconclusiveness in Kc and ET reluctant in any place in the world. Although, in estimation of crop water requirement, suggested coefficients were used, but there are differences in amount and calculation methods of Kc between various crops. With measurement of melon evapotranspiration, Lovelli et al. (2005) showed that the experimental Kc was less than the Kc suggested by FAO-56.
The main objectives of this study were:
(1) Determining the water requirement of cauliflower and
(2) Determining (single & dual) crop coefficient of cauliflower.

II. MATERIALS AND METHODS

For better crop production, water should be applied as per crop evapotranspiration of the crop. Estimation of crop evapotranspiration is essential for efficient planning and proper management of irrigation water. The crop evapotranspiration estimates require specific values of crop coefficient for a particular crop. The values of crop coefficient vary mainly with the crop characteristics, irrigation method, crop planting date, rate of crop development, length of growing season, and prevailing climatic conditions.
The study area, Training cum Demonstration Farm, Water Resources Engineering Management Institute, Samiala, Dist. Vadodara, Gujarat, India lies at latitude 73.12˚ N and longitude 22.25˚ E. Cauliflower (Brassica Oleraces L.) variety Vishnu is selected as a crop having crop period of 90 days and is irrigated by micro irrigation system. Daily observed data for maximum temperature, minimum temperature, dry bulb temperature, wet bulb temperature, sunshine hours, wind velocity and relative humidity are collected. Soil Analysis viz. soil type field capacity and permanent wilting point, infiltration rate, pH, electric conductivity is determined.

Reference Crop Evapotranspiration

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sm-1 and an albedo of 0.23. The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground. The fixed surface resistance of 70 sm-1 implies a moderately dry soil surface resulting from about a weekly irrigation frequency. The concept of ETo was introduced to study the evaporation demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiration surface, soil factors do not affect ETo. The only factor affecting ETo is climatic parameters and can be computed from meteorological data.
The Committee on Irrigation Water Requirements of the American Society of Civil Engineers (ASCE) recommended the FAO Penman-Monteith method as the sole standard method for the computation of reference crop evapotranspiration, ETo as it can be used for wide range of locations and climates.
The FAO Penman-Monteith equation is used for computation of daily ETo.

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$$ETo = \frac{0.408\,\Delta\,(Rn - G) + \gamma\,\frac{900}{T+273}\,u2\,(es - ea)}{\Delta + \gamma\,(1 + 0.34\,u2)} \quad (1)$$

In which,
ETo - Reference evapotranspiration, mm/day,
Rn - Net radiation at the crop surface , MJ/ m2 /day
G - Soil heat flux density , MJ /m2/ day
T - Mean daily air temperature at 2 m height, °C
u2 - Wind speed at 2 m 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 / °C
γ - Psychrometric constant, kPa / °C

Decision Support System for Estimating Reference Evapotranspiration (DSS_ET Model version 3.0) software is used to calculate reference crop evapotranspiration.

Crop Water Requirement by Dual Crop Coefficient Approach

Crop water requirement is determined as per the "Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56".

The calculation procedure for crop water requirement ETc, consists of:

a. Identifying the lengths of crop growth stages, and selecting the corresponding basal crop coefficient, Kcb
b. Adjusting the selected Kcb coefficients for climatic conditions during each stage
c. Constructing the basal crop coefficient curve
d. Determining daily Ke values for surface evaporation and calculating evapotranspiration of crop, ETc as the product of ETo and (Kcb + Ke).

Dual crop coefficient (Kcb + Ke)

The dual coefficient approach,given by Allen et al. (1998) requires more numerical calculations than the procedure using the single time-averaged Kc coefficient. The dual procedure is best for real time irrigation scheduling, for soil water balance computations and for research studies where effects of day-to-day variations in soil surface wetness, the resulting impacts on daily ETc, the soil water profile & deep percolation fluxes are important. This is the case for high frequency irrigation with micro irrigation systems. In the dual crop coefficient approach, the effects of crop transpiration and soil evaporation are determined separately. The process consists of splitting Kc into two separate coefficients, one for crop transpiration, i.e., the basal crop coefficient (Kcb), and one for soil evaporation (Ke).

The basal crop coefficient (Kcb) is defined as the ratio of the crop evapotranspiration over the reference evapotranspiration (ETc/ETo) when the soil surface is dry but transpiration is occurring at a potential rate, Therefore, 'Kcb ETo' represents primarily the transpiration component of ETc. The 'Kcb ETo' does include a residual diffusive evaporation component supplied by soil water below the dry surface and by soil water from beneath dense vegetation.

$$Kcb = Kcb\,(Tab) + [0.04(u2-2) - 0.004(RHmin - 45)](h/3)^{0.3} \quad (2)$$

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Kcb (Tab) - Value for Kcb mid or Kcb end (if RHmin $\geqslant$ 45 %) taken from FAO 56

u2 - Mean value for daily wind speed at 2 m height over grass during the mid or late season growth stage for 1 m /s $\leq$ u2 $\leq$ 6 m / s

RHmin - Mean value for daily minimum relative humidity during the mid- or late season growth stage, % for 20% $\leq$ RHmin $\leq$ 80%

h - Mean plant height during the mid or late season stage, m for 20% $\leq$ RHmin $\leq$ 80%

When the potential energy of the soil water drops below a threshold value, the crop is said to be water stressed. The effects of soil water stress are described by multiplying the basal crop coefficient by the water stress coefficient, Ks. In this study irrigation scheduling is carried out in such a way that there is no soil water stress. i.e. Ks =1 for entire crop period.

Evaporation component (Ke ETo)

The soil evaporation coefficient, Ke, describes the evaporation component of ETc. When the topsoil is wet, following rain or irrigation, Ke is maximum. When the soil surface is dry, Ke is small and even zero when no water remains near the soil surface for evaporation.
When the soil is wet, evaporation from the soil occurs at the maximum rate. The crop coefficient (Kc = Kcb + Ke) can never exceed a maximum value, Kc max. This value is determined by the energy available for evapotranspiration at the soil surface When the topsoil dries out, less water is available for evaporation and a reduction in evaporation begins to occur in proportion to the amount of water remaining in the surface soil layer.

Crop Water Requirement by Single Crop Coefficient Approach

The calculation procedure for crop water requirement ETc, consists of:

a. Identifying the lengths of crop growth stages, and selecting the corresponding Kcini, Kc mid and Kc end from FAO 56.
b. Adjusting the selected Kcini to reflect wetting frequency of soil surface and irrigation system.
c. Adjust, Kc mid and Kc end to local climatic conditions.
d. Constructing crop coefficient curve.
e. Determining daily ETc as the product of ETo and Kc value of each day.

III. RESULTS AND DISCUSSION

Table 1 shows basal crop coefficients for dual crop coefficient approach and Kc values for single crop coefficient approach for various growth stages of cauliflower. Figure 1 shows variation of Kcb, Kc dual, Kc single and Ke with respect to crop period for cauliflower and Figure 2 depicts variation of ETo and ETc for single crop coefficient and dual crop coefficient with respect to crop period for cauliflower.

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Table 1: Basal Crop Coefficient Kcb for dual crop coefficient and single crop coefficient for various crop growth stages for Cauliflower

Growth stages	Period, days	RHmin, %	Basal crop coefficient, Kcb for dual crop coefficient	Single crop coefficient
Initial	20	47.55	0.15	0.58
Development	35	46.62	0.55	0.82
Mid	25	50.20	0.95	1.05
Late	10	54.83	0.85	0.95

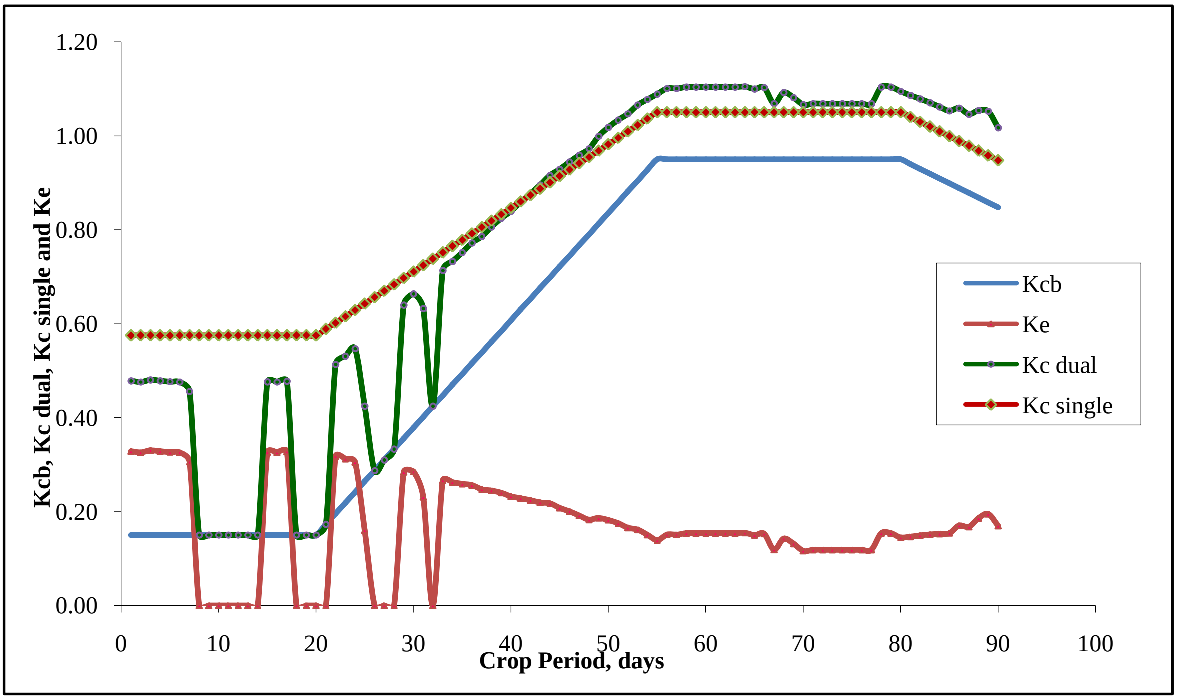

Fig. 1 Variation of Kcb, Kc dual, Kc single and Ke with respect to crop period for cauliflower

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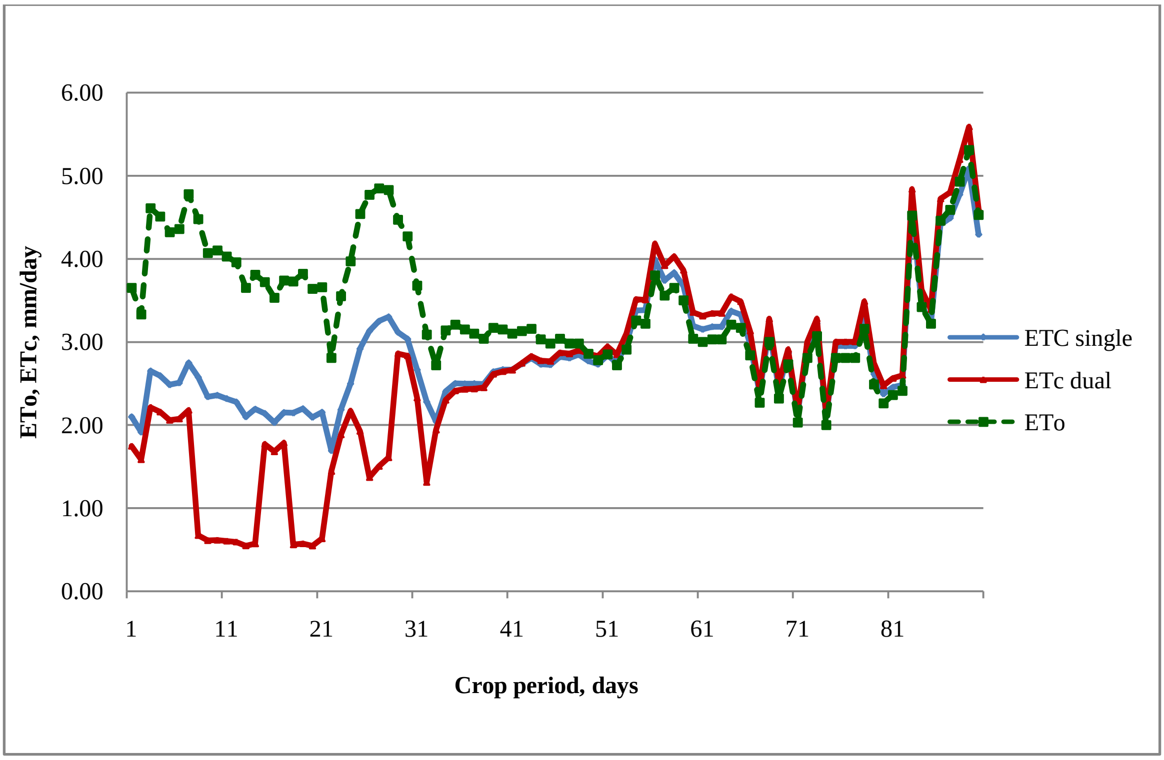

Fig. 2 Variation of ETo and ETc for single crop coefficient & dual crop coefficient with respect to crop period for cauliflower

From Table 1 and Fig.1 it is observed that Kc value for single crop coefficient is higher than Kc dual. In initial period Kc value varies with frequency of irrigation. During the initial period, the leaf area is small, and evapotranspiration is predominately in the form of soil evaporation. Therefore, the Kc during the initial period (Kc ini) is large when the soil is wet from irrigation and rainfall and is low when the soil surface is dry. The time for the soil surface to dry is determined by the time interval between wetting events, the evaporation power of the atmosphere (ETo) and the importance of the wetting event.

For this study micro irrigation system is used and frequency of wetting is one or two days. Cauliflower water requirements (ETc) determined were 256 mm and 237 mm for single and dual crop coefficient approach, respectively during the growing season. From Fig.2 it reveals that maximum differences between ETc of single and dual values were observed at initial stage. At mid season and late season stage, ETc for both the approaches is very close. From this study it is observed that process of evapotranspiration during initial stage can be well expressed by dual crop coefficient approach and crop water requirement can by estimated precisely by this approach.

IV. CONCLUSION

- Cauliflower water requirements (ETc) determined are 256 mm and 231 mm for single and dual crop coefficient approach, respectively during the growing season.

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- The dual coefficient approach requires more numerical calculations than the procedure using the single time-averaged Kc coefficient.
- The dual crop coefficient approach is best for real time irrigation scheduling, for soil water balance computations, and for research studies where effects of every day variations in soil surface wetness and the resulting impacts on daily ETc and the soil water profile are important.
- Dual crop coefficient approach is best suited for high frequency irrigation with micro irrigation systems.
- Also, this study reveals that dual crop coefficient is more precise but the advantage of single crop coefficient is simpler for a user.
- These results can be useful for agricultural planning and efficient management of irrigation for cultivation of cauliflower.

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Dr. Parekh is Life Member of various professional bodies like Indian Society of Hydraulics, Indian Water Resources Society, Association of Hydrologists of India and Association of Agrometeorologists and Indian Society of Geomatics. She is chairman of Board of studies of WREMI and member of Faculty Board of Tech. & Engg. She is also joint secretary of Gujarat Chapter of Association of Hydrologists of India. She Worked as Principal Investigator for Research Project funded by Gujarat Council on Science and Technology and completed five institutional consultancy projects. She is recipient of “Prof. S.C. Puranik Young Scientist Award” for the award winning paper in 2004 by Association of Hydrologist of India. She has published 28 Research Papers in various International/ National Journals/ Conferences.