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Reference evapotranspiration (ETo) and crop water requirement (ETc) of wheat and maize in Gujarat

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ABSTRACT

The reference evapotranspiration (ETo) is an important agrometeorological parameter which has been used in a number of applications. In present study daily ETo was determined for 16 stations of Gujarat having long period (10-20 years) weather data following P-M approach. The Kc values for maize and wheat as given in FAO-56 was used in which Kc_{mid} and Kc_{end} were corrected for climatic conditions of stations. The corrected Kc values were used to calculate the daily crop water requirement (ETc) for wheat and rabi maize crops grown at different locations of Gujarat. The results revealed that during winter season (Nov. 15 to March 13) the mean daily (ETo) varies from 4.2 to 7.6 mm day-1. However the large variation in ETo across the locations (2.9 to 9.8 mm day^{-1}) was observed, the lowest being at Khedbrahma and highest being at Targadia. The correction applied in Kc_{mid} and Kc_{end} suggested that at most of the stations Kc_{mid} and Kc_{end} for wheat crop were higher than that of FAO values while the corrected Kc values for maize were found to be less than that given by FAO. The mean water requirement (ETc) of wheat during its initial stage was found to be lower and almost constant and it increased continuously during developmental stage (from 1.9 to 5.2 mm day^{-1}) and during the mid season stage (from 5.6 to 7.5 mm day^{-1}) and decreased during the late-season stage (from 7.3 to 3.6 mm day^{-1}). The seasonal water requirement across the locations varies between 400.5 mm (Khedbrahma) to 684.0 mm (Arnej). The mean water requirement of maize during initial stage is 1.3 mm day^{-1}, during developmental stage 1.4 to 5.0 mm day^{-1}, during the mid season stage ETc varies between 5.0 to 6.6 mm day^{-1} and during late-season stage it decreases from 6.4 to 2.5 mm day^{-1} . The seasonal water requirement of rabi maize varies between 330.7 mm (Khedbrahma) to 520.5 mm (Bharuch).

Keywords: FAO Penman-Monteith method, Reference evapotranspiration (ETo), Crop evapotranspiration (ETc), crop coefficient (Kc), wheat, maize.

Water is one of the most essential natural resource which plays a vital role in maintaining biodiversity, our health, social welfare and our economic development (Donald, 1968). In planning and management of available water resources for agricultural sector, the defining strategies become a national and global priority. The reference evapotranspiration (ETo) is defined as the loss of water to the atmosphere by evaporation and transpiration from an extended surface of 8-12 cm tall green grass cover, usually a well-watered, actively growing and completely shading the ground. By applying a crop coefficient (Kc) values, this ETo can be used to estimate the crop evapotranspiration (ETc), (Doorenbos and Pruitt, 1975). Tyagi *et al.* (2000) developed crop coefficients for wheat and maize from ETc measurements and weather data in Karnal.

The adoption of exact or correct amount of water and correct timing of application is very essential for scheduling irrigations to meet the crop's water use demands and for optimum crop production. Estimation of crop water requirements (ETc) is one of the main components used in irrigation planning, design and operation (Rowshon *et al.*, 2013). Jensen *et al.* (1990), provided detailed reviews of the methods commonly used to determine evapotranspiration and estimated crop water requirements.

In this paper attempt has been made to determine reference evapotranspiration (ETo), correct value of crop coefficient (Kc) and the crop water requirement (ETc) of wheat and maize of Gujarat using long period weather data of different stations of Gujarat.

MATERIALS AND METHODS

Geographically Gujarat state is located between latitude 20°01' N and 24°01' N and longitude 68°04' E and

74o 04' E. It is the westernmost state of India. For present study sixteen stations of Gujarat were selected (Table 1). The daily weather data (maximum temperature, minimum temperature, morning relative humidity, afternoon relative humidity, sunshine hour and wind speed) were obtained from Agromet data bank, Department of Agricultural Meteorology, Anand Agricultural University, Anand.

Estimation of reference evapotranspiration (ETo)

Penman-Monteith method as given in FAO-56 (Allen *et al.,* 1998) was used for computation of reference evapotranspiration (ETo). Each parameter required for calculation of ETo was derived/calculated using programme developed in MS excel sheet. The details of procedure adopted for calculation are described hereunder.

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where, ETo is reference evapotranspiration (mm day^{-1}), Rn is net radiation at the crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), Ta is mean daily air temperature (°C), u_2 is wind speed at 2 m height (m s^{-1}), es is saturation vapor pressure (kPa), ea is actual vapor pressure (kPa), es - ea is saturation vapor pressure deficit (kPa), Δ is slope saturation vapor pressure curve (kPa°C^{-1}) and γ is psychrometric constant (kPa°C^{-1}).

The six weather parameters (Tmax, Tmin, RHmax, RHmin, n and u_2), altitudes and latitudes were used to compute each parameter required for FAO Penman-Monteith model, through programme developed in MS Excel. Firstly, wind speed was converted for height (3m to 2m) and unit (km h^{-1} to m s^{-1}), thereafter pressure was adjusted for altitude of concerned locations. The equations for computing each parameter are given here below:

The saturation vapor pressure (e_s) derived from air temperature and actual vapor pressure (e_a) derived from relative humidity.

Slope of saturation vapor pressure (Δ)

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27 * T_a}{T_a + 237.3}\right)\right]}{(T_a + 237.3)^2}$$

Where, Δ is slope of saturation vapor pressure (kPa°C^{-1}), Ta is mean daily air temperature (ºC) and exp is base of natural logarithm (2.7183).

Psychrometric constant (γ)

$$\gamma = \frac{C_p * P}{\varepsilon\,\lambda} = 0.665 * 10\text{-}3\ P$$

Where, γ is psychrometric constant (kPa °C^{-1}), Cp is specific heat at constant pressure = 1.013 x 10-3 (MJ kg^{-1} °C^{-1}), P is atmospheric pressure (kPa), e is ratio molecular weight of water vapour/dry air = 0.622 and λ is latent heat of vaporization = 2.45 MJ kg^{-1} (at 20°C).

For the computation of radiation term for each day of year and for different latitude was estimated from the solar constant, the solar declination and the time of the year.

Extraterrestrial radiation (Ra)

$$R_a = \frac{24(60)}{\pi} G_{sc} * d_r [\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)]$$

Where, Ra is extraterrestrial radiation (MJ m^{-2} day^{-1}), Gsc is solar constant (0.0820 MJ m^{-2} min^{-1}), dr is inverse relative distance Earth-Sun (radian), ω_s is sunset hour angle (radian), ϕ is latitude (radian) and δ is solar declination (radian).

Solar radiation/Short wave radiation (Rs)

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a$$

Where, Rs is solar or shortwave radiation (MJ m^{-2} day^{-1}), n is actual duration of sunshine (hours), N is maximum possible duration of sunshine or daylight hours (hour) and $a_s + b_s$ fraction of extraterrestrial radiation reaching the earth on clear days (n = N).

Inverse relative distance earth-sun (dr)

$$d_r = 1 + 0.033 \cos\left[\frac{2\pi}{365} J\right]$$

Solar declination (δ)

$$\delta = 0.409 \sin\left[\frac{2\pi}{365} J - 1.39\right]$$

Where, J is Julian day/Number of the day in the year

Sunset hour angle (ωs)

$$\omega_s = \arccos[-\tan(\varphi)\tan(\delta)]$$

Where, φ is latitude (radian) and d is solar declination (radian).

Daylight hours (N)

The daylight hours/maximum possible duration of sunshine N, was calculated by:

$$N = \frac{24}{\pi}\omega_s$$

Where, ωs is sunset hour angle (radian) and N is maximum possible duration of sunshine or daylight hours (hour).

Clear-sky solar radiation (R_{so})

$$R_{so} = (a_s+b_s)\, Ra$$

Where, R_{so} is clear-sky solar radiation (MJ m^{-2} day^{-1}).

Net solar or net shortwave radiation (R_{ns})

The net shortwave radiation resulting from the balance between incoming and reflected solar radiation was computed as:

$$Rns = (1\text{-}a)\, Rs$$

Where, R_{ns} is net solar or shortwave radiation (MJ m^{-2} day^{-1}), a is albedo or canopy reflection coefficient (0.23 for the hypothetical grass reference crop), (dimensionless) and Rs is incoming solar radiation (MJ m^{-2} day^{-1}).

Net long wave radiation (R_{nl})

$$R_{nl} = \sigma\left[\frac{(T_{max,K})^4 + (T_{min,K})^4}{2}\right](0.34 - 0.14\sqrt{e_a})\left(1.35\frac{R_S}{R_{so}} - 0.35\right)$$

Where, R_{nl} is net outgoing long wave radiation (MJ m^{-2} day^{-1}), s is Stefan-Boltzmann constant = 4.903 10^{-9} (MJ m^{-2} day^{-1}), T_{max},K is maximum temperature (°K) T_{min},K is minimum temperature (°K) e_a is actual vapor pressure(kPa), R_s is solar radiation (MJ m^{-2} day^{-1}) and R_{so} is clear-sky solar radiation (MJ m^{-2} day^{-1}).

Net radiation (R_n)

$$R_n = R_{ns} - R_{nl}$$

Where, R_n is net radiation (MJ m^{-2} day^{-1}).

Soil heat flux density (G)

For daily/ten day period calculation, G taken as zero (0) because soil heat flux is small compared to R_n. As the magnitude of soil heat flux beneath the grass reference surface is relatively small, it was ignored.

Determination of crop coefficient (Kc)

The crop coefficients were determined for wheat and maize crops at different selected locations of Gujarat. The crops were divided into four growth stages (initial, developmental, mid-season and late-season). The Kc_{ini} value given in FAO-56 (Allen *et al.*, 1998) was used as such. The crop coefficients (Kc_{mid} and Kc_{end}) values for wheat and maize (Table 2), were corrected for each locations for climates where, RH_{min} differs from 45% or where u2 larger or smaller than 2.0 m s^{-1}.

Crop coefficient (Kc) values for developmental stage and late season stage for each of the crop was calculated by linear interpolation. The Kc_{mid} and Kc_{end} values were corrected as follows:

$$Kc_{mid} = Kc_{mid\ (tab)} + [0.04\,(u_2 - 2) - 0.004(RH_{min} - 45)]\left[\frac{h}{3}\right]^{0.3}$$

$$Kc_{end} = Kc_{end\ (tab)} + [0.04\,(u_2 - 2) - 0.004(RH_{min} - 45)]\left[\frac{h}{3}\right]^{0.3}$$

Where;

Kc_{mid} (Tab) = value for Kc_{mid} taken from reference table (Table 2),

Kc_{end} (Tab) = value for Kc_{end} taken from reference table (Table 2),

u_2 = mean value for daily wind speed at 2 m height over grass during mid season growth stage (ms^{-1}), for 1m s^{-1}= u_2 = 6m s^{-1},

RHmin = mean value of daily minimum relative humidity during mid season growth stage (%), for 20% = RHmin = 80%,

h = mean plant height during mid season growth stage (m) for 0.1 m < h < 10 m.

Crop water requirement (ETc)

The crop evapotranspiration differs distinctly from the reference evapotranspiration (ETo) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The difference in evaporation and transpiration between both surfaces was combined into single coefficient Kc. In the present study, crop coefficient approach was used for computation of crop water requirements (Doorenbos and Pruitt, 1975).

$$ETc = Kc * ETo$$

Where,

ETc = crop evapotranspiration/Crop water requirement (mm day^{-1}), ETo = reference evapotranspiration (mm day^{-1}), Kc = crop coefficient.

The daily ETc computed were summed for different growth stages of crop and total seasonal crop water was determined for wheat and maize crops. For wheat crop November15 to March 13 period was selected for determination of ETc while for rabi maize November 15 to February 27 period was selected.

RESULTS AND DISCUSSION

Daily variation of ETo at different locations

The daily variation of ETo during winter season period at sixteen stations of Gujarat are presented in Fig. 1. It is observed that there is large fluctuation in daily ETo at

Table 1: Altitudes, latitudes, longitudes and data availability of different agrometeorological stations

Sl. No.	Station	Period of data used	Altitude (m)	Latitude (N)	Longitude (E)
1	Amreli	1993-2013	118	21° 36'	71° 13'
2	Anand	1993-2013	40	22° 32'	72° 59'
3	Arnej	1993-2013	14	22° 35'	72° 17'
4	Bharuch	1993-2013	17	21° 43'	73° 01'
5	Derol	1993-2010	32	22° 38'	73° 30'
6	Godhra	1993-2013	122	22° 46'	73° 37'
7	Junagadh	1993-2013	89	21° 31'	70° 27'
8	Khandha	1994-2010	33	22° 04'	73° 02'
9	Khedbrahma	1993-2008	203	24° 02'	73° 03'
10	Navsari	1993-2013	14	20° 57'	72° 55'
11	Nawagam	1993-2013	32	22° 48'	72° 34'
12	Paria	1993-2013	23	20° 26'	72° 51'
13	SK Nagar	1994-2013	155	24° 21'	72° 20'
14	Surat	1993-2012	11	21° 12'	72° 49'
15	Targadiya	1993-2013	136	22° 18'	70° 48'
16	Vadodara	1993-2012	35	22° 18'	73° 11'

Table 2: FAO crop coefficients (Kc) and mean maximum plant heights for non stressed, well-managed crops in sub-humid climates (RH min = 45%, u2 = 2 m s-1) (Source: FAO-56 Allen et al. 1998).

Crops	Kc ini	Kc mid	Kc end	Crop duration (days)	Mean maximum crop height (m)
Wheat	0.4	1.15	0.41	120	0.8
Maize	0.3	1.2	0.35	105	1.5

Table 3: Corrected crop coefficient (Kc) for wheat at different stations of Gujarat

Station	Kc mid		Kc end	
	FAO	Corrected	FAO	Corrected
Amreli	1.15	1.1565	0.41	0.4165
Anand	1.15	1.15	0.41	0.41
Arnej	1.15	1.1653	0.41	0.4253
Bharuch	1.15	1.1569	0.41	0.4169
Derol	1.15	1.15	0.41	0.41
Godhra	1.15	1.15	0.41	0.41
Junagadh	1.15	1.1574	0.41	0.4174
Khandha	1.15	1.15	0.41	0.41
Khedbrahma	1.15	1.15	0.41	0.41
Navsari	1.15	1.15	0.41	0.41
Nawagam	1.15	1.1397	0.41	0.3997
Paria	1.15	1.15	0.41	0.41
SK Nagar	1.15	1.15	0.41	0.41
Surat	1.15	1.1299	0.41	0.3899
Targadiya	1.15	1.1549	0.41	0.4149
Vadodara	1.15	1.15	0.41	0.9

Table 4: Corrected crop coefficient (Kc) for maize at different locations of Gujarat

Station	Kc mid		Kc end	
	FAO	Corrected	FAO	Corrected
Anand	1.2	1.2	0.35	0.35
Bharuch	1.2	1.2114	0.35	0.3614
Derol	1.2	1.2	0.35	0.35
Godhra	1.2	1.2	0.35	0.35
Khedbrahma	1.2	1.2	0.35	0.35
Navsari	1.2	1.2	0.35	0.35
Paria	1.2	1.2	0.35	0.35
SK Nagar	1.2	1.2	0.35	0.35
Surat	1.2	1.1804	0.35	0.3304
Vadodara	1.2	1.2	0.35	0.35

Table 5: Stage wise mean crop water requirement for wheat and maize

Month	Initial stage	Develovpmental stage	Mid season	Late season	Total
Crop / Wheat					
Stage Duration	15 Nov - 4 Dec	5 Dec - 3 Jan	4 Jan - 17 Feb	18 Feb - 13 Mar --	
Growth stages	Ini. stg	Devel. stg	Mid-seas.	Late-seas.	–
Period (days)	20	30	45	25	120
ETo (mm day-1)	4.8	4.6	5.5	7.0	–
ETc (mm day-1)	1.9	3.5	6.3	5.3	–
Total ETc (mm)	38.0	106.2	285.2	131.9	561.3
Crop Maize					
Stage Duration	15 Nov - 29 Nov	30 Nov - 29 Dec	30 Dec - Feb	8 Feb - 27 Feb	–
Period (days)	15	30	40	20	105
ETo (mm day^{-1})	4.5	4.2	4.9	6.0	–
ETc (mm day^{-1})	1.3	3.2	5.8	4.5	–
Total ETc (mm)	20.1	94.5	232.9	89.5	437.0

different stations of Gujarat. During November and December the ETo is about 4.5 mm day^{-1}. From January onward the ETo increases slowly and reaches to 7.6 mm day^{-1} at the end of the season. It is observed that the Amreli, Arnej, Bharuch, Junagadh and Targadiya stations have higher seasonal ETo (700 to 800 mm), whereas Anand, Derol, Khedbrahma and Paria have lower seasonal ETo (475 to 600 mm). The stations like Khandha, Godhra, Navsari, Nawagam, SK Nagar, Surat and Vadodara have moderate seasonal ETo (600-650 mm). Beside latitudinal variation, the variation in wind speed, temperature and RHmin is attributed to variation in ETo across the locations.

Corrected crop coefficient (Kc) for wheat and maize

The general Kc curve for wheat and maize is given in Fig. 2. The corrected Kc values for wheat at sixteen stations of Gujarat for mid-season stage (Kc_{mid}) and late-season stage (Kc_{end}) along with FAO Kc values are given in Table 3. According to FAO, Kcmid value for wheat is 1.15 and Kc_{end} value is 0.41(Table 2). It is seen from Table 3 that the correction in Kc_{mid} and Kc_{end} values are applied at seven locations and it is less than FAO values at two stations viz. Surat and Nawagam while, both Kc_{mid} and Kc_{end} values are higher than the FAO values at Amreli, Arnej, Bharuch, Junagadh and Targadiya.

The Kc values were corrected for maize crop at ten stations (Table 4). As per FAO Kc_{ini} is 0.3, Kc_{end} is 1.2 and Kc_{end} is 0.35 (Table 2). The correction in Kc values was applied at only two locations viz. Bharuch and Surat. At Bharuch Kc values for mid and end values are higher than

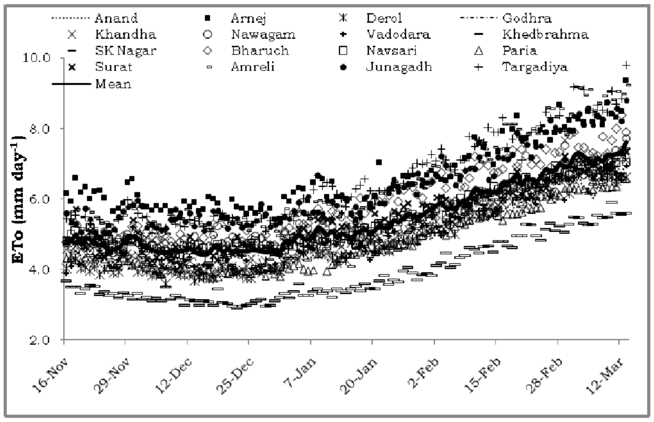

Fig. 1: Daily variation of ETo during winter season (Nov. 15–March 13) at sixteen stations of Gujarat

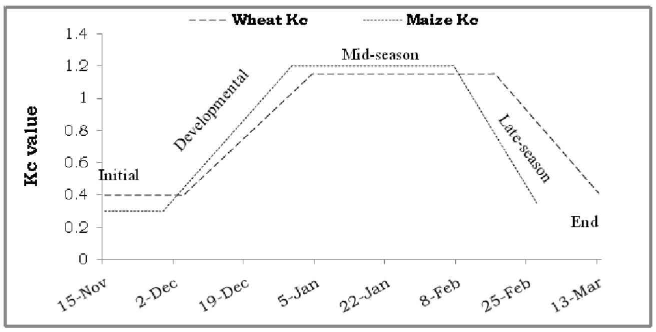

Fig. 2: Crop coefficient curve for wheat and maize

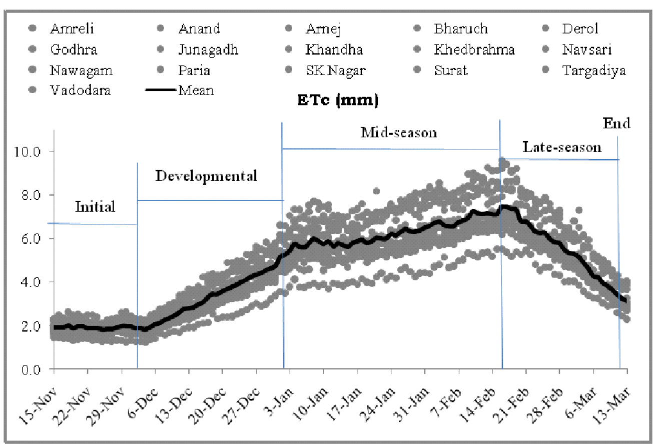

Fig. 3: Daily variation in ETc of wheat at different locations of Gujarat

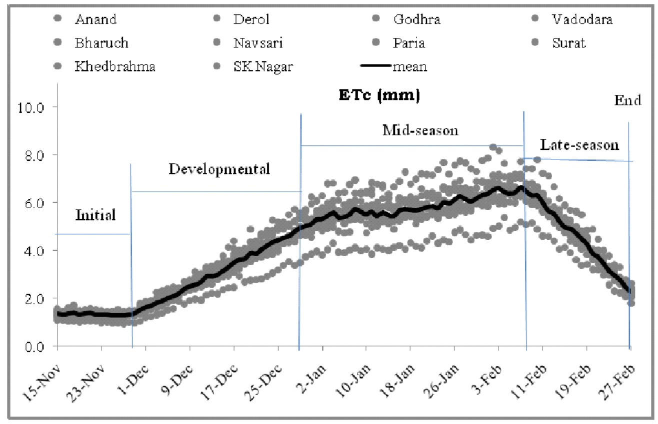

Fig. 4: Daily variation in ETc of rabi maize at different locations of Gujarat

FAO values, while at Surat both Kc_{mid} and Kc_{end} values are less than the FAO Kc values.

Crop water requirement (ETc)

ETc of wheat

The daily ETc of wheat determined for sixteen stations along with the mean are presented in Fig. 3. The mean water requirement of wheat during its initial stage is almost constant and its value is about 1.8 mm day^{-1}, however within the stage slight variation in ETc is observed across the locations, where it varies between 1.5 to 2.8 mm day^{-1}. During developmental stage, the water requirement (ETc) of wheat increases continuously and it varies between 1.9 to 5.2 mm day^{-1}, whereas across the locations it varies between 1.4 to 7.1 mm day^{-1}. During mid season stage, the mean water requirement further increases continuously and varies between 5.6 to 7.5 mm day^{-1} whereas across the locations it varies between 3.8 to 9.6 mm day^{-1}. During the late-season stage ETc decreases progressively up to end of crop season. The ETc at this stage varies between 7.3 to 3.6 mm day^{-1} whereas across the locations it varies between 8.7 to 2.6 mm day^{-1}. The highest water requirement is observed at Arnej (684.0 mm) and Targadiya (679.7 mm) while the lowest is observed at Khedbrahma (400.5 mm) and Paria (419.1 mm). The stage wise mean ETc for wheat is 38.0, 106.0, 285.2, and 131.9 mm during initial stage, developmental stage, mid season stage and during late-season stage respectively (Table 5). Pandey *et al* (2008) reported slightly less water requirment of wheat (265 to 347 mm) in Narmada canal command area of Gujarat.

ETc of maize

The daily ETc for maize determined for ten stations are presented in Fig. 4. In the maize mean water requirement during initial stage is 1.3 mm day^{-1}, however within the stage slight variation in ETc is observed across the locations, where it varies between 1.1 to 1.7 mm day^{-1}. During developmental stage, ETc increases and it varies between 1.4 to 5.0 mm day^{-1}, whereas across the locations it varies between 1.0 to 5.7 mm day^{-1}. During the mid season stage mean water requirement also increases and varies between 5.0 to 6.6 mm day^{-1} whereas across locations it varies between 3.8 to 8.3 mm day^{-1}. During the late-season stage ETc decreases progressively up to end of crop season. The ETc at this stage varies between 6.4 to 2.5 mm day^{-1} where as across the locations it varies between 7.8 to 1.8 mm day^{-1}. The stage wise mean ETc for maize is 20.1, 94.5, 232.9 and 89.5 mm during initial stage, developmental stage, mid season stage and during late-season stage respectively (Table 5). The total water requirement of maize is higher at Bharuch (520.5 mm) whereas lower at Khedbrahma (380.7 mm). Pandey *et al* (2008) reported water requirment of maize between (337 to 398 mm)in Narmada canal command area of Gujarat. Similar results are reported by Sahu and Sastry (1993) and Kingra *et al.* (2004) in Gujarat and Punjab regions respectively.

It is seen that the amount of water requirement increases with the stage of crop and across the locations. Variation in water requirement is more in mid-season stage followed by developmental stage of crops across the locations and less variation is observed in initial stage.

CONCLUSION

This study established precise estimation of evapotranspiration which was the only beneficial water loss from the field. The reference evapotranspiration (ETo) higher in Saurashtra region (Amreli, Junagadh, Targadiya) Bhal region (Arnej) while lower in Northern region (Khedbrahma, SK Nagar) and South Gujarat (Paria, Navsari) of Gujarat.

The corrected Kc value can be used for determining crop water requirement at different locations of Gujarat. The corrected Kc values for wheat crop were higher than FAO values while for maize these were less at Surat and higher than FAO values at Bharuch. The ETc was found to vary with stage of crop and location. ETc of wheat was found to be more than that of maize. The information generated can be useful for irrigation scheduling.

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