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REFERENCE AND CROP EVAPOTRANSPIRATION ESTIMATION FOR MUSTARD AND CHICKPEA AT DIFFERENT LOCATIONS OF GUJARAT

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ABSTRACT

The accurate estimation of crop water requirement which depends on duration of crop, growth stage, their growing season and location are essentially required for efficient irrigation water management and water resource management in agriculture. The study was therefore carried out to estimate crop evapotranspiration (ETc) for winter crops (mustard and chickpea) at eighteen stations of Gujarat, India using crop coefficient (Kc) and reference evapotranspiration (ETo). The reference evapotranspiration (ETo) was determined by Penman-Monteith method. The Kc values for winter chickpea and mustard as given in FAO-56 were corrected for climatic condition of stations. The results revealed that during winter season (November to February) the mean daily reference evapotranspiration (ETo) varies from 4.4 to 7.4 mm day^{-1}. However, the large variation in ETo across the locations (2.9 to 10.3 mm day^{-1}) was observed. The mean water requirement (ETc) of chickpea during its initial stage was found to be almost constant (2.0 mm day^{-1}) and it increased continuously during developmental stage from 2.0 to 4.5 mm day^{-1}, it further increased during the mid season and reached to its peak value of 5.9 mm day^{-1} at the end of this stage and during the late-season stage ETc decreased progressively from 5.6 to 2.5 mm day^{-1}. The mean water requirement (ETc) of mustard during its initial stage was found to be almost constant (1.7mm day^{-1}) and it increased continuously upto 4.5 mm day^{-1} during developmental stage, it further increased and reached to its peak value of 5.9 mm day^{-1} during the mid and ETc decreased progressively from 5.6 to 2.5 mm day^{-1} during the late-season stage. However total crop water requirement of mustard (515.0 mm) was more than that of chickpea (470.2 mm). The results are useful for planning the irrigation scheduling in winter season at different locations of Gujarat.

Keywords- Penman-Monteith method, Reference evapotranspiration (ETo), Crop evapotranspiration (ETc), Crop coefficient (Kc), Chickpea, Mustard

1. INTRODUCTION

Estimation and 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 demands for optimum crop production. The irrigation scheduling based on crop water requirement (ETc) is widely used, which is determined by multiplying crop coefficient (Kc) values with reference evapotranspiration (ETo) (Doorenbos and Pruitt, 1975). Based on availability of weather data various methods (Blaney-Criddle, 1950; Turc, 1961; Christiansen, 1968; Priestly-Taylor, 1972; Hargreaves-Samani, 1985; FAO Penman-Monteith method: Allen *et al.*, 1998) have been suggested. Among all the methods FAO Penman-Monteith method (Allen *et al.*, 1998)

have been found very close to the actual measurement of ETo compared to other methods (Patil and Gorantiwar, 2009), hence universally accepted method.

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 but due to non availability, it was estimated by pan evaporation (Chaudhari *et al.*, 1999). Crop coefficient (Kc) values for most of the crops are given in FAO-56 but these values need to be corrected with local climatic parameters (Gadge *et. al.*, 2011; Shanker *et al.*, 2012).

Tyagi *et al.*, (2000) used lysimeter approach for accurate estimation of crop water requirement (ETc) of wheat and sorghum in Karnal. In Gujarat state Pandey *et al.* (2008) determined crop water requirement of different crops using DSSAT model. Mehta and Pandey (2015) reported ETo, ETc and corrected Kc values for wheat and winter maize crops at different locations of Gujarat. In this paper, reference evapotranspiration (ETo), crop coefficient (Kc) and crop water requirement (ETc) has been determined for winter grown chickpea and mustard crops at different stations of Gujarat using long period weather data.

2. METHODOLOGY

Gujarat is located on the west coast of India, marked by an arid and dry climate, with a little bit of rain during the monsoons. Winters in Gujarat are mild, pleasant and dry. The long term daily weather data (maximum temperature, minimum temperature, morning relative humidity, afternoon relative humidity, sunshine hour and wind speed) of eighteen stations (Table 1) were obtained from Agromet data bank, Department of Agricultural Meteorology, Anand Agricultural University, Anand for computing reference evapotranspiration (ETo).

2.1. *Estimation of reference evapotranspiration (ETo)*

From the original Penman-Monteith equation and the equation of aerodynamic and surface resistance, as given in FAO-56 (Allen *et al.*, 1998) was used to estimate reference evapotranspiration (ETo) for daily timesteps as:

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

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

By using altitude, latitude and climatological data (T_{max}, T_{min}, RH_{max}, RH_{min}, n and u_2), each parameter required for Penman-Monteith model namely: slope of saturation vapor pressure (Δ), psychrometric constant (γ), extraterrestrial radiation (R_a), solar radiation/short wave radiation (R_s), inverse relative distance earth-sun (d_r), solar declination (δ), sunset hour angle (ω_s), daylight hours (N), clear-sky solar radiation (R_{so}), net solar or net shortwave radiation (R_{ns}), net long wave radiation (R_{nl}), net radiation (R_n) and soil heat flux density (G) were computed through programme developed in MS Excel (Mehta and Pandey, 2015).

2.2. *Crop coefficient (Kc)*

To determined crop coefficient values for chickpea and mustard at different locations of Gujarat, the crop growing period was divided into four growth stages (initial, developmental, mid-season and late-season). Due to unavailability of wetting and drying event data of the soil, 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 chickpea and mustard were corrected at each locations for climate where, RH_{min} differs from 45% or where u_2 larger or smaller than 2.0 m s^{-1}.

The linear interpolation was used to compute crop coefficient (Kc) values for developmental stage and late season stage for each of the crop. 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 3),

$Kc_{end\ (Tab)}$ = value for Kc_{end} taken from reference table (Table 3),

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

RH_{min} = mean value of daily minimum relative humidity during mid season growth stage (%), for $20\% \leq RH_{min} \leq 80\%$,

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

2.3. *Crop evapotranspiration/Crop water requirement (ETc)*

Crop coefficient (Kc) value is important information which is used to calculate the amount of crop water requirement whereby the effects of various weather conditions are incorporated. In the present study, crop water requirement (ETc) was determined on daily basis by multiplying reference evapotranspiration (ETo) with crop coefficient (Kc) value, (Doorenbos and Pruitt, 1975).

ETc = Kc * ETo

The daily ETc was summed for different growth stages of crop and total seasonal crop water requirement was determined for chickpea and mustard. For the determination of ETc, November 01 to February 28 period was selected for both mustard and chickpea crop.

3. RESULTS AND DISCUSSION

3.1 Monthly and seasonal variation of ETo at different locations

Monthly and seasonal ETo values were estimated using Penman-Monteith equation during winter season (November to February) at eighteen stations of Gujarat for available climatic data. The values indicated that monthly ETo was lowest during December whereas highest during February and seasonal ETo varied from a minimum value of 586.0 mm at Khedbrahma to the highest value of 983.6 mm at Arnej (Table 2) at different locations. It is observed that Amreli, Arnej, Bharuch, Junagadh, Targadiya and Viramgam stations have higher monthly and seasonal ETo whereas, Anand, Derol, Khedbrahma, Paria and SK Nagar have lower seasonal ETo. The stations like Dhandhuka, Godhra, Khandha Navsari, Nawagam, Surat and Vadodara have moderate monthly and seasonal ETo.

3.2 Corrected crop coefficient (Kc) for chickpea and mustard

The crop coefficient (Kc) curve with respect to crop period for chickpea and mustard along with their mean ETo, mean ETc of chickpea and mustard is given in Fig. 1. During the initial period, the leaf area is small, and evapotranspiration is predominately in the form of soil evaporation. According to FAO, Kc_{ini}, Kc_{mid} and Kc_{end} value for chickpea is 0.4, 1.0 and 0.35 respectively (Table 3). The crop coefficient values corrected for chickpea at sixteen stations of Gujarat along with FAO Kc values are presented in Table 4. The correction applied at seven stations for chickpea suggested that both Kc_{mid} and Kc_{end} values are higher at Arnej and Junagadh whereas lower at Amreli, Bharuch, Surat, Targadiya and Viramgam when compared with that of FAO values.

Mustard is grown at fifteen stations of Gujarat out of which, correction in both Kc_{mid} and Kc_{end} were applied at six stations. According to FAO, Kc_{ini} is 0.35, Kc_{mid} is 1.15 and Kc_{end} is 0.35 (Table 3). It is seen from Table 5 that the corrected Kc_{mid} and Kc_{end} values were higher at Amreli, Bharuch and Junagadh whereas corrected Kc values were less than that of FAO values at Nawagam, Surat and Targadiya.

3.3. *Crop water requirement/crop evapotranspiration (ETc)*

3.3.1 ETc of chickpea

The water requirement of chickpea for sixteen stations along with the mean values (Fig. 2) shows that mean daily water requirement increases with passes of time and its value during initial, developmental, mid and maturation stage is 2.0, 3.2, 5.0 and 4.1 mm day^{-1} respectively. Large variation is observed across the locations during its growing period, where it varies from 1.4 to 7.4 mm day^{-1}. Among the locations, highest seasonal ETc is observed at Targadiya (564.9 mm) followed by Amreli (556.4 mm) while the lowest at Khedbrahma (334.1) followed by Paria (416.0 mm). The stage wise mean ETc for chickpea is 30.6, 113.0, 223.4, and 103.2 mm during initial, developmental, mid season and late season stages respectively (Table 6). Crop water requirement of chickpea 209 to 343 mm and 232 to 249 mm reported by Rao and Poonia (2004) and Pandey *et al.* (2008) respectively is less as compared to present study.

3.3.2 ETc of mustard

The crop water requirement of mustard (Fig. 3), the crop requires maximum amount of water at the crop development and mid season stage. Daily mean water requirement during initial, developmental, mid and maturity stage is 1.7, 3.4, 5.7 and 4.5 mm day^{-1} respectively. Large variation is observed across the locations during its growing period, where it varies from 1.2 to 8.5 mm day^{-1}. The stage wise mean ETc for mustard is 26.0, 119.1, 256.8 and 113.2 mm during initial, developmental, mid season and late season stages respectively (Table 6). The total water requirement is highest at Targadiya (625.1 mm) and lowest at Khedbrahma (368.2 mm).

It is seen that the amount of water requirement increases with the stage of crop and across the locations large variation is observed. Continuous fluctuations in the crop evapotranspiration can be attributed to the effect of daily weather parameters, altitude and latitude of stations. Crop water requirement (ETc) pattern of chickpea is same as mustard, however the water requirement of mustard during developmental and mid season stage is higher than the chickpea due to more leaf area index.

4. CONCLUSION

Based on result obtained, it is found that evapotranspiration based irrigation scheduling can lead to optimum irrigation water use. This study established precise estimation of evapotranspiration which is the only beneficial water loss from the field and to meet the crop water requirement with less irrigation water supply. The corrected Kc values can be used to determine ETc of chickpea and mustard. As practically visualized in the present study, this information could be useful for irrigation scheduling of chickpea and mustard under arid and semi-arid conditions in the western part of India.

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

Sl. No.	Station	Period of data used	Altitude (m)	Latitude (^{O}N)	Longitude (^{O}E)
1	Amreli	1993-2013	118	21^{o} 36'	71^{o} 13'
2	Anand	1993-2013	40	22^{o} 32'	72^{o} 59'
3	Arnej	1993-2013	14	22^{o} 35'	72^{o} 17'
4	Bharuch	1993-2013	17	21^{o} 43'	73^{o} 01'
5	Derol	1993-2010	32	22^{o} 38'	73^{o} 30'
6	Dhandhuka	1996-2013	19	22^{o} 23'	71^{o} 59'
7	Godhra	1993-2013	122	22^{o} 46'	73^{o} 37'
8	Junagadh	1993-2013	89	21^{o} 31'	70^{o} 27'
9	Khandha	1994-2010	33	22^{o} 04'	73^{o} 02'
10	Khedbrahma	1993-2008	203	24^{o} 02'	73^{o} 03'
11	Navsari	1993-2013	14	20^{o} 57'	72^{o} 55'
12	Nawagam	1993-2013	32	22^{o} 48'	72^{o} 34'
13	Paria	1993-2013	23	20^{o} 26'	72^{o} 51'
14	SK Nagar	1994-2013	155	24^{o} 21'	72^{o} 20'
15	Surat	1993-2012	11	21^{o} 12'	72^{o} 49'
16	Targadiya	1993-2013	136	22^{o} 18'	70^{o} 48'
17	Vadodara	1993-2012	35	22^{o} 18'	73^{o} 11'
18	Viramgam	1999-2012	24	23^{o} 08'	72^{o} 02'

Table 2: Monthly reference evapotranspiration (ETo) during winter season (November to February) at different stations of Gujarat

Stations	Nov	Dec	Jan	Feb	Total
Amreli	169.8	165.6	185.8	220.2	741.5
Anand	136.1	127.5	141.1	163.8	568.5
Arnej	183.4	177.2	192.2	215.4	768.2
Bharuch	149.9	149.8	178.4	200.0	678.0
Derol	126.8	120.9	145.3	171.5	564.5
Dhandhuka	146.1	133.1	156.2	181.5	616.9
Godhra	146.9	140.7	150.8	173.5	612.0
Junagadh	164.1	167.9	185.7	209.0	726.7
Khandha	142.8	126.6	150.7	176.6	596.7
Khedbrahma	107.6	96.6	109.6	136.1	449.9
Navsari	151.7	142.2	156.8	181.2	631.9
Nawagam	142.2	148.2	161.7	174.3	626.3
Paria	133.6	123.9	137.9	161.2	556.6
SK Nagar	141.7	132.2	144.4	174.1	592.4
Surat	145.5	140.3	164.2	177.9	627.9
Targadiya	166.7	165.4	194.0	222.2	748.3
Vadodara	141.2	130.5	150.7	172.2	594.6
Viramgam	170.9	168.0	183.6	200.8	723.2

Table 3: FAO crop coefficients (Kc) and mean maximum plant heights for non stressed, well-managed crops in sub-humid climate (RH_{min} = 45%, u_2 = 2 m s^{-1}) (Allen *et al.* 1998)

Crops	Kc_{ini}	Kc_{mid}	Kc_{end}	Crop duration (days)	Mean maximum crop height (m)
Chickpea	0.4	1.0	0.35	120	0.4
Mustard	0.35	1.15	0.35	120	1.3

Table 4: Corrected crop coefficient (Kc) for chickpea at different stations of Gujarat

Station	Kc mid		Kc end	
	FAO	Corrected	FAO	Corrected
Amreli	1.0	0.9990	0.35	0.3490
Anand	1.0	1.0	0.35	0.35
Arnej	1.0	1.0070	0.35	0.3570
Bharuch	1.0	0.9984	0.35	0.3484
Derol	1.0	1.0	0.35	0.35
Dhandhuka	1.0	1.0	0.35	0.35
Godhra	1.0	1.0	0.35	0.35
Junagadh	1.0	1.0012	0.35	0.3512
Khedbrahma	1.0	1.0	0.35	0.35
Navsari	1.0	1.0	0.35	0.35
Paria	1.0	1.0	0.35	0.35
SK Nagar	1.0	1.0	0.35	0.35
Surat	1.0	0.6756	0.35	0.3256
Targadiya	1.0	0.9984	0.35	0.3484
Vadodara	1.0	1.0	0.35	0.35
Viramgam	1.0	0.9906	0.35	0.3406

Table 5: Corrected crop coefficient (Kc) for mustard at different locations of Gujarat

Station	Kc mid		Kc end	
	FAO	Corrected	FAO	Corrected
Amreli	1.15	1.1585	0.35	0.3585
Anand	1.15	1.15	0.35	0.35
Bharuch	1.15	1.1573	0.35	0.3573
Derol	1.15	1.15	0.35	0.35
Godhra	1.15	1.15	0.35	0.35
Junagadh	1.15	1.1592	0.35	0.3592
Khandha	1.15	1.15	0.35	0.35
Khedbrahma	1.15	1.15	0.35	0.35
Navsari	1.15	1.15	0.35	0.35
Nawagam	1.15	1.1443	0.35	0.3443
Paria	1.15	1.15	0.35	0.35
SK Nagar	1.15	1.15	0.35	0.35
Surat	1.15	1.1275	0.35	0.3275
Targadiya	1.15	1.1494	0.35	0.3494
Vadodara	1.15	1.15	0.35	0.35

Table 6: Stage wise mean crop water requirement for chickpea and mustard

Crop	**Chickpea**				
Growth stages	**Initial stage**	**Developmental stage**	**Mid season stage**	**Late season stage**	**otal**
Date	01 Nov-15 Nov	16 Nov-20 Dec	21 Dec-03 Feb	04 Feb-28 Feb	--
Period (days)	15	35	45	25	120
Total ETo (mm)	76.1	164.0	228.2	159.5	627.8
Total ETc (mm)	30.6	113.0	223.4	103.2	470.2
Eto (mm day^{-1})	5.1	4.7	5.1	6.4	5.2
ETc (mm day^{-1})	2.0	3.2	5.0	4.1	3.9
Crop	**Mustard**				
Period (days)	15	35	45	25	120
Total ETo (mm)	76.1	164.0	228.2	159.5	627.8
Total ETc (mm)	26.0	119.1	256.8	113.2	515.0
ETo (mm day^{-1})	5.1	4.7	5.1	6.4	5.2
ETc (mm day^{-1})	1.7	3.4	5.7	4.5	4.3

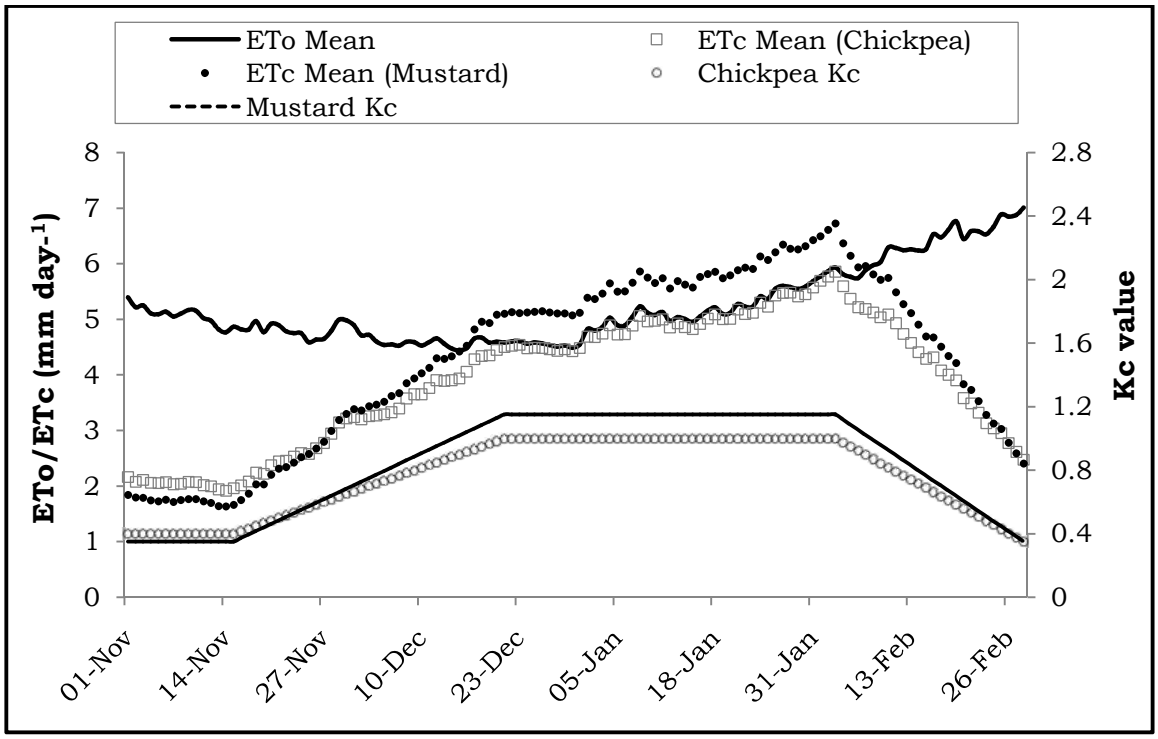

Fig. 1: Daily variation in mean reference evapotranspiration (ETo), mean crop water requirement (ETc) and Crop coefficient (Kc) curve with respect to crop period of chickpea and mustard

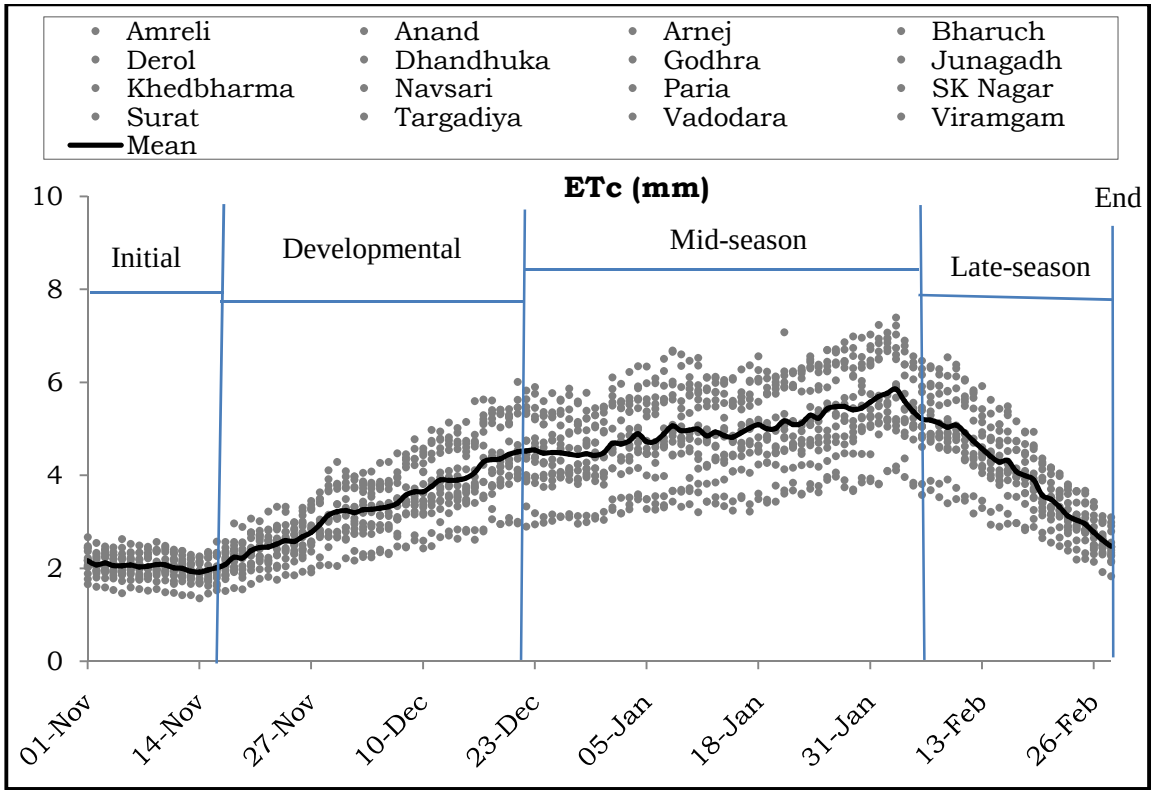

Fig. 2: Daily variation in ETc of chickpea at different locations of Gujarat

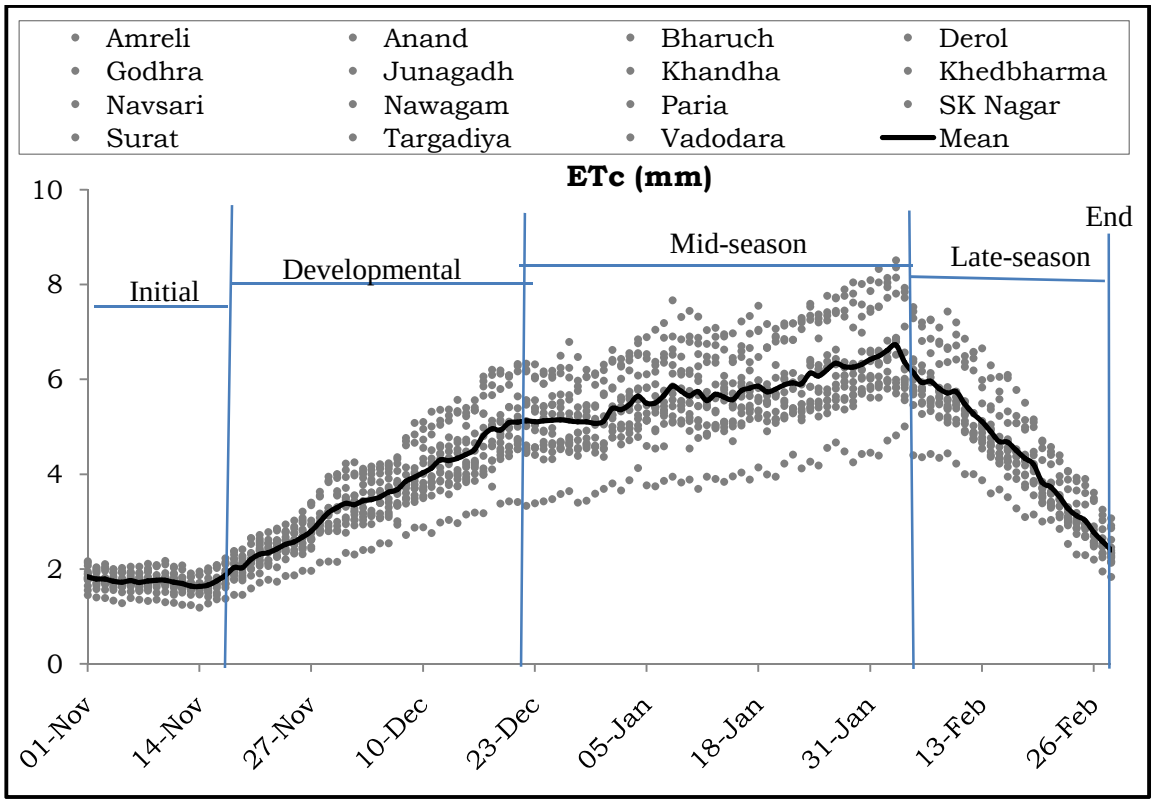

Fig. 3: Daily variation in ETc of mustard at different locations of Gujarat