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Full Length Research Paper

Climate reactive strategies for improving cotton yield: A case study ofGujarat State, India

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Moisture stress at the critical stage is a major constraint in rainfed cotton. Assessment of reference evapotranspiration (ETo) and its utilization strategy is imperative to boost rainfed cotton production. To overcome, daily meteorological parameters of 10 cotton growing districts of Gujarat, India were recorded from 2001 to 2011 and multiple regressions between lint yields and various climatic variables, crop evapotranspiration (ETc) at four critical stages of cotton were done. Water deficit, surplus, actual evapotranspiration, soil storage, change in soil water storage was calculated for different non-Bt. and Bt. cotton-growing years. The results revealed that ETo was 662-947, 414-687, and 1076-1596 mm, and rainfall was 490-1150, 5.5-35, and 442-1210 mm from June to December, January-April and overall crop growth period, respectively. The impact of rainfall, ETc on lint yield was 51 to 92 % (R2) and was highly significant at the critical growth stage. The ETc was 670 to 936 mm and the water use efficiency (WUE) was 0.13 to 0.83 kg /ha-mm. Low WUE was recorded in non-Bt growing years. Based on the meteorological parameters, it is concluded that under rainfed situation the supplemental irrigation is essential after the withdrawal of monsoon rain and in extended cotton (January-April). The conserved rainwater could be effectively used during the cotton boll development stage, which intern increases the lint yield as well as WUE.

Keywords: Climatic variables, Climatic Water Balance Parameters, Rainfed cotton, Reference ETo, WUE

INTRODUCTION

Among all-fiber crops, cotton is a major cash crop. It is being commercially grown in more than 80 countries in the longitudinal between 37 ^{0} N and 32 ^{0} S. It is widely adopted in a semi-arid and arid environment and is either grown in irrigated or rainfed conditions. About 53% of the world's production comes from supplemental irrigation or full irrigation and the remaining 47 % comes from the rain-fed area (ICAC, 2014). At the world level, the cultivated area is increasing at a faster rate because of more earning from this fiber crop; however, the total production is not matching with demand at the global level. During 1950-51, the total cultivated area was 285 lakh ha and it increased to 335 lakh ha (17.5 %) during 2010-11. Now the total production has also been increased at an alarming rate from 66.74 lakh tonnes in 1950-51 to 253.68 lakh tonnes (280 %) in 2010-11. The productivity at the world level has also been improved substantially from 234 kg/ha in the year 1950-51 to 759 kg/ha (224 %) in 2010-11(ICAC, 2014). However, the magnitudes of productivity in different countries are changing significantly with time because of the adoption of improved crop production technology, changing climatic variables, and the degree of resource utilization by the farmers. In the Asia region, this crop is being grown in 12 countries and the share of cultivated area, production, and consumption is 66.4 %, 68.0 %, and 80.4 %, respectively over the world cotton scenario. Among 12 Asian countries, China, India, and Pakistan are contributing their major share in the area, production, and productivity.

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Water is the primary resource that controls the plant growth and the scarcity of the water has severely hampered the overall outcome and socio-economic status of the farmers. With the help of GlobWat model (Global Water Balance Model) by using AQUASTAT-a database of FAO 2013, significant reduction of water for irrigation due to human intervention has been recorded as 70% of the freshwater has been withdrawn in agriculture alone and the consumptive use of water in irrigated agriculture has gone to the extent of 90 % (Hoogeveen et al., 2015). As irrigated agriculture is the main component of water demand and driver of freshwater in any region of the world, it is thus highly essential to make effective use of water in the agriculture sector.

In India, cotton is being cultivated predominantly in the arid and semi-arid region of the country in 12.586 million ha area (DAC, 2018) however, the productivity is quite low as only 35.3 % of the cultivated area is under irrigation. In the irrigated area (93.5 to 100 % of the cultivated area) of the states like Punjab, Haryana, Rajasthan, the productivity is comparatively more than the areas of different states where the maximum cultivated area is rain-fed. In Gujarat state, productivity is comparatively higher than other rainfed areas of the country due to the development of water resources structures. To improve the productivity of cotton in rain-fed areas, there is urgent need to make water resources structures at micro-level basis so that the supplemental irrigation during long dry spell period as well as after recedes of the rainy season, will support to cotton crop, when the crop suffers from moisture stress as well as the occurrence of aberrant weather parameters. Among the 52 factors, about 6 weather parameters(maximum and minimum temperature, sunshine period, wing speed, relative humidity, rainfall) influences crop growth, however maximum and minimum temperature and rainfall plays a major role on growth and development of cotton in an arid and semiarid region of the country.

Impact of Climatic variables on Cotton Growth

Cotton being a perennial shrub, grows well under semi-desert area and requires warm temperature for vegetative growth, but the excessively high temperature during flowering and early boll development stages reduces yield (Oosterhuis, 1999). Thermal kinetic windows (TKW) for enzyme activity strongly correlate with optimal temperature and general metabolism. TKW of cotton is between 23.5 to 32 ^{0}C (Burke et al. 1988). If the daily temperature exceeds this limit, then crop development and productivity gets affected. The optimum temperature for vegetative growth is 30 ^{0}C and higher than 35 ^{0}C, growth rate and photosynthesis of cotton start decreasing (Bibi et al., 2008; 2010). If day/night temperature exceeds 40/20 ^{0}C, the reduction in total biomass is 50 %. The reproductive stage is highly sensitive to a higher temperature before and after anthesis. High temperature hastens the appearance of a square, flower, and mature boll. The temperature over 30/20 ^{0}C in day/night results in low retention of bolls. Cool temperature is the major limitation on crop productivity in the temperate region (Reddy et al., 1991). The cool temperature below 22 ^{0}C at night hinders boll development, cotton yield, and fiber properties (Liakatas et al., 1998). As plant canopy temperature exceeds 40 ^{0}C, the production of bolls is reduced considerably. Three weeks of exposure to 40 ^{0} C for 2 hours resulted in only 40 % boll retention and at the same temperature (40 ^{0}C) for 14 hours resulted in 0 % boll retention (Reddy et al.,1992). For growing of cotton crops in an arid and semi-arid region in India, the desired level of weather parameters is available however rainfall pattern is quite erratic, due to which the productivity is declining at higher magnitude particularly in light to medium type of soils where water retentive capacity is very low. Hence it is highly essential to assess evaporative water demand (ETo) for cotton crops and provide suitable alternatives to the cotton-growing farmers of arid and semiarid regions for improvement of cotton productivity.

Cotton productivity is also controlled by climate variables and carbon dioxide (CO_2) concentration. Due to the anthropogenic activities, the concentration of CO_2 in the atmosphere has increased by > 28 % over the present level of 360 ppm and it may further aggravate if suitable management practices are not adopted well in advance (IPCC, 2001). In the 21 st century, the concentration of CO_2 may increase to the tune of 970 ppm as the industrial revolution is liberating more CO_2 in the atmosphere. As a result of the higher concentration of CO_2, the global temperature may increase in the range of 1.4 to 5.8 ^{0} C over the normal temperature. In cotton crop, the high temperature increases male sterility in flowers, bud shedding, alter boll development, boll size, and reduces the availability of carbohydrate and maturity period considerably (Reddy etal.,1999; Loka and Oosterhuis, 2010). Relative humidity (RH) directly or indirectly affects the yield of crops (Dubey et al., 1995). Higher RH increases the infestation of sucking pests and damages the cotton crop subsequently if the adequate quantity of pesticide spraying is not done in proper time (Singh et al., 2009). The wind speed, sunshine hour period also plays a significant role in harvesting the potential yield of cotton. High wind speed during the initial crop growth period in arid climate regions, damages the cotton seedling, increases the water requirement of crop and reduces the humidity within crop canopy as well as surrounding areas of crop.

In India, a long term study made by Kumar (2015) showed that the surface air temperature increased by 0.4 ^{0}C linearly in the past century. The warming trend at present has been observed in the West Coast, Central India, Interior Peninsula, and North-Eastern India. Based on this projection, the agriculture sector is being badly affected concerning more water demand as an increase in surface air temperature enhance the evaporative demand of the crop. He further analyzed and projected the production scenario of cereal crops and reported that with every 1 ^{0}C rise in temperature, there will be a reduction in wheat production by 4 to 5 million tonnes by the end of the 21st century and the total food grain production by 10 to 40%. Such heavy loss of food grain production due to the increase in surface air temperature, soon may affect the livelihood of the farmers who are fully dependent on agriculture.

Impact of Irrigation water

Xiao etal., (2000) explained that imposing four irrigation regimes in pots by applying irrigation water at 0.85, 0.70, 0.55, and 0.40 ET, the cotton fruit-bearing branches, squares, boll numbers, boll size were increased with increasing water supply. Similarly in the greenhouse when cotton was grown at 43 % or 76 % RH and sprayed daily with abscisic acid (ABA) or distilled water; the plants had higher transpiration rate and low stomatal conductance in lower RH (Barbour and Farquhar, 2000). In Texas (USA), plant growth and yield of rainfed cotton (Pima cotton cv. S-6) were less in humid area than in an arid area with low humidity (Guo et al., 1994), because, under the arid condition, higher vapor pressure deficit shows high transpiration rate, low leaf water potential. Considering the major constraints of cotton production and productivity in India, the impact studies with regards to climatic variables and water balance scenarios in two types of soil have been carried out with the help of daily meteorological data of cotton growing districts of Gujarat.

MATERIAL AND METHODS

Computation of Reference ETo

The daily meteorological data of ten cotton growing districts of Gujarat state were collected from Indian Meteorological Department (Govt. of India) Pune, for the period from 2001 to 2011 and the reference evapotranspiration (ETo) was calculated by temperature-based ET method of Hargreaves and Samani (1985) as per the following equation:

$$ET_0 = 0.0023R_a(TC + 17.8)TR^{0.50} \text{ ----- (1)}$$

Where,
ETo = reference evapotranspiration (mm/ day)
Ra = extra-terrestrial radiation (mm/ day)
TR = Tmax.-Tmin. (^{0} C)
TC = mean temperature (0 C); mean temperature = (T max+Tmin)/2
The monthly reference ETo and the rainfall pattern were prepared from 20th June every year as the normal monsoon rainfall is received during 11 - 17 June and the farmers start sowing of cotton crop thereafter. Under the rainfed condition, the farmers finish their boll picking operation up to December end and those who are having irrigation facility, they continue their cotton crop up to March-April end. Based on the reference ETo and rainfall pattern, the water surplus and deficit period have been identified with soil water storage.

Climatic Water Balance

The climatic water balance has been computed as per Thornthwaite and Mather (1955) procedure by considering the storage capacity of the soils of Ahmedabad district of Gujarat (Sharma et. al.,2006) as an example to assess the magnitude of the soil moisture surplus and deficit during the crop growing period (Table I). The equation for the water balance is given below for reference. In this equation, water is stored in the soil reservoir until the soil water content (SW) exceeds the available water capacity (AWC), at which point the excess water goes into storage (S) or runoff where the provision of storage is not made at field level. For determining the soil water budget, it requires a track of the accumulated potential water loss (APWL) and the amount of water in the soil (SW). In this equation, three conditions of the soil water movement occur due to the variable amount of ETo, rainfall, and the soil water available in the profile.

Situation at field level	SW	APWL	Excess
i)Soil is drying $\Delta P < 0$	$= AWC \exp\left(\frac{APWL_t}{AWC}\right)$	$= APWL_{t-1} + \Delta P$	= 0
ii)Soil is wetting $\Delta P > 0$ but $SW_{t-1} + \Delta P \le AWC$	$= SW_{t-1} + \Delta P$	$= AWC \ln\left(\frac{SW_t}{AWC}\right)$	= 0
iii)Soil is wettingabove storage capacity $\Delta P > 0$ but $SW_{t-1} + \Delta P > AWC$	$= AWC$	= 0	$= SW_{t-1} + \Delta P - AWC$

When P>PET, AET =PET;When P<PET, AET = dSW + P;AWC = Available Water Capacity(field capacity-wilting point)X(soil depth):; SW = Available Soil Water (i.e.above wilting point.); APWL = Accumulated Potential Water Loss (negative);ΔP = Net rainfall amount; P – PET;P = Rainfall ;PET = Potential Evapotranspiration; AET = Actual Evapotranspiration; Deficit=defined when PET>AET; Surplus=defined when SW>AWS
Based on the output of the above equations, the daily monitoring of available soil moisture, changes in soil moisture storage, deficit, surplus, AET was performed and the suggestions have been given to the farmers for irrigation at various magnitudes of available soil moisture depletion. Generally, in the farmer's field, the irrigation date is suggested when 50 % of the available soil moisture

Table I: a Soilwater retention capacity of Gujarat State.

Depth (cm)	Soil- Clay(%)			Available Soil moisture Water retention (%)		(%)	Depth (mm)
	Sand	Silt	Clay	33kPa	1500 kPa		
0-18	26	29	45	30.5	14.2	16.3	29.34
18-55	23	25	52	28.4	13.5	14.9	53.64
55-82	22	38	40	29.3	13.9	15.4	40.04
82-145	20	38	42	31.5	14.5	17.0	108.80
Mean	22.75	32.5	44.75	29.93	14.03	15.87	231.82

Table I:b Ahmedabad – Oganej Series

Depth (cm)	Available soil moisture Sandy loam(%)			Water retention (%)		(%)	Depth (mm)
	Sand	Silt	Clay	33kPa	1500 kPa		
0-18	62.1	20.1	17.8	15.4	6.4	9.0	16.20
18-46	57.9	22.7	19.3	16.8	7	9.8	27.44
46-73	59	23.9	17.1	16.3	6.4	9.9	26.73
73-105	59.2	23.9	16.9	16.3	6.4	9.9	31.68
105-150	58	25.2	16.8	16.6	6.4	10.2	45.9
Mean	59.24	23.16	17.58	16.28	6.52	9.76	146.5

is depleted in the case of surface irrigation and at 8-10 % depletion in the case of a drip irrigation method (Singandhupe et. al., 2003, 2008).

So considering the water demand and supply scenario of different districts of Gujarat state, the effect of moisture stress and the climatic variables on lint yield of cotton growing districts of Gujarat state has been analyzed and the possible technological interventions have been suggested to the planners/ researchers and irrigation engineers /hydrologists for further studies on the development of water resources structures and adoption of irrigation methods for irrigating cotton crop during long dry spell period.

Changes of climatic variables on soil moisture availability pattern

The impact of climatic parameters on changes in soil moisture availability of different districts have been analyzed with statistical parameters to assess the variation of the parameters and probable suggestions to the farmers, researchers for further study at district/ micro-levels.

RESULTS AND DISCUSSION

ETo and rainfall pattern :

In East- Central part of Gujarat, the estimated crop water demand and the rainfall received during the period from June to December is comparatively similar except in Vadodara, and in Anand districts, the amount of rainfall is higher than crop water demand. But in the Kheda district, the quantity of the rainfall received is 48.3 % less than the crop water demand. As far as the monthly distribution of rainfall against the crop water demand is concerned, the rainfall received during the monsoon period (July to September) is 74 % higher than ETo (421mm) in Ahmedabad, 90% higher than ETo (427mm) in Anand, 148 % higher than ETo (399 mm) in Vadodara district. Hence the excess amount of rainfall during these three months needs to be conserved /stored effectively and utilized during the non-monsoon period. But in Kheda district, the rainfall amount and crop water demand during the above period are quite comparable (385.9 mm ETo and 384.9 mm rainfall) and hence only in-situ conservation measures are enough, provided the rainfall distribution is uniform. In subsequent crop growth period (October to December), the crop water demand in these districts is quite high as compared to the rainfall amount received and hence, the crop needs supplemental irrigation to harvest potential crop yield (Table II). In the subsequent period also (January to April) when the farmers continue their cotton crop, a huge amount of irrigation water is required (627 to 648 mm) as against the very minimum amount of rainfall received (6 to 60 mm). Generally, the farmers exploit groundwater/surface water for irrigating their field crops during the rainless period and harvest very good crop yield as it has been experienced by the farmers from the irrigated area. In remaining areas/regions of the Gujarat state, similar crop water demand scenarios and rainfall patterns are recorded and hence the adequate water conservation techniques/methods are required to use rainwater and irrigation water effectively.

Effect of climatic variables and crop

The multiple regression analysis of lint yield of cotton vs climatic variable i.e. rainfall, crop ETc at four critical crop growth stages after 20 June (initial period 31 days, crop development 50 days, mid-season 55 days, late-stage 45 days) were carried out by considering the lint yield as the dependent variable and climatic parameter (rainfall), ETc as independent variables. The effect of the climatic parameters on lint yield was significant, particularly during reproductive stages. In different districts of Gujarat state, the response of the rainfall, ETc on lint yield was found to be 51 % to 92 %(R^2). The effect of rainfall during crop development and the mid-stage was highly significant as the crop was in flowering to boll development stages. The stage-wise impact of rainfall pattern on lint yield showed positive effect as the rainfall received during different growth stages enhanced the availability of soil moisture vis-a-vis plant nutrients except in Banaskanta, Rajkot, and Anand districts, the effect of rainfall was negative as the very limited amount to nil rainfall was recorded during this period. Similarly, the effect of ETcrop on lint yield was in a positive trend, and with increasing crop evapotranspiration, there was an improvement on lint yield (Table III a, b). When the daily maximum and minimum temperature trend was analyzed for the period from 2001 to 2011 of Ahmedabad district, it was observed that in October, the average maximum and minimum temperature was 35.8 ^{0}C to 21.5 ^{0}C respectively, and the range of maximum temperature was 35.0^0 to 36.9 ^{0}C and minimum temperature was 18.6^0 to 24.4 ^{0}C. The standard deviation and coefficient of variation for maximum temperature were 0.4 ^{0}C and 1.06 % respectively. The corresponding values for the minimum temperature were 2.06 ^{0}C and 9.56%. In the remaining crop growing period, the values of these parameters were quite good except in June and in the early period of July, these were comparatively higher than October temperature. In the rest of the cotton-growing districts, similar climatic trends were recorded. From these meteorological observations, it is predicted that during October where the crop is in flowering to boll development stages, the effect of higher temperature and depletion of available soil moisture from the soil profile severely affect the yield of the cotton crop, if irrigation is not provided with the same amount, which is depleted from the soil profile. Miller et al., (1996) through multiple regression analysis, considering different weather temperatures as independent variables and lint yield as the dependent variable found that 50 % variation in yield was shared by weather parameters and the remaining 50 % by management practices. They further identified that the most important factor for flower and boll production is evaporation, sunshine duration, humidity, and surface soil temperature.

In Egypt Sawan et al., (2005) studied the effect of climatic factors on flowers and boll development on Giza 45 cotton from 62 to 68 days after sowing of cotton. They monitored the flower and boll development scenarios daily and correlated with weather parameters, which were measured at field level only. The data indicated that evaporation, minimum relative humidity, and sunshine duration were most effective during fifteen days preceding and succeeding in boll production and retention. There was a negative impact of evaporation and sunshine duration on boll retention. It is thus inferred that low evaporation rate and reduced sunshine duration and high humidity enhances flower and boll formation. Maximum temperature showed a low but negative correlation with flower production and minimum temperature showed non- significant effect. Daily soil temperature at 06.00 h showed a positive effect and at 18.00 h showed negative effect as higher soil temperature during evening time increases moisture stress in the plant system. A similar trend was recorded in the cotton plant by Kaur and Singh (1992) as the moisture stress reduced the production of flower during flowering stages. In southwest Spain at Cordoba Orgaz et al., (1992) conducted a field experiment with five cotton varieties and imposed different amounts of irrigation water i.e. from 40 to 100 % of ET crop. They found that the water production function was linear with increasing supply of irrigation water. The most important climatic factor is sunshine duration, where the crop is exposed for better growth. It has been observed by Bhatt (1977) that less sunshine harms boll development. The most suitable duration of sunshine for boll development is 11.7 h and if it is increased to 13 h at maximum air temperature up to 44 ^{0} C, the boll development is drastically retarded. Maximum temperature above 32 ^{0}C during development (June to August) and flowering stage (October - December) compared to normal temperature affect the growth and phenology of the crop. Fiber length is also restricted when the maximum temperature is beyond 32 ^{0}C. During night hours, the warm temperature above 25 ^{0}C causes higher respiration and reduction of stored assimilates (Bange, 2007). Gupta and Pandey (1991) from Gujarat analyzed the impact of rainfall on

Table II. ETo and rainfall (mm) during cotton growing period 2001-2011.

	East –Central Gujarat Region								North Gujarat Region				Saurashtra Region							
Month	Ahmedabad		Anand		Vadodara		Nadiad (Kheda)		Desa (Banaskantha)		Bhuj		Amreli		Bhaunagar		Rajkot		Dwarka	
	ETo	Rf	ETo	Rf	ETo	Rf	ETo	Rf	ETo	Rf	ETo	Rf	ETo	Rf	ETo	Rf	ETo	Rf	ETo	Rf
June	65.1	60.7	62.8	112.9	59.6	127.8	50.8	28.2	64.7	16.5	59.6	37.6	60.2	188.1	64.1	152.2	62.7	99.7	38.4	43.0
July	149.4	293.2	145.2	338.4	140.6	387.3	132.0	142.0	171.1	266.6	146.1	152.7	145.7	248.8	156.1	232.8	148.8	308.9	103.8	225.6
Aug	133.7	333.7	139.2	325.1	127.4	423.6	123.4	142.9	147.8	242.4	133.8	178.3	130.9	176.5	141.8	195.3	134.8	262.3	99.3	197.1
Sep	138.0	105.8	142.9	152.0	131.3	179.8	130.5	100.3	150.7	104.9	141.4	78.2	140.6	153.3	137.1	158.2	143.1	161.4	99.1	150.9
Oct	157.8	8.9	157.4	35.5	154.2	17.9	159.8	10.3	169.8	13.3	157.2	1.9	163.3	31.0	153.5	18.4	161.7	12.1	119.0	19.6
Nov	127.6	9.4	131.4	19.0	127.7	10.4	134.7	4.3	132.9	35.6	122.0	40.7	136.0	22.8	125.2	18.5	130.6	30.4	107.9	14.8
Dec	109.1	1.1	110.4	0.0	111.2	3.6	112.8	8.3	110.4	0.9	101.6	0.8	124.7	0.8	111.1	0.0	112.3	1.0	94.2	1.5
S.Total	880.9	812.8	889.3	982.8	852.0	1150.5	844.0	436.3	947.4	680.1	861.7	490.2	901.5	821.4	889.0	775.5	894.0	875.8	661.9	652.3
Jan	110.7	1.5	112.0	0.0	114.3	2.2	115.6	1.4	112.1	7.6	103.5	2.0	125.2	0.0	113.0	0.8	117.8	0.0	96.2	1.0
Feb	129.8	6.4	132.7	14.0	131.5	50.4	130.8	4.6	129.8	20.8	123.0	1.8	142.7	0.0	130.1	3.8	133.3	1.3	94.2	8.3
Mar	184.9	4.1	187.6	0.8	187.1	0.7	185.7	0.0	189.3	2.0	178.4	6.2	197.5	8.0	179.5	5.1	189.6	1.1	110.4	4.0
Apr	209.0	6.0	215.5	0.0	210.2	6.8	195.2	0.0	217.3	4.5	202.5	0.0	221.2	0.4	201.2	8.0	217.4	3.1	112.8	0.0
Total	634.4	17.9	647.9	14.8	643.1	60.1	627.3	6.0	648.4	34.9	607.4	9.9	686.6	8.4	623.8	17.7	658.0	5.5	413.7	13.3
G.Total	1515.3	830.7	1537.2	997.6	1495.0	1210.5	1471.3	442.2	1595.8	715.0	1469.1	500.1	1588.1	829.8	1512.8	793.1	1552.1	881.2	1075.6	665.7

Notes: ETo- Reference evapotranspiration; Rf- Rainfall; **Source**: Authors' work.

seed cotton yield and reported negative trends under minimum and maximum rainfall. Due to uneven distribution of rainfall in any region of the country, the effect of minimum rainfall increases moistures stresswithin the crop root zone and maximum rainfall increase waterlogged condition in the field and damages the roots due to lack of adequate aeration.

Climatic water balance studies

The water balance data of the Ahmedabad district is shown (Figure 1). In the case of heavy soil where the clay content is quite high the water storage capacity is 232 mm in 145 cm soil depth. Due to continuous rainfall, the soil profile water was reached to its potential capacity of 232 mm on 31 July andthe rainfall of about

Table III a. Regression analysis between lint yield x rainfall (2001-2011).

Location	Parameters	Equations and Coefficients					R^2	F Value
		Intercept	I	CD	MS	LS		
Ahmadabad	Coefficients	119.2	+ 0.065	+ 0.18	+ 0.14	+ 6.22	0.70	3.48
	S.E.	72.4	0.21	0.11	0.29	2.25		
	T – Value	1.60	0.31	1.55	0.48	2.76		
	P – Value	0.16	0.77	0.17	0.65	0.06		
Amreli	Coefficients	145.3	+ 0.21	+ 0.71	+ 0.64	+ 1.92	0.66	2.43
	S.E.	136.6	0.26	0.38	0.44	2.16		
	T – Value	1.1	0.82	1.86	1.44	0.88		
	P – Value	0.34	0.45	0.12	0.21	0.42		
Baroda	Coefficients	240.3	+ 0.01	+ 0.13	+ 0.48	+ 14.3	0.37	0.89
	S.E.	177.2	0.27	0.18	0.81	7.82		
	T – Value	1.35	0.05	0.68	0.59	1.82		
	P – Value	0.22	0.96	0.52	0.57	0.12		
Bhavnagar	Coefficients	225.6	- 0.11	+ 0.45	+ 1.39	+ 3.04	0.62	2.42
	S.E.	285.5	0.45	0.65	0.50	3.73		
	T – Value	0.79	- 0.24	0.69	2.77	0.82		
	P – Value	0.28	0.17	0.13	0.01	0.08		
Desa – Banaskantha	Coefficient	331.2	- 0.1	+ 0.69	+ 0.75	- 3.50	0.55	1.82
	S.E.	138.1	0.54	0.27	0.68	- 2.41		
	T – Value	2.40	- 0.19	2.56	1.10	- 1.47		
	P – Value	0.05	0.85	0.04	0.32	0.19		
Kheda	Coefficients	429.9	- 0.03	+ 0.08	+ 0.56	+ 13.9	0.26	0.53
	S.E.	111.2	0.60	0.32	1.50	17.5		
	T – Value	3.7	- 0.05	0.25	0.37	0.79		
	P – Value	0.01	0.96	0.74	0.72	0.46		
Rajkot	Coefficients	51.3	+ 0.26	+ 1.29	+ 1.01	- 5.58	0.62	2.50
	S.E.	239.1	0.62	0.51	0.66	3.19		
	T – Value	0.21	0.42	2.51	1.52	- 1.8		
	P – Value	0.84	0.69	0.05	0.18	0.18		
Anand	Coefficients	578.8	- 0.5	+ 0.1	+ 1.8	- 2.2	0.53	1.39
	S.E.	119.4	0.4	0.2	1.1	3.6		
	T – Value	4.8	- 1.4	0.4	1.7	- 0.6		
	P – Value	0.0	0.2	0.7	0.2	0.6		

Notes: I-Initial stage (20 June to 20 July -31 days) X_1, CD- Crop development (21 July to 8 September -50days) X_2,MS- Mid-season (9 September to 2 November -55 days) X_3 , LS= Late season (3 November to 18 December -45 days) X_4 ; **Source**: Authors' work.

188 mm which was received during 1 to 16 August was found to be in excess and this excess amount of rainfall can be effectively stored in a small reservoir and it can be used once the depletion of available water occurs to the extent of 50 % in subsequent periods. As per the computation of the climatic water balance of this location, fifty percent depletion of available soil moisture was found on 16 October. If the farmers use the excess rainwater during this period where the Bt cotton crop is in the flowering to boll development stages, they can harvest very good seed cotton yield. In the case of sandy loam soil where the water storage capacity is 146.7 mm in 150 cm soil depth, the soil profile was fully recharged on 26 July and the rainfall amount of 188.3 mm which

Table III b. Regression analysis between lint yield and crop ETo (2001-2011).

Location	Parameters	Equations and Coefficients Intercept	I	CD	MS	LS	R^2	F Value
Ahmedabad	Coefficients	859.9	+ 4.41	+3.32	- 2.45	- 4.65	0.92	16.99
	S.E.	316.5	2.31	1.35	1.03	2.13		
	T – Value	2.71	1.91	2.45	- 2.38	2.18		
	P – Value	0.03	0.10	0.05	0.05	0.07		
Amreli	Coefficients	- 1384	+ 15.6	+ 9.24	- 6.38	+ 0.54	0.51	1.30
	S.E.	2471.8	21.0	8.54	3.23	7.33		
	T – Value	- 0.56	1.22	1.08	- 1.97	0.07		
	P – Value	0.60	0.28	0.33	0.11	0.94		
Bhavnagar	Coefficients	6215.3	-4.08	+2.8	- 10.13	-17.5	0.89	12.63
	S.E.	825.0	4.2	4.60	3.3	4.99		
	T – Value	7.53	-0.97	0.61	-3.1	-3.5		
	P – Value	0	0.37	0.56	0.02	0.01		
Baroda	Coefficients	1336.1	+ 13.6	+ 4.37	- 4.37	- 7.57	0.89	12.5
	S.E.	1125.8	8.82	2.53	1.11	3.59		
	T – Value	1.18	1.54	1.72	- 3.94	- 2.10		
	P – Value	0.28	0.17	0.13	0.01	0.08		
Desa Basankantha	Coefficients	400.0	+ 8.16	+ 1.21	- 2.4	+7.1	0.50	1.48
	S.E.	866.2	7.1	4.0	4.4	7.8		
	T – Value	- 0.5	1.1	0.3	- 0.5	0.9		
	P – Value	0.7	0.3	0.8	0.6	0.4		
Kheda	Coefficients	- 287.1	+ 22.8	+ 2.4	+ 0.2	- 6.0	0.47	1.32
	S.E.	1476.6	14.1	3.9	2.6	2.1		
	T – Value	- 0.2	1.6	0.6	0.1	- 0.4		
	P – Value	0.9	0.2	0.6	0.9	0.40		
Rajkot	Coefficients	4851.3	+ 18.6	- 4.0	- 15.0	+ 3.9	0.58	2.11
	S.E.	4145.1	32.4	12.1	5.8	18.5		
	T – Value	1.2	0.6	- 0.3	- 2.6	0.21		
	P – Value	0.3	0.6	0.8	0.04	0.8		
Anand	Coefficients	1457.4	+ 2.1	+ 3.1	- 4.8	+ 0.6	0.63	2.17
	S.E.	464.2	3.8	2.4	2.3	4.0		
	T – Value	3.1	0.6	1.3	- 2.1	0.2		
	P – Value	0.0	0.6	0.3	0.1	0.9		

Notes: I-Initial stage (20 June to 20 July -31 days), CD- Crop development (21 July to 8 September -50days), MS- Mid-season (9 September to 2 November -55 days), LS- Late season (3 November to 18 December -45 days); **Source**: Authors' work.

was received up to August 16, was non-effective. Thereafter the depletion of soil moisture occurred due to non-receipt of rainfall. Generally in October, the crop suffers from moisture stress due to low water retentive capacity and fast drying nature of the light soil as compared to heavy soil. Hence it is suggested that in light soils, early maturing Bt. hybrid cotton and high-density planting system i.e. close spacing can be advocated to the farmers. A similar trend was also recorded in another cotton-growing district of Gujarat where rainfall amount and its distribution is similar which is not shown here.

Response of rainfall and atmospheric temperature on soil water status

The response of daily rainfall and temperature data of only

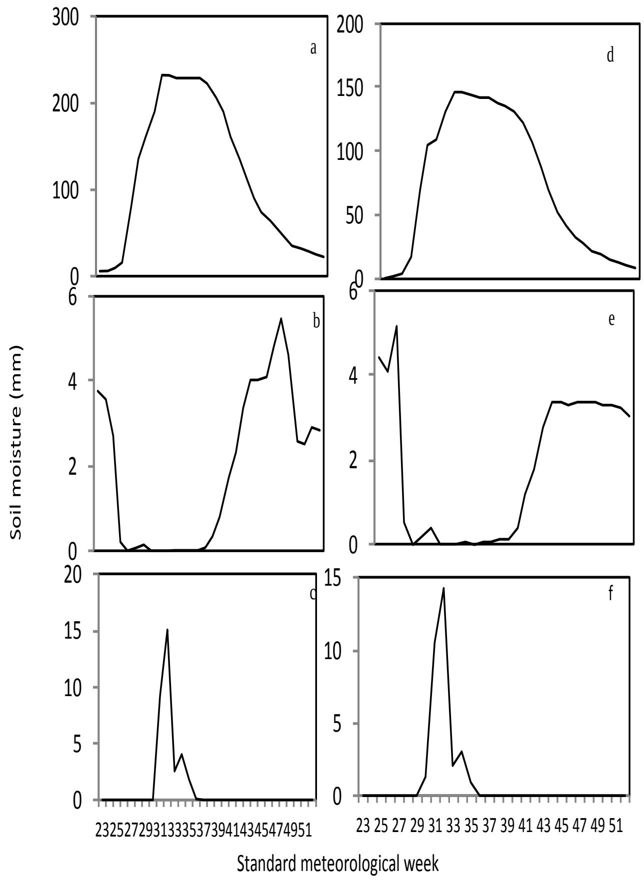

Figure1. Soil moisture status changes for clay soil - (a) Storage, (b) Deficit, (c) Surplus and for sandy loam soil - (d) Storage, (e) Deficit, (f) Surplus

Ahmedabad district was regressed to assess the magnitude of these parameters on ETo, storage of soil moisture, AET, surplus and deficit for the period from June 20, to December 18, by using the rainfall for above parameters and the maximum air temperature data on ETo. The responses of these parameters are presented in Figure 2-3. The rainfall received during the crop growing period has a positive effect on soil water storage, actual evapotranspiration, and surplus water and negative effect on ETo, water deficit which has been expressed on slope parameters of the regression equation. This trend indicates that more amount with a good distribution of the rainfall enhances water storage during the crop growth period, reduces water deficit in the soil profile, and increases surplus water on the soil surface or goes as runoff. During the early crop growth period (June 20 to July 20), the amount of rainfall received was 200.7 mm; in the crop growth development period it was 476.09 mm; in the midseason period it was 70.22 mm and in the last stage, it was only 4.05 mm. However, the values of ETo during the corresponding period were 65.6 mm, 175.5 mm, 337.5mm, and 231.8 mm respectively. Similarly, the maximum air temperature has also increased the daily ETo and the magnitude of the increase has been explained by 10.2 %. Similarly, the rainfall has also contributed to ETo, soil water storage, AET, surplus, and deficit to the extent of 4.0 to 50 %.

ET crop and water use efficiency of cotton

For calculation of water use efficiency, the value of ET crop was taken for the period from 20th June to 18th December (180 days growing period) as this period was considered for computing stage-wise multiple regression analysis. The water use efficiency (lint yield kg per ha / ha-mm ET crop) was calculated year -wise. However, these parameters were calculated for two sets: the first set was used before the introduction of Bt. cotton (up to 2002-03) and the second set was used after the introduction of Bt hybrid cotton(2003-04 to 2011-12) as per the government of India notification. The results are presented in Table IV revealed that the introduction of Bt hybrid cotton in India has improved the economic return of the farmers as the productivity of Bt hybrid cotton has

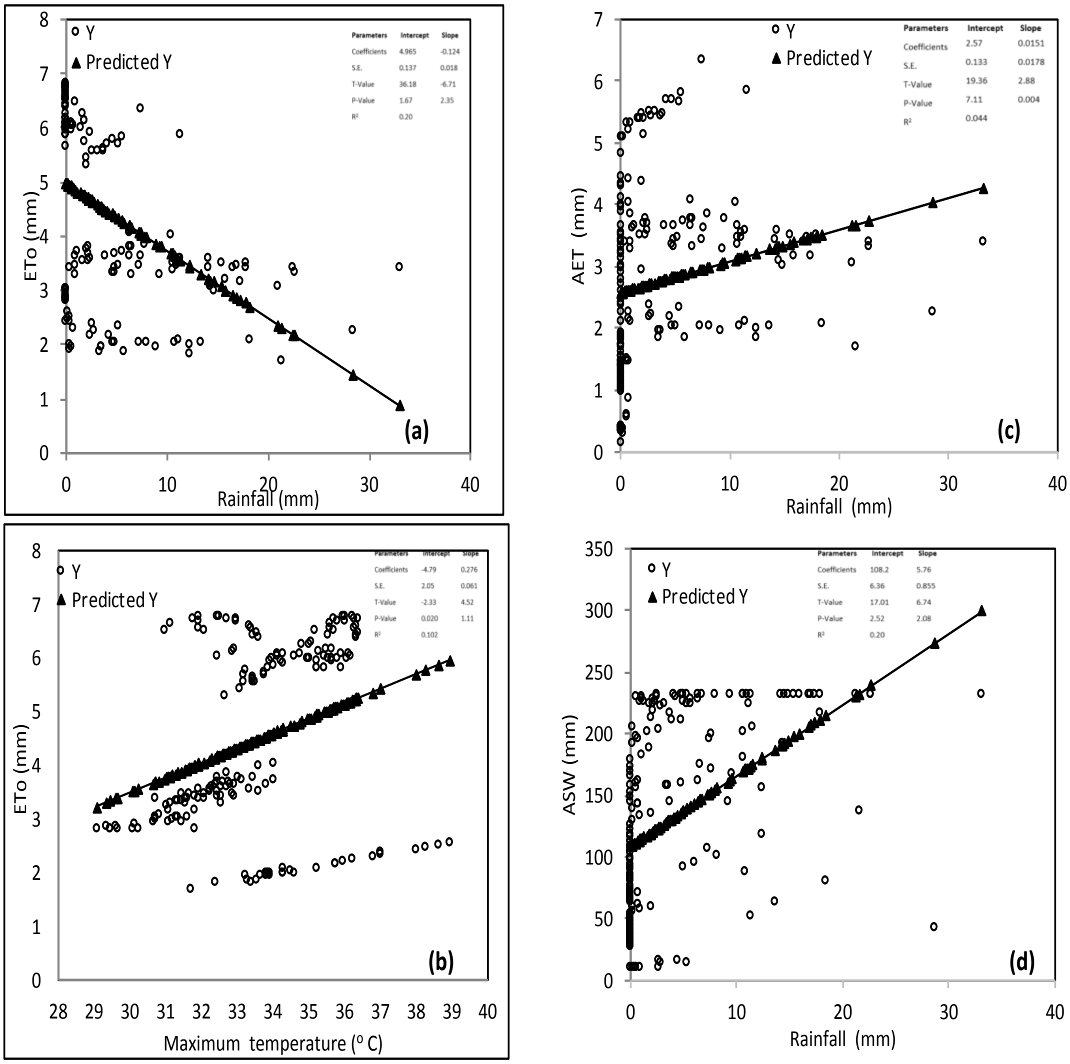

Figure. 2 Impact of climatic variables on lint yield. a) Rainfall vs ETo ,(b) Max Temp vs ETo, (c) Rainfall vs AET, (d) Rainfall vs ASW

increased to the tune of 62.6 % in Kheda district to 514.7% in Rajkot district. Similarly, the magnitude of increase in water use efficiency was 68.9% to 513.8% in respective districts. On the contrary, the ET crop was higher during the non-Bt cotton-growing year as compared to Bt cotton-growing years but the productivity was not improved to the extent which was recorded subsequently. During the Bt hybrid cotton-growing years, the development of water resources structures and subsequently the adoption of drip irrigation with fertigation in these areas has boosted the productivity and water use efficiency of the cotton crop. The cooling effect of the crop due to introduction of irrigation has also reduced the atmospheric demand which has finally resulted in lower ET crops during Bt cotton-growing years as compared to non-Bt cotton-growing years. Singandhupe (2017) has studied the impact of irrigation on changes of climatic parameters in the canal command area of Maharashtra, India and reported that due to development of water resources structures (medium irrigation projects) and continuous supply of water for irrigation to field crops throughout the year for 26 years (1975 -1995) has reduced the ETo by 9 %.

In Turkey, the field experiment was carried by Unlu et al. (2007) for three years (1993, 1994 and 1995) in *G. hirsutum* cotton in different furrow irrigation methods i.e. continuous flow furrow irrigation, surge flow furrow irrigation, cut back furrow irrigation, variable alternate flow furrow irrigation with a discharge rate of 0.072 m3 per hour. They observed maximum seed cotton yield 3690

Table IV. ET crop, and water use efficiency of cotton.

Location	Lint yield (kg/ha)		ET crop (mm)		WUE (kg lint/ ha-mm ET crop)	
	Before Bt	After Bt	Before Bt	After Bt	Before Bt	After Bt
Ahmedabad	107.1	284.3	793.9	721.9	0.135	0.394
Anand	173.9	597.4	820.5	727.8	0.210	0.830
Amreli	151.3	564.4	936.4	891.8	0.161	0.636
Baroda	206.6	492.2	731.4	670.3	0.284	0.734
Bhavnagar	185.3	632.6	795.1	709.2	0.232	0.897
Banaskanth	156.5	678.3	786.0	784.8	0.200	0.857
Kheda(Nadia)	324.7	527.8	723.0	700.3	0.447	0.755
Rajkot	124.5	765.3	761.5	735.0	0.163	1.043

Notes: Before Bt. cotton period 2001-2002; After Bt. cotton period -2003-2011 **Source**: Authors' work.

and 3780 kg /ha in case of surge flow and cut backflow furrow irrigation, respectively, but the water use efficiency (WUE) was low (0.30 and 0.23 kg /ha-m^3, respectively) as compared to continuous flow furrow irrigation in which the yield was 2775 kg/ha and WUE was 2.29 kg/ha-m^3. Accordingly, several studies have been conducted in cotton and various field crops and saved a significant amount of excess water in the cutback flow furrow irrigation method (Humphrey, 1978) by runoff recovery system without cut back (Johnson 1990). The intermittent water application i.e. surge flow during advance phase (Stringham and Keller 1979, Jalali – Farahani et al., 1993) and the variable/fixed alternate furrow (Stewart etal., 1981; Tang et. al. 2005) are the important water management techniques in furrow irrigation in cotton for improving water use efficiency. These methods may be introduced for increasing water use efficiency in the cotton-growing district of Gujarat state where the farmers are not in a position to install a drip irrigation system. In the case of drip irrigation method where the irrigation water is placed near the crop root zone, the crop yield and water use efficiency is quite high. Du et. al. (2008) conducted a field experiment on cotton crop in North West China for two years in drip irrigation system with two treatment (conventional drip irrigation: both side of rows, and both side of plant row alternately) with three irrigation levels 15, 22.5 and 30 mm in the first year 2004 and 12, 18 and 24 mm in the second year 2005. Higher water use efficiency was recorded in alternate row irrigation through drip irrespective of irrigation levels followed and 31-33% higher seed cotton yield in this system. This concept of partial root zone wetting/ drying has been found quite beneficial in recent times by several workers and implemented this practice in several crops (Kang et al., 1998; 2000).

In India, Singh et. al., (2001) have reported 37.3 % to 56.3 % saving of water and water use efficiency in the drip system in cotton crops. At Bhatinda center of All India Coordinated Research Project on Weed Management (AICRP-WM), three methods of irrigation (check basin, irrigation in each furrow, irrigation in alternate furrow) were tested in Bt cotton during 1999-2000 with canal water, bore well water and alternate irrigation of canal and bore well water. It was found that alternate irrigation was recorded maximum seed cotton yield (0.72 t/ha) and saved 48.1 % water than the check basin method. Irrigation through canal water was effective than bore well water. At Rahuri center, drip irrigation at 2 days interval with fertigation (100: 50: 50 kg, N, P2 O5, and K2O/ha) recorded maximum seed cotton yield (3.02 t/ha). Drip irrigation required 58.6 cm irrigation water as against 90.1 cm in surface irrigation with paired row planting; however single row planting required 101.1 cm irrigation water. During 2003 in the Sriganganagar center, three irrigation levels were tested in cotton crops and compared the yield and water use efficiency with the surface irrigation method. The result was quite promising and irrigation provided at 1.0 ETc gave maximum yield (1.94 t/ha) with WUE of 25.9 kg/ha-cm as compared to 1.59 t/ha with WUE of 23.8 kg/ ha –cm in surface irrigation method. It is thus inferred that the drip irrigation system increased both WUE and seed cotton yield irrespective of soil types and agro-climatic condition, it is cultivated.

Impact of ET crop on WUE

A simple linear regression of ET crop as independent variable and WUE as dependant variable in two separate sets of data i.e. Btcotton years (2003-2011) and non-Bt cotton-growing years(2001-2002) was carried out to assess the magnitude of impact on WUE. In this case, two sets were prepared irrespective of the district data and the total number of observations was 16 in the case of non-Bt cotton and 71 in the case of Bt hybrid cotton. In Both non-Bt and Bt cotton-growing years, the intercept was significant (Table IV and Figure 3), however, the magnitude was quite high (t= 4.15) in Bt hybrid cotton years as compared to non-Bt cotton years (t=2.198). Similarly, the intercept in the case of Bt cotton was highly significant with a positive impact on WUE. This indicates that with increasing each amount of ET crop, there was an increase in WUE in Bt cotton. Hence it is highlyessential to make provision of supplemental irrigation by conserving excess rainfall which is recorded in July, August, and September and can be used during the water stress period and increase the crop yield and improve water use efficiency.

CONCLUSION

The cotton crop is a long duration that needs a significant amount of water throughout the crop growing period. After sowing, it sustains on rainfall amount received during the monsoon period. During the monsoon period particularly from September, the crop in flowering to boll development stage, however from October onwards, when the monsoon is withdrawn, the crop suffers from moisture stress and the lint yield is adversely affected. In irrigated areas, the farmers provide supplemental irrigation in October and November months and harvest satisfactory seed cotton/ lint yield particularly in the state of Gujarat where 56.7 % cotton area is under irrigation. But in some of the cotton-growing districts, the farmers are harvesting very low yield. Hence our assessment of water demand scenarios through this study may help planners, irrigation engineers, irrigation agronomists to make proper planning of rainwater harvesting and effective use of harvested rainwater through pressurized irrigation systems instead of flood irrigation methods. The weather parameter also plays a very important role in crop growth and development. The increase in temperature during crop growing period substantiates a significant amount of water demand and effective planning and development of water resources structure may recoup the water needs of the crop, particularly during non-rainy days. After the introduction of Bt hybrid cotton in 2003, the lint yield, and water use efficiency has increased at a substantial rate, and hence the development of irrigation resources at a micro-level should be created to harvest potential yield of cotton in such climatic situations and soil types in the state of Gujarat, India.

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