Simulation of eintra-seasonal climatic variability, potential yield, and yield gap of sugarcane for the south Gujarat region, India

ABSTRACT

The validated CANEGRO (DSSAT v4.7) model was used to simulate the intra-seasonal climatic variation, *viz.* ~~maximum temperature, minimum~~ temperature (-3 ºC to +3 ºC), and rainfall (-25% to +25%) variability in sugarcane yield and quantifying the yield gap of sugarcane at Navsari, Bharuch, Surat, and Valsad districts of south Gujarat region under the various management options included dates of planting, irrigations, and fertilizers application and compared with the reported yield of the districts.The ~~effect of intra-seasonal variation in temperature and rainfall revealed that,~~ cane yield increased with an increase in rainfall and a decrease in temperature~~, while~~. In contrast, the cane yield decreased with a decrease in rainfall and an increase in temperature. The extent of effect was found to vary with crop growth stages ~~of the crop~~.The potential yield of sugarcane simulated by the model in different districts ~~were~~ was found to vary between 107.0 to 114.7 t ha^{-1}, while the reported yield in these districts varied between 68.1 to 72.0 t ha^{-1}. This resulted in a total yield gap between 38.9 to 45.5 t ha^{-1} in different districts. The highest yield gap was in Navsari district while the lowest yield gap was found in Bharuch district.

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Keywords: Simulation, Climatic variability, Sugarcane, ~~and~~ Yield gap

INTRODUCTION

In India, sugarcane occupies about 5.89 million hectares ~~area~~ with a total production of 490.53 million tons at an average productivity of 83.3 t ha^{-1} (Anon., 2024).In Gujarat, sugarcane is cultivated in an area of 1.81 lakh ha with production and productivity of 134.6 lakh tons and 75.5 tha^{-1}, respectively (Anon., 2024).Sugarcane being a tropical plant, its growth and yield are more sensitive to weather conditions (Kushwaha and Pal, 2000).The low

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sugarcane yields in Indian States are due to extreme weather conditions, *viz.*, very high and very low temperatures, and prolonged dry spells in monsoon seasons. Long duration of flooding and reduction of solar radiation at some critical growth phases during wet spells are also detrimental factors for growth and yield. Spatial variation of ~~sun shine~~ sunshine hours from tropical to sub-tropical regions also ~~play~~playsan important role in sugarcane yield variation. The low productivity of sugarcane is mainly caused by late planting (April- May) (Singh *et. al*., 2008, Singh *et al*., 2010). Sugarcane is ~~long duration~~ long-durationcrop ~~it~~ and~~is~~ highly influenced by climatic variability such as high temperatures during the summer and very low minimum temperatures in winter which ~~ultimately~~ highly influence the ultimate yield of the crop (Samui *et al*., 2003). So, it is very important to analyze the impact and effect of climatic variations on yields (Singh *et al*., 2010).Quantifying the potential yield of a crop is the key to ~~understand~~understandingthe existing yield gaps and ~~identify~~ identifyingthe most important constraints to achieve optimal yield and profit. Understanding the causes of these yield gaps~~,~~ allows ~~to~~ forimproving yield and profit in a sustainable ~~matter~~manner. Crop simulation models have been used to determine the potential yield of~~crop~~ cropswith which, the yield gap in a given environmental situation can be determined and possibilities for the yield improvement can be assessed. The yield targets serve as a reference for calculating the required agronomic inputs and for assessing their environmental effects. In this paper, an attempt has been made to study the impact of intra-seasonal climatic variability on sugarcane yield and to assess the potential yield and yield gap analysis of sugarcane in different districts of South Gujarat by using the CANEGRO model.

MATERIALS AND METHODS

The field experimental data of sugarcane for November planting and Decemberplanting were collected from Main Sugarcane Research Station, N.A.U., Navsari, Gujarat, India situated at 20° 57' N latitude and 72° 54' E longitude and at an altitude of 11.89

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m above mean sea level.The CANEGRO (DSSAT v4.7) model was calibrated and validated using field experimental data (Parmar *et al*., 2019).The validated model was used to study the impact of intra-seasonal climatic variability on sugarcane yields over the south Gujarat region. For this, the monthly values of climatic parameters *viz.* temperature and rainfall was wereincreased and decreased by -3 to 3 °C for the temperature at 1°Cinterval intervals and rainfall changed by ± 10, ± 15, and ± 25 percentand input weather file was created for use in CANEGRO model and yield was simulated under varying climatic conditions. The percent departure from the yield was calculated. The CANEGRO model was used to evaluate the potential yield of sugarcane for (the 2011-2012 andto 2014-15) periods in the Navsari, Bharuch, Surat, and Valsad districts of South Gujarat. The corresponding the weather data,soil data, and crop management data for each station were collected from research station stationssituated in that district. The districts wise actual sugarcane yield for same period was obtained from The Directorate of Agriculture, Government of Gujarat.Potential The potentialyield was defined as the maximum yield of a crop at a particular station under unlimited of water and nutrients nutrientsupply with optimum cultural management.Attainable The attainableyieldwasdefined as the yield that a farmer could achieve using the bestmanagement practices like optimum planting date, irrigation,fertilizer,*etc.*However, attainable yield yieldsare obtained bydelayed planting by 15 days, which was simulated by using the CANEGRO model.The management yield gap was calculated as the difference between attainable yield and actual yield and the planting yield gap was calculated as the difference between potential yield and attainable yield.District wiseDistrict-wise yield gap was calculated as the difference between the potential and actual yield of sugarcane crop cropsin selected districts.

RESULTS AND DISCUSSION

Effect of temperature variability on different planted sugarcane

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The effect of change in maximum temperature during different months on cane yield under November and December planted conditions are presented in ~~Table~~ Tables1& 2.Results showed that with the increase in maximum temperature and minimum temperature during different months, the cane yield ~~were~~ was found to decrease. Whereas ~~andwith decrease in maximum temperature and minimum temperature~~the cane yield of sugarcane ~~were~~was increasedwith the decrease in maximum temperature and minimum temperature, irrespective of the month. However~~,~~ the magnitude of increase and decrease was found to vary with the month and stage of the crop.

~~**Change in maximum temperature**~~

In November planted sugarcane, the increase in maximum temperature by 3°C resulted decrease incane yield by -0.9 to -3.6%, while with a decrease in maximum temperature, the increase in cane yield was of the order of 1 to 2.9% during the emergence period (November & December months).~~Similar~~ A similareffect was observed during the tillering period (January to March) with slight variation. It may be noted that with a change in maximum temperature by ± 1°C during the emergence & tillering period the change in cane yield was less than ±2.2 %.~~, h~~However, if the maximum temperature was changed by ± 3°C, the change in cane yield was of the order of ± 10 percent. During the grand growth period (April to July), the effect of change in maximum temperature was found to be maximum among all the months. With a change of ± 1°C in maximum temperature, the change in cane yield was observed by ± 2.8 %, and with a change of ± 3°C, the change in cane yield was ± 2 to 14%. During the maturity period (August to October), the effect was generally lower than that observed during the grand growth period (Table 1).In December planted sugarcane, the increase in maximum temperature by 3 °C resulted ina decrease in cane yield by -0.9 to -4.7 %, while with a decrease in maximum temperature, the increase in cane yield was of the order of 1 to 3.4 % during emergence period (December & January months), while in tillering

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period (February to April) with slight variation. It may be noted that with a change in maximum temperature by ± 1°C during the emergence & tillering period, the change in cane yield was less than ±2.2 %. However, if the maximum temperature was changed by ± 3 °C, the change in cane yield was of the order of ± 2-12%.

Table 1: Change in cane yield (%) with incremental change in maximum temperatures (± 3 °C) under November and December planted sugarcane

Month	Change in cane yield (%) in November planted sugarcane						Month	Change in cane yield (%) in December planted sugarcane					
	-3	**-2**	**-1**	**1**	**2**	**3**		**-3**	**-2**	**-1**	**1**	**2**	**3**
November	1.0	0.5	0.3	-0.3	-0.5	-0.9	December	1.0	0.6	0.3	-0.3	-0.5	-0.9
December	2.9	1.8	0.8	-0.9	-2.0	-3.6	January	3.4	2.7	0.9	-1.1	-2.1	-4.7
January	6.3	3.3	1.4	-1.2	-3.2	-6.6	February	6.8	2.4	1.7	-1.4	-2.6	-6.3
February	8.3	2.8	1.9	-1.7	-3.0	-7.6	March	8.1	3.9	1.8	-2.1	-3.6	-8.9
March	9.0	4.3	2.0	-2.2	-4.0	-9.7	April	11.3	5.0	2.0	-2.2	-4.8	-11.5
April	13.3	5.9	2.5	-2.8	-5.8	-13.9	May	9.9	3.7	1.9	-2.2	-3.7	-9.2
May	11.1	4.2	1.8	-2.3	-4.0	-10.3	June	6.9	2.3	1.5	-1.0	-2.7	-6.3
June	6.3	3.1	1.3	-1.5	-3.2	-6.2	July	5.7	2.2	0.9	-1.3	-2.2	-5.2
July	5.2	2.8	1.1	-1.4	-2.4	-5.1	August	4.7	1.8	0.9	-1.2	-1.9	-3.9
August	5.0	2.1	0.9	-1.1	-2.0	-4.3	September	5.1	2.1	1.0	-1.2	-1.8	-4.9
September	4.8	1.8	0.9	-1.0	-1.8	-4.6	October	7.6	3.1	1.8	-1.6	-2.8	-7.2
October	6.7	2.9	1.9	-1.4	-2.7	-6.6	November	6.9	3.5	1.5	-2.0	-3.0	-5.5

During the grand growth period (May to August), the effect of change in maximum temperature was found to be maximum among all the months. With the change of ± 1°C in maximum temperature, the change in cane yield was observed by ± 2.2 %, and with a change of ± 3°C, the change in cane yield was ± 2 to 10 %. During the maturity period (September to November), the effect was generally lower than that observed during the grand growth period

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(Table 1).Higher temperature reduces the rate of photosynthesis andincrease increasesrespiration and reduces the rate of photosynthesis, growth, and yield (Fageria*et al*., 2010).

Change in minimum temperature

In November planted sugarcane, the results showedsthat during the emergence period (November & December months), the increase in minimum temperature by 3°C resulted decrease in cane yield by -0.9to -3.2, while with a decrease in minimum temperature, the increase in cane yield was of the order of 1.0 to 3.7 % (Table 2). Similar A similareffect was observed during the tillering period (January to March) with slight variation. It may be noted that with a change in minimum temperature by ± 1°C during the emergence & tillering period, the change in cane yield was less than ± 2.4, however, if the minimum temperature was changed by ± 3 °C, the change in cane yield was the order of ± 2 to-±10 percent.During the grand growth period (April to July),with the change of ± 1 °C in minimum temperature the change in cane yield was observed by ± 1 to 2.4 % and with the change of ± 3 °C, the change in cane yield was ± 2 to 12 %. While,in the maturity period (August to October), the effect was generally lower than that observed during the grand growth period.In December planted sugarcane, the increase in minimum temperature by 3 °C resulted decrease in cane yield by -0.9 to -3.7 %, while with a decrease in minimum temperature, the increase in cane yield was 1 to 3.4 during the emergence period (December & January months).Similar A similareffect was observed during the tillering period (February to April) with slight variation. It may be noted that with a change in minimum temperature by ± 1 °C during the emergence & tillering period the change in cane yield was less than ± 3 %, however, if the minimum temperature was changed by ± 3 °C, the change in cane yield was of the order of ± 2-10 percent. During the grand growth period (May to August), with change of ± 1 °C in

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minimum temperature, the change in cane yield was observed by ± 0.9 to 2.2 %, and with the change of ± 3 °C, the change in cane yield was ± 2 to 10 %. During the maturity period (September to November), the effect was generally lower than that observed during the grand growth period.Lowtemperature reduces vegetativegrowth rate~~,~~and enrichment of sucrose in the sugarcane and cane yield(Fageria*et al.*, 2010).

Table 2: Change in cane yield (%) with incremental change in minimum temperatures (± 3 °C) under November and December planted sugarcane

	Change in cane yield (%) in November planted sugarcane							Change in cane yield (%) in December planted sugarcane~~(%)~~					
Month	**-3**	**-2**	**-1**	**1**	**2**	**3**	**Month**	**-3**	**-2**	**-1**	**1**	**2**	**3**
November	1.0	0.6	0.2	-0.3	-0.6	-0.9	December	1.0	0.6	0.3	-0.3	-0.7	-0.9
December	3.7	2.4	1.1	-1.4	-1.8	-3.2	January	3.4	1.9	0.9	-1.1	-1.8	-3.7
January	6.2	3.9	1.7	-2.4	-3.1	-5.4	February	9.0	4.0	2.3	-2.6	-3.4	-8.5
February	8.7	4.1	2.2	-2.7	-3.2	-8.1	March	7.6	4.3	1.9	-1.4	-2.3	-9.1
March	8.7	4.8	2.2	-1.4	-2.4	-9.7	April	10.0	3.4	1.9	-1.9	-3.8	-10.3
April	12.0	4.0	2.3	-2.4	-4.5	-12.4	May	8.8	3.7	2.2	-2.0	-3.5	-9.6
May	9.8	4.1	2.2	-2.2	-4.0	-10.4	June	6.7	2.7	1.3	-1.1	-2.3	-6.1
June	6.9	2.9	1.2	-1.5	-2.8	-7.0	July	5.7	2.4	1.2	-0.9	-1.8	-5.2
July	5.8	2.5	1.0	-1.3	-2.3	-5.5	August	4.9	2.2	1.2	-1.0	-1.7	-4.8
August	4.7	2.1	0.9	-1.1	-1.9	-4.6	September	5.5	2.3	1.2	-1.0	-1.8	-5.2
September	5.4	2.2	1.1	-1.2	-2.2	-5.1	October	9.0	3.7	2.0	-1.7	-5.0	-9.1
October	8.4	3.2	1.8	-1.5	-4.6	-8.5	November	7.9	5.2	1.9	-1.3	-3.7	-7.0

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Effect of rainfall variability on different planted sugarcane

The effect of rainfall on the cane yield of sugarcane planted during November and December ~~planted are~~ispresented in Table 3. Results revealed that with an increase in rainfall, the cane yield was found to increase, and with a decrease in rainfall the cane yield was found to decrease. The magnitude of yield variation was found to vary with the month. It may be noted that with the same amount of increase or decrease in rainfall, the yield reduction was more than the yield gain.During June, with an increase in rainfall by 10 to 25%, the increase in cane yield was observed to be 7.6 to 16.6 %, while with a decrease in rainfall by the same amount, the decrease in cane yield was -15 to -24.3%. In ~~the month of~~ July, the effect of rainfall variation was maximum, i.e. with ± 10 to 25 % change in rainfall, the cane yield variation was -26.7 % to +20.8. The effect of rainfall variation in August was found to be the lowest one. It was between -10.8% to +8.9% with a c~~C~~hange in rainfall from -25% to +25%~~ respectively~~. The pattern was similar in September, with a change in yield slightly higher than that of August. Thus, rainfall during the June and July months ~~are~~ isvery crucial for sugarcane ~~crop~~crops.

Table 3: Percent change in cane yield (%) due to variation of rainfall in November and December planted sugarcane

Month	Change in cane yield (%) in November planted sugarcane						Month	Change in cane yield (%) in December planted sugarcane					
	-25	**-15**	**-10**	**10**	**15**	**25**		**-25**	**-15**	**-10**	**10**	**15**	**25**
June	-24.3	-17.9	-15.0	7.6	14.5	16.6	June	-27.1	-19.4	-15.6	8.4	15.3	18.3
July	-26.7	-22.0	-14.7	9.0	16.6	20.8	July	-27.2	-23.0	-15.4	9.1	16.7	21.9
August	-10.8	-8.1	-4.2	3.6	5.4	8.9	August	-10.0	-7.2	-4.0	3.6	5.4	8.2
September	-17.4	-11.6	-8.6	6.1	7.1	9.7	September	-15.8	-10.4	-7.9	5.4	6.5	8.4

During December planted sugarcane the effect of rainfall in ~~the month of~~ June, with an increase in rainfall by 10 to 25 %, the increase in cane yield was observed to be 8.4 to 18.3 %, while a decrease in rainfall by the same amount, the decrease in cane yield was -15.6 to -27.1 %. In ~~the month of~~ July, the effect of rainfall variation was maximum, i.e. with ± 10 to 25 % change in rainfall the yield variation was -27.2 % to +21.9. The effect of rainfall

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variation in August was found to be the lowest one. It was between -10 % to +8.2% to with a c~~C~~hange in rainfall from -25% to +25 %. The pattern was similar in September, with a change in yield slightly higher than that of August.However, good productions arealso being taken in the regions having ~~a~~ 600mm to 3000 mm rainfalls, whichdepends on ~~adoptive~~ adaptivemeasures, selection of varieties,and farming methods (ICAR 2000).

~~Estimation of~~ Potential yields and yield gaps~~analysis~~ of sugarcane

~~Actual yield~~

In the Surat district, the sugarcane ~~mean~~ actual yield was the highest ~~among it was~~(72 t ha^{-1}), which was followed by Navsari, Bharuch, and Valsad withactual yields of 69.2 t ha^{-1}, 68.1 t ha^{-1},and 68.7 t ha^{-1},respectively.

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~~Potential yield~~

The potential yield simulated by the CANEGRO model was also found to be ~~the~~ higher ~~yield~~ in the Navsari district (114.7t ha^{-1}) and it was 1.7 times higher than the actual yield (69.2t ha^{-1}). The potential yield in the Bharuch district (107t ha^{-1}) was also higher than the reported yield (68.1t ha^{-1}) (Table 4). The potential yield in the Surat district (112.8 t ha^{-1}) was 1.6 times higher than the actual yield (72t ha^{-1}). The potential yield in the Valsad district (112.2t ha^{-1}) was 1.7 times higher than the actual yield (68.7t ha^{-1}). It may be seen from ~~the~~ Table 4, that the potential yields were not only higher but also more stable over five years period as ~~CV per cent~~the coefficient of variation was less (5.1 to 8.3) in comparison to ~~higher CV per cent of~~ the reported yield (5.2 to 10.3%~~ per cent~~). Singh *et al.*, (2019) also reported a higher potential yield of sugarcane~~crop~~crops. This m~~ay~~ight be due to the fact that the

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potential conditions were assured to be free from biotic and abiotic stress (Aggarwal and Kalra,1994).

~~Attainable yield~~

The attainable yield was ~~also~~ the highest in Navsari district (98.6 t ha^{-1}) and the lowest ~~yield~~ in Bharuch district (94 t ha^{-1}). The attainable yield in Surat district was 98.3 t ha^{-1} while in Valsad district, it was 96.5 t ha^{-1}. The CV per cent of attainable yield was more or less and similar to that obtained for potential yield (Table 4).

~~Management yield gap~~

The ~~results show that the~~ highest management yield gap (29.4t ha^{-1}) was in the Navsari district and the lowest management yield gap (25.9 t ha^{-1}) was in the Bharuch district. The management yield gap in the Surat district was 26.2 t ha^{-1}and the management yield gap in the Valsad district was 27.8t ha^{-1}(Table 4). Thus, there is large scope in increasing the yield through timely management of sugarcane cultivation in these regions.

~~Planting yield gap~~

The planting yield gap was the highest (16.1 t ha^{-1}) in the Navsari district and lowest (13 t ha^{-1}) in the Bharuch district (Table 4). The planting yield ~~gap~~ gaps were found at 14.6 and 15.7 t ha^{-1}inSurat and Valsad ~~district~~ districts,respectively and it indicated the possibility to obtain higher attainable yield from these areas with the fine adjustment of planting dates.

~~Total yield gap~~

The highest total yield gap (45.5 t ha^{-1}) was in the Navsari district and the lowest yield (38.9tha^{-1}) in the Bharuch district. The total yield gap in the Surat district was 40.8 t ha^{-1} and in the Valsaddistrict, it was 43.5t ha^{-1}(Table 4). The coefficients of variation were between 15 to 19 percent, suggesting higher ~~uncertainly~~ uncertaintywhich is mainly attributed to higher variability in thereported yield.

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Table 4: Actual yield, potential yield, attainable yield, and yield gaps of sugarcane in different districts of South Gujarat

Parameters	Yield (t ha^{-1})			Yield gap (t ha^{-1})		
	Actual	Potential	Attainable	Management	Planting	Total
			Navsari			
Mean	69.2	114.7	98.6	29.4	16.1	45.5
SD	3.6	6.6	3.7	4	4.4	8.1
CV%	5.2	5.8	3.8	13.6	27.3	17.8
			Bharuch			
Mean	68.1	107	94	25.9	13	38.9
SD	4.7	6.3	6.3	4.2	3.2	6.3
CV%	6.9	5.9	6.7	16.2	24.6	16.2
			Surat			
Mean	72	112.8	98.3	26.2	14.6	40.8
SD	4	9.4	8.6	4.7	5	6.4

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CV%	5.6	8.3	8.7	17.9	34.2	15.7
Valsad						
Mean	68.7	112.2	96.5	27.8	15.7	43.5
SD	7.1	5.7	4.9	5	4.9	8.1
CV%	10.3	5.1	5.1	18	31.2	18.6

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CONCLUSION

The ~~simulation analysis revealed that the effect of intra-seasonal variation in temperature and rainfall revealed that,~~ cane yield increased with an increase in rainfall and a decrease in temperature~~, while~~. In contrast, the yield decreased with a decrease in rainfall and an increase in temperature. The extent of effect was found to vary with crop growth stages of the crop.~~Large~~ A large yield gap was found in sugarcane production in the South Gujarat region, the highest yield gap was in the Navsari district while the lowest yield gap was in the Bharuch district. It ~~is~~ indicates that there is a potential scope to improve cane yield with the optimum planting window and good management practices for the region.

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