

Simulate intra-seasonal climatic variability, potential yield and yield gap of sugarcane for 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°C to $+3^{\circ}\text{C}$) 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 option 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 increase in rainfall and decrease in temperature, while the cane yield decreased with decrease in rainfall and 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 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 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.

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 83.3 t ha^{-1} (Anon., 2024). In Gujarat, sugarcane is cultivated in area of 1.81 lakh ha with production and productivity of 134.6 lakh tons and 75.5 t ha^{-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

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 hours from tropical to sub-tropical regions also play 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 crop it is highly influenced by climatic variability such as high temperature during the summer and very low minimum temperatures in winter which ultimately highly influence the ultimate yield of 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 the existing yield gaps and identify the most important constraints to achieve optimal yield and profit. Understanding the causes of these yield gaps, allows to improving yield and profit in a sustainable matter. Crop simulation models have been used to determine potential yield of crop with 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 CANEGRO model.

MATERIALS AND METHODS

The field experimental data of sugarcane for November planting and December planting 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 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 south Gujarat region. For this, the monthly values of climatic parameters *viz.* temperature and rainfall was increased and decreased by -3 to 3 °C for temperature at 1°C interval and rainfall changed by ± 10 , ± 15 and ± 25 percent and 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 (2011-2012 to 2014-15) periods in 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 situated in that district. The districts wise actual sugarcane yield for same period was obtained from The Directorate of Agriculture, Government of Gujarat. Potential yield was defined as the maximum yield of a crop at particular station under unlimited of water and nutrients supply with optimum cultural management. Attainable yield was defined as the yield that farmer could achieve using the best management practices like optimum planting date, irrigation, fertilizer *etc.* However, attainable yield are obtained by delayed planting by 15 days, which was simulated by using 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 wise yield gap was calculated as the difference between the potential and actual yield of sugarcane crop in selected districts.

RESULTS AND DISCUSSION

Effect of temperature variability on different planted sugarcane

The effect of change in maximum temperature during different months on cane yield under November and December planted conditions are presented in Table 1 & 2. Results show that with increase in maximum temperature and minimum temperature during different

months the cane yield were found to decrease and with decrease in maximum temperature and minimum temperature the cane yield of sugarcane were increased, irrespective of month, 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 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 effect was observed during tillering period (January to March) with slight variation. It may be noted that with change in maximum temperature by $\pm 1^{\circ}\text{C}$ during emergence & tillering period the change in cane yield was less than ± 2.2 %, however, if the maximum temperature was changed by $\pm 3^{\circ}\text{C}$, the change in cane yield was of the order of ± 10 percent. During grand growth period (April to July) the effect of change in maximum temperature was found to be maximum among all the months. With change of $\pm 1^{\circ}\text{C}$ in maximum temperature the change in cane yield was observed by ± 2.8 % and with change of $\pm 3^{\circ}\text{C}$, the change in cane yield was ± 2 to 14 %. During maturity period (August to October), the effect was generally lower than that observed during grand growth period (Table 1). In December planted sugarcane, the increase in maximum temperature by 3 °C resulted decrease in cane yield by -0.9 to -4.7 %, while with 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 period (February to April) with slight variation. It may be noted that with change in maximum temperature by $\pm 1^{\circ}\text{C}$ during emergence & tillering period the change in cane yield was less than ± 2.2 %, however, if the maximum temperature was changed by $\pm 3^{\circ}\text{C}$, the change in cane yield was of the order of ± 2 -12%.

Table 1: Change in cane yield (%) with incremental change in maximum temperatures ($\pm 3\text{ }^{\circ}\text{C}$) under November and December planted sugarcane

Month	Change in cane yield (%)						Month	Change in cane yield (%)					
	-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 grand growth period (May to August) the effect of change in maximum temperature was found to be maximum among all the months. With change of $\pm 1\text{ }^{\circ}\text{C}$ in maximum temperature the change in cane yield was observed by $\pm 2.2\%$ and with change of $\pm 3\text{ }^{\circ}\text{C}$, the change in cane yield was ± 2 to 10% . During maturity period (September to November), the effect was generally lower than that observed during grand growth period (Table 1). Higher temperature reduces the rate of photosynthesis and increase respiration and reduces growth and yield (Fageria *et al.*, 2010).

Change in minimum temperature

In November planted sugarcane result shows during the emergence period (November & December months), the increase in minimum temperature by 3 °C resulted decrease in cane yield by -0.9 to -3.2, while with decrease in minimum temperature the increase in cane yield was of the order of 1.0 to 3.7 % (Table 2). Similar effect was observed during tillering period (January to March) with slight variation. It may be noted that with change in minimum temperature by $\pm 1^{\circ}\text{C}$ during emergence & tillering period the change in cane yield was less than ± 2.4 , however, if the minimum temperature was changed by $\pm 3^{\circ}\text{C}$, the change in cane yield was the order of ± 2 -10 percent. During grand growth period (April to July) the change of $\pm 1^{\circ}\text{C}$ in minimum temperature the change in cane yield was observed by ± 1 to 2.4 % and with change of $\pm 3^{\circ}\text{C}$, the change in cane yield was ± 2 to 12 %. While, maturity period (August to October), the effect was generally lower than that observed during 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 decrease in minimum temperature the increase in cane yield was 1 to 3.4 during the emergence period (December & January months). Similar effect was observed during tillering period (February to April) with slight variation. It may be noted that with change in minimum temperature by $\pm 1^{\circ}\text{C}$ during emergence & tillering period the change in cane yield was less than ± 3 %, however, if the minimum temperature was changed by $\pm 3^{\circ}\text{C}$, the change in cane yield was of the order of ± 2 -10 percent. During grand growth period (May to August) with change of $\pm 1^{\circ}\text{C}$ in minimum temperature the change in cane yield was observed by ± 0.9 to 2.2 % and with change of $\pm 3^{\circ}\text{C}$, the change in cane yield was ± 2 to 10 %. During maturity period (September to November), the effect was generally lower than that observed during grand growth period. Low temperature reduces vegetative growth rate, 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 ($\pm 3^\circ\text{C}$) under November and December planted sugarcane

Month	Change in cane yield (%)						Month	Change in cane yield (%)					
	-3	-2	-1	1	2	3		-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

Effect of rainfall variability on different planted sugarcane

The effect of rainfall on cane yield of sugarcane planted during November and December planted are presented in Table 3. Results revealed that with increase in rainfall, the cane yield was found to increase, and with 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 same amount of increase or decrease in rainfall, the yield reduction was more than the yield gain. During June, with increase in rainfall by 10 to 25 % the increase in cane yield was observed to be 7.6 to 16.6 %, while decrease in rainfall by 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 Change in rainfall from -25 % to +25 % respectively. The pattern was similar in September, with change in yield slightly higher than that of August. Thus, rainfall during June and July months are very crucial for sugarcane crop.

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

December planted sugarcane

Month	Change in cane yield (%)						Month	Change in cane yield (%)					
	-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 increase in rainfall by 10 to 25 % the increase in cane yield was observed to be 8.4 to 18.3 %, while decrease in rainfall by 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 variation in August was found to be the lowest one. It was between -10 % to +8.2 to with Change in rainfall from -25% to +25 %. The pattern was similar in September, with change in yield slightly higher than that of August. However, good productions are also being taken in the regions having a 600mm to 3000 mm rainfalls, which depends on adoptive measures, selection of varieties, farming methods (ICAR 2000).

Estimation of Potential yield and yield gap analysis

Actual yield

In Surat district the sugarcane mean yield was highest among it was 72 t ha⁻¹ followed by Navsari, Bharuch and Valsad with 69.2 t ha⁻¹, 68.1 t ha⁻¹ and 68.7 t ha⁻¹ respectively.

Potential yield

The potential yield simulated by the CANEGRO model was also found to be the higher yield in Navsari district (114.7t ha⁻¹) and it was 1.7 times higher than actual yield (69.2t ha⁻¹). The potential yield in Bharuch district (107t ha⁻¹) was also higher than the reported yield (68.1t ha⁻¹) (Table 4). The potential yield in Surat district (112.8 t ha⁻¹) was 1.6 times higher than actual yield (72t ha⁻¹). The potential yield in Valsad district (112.2t ha⁻¹) was 1.7 times higher than 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 was less (5.1 to 8.3) in comparison to higher CV per cent of reported yield (5.2 to 10.3 per cent). Singh *et al.*, (2019) also reported higher potential yield of sugarcane crop. This may be due to the fact that the potential conditions were assured to be free from biotic and abiotic stress (Aggarwal and Kalra,1994).

Attainable yield

The attainable yield was also 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 Navsari district and the lowest management yield gap (25.9 t ha⁻¹) in Bharuch district. The management yield gap in Surat district was 26.2 t ha⁻¹ and the management yield gap in

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 highest (16.1 t ha⁻¹) in Navsari district and lowest (13 t ha⁻¹) in Bharuch district (Table 4). The planting yield gap were found 14.6 and 15.7 t ha⁻¹inSurat and Valsad district 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 yield gap (45.5 t ha⁻¹) was in Navsari district and the lowest yield (38.9tha⁻¹) in Bharuch district. The total yield gap in Surat district was 40.8 t ha⁻¹ and in Valsaddistrict it was 43.5t ha⁻¹(Table 4). The coefficients of variation were between 15 to 19 percent, suggesting higher uncertainly which is mainly attributed to higher variability in thereported yield.

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
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

CONCLUSION

The simulation analysis revealed that the effect of intra-seasonal variation in temperature and rainfall revealed that, cane yield increased with increase in rainfall and decrease in temperature, while the yield decreased with decrease in rainfall and increase in

temperature. The extent of effect was found to vary with crop growth stages of the crop. Large yield gap found in sugarcane production in South Gujarat region, the highest yield gap was in Navsari district while the lowest yield gap was in Bharuch district. It is indicate that there is potential scope to improve cane yield with the optimum planting window and good management practices for the region.

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