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Simulation of Intra-seasonal Climatic Variability, Potential Yield and Yield Gap of Sugarcane for the South Gujarat Region, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The validated CANEGRO (DSSAT v4.7) model was used to simulate the intra-seasonal climatic variation viz. temperature (-3ºC to +3ºC) 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

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fertilizers application and compared with the reported yield of the districts. The cane yield increased with an increase in rainfall and a decrease in temperature. 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. The potential yield of sugarcane simulated by the model in different districts 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.

Keywords: Simulation; climatic variability; sugarcane; potential yield; yield gap.

1. INTRODUCTION

In India, sugarcane occupies about 5.89 million hectares with a total production of 490.53 million tons at an average productivity of 83.3 t ha^{-1} (Anonymous, 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 t ha^{-1}, respectively (Anonymous, 2024). Sugarcane being a tropical plant, its growth and yield are more sensitive to weather conditions (Kushwaha & 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 sunshine hours from tropical to sub-tropical regions also plays an 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 and highly influenced by climatic variability such as high temperatures during the summer and very low minimum temperatures in winter which 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 understanding the existing yield gaps and identifying the most important constraints to achieve optimal yield and profit. Understanding the causes of these yield gaps allows for improving yield and profit in a sustainable manner. Crop simulation models have been used to determine the potential yield of crops 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 the CANEGRO model.

2. 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 the south Gujarat region. For this, the monthly values of climatic parameters *viz*. temperature and rainfall were increased and decreased by -3 to 3°C for the temperature at 1°C intervals 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 the year 2011-12 to 2014-15 periods in the Navsari, Bharuch, Surat and Valsad districts of South Gujarat. The corresponding weather data, soil data and crop management data for each station were collected from research stations situated in that district. The districts wise actual sugarcane yield for same period was obtained from The Directorate of Agriculture, Government of Gujarat. The potential yield was defined as the maximum yield of a crop at a particular station under unlimited water and nutrient supply with optimum cultural management. The attainable yield was defined as the yield that a farmer could achieve using the best management practices like optimum planting date, irrigation, fertilizer *etc.* However, attainable yields are obtained by delayed 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-wise yield gap was calculated as the difference between the potential and actual yield of sugarcane crops in selected districts.

3. RESULTS AND DISCUSSION

3.1 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 Tables 1 & 2. Results showed that with the increase in maximum temperature and minimum temperature during different months, the cane yield was found to decrease. Whereas the cane yield of sugarcane was increased with 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.

In November planted sugarcane, the increase in maximum temperature by 3°C resulted decrease in cane 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). A similar effect 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%. 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 in a 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 the emergence period (December & January months), while in tillering 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 to ±12%.

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

In November planted sugarcane, the results showed that 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 a decrease in minimum temperature, the increase in cane yield was of the order of 1.0 to 3.7% (Table 2). A similar effect 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 ±2.7, 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 ±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). A similar effect 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 to ±10 percent. During the grand growth period (May to August), with change of ±1°C in minimum temperature the change in cane yield was observed by ± 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. Low temperature reduces vegetative growth rate and enrichment of sucrose in the sugarcane and cane yield (Fageria et al., 2010).

3.2 Effect of Rainfall Variability on Different Planted Sugarcane

The effect of rainfall on the cane yield of sugarcane planted during November and December is presented in Table 3. Results revealed that in November planted sugarcane 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 July, the effect of rainfall variation was maximum, i.e. with ±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 change in rainfall from ±25%. 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 is very crucial for sugarcane crops.

During December planted sugarcane the effect of rainfall in 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 July, the effect of rainfall variation was maximum, i.e. with ±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 a change in rainfall from ±25%. The pattern was similar in September, with a change in yield slightly higher than that of August. However, good productions are also being taken in the regions having 600mm to 3000 mm rainfalls, which depends on adaptive measures, selection of varieties and farming methods (ICAR, 2000).

3.3 Potential Yields and Yield Gaps of Sugarcane

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

The potential yield simulated by the CANEGRO model was also found to be higher in the Navsari district (114.7 t ha^{-1}) and it was 1.7 times higher than the actual yield (69.2 t ha^{-1}). The potential yield in the Bharuch district (107.0 t ha^{-1}) was also higher than the reported yield (68.1 t ha^{-1}) (Table 4). The potential yield inthe Surat district (112.8 t ha^{-1}) was 1.6 times higher thanthe actual yield (72 t ha^{-1}). The potential yield in the Valsad district (112.2 t ha^{-1}) was 1.6 times higher than the actual yield (68.7 t ha^{-1}). It may be seen from Table 4, that the potential yields were not only higher but also more stable over five years period as the coefficient of variation was less (5.1 to 8.3) in comparison to the reported yield (5.2 to 10.3%). Singh et al. (2019) also reported a higher potential yield of sugarcane crops. This might be due to the fact that the potential conditions were assured to be free from biotic and abiotic stress (Aggarwal & Kalra, 1994).

The attainable yield was the highest in Navsari district (98.6 t ha^{-1}) and the lowest in Bharuch district (94.0 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).

The highest management yield gap (29.4 t 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 27.8 t ha^{-1} (Table 4). Thus, there is large scope in increasing the yield through timely management of sugarcane cultivation in these regions.

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

Table 2. Change in cane yield (%) with incremental change in minimum 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	0.6	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

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

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	4.0	4.4	8.1
CV%	5.2	5.8	3.8	13.6	27.3	17.8
Bharuch						
Mean	68.1	107.0	94.0	25.9	13.0	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	72.0	112.8	98.3	26.2	14.6	40.8
SD	4.0	9.4	8.6	4.7	5.0	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	5.0	4.9	8.1
CV%	10.3	5.1	5.1	18.0	31.2	18.6

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 gaps were found at 14.6 t ha^{-1} and 15.7 t ha^{-1} in Surat and Valsad districts, respectively and it indicated the possibility to obtain higher attainable yield from these areas with the fine adjustment of planting dates.

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

4. CONCLUSION

The cane yield increased with an increase in rainfall and a decrease in temperature. 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. 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 indicates that there is a potential scope to improve cane yield with the optimum planting window and good management practices for the region.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Aggarwal, P. K., & Kalra, N. (1994). Analyzing the limitations set by climatic factors, genotype, and water and nitrogen availability on productivity of wheat II. Climatically potential yields and management strategies. *Field Crops Research*, 38, 93–103.

Anonymous. (2024). https://sugarcane.dac.gov.in/schemes/APY.pdf

Fageria, N. K., Virupax, C. B., & Jones, C. A. (2010). *Growth and mineral nutrition of field crops* (3rd ed.). CRC Press, 437–456.

ICAR (Indian Council of Agricultural Research). (2000). *Handbook of agriculture* (5th ed.). New Delhi.

Kushwaha, W. S., & Pal, Y. (2000). Sugarcane weather relationship in Northwest Uttar Pradesh. *Tropmet-2000, Oce. & Atmos.*, 5(8), 564–570.

Parmar, P. K., Mali, S. C., Arvadiya, L. K., Patel, D. P., Viyol, S. V., & Pandey, V. (2019). Calibration and validation of CANEGRO model for sugarcane in south Gujarat region. *Journal of Agrometeorology*, 21(3), 388–391.

Samui, R. P., John, G., & Kulkarni, M. B. (2003). Impact of weather on yield of sugarcane at different growth stages. *Journal of Agricultural Physics*, 3, 119–125.

Singh, K. K., Mall, R. K., Singh, R. S., & Srivastava, A. K. (2010). Evaluation of CANEGRO sugarcane model in East Uttar Pradesh, India. *Journal of Agrometeorology*, 12(2), 181–186.

Singh, K. K., Singh, R. S., Bhengra, A. H., & Singh, P. (2019). Yield gap analysis of sugarcane in different agro-climatic zones of Uttar Pradesh using DSSAT-CANEGRO model. *Vayu Mandal*, 45(1), 9–25.

Singh, V. K., Shukla, A. K., Gill, M. S., Sharma, S. K., & Tiwari, K. N. (2008). Improving sugarcane productivity through balanced nutrition with potassium, sulphur, and magnesium. *Better Crops – India*, 2(1), 12–14.

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