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Sensitivity analysis of CROPGRO- cotton model to intra-seasonal climatic variability in middle Gujarat

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ABSTRACT

The CROPGRO-Cotton model was first calibrated and validated with the six years (2011-12 to 2016-17) of experimental data collected at Regional Research Station, A.A.U., Anand for two cultivars of cotton (DCH 32 and G. Cot. Hy. 102) to study the effect of intra-seasonal climatic variability on seed cotton yield. The model sensitivity analysis was carried out by incremental change in climatic parameters (maximum and minimum temperature from -3^0 to +3^{0}C) and rainfall (-25% to +25%). Results revealed that elevated temperature had negative effect on seed cotton yield and reduced temperature had positive effect on seed cotton yield. The varieties DCH 32 was slightly less affected by the temperature variation than G. Cot. Hy. 102. Temperature variation during October to December was found to have maximum effect on cotton crop. The effect of minimum temperature on seed cotton yield was more than that observed with maximum temperature.Cotton crop was affected more by variation in rainfall during September in comparison to that of July and August.

Keywords : Intra-seasonal temperature, rainfall, CROPGRO- cotton

Cotton (*Gossypium hirsutum* L.) is one of the major cash crops of India, popularly known as "white gold and "King of fibres for its role in the national economy in terms of foreign exchange earnings and employment generation. It is the world's leading source of natural textile fibre and fifth largest oilseeds crop which covers forty per cent of the global textile need (APTMA, 2012) and 3.3 per cent of edible oil (FAS, 2014) respectively. This crop provides livelihood to sixty million people in India by way of support of agriculture, processing and textiles and it contributes to twenty nine per cent of the national GDP (Khadi, 2010). India has the credit of the largest area under cotton (126.55 lakh ha) and ranks second in cotton production (400 lakh bales) during 2014-15 (Nagender, 2017). However, the productivity of seed cotton in India is 537 kg ha^{-1} which is below the world average of 790 kg ha^{-1}.

Climate affects crop growth interactively, sometimes resulting in unexpected responses to prevailing conditions. Many factors, such as length of the growing season, climate (including solar radiation, temperature, light, wind, rainfall and dew), cultivar, availability of nutrients and soil moisture, pests and cultural practices affect cotton growth (El-Zik, 1980). Temperature is also a primary factor controlling rates of plant growth and development. Hodges *et al*. (1993) found that the optimum temperature for cotton stem and leaf growth, seedling development and fruiting was almost 30°C, with fruit retention decreasing rapidly as the time of exposure to 40°C increased. Reddy *et al.* (1999) also observed that high temperatures produce bud shedding in cotton and they further reported that temperature regimes alter boll development, boll size and the maturity period both decreased as the temperature increased.

The CROPGRO-Cotton model is a member of the CROPGRO group of models (Hoogenboom, 1992) in DSSAT. Crop models have been described as a "quantitative schemes for predicting the growth, development and yield of a crop, given a set of genetic coefficients and relevant environmental variables" (Monteith, 1996). Models can be used to predict crop growth, development and yield as a function of soil, climate, weather, and crop management conditions. Crop simulation models have been used to study the effect of intra-seasonal variation in temperature on yield of wheat in India (Sandhu *et al.,* 2016). Patil *et al*. (2018 a & b) have reported the effect of intra-seasonal variation of temperature on tuber yield of potato and seed yield of pigeonpea in Gujarat using DSSAT group of models.Temperature is a primary environmental factor controlling growth and developmental rates of plants, yet little specific information is available regarding cotton (*Gossypium hirsutum* L.) responses to temperature. Information covering a wide range of temperatures would be useful for predicting both developmental and growth rates in cotton. The objective of this study was to assess the effect of intra-seasonal climatic variability on seed cotton yield of cotton in middle Gujarat using CROPGRO- cotton model.

MATERIALS AND METHODS

Experimental and weather data

The data collected during six years of experimentation (2011-12 to 2016-17) on two cultivars (V_1- DCH 32 and, V_2- G. Cot. Hy. 102) of cotton was obtained from Regional Research Station, Anand Agricultural University, Anand. Seeds were sown on the onset of monsoon with spacing of

Table 1: Mean seed cotton yield (kg ha^{-1}) of cotton of two varieties during six years (2011-12 to 2016-17)

Year	V_1: (DCH 32)	V_2: (G. Cot. Hy. 102)
2011-12	1287	941
2012-13	394	803
2013-14	1115	1152
2014-15	444	414
2015-16	1506	983
2016-17	1337	996
2017-18	1014	882

Table 2: Genotype coefficients of cotton cultivars DCH - 32 and G Cot. Hy. 102

Parameters	Description of parameters	Genotype coefficients	
		DCH - 32	G.Cot.Hy.102
CSDL	Critical Short Day Length below which reproductive development progresses with no day length effect (for short day plants) (hour)	23	23
PPSEN	Slope of the relative response of development to photoperiod with time (Positive for short day plants) (1/hour)	0.01	0.01
EM-FL	Time between plant emergence and flower appearance (R1) (photothermal days)	42	40
FL-SH	Time between first flower and first pod (R3) (photothermal days)	13	15
FL-SD	Time between first flower and first seed (R5) (photothermal days)	18	21
SD-PM	Time between first seed (R5) and physiological maturity (R7) (photothermal days)	55	51
FL-LF	Time between first flower (R1) and end of leaf expansion (photothermal days)	70	67
LFMAX	Maximum leaf photosynthesis rate at 300 C, 350 vpm CO_2 and high light (mg CO_2/m^2-s)	1.3	1.3
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm^2/g)	390	390
SIZLE	Maximum size of full leaf (three leaflets) (cm^2)	390	390
XFRT	Maximum fraction of daily growth that is partitioned to seed+shell	0.75	0.75
WTPSD	Maximum weight per seed (g)	0.18	0.18
SFDUR	Seed filling duration for pod cohort at standard growth conditions (photothermal days)	35	35
SDPDV	Average seed per pod under standard growing conditions (#/pod)	27	27
PODUR	Time required for cultivar to reach final pod load under optimal conditions (photothermal days)	10	10
THRSH	Threshing percentage. The maxi. ratio of seed [seed/(seed+shell)]	79	75
SDPRO	Fraction protein in seeds [g(protein)/g(seed)]	0.141	0.151
SDLIP	Fraction oil in seed [g(oil)/g(seed)]	0.12	0.12

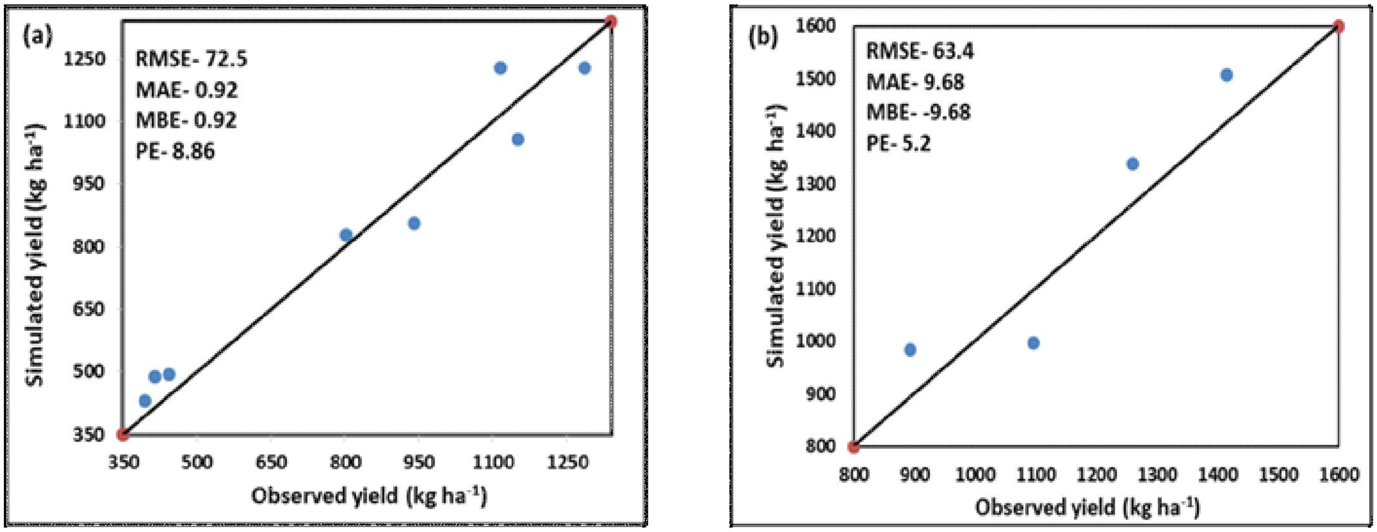

Fig. 1: Observed and simulated seed cotton yield of cotton during (a) calibration period (2011to 2014) and (b) validation (2015 and 2016) of CROPGRO-cotton model

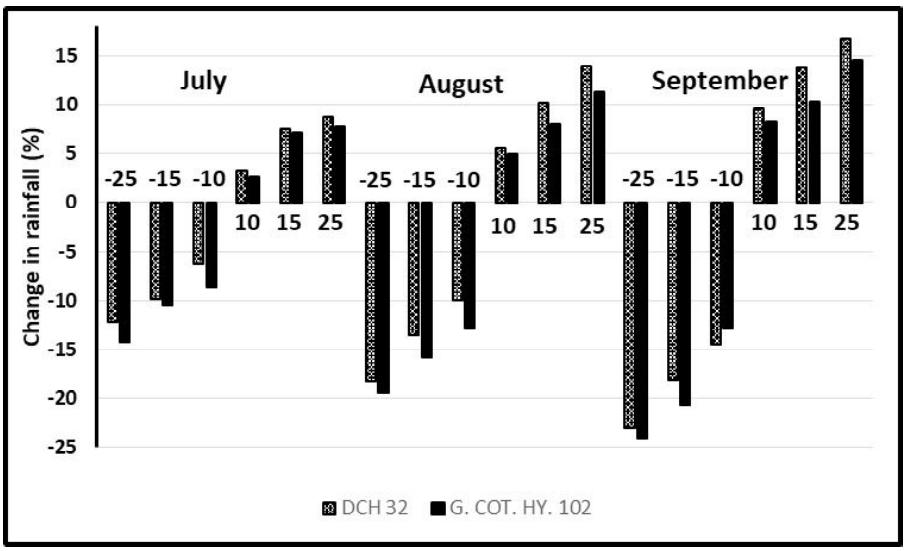

Fig. 2 : Effect of intra-seasonal variation of rainfall on seed cotton yield

120cm x 45cm and with recommended dose of fertilizer 240:40:25 NPK kg ha^{-1} during all the growing seasons. The soil type of the experimental site was sandy loam a true representative soil of the region. Irrigation was applied during dry spell and plant protection measures were followed as per the scheduled package of practices. The corresponding weather data was obtained from Department of Agricultural Meteorology, Anand Agricultural University, Anand.

CROPGRO- cotton model

The DSSAT family of CROPGRO- cotton model (Hoogenboom *et al.,* 2004) was employed to simulate seed cotton yield of cotton crop. The model was calibrated and validated for two cultivars with the experimental data. The model was calibrated with the four years (2011-12 to 2014-15) of experimental data and validated with two years (2015-16 and 2016-17) data. The cultivar coefficients were estimated by repeated iteration's by running the GLUE coefficient estimator until a close match between simulated and observed seed cotton yield was obtained (Table 2).

The model performance was evaluated using test criteria viz. root mean square error (RMSE), mean absolute error (MAE), mean bias error (MBE), coefficient of determination (R^2) and per cent error (PE) and calculated as reported by Patil and Patel (2017).

Impact studies

The validated CROPGRO-cotton model was used to

Table 3: Intra seasonal effects of maximum and minimum temperature on seed cotton yield in different months

Months	Change in temperature	Maximum temperature		Minimum temperature	
		DCH 32	G. COT. HY. 102	DCH 32	G. COT. HY. 102
July	-3	4.7	5.1	4.4	4.6
	-2	3.1	2.8	2.6	2.7
	-1	1.2	1.4	0.9	1.1
	1	-1.7	-2.1	-1.5	-1.8
	2	-3.5	-3.9	-3.3	-3.7
	3	-5.3	-5.5	-4.6	-5.0
August	-3	9.6	10.2	9.0	9.3
	-2	6.2	6.6	5.6	6.3
	-1	2.2	2.1	1.9	2.1
	1	-2.5	-3.0	-2.3	-2.4
	2	-5.1	-5.6	-4.6	-5.1
	3	-7.8	-8.3	-7.1	-7.6
September	-3	10.7	10.9	9.9	10.2
	-2	8.6	8.5	8.0	8.2
	-1	4.2	4.0	3.7	3.7
	1	-4.5	-4.1	-4.3	-4.6
	2	-8.9	-7.6	-8.4	-8.1
	3	-11.7	-12.1	-11.2	-11.0
October	-3	9.3	9.9	8.8	9.4
	-2	8.2	8.5	7.9	8.0
	-1	6.3	6.5	5.6	5.9
	1	-5.9	-6.1	-5.8	-5.9
	2	-9.4	-10.1	-9.3	-9.9
	3	-12.7	-12.3	-11.5	-11.6
November	-3	9.5	9.8	9.2	9.6
	-2	8.6	8.2	8.6	8.1
	-1	6.5	6.1	6.2	6.6
	1	-6.1	-6.2	-5.9	-6.0
	2	-9.8	-9.9	-9.6	-9.3
	3	-12.3	-12.5	-11.5	-11.1
December	-3	9.8	9.7	9.5	9.7
	-2	8.0	8.6	7.2	7.8
	-1	5.9	6.3	5.4	5.8
	1	-6.5	-6.7	-6.2	-6.1
	2	-9.6	-9.5	-9.4	-9.6
	3	-13.1	-11.3	-12.1	-11.8
January	-3	9.6	9.9	9.0	9.2
	-2	6.3	6.6	5.8	6.2
	-1	4.4	4.9	4.2	4.4
	1	-5.1	-5.6	-4.5	-4.8
	2	-7.2	-7.5	-6.1	-6.3
	3	-9.5	-9.7	-9.0	-9.2

study the effect of intra seasonal variation of temperatures and rainfall on seed cotton yield of both varieties under normal conditions i.e by normal weather data and management practices. Climatic variability was studied by incremental change in the monthly maximum and minimum temperatures from -3^{0}C to 3^{0}C during July to January months at 1^{0}C interval and rainfall change by ±10, ±15 and ±25 per cent during July to September. The simulated seed cotton yields were compared with the mean observed yield and the per cent departure were calculated.

RESULTS AND DISCUSSION

Seed cotton yield

The mean observed seed cotton yield of two cultivars of cotton during six years are presented in Table 1. Among different varieties, the maximum seed cotton yield (1014 kg ha^{-1}) was observed in Cv. DCH 32 and lowest under cv. G. Cot. Hy. 102 (882 kg ha^{-1}). During five years of experimentation, the mean seed cotton yield varied between 1506 kg ha^{-1} in 2015-16 to 394 kg ha^{-1} in 2012-13 (Table 1).

Calibration and validation

The observed and simulated seed cotton yield of cotton cultivars during calibration (2011-12 to 2014-15) and validation period (2015-16 and 2016-17) are presented in Fig. 1. The model performance evaluated by test criteria viz. RMSE (72.5), MBE (0.92), MAE (0.92) and PE (8.8) for calibration years indicated close relationship with minimum error. During validation period also the performance of model was quite satisfactory as indicated by the test criteria (RMSE:63.4, MBE:-9.68, MAE:9.68 and PE- 5.2). Hence this model can be used to simulate the tuber yield of different cultivars under different environment.

Effect of temperature variations on varieties

The effect of increase and/or decrease in maximum and minimum temperatures from -3^{0}C to +3^{0}C in different months on seed cotton yield of two varieties of cotton are presented in Table 3. It is seen that the increase in maximum as well as minimum temperature caused decrease in seed cotton yield in the cultivars, the magnitude varied with the cultivars, as well as the period and the extent of increase in temperature. Overall, the effect of maximum temperature variation was higher (-13.1 to +10.7%) in DCH 32 than that in G. Cot. Hy. 102 (-12.5 to 10.9%). The response of change in maximum temperature was higher in December. The change in maximum temperature during September to December had profound influence on seed cotton yield in comparison to other months (Table 3). Kumar *et al.,* (2017) and Singh *et al.,* (2008) also reported that increasing daily maximum temperature led to decrease in the yield and similar trend was observed in decreasing maximum temperature increase yield.

The effect of change in minimum temperature on seed cotton yield of both the cultivars was slightly less than that observed with maximum temperature (Table 3). The increase in minimum temperature up to 3^{0}C had highest (-12.1%) yield reduction in cv. DCH 32 followed by -11.8 per cent in G. Cot. Hy. 102. During October to December, the increase in minimum temperature by 3^{0}C had highest reduction in seed cotton yield (-12.5 to -11.5%) of DCH 32 followed by -11.8 to -11.6 per cent reduction in G. Cot. Hy. 102. Thus the cultivar G. Cot. Hy. 102 was less influenced by change in temperatures in comparison to DCH 32.Kumar *et al.,* (2017) also revealed that increase in minimum temperature decreased seed cotton yield.

Effect of rainfall variation on varieties

The effect of increase and/or decrease in rainfall by ±10, ±15 and ±25 per cent in the months of July, August and September on seed cotton yield of two varieties of cotton are presented in Fig. 2. It is seen that the increase in rainfall caused increase in seed cotton yield in both the cultivars, the magnitude varied with the cultivars, as well as the period and the extent of increase rainfall. The variation was highest in the month of September viz. -24.1 to 14.5 per cent in Cv. G. Cot. Hy. 102 and -22.9 to 16.7 per cent in DCH 32. Rainfall during September month affected most on seed cotton yield in both the varieties followed by August and July months. Cv. DCH 32 was less affected due to rainfall as compared to Cv. G. Cot. Hy. 102 (Fig. 2). Similar results were reported by earlier workers Kumar *et al.,* (2017) and Singh *et al.* (2008).

CONCLUSION

The CROPGRO- cotton model of DSSAT family, calibrated and validated for two cultivars of cotton, simulated the seed cotton yield of cotton under different environment satisfactorily with error per cent less than 10. Hence this model can be used for studying the effect of different environments and management practices on cotton crop in middle Gujarat. The increase and decrease in maximum and minimum temperatures and rainfall had negative/postive impact of seed cotton yield of cotton, the extent of which varied with cultivars and the period/month of temperature change. Overall minimum temperature is found to have less impact on seed cotton yield in all months as compared to maximum temperature.

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