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Sensitivity analysis of three pearl millet cultivars to varying temperature and CO_2 concentration on summer pearl millet in south Saurashtra Agro-climatic zone of Gujarat using CERES-MILLET model

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ABSTRACT

The sensitivity analysis of three cultivars (GHB 538, GHB 558 and GHB 732) of pearl millet was performed to study the impact of climate change on summer pearl millet in south Saurashtra Agro-climatic zone of Gujarat using calibrated CERES-millet model by changing maximum and minimum temperatures by -4 to +4 °C and increasing concentration of CO_2 upto 530 ppm. Results revealed that with increase in maximum temperature by 4 °C, the grain yield was decreased by 11.4 to 19.9 % and anthesis and maturity was decreased by 10 to 13 days in different cultivars. The effect of minimum temperature was also of the similar order to maximum temperature, but the varietal differences were observed. The simulated grain yield increased up to 18.2 %, anthesis increased up to 11 days and maturity increased up to 17 days with elevated CO_2 concentration of 530 ppm.

Keywords: CERES-millet, climate change, CO_2, pearl millet, sensitivity analysis, temperature.

INTRODUCTION

India is the largest producer of pearl millet in the world. In India major producing states are Rajasthan (46 %), Maharashtra (19 %), Gujarat (11 %), Uttar Pradesh (8 %) and Haryana (6 %), which share about 90 per cent of total pearl millet production. Pearl millet occupies an area of 7.12 million hectares with a production of 8.06 million tonnes and productivity of 1132 kg/ha in the country. While in Gujarat, Total grown area 4.31 lakh hectares with a total production of 9.31 lakh tonnes and productivity of 2158 kg/ha. (Anon. 2017) [1]. Current variation in crop productivity and yield among different regions, are likely to become greater due to impact of climate change. Crop production is affected biophysically by meteorological variables including rising temperatures, changing precipitation regimes and increased atmospheric carbon dioxide levels. The climate changes involve in the next century are mostly attributed to the increasing concentration of CO_2 and other "greenhouse gases". The biophysical effects of climate change on agricultural production will be positive in some agricultural systems and regions, while negative in others and these effects will vary through time. Globally, the mean temperature has increased by 0.7 °C and it is projected to increase by 1.8 to 4.0 °C by 2100 (IPCC, 2014) [2]. In addition to increase in temperature, the increase in frequency of extreme weather events viz., heat waves, floods, cyclones and droughts. These events are bound to affect the agricultural production. Most of the simulation studies have shown a decrease in the duration and yield of crops as temperature increased in different parts of India. The nutritional quality of cereals and pulses may also be moderately affected which, in turn, will have consequences for our nutritional security. The change in climate may bring about changes in population dynamics, growth and distribution of insects and pests. Global reports indicate a loss of 10-40 % in crop production by 2100. Increasing temperature would increase fertilizer requirement for the same production targets result in higher emissions.

MATERIALS AND METHODS

The field experiment was conducted during summer season of year 2019 at Instructional Farm, Department of Agronomy, JAU, Junagadh (Gujarat). Geographically the experimental site was situated at 21.51° N latitude and 70.55° E longitude at an altitude of 83 m above mean sea level. The experiment was laid out in split plot design, consisting 36 treatment combinations comprised of four sowing dates were 25th January (D_1), 5th February (D_2), 15th February (D_3) and 25th February (D_4) and three varieties were GHB-538 (V_1), GHB-558 (V_2) and GHB-732 (V_3) with three replications.

The reference, optimum or base yield for all cultivars selected in this study was simulated by running the CERES-millet model with daily normal weather data set. One variable at a time was modified and its effect was studied on yield, anthesis and maturity of cultivars. however, all other variables were kept the normal as such (Hundal and Kaur, 2007) [3]. Hence, the obtained yield simulated for all cultivars were considered as reference or base yield. Sensitivity analysis is an important way of evaluating models. It helps to better understand variation in output to change in inputs. The analysis was done with input parameters which include maximum and minimum temperatures and CO_2 concentration. The sensitivity analysis of climate change was carried out by increasing and decreasing maximum and minimum temperature by -4 to +4 °C and CO_2 level of 440, 470, 500 and 530 ppm in input file of the model.

RESULTS AND DISCUSSION

The present study was carried out mainly to establish the sensitivity of CERES-millet model in relation to grain yield, anthesis and maturity of various cultivars of pearl millet affected by individual weather parameters.

Table 1: Effect of maximum temperature, minimum temperature and CO_2 concentration on grain yield of pearl millet cultivars.

	Cultivars					
	V_1 – GHB 538		**V_2 – GHB 558**		**V_3 – GHB 732**	
Base yield	**4070 kg/ha**		**4914 kg/ha**		**5020 kg/ha**	
Change in parameter	**Simulated grain yield (kg/ha)**	**% Change over base yield**	**Simulated grain yield (kg/ha)**	**% Change over base yield**	**Simulated grain yield (kg/ha)**	**% Change over base yield**
Maximum temperature (°C)						
-4	4652	14.3	5744	16.9	5701	13.6
-3	4511	10.8	5630	14.6	5628	12.1
-2	4433	8.9	5500	11.9	5542	10.4
-1	4200	3.2	5241	6.7	5322	6.0
+1	4010	-1.5	4800	-2.3	4811	-4.2
+2	3901	-4.2	4710	-4.2	4721	-6.0
+3	3744	-8.0	4214	-14.2	4335	-13.6
+4	3607	-11.4	4021	-18.2	4021	-19.9
Minimum temperature (°C)						
-4	4600	13.0	5684	15.7	5641	14.8
-3	4460	9.6	5570	13.3	5550	12.9
-2	4386	7.8	5440	10.7	5482	11.6
-1	4150	2.0	5181	5.4	5262	7.1
+1	3940	-3.2	4740	-3.5	4751	-3.3
+2	3901	-4.2	4650	-5.4	4661	-5.1
+3	3690	-9.3	4154	-15.5	4275	-13.0
+4	3550	-12.8	3961	-19.4	3920	-20.2
CO_2 concentration levels (Base value 410 ppm)						
440	4210	3.4	5200	5.8	5210	3.8
470	4430	8.8	5345	8.8	5366	6.9
500	4621	13.5	5614	14.2	5679	13.1
530	4810	18.2	5789	17.8	5843	16.4

Table 2: Effect of maximum temperature, minimum temperature and CO_2 concentration on anthesis of pearl millet cultivars.

	Cultivars					
	V_1 – GHB 538		**V_2 – GHB 558**		**V_3 – GHB 732**	
Base anthesis	**60 days**		**62 days**		**64 days**	
Change in parameter	**Simulated anthesis days**	**Change in anthesis days**	**Simulated anthesis days**	**Change in anthesis days**	**Simulated anthesis days**	**Change in anthesis days**
Maximum temperature (°C)						
-4	66	6	70	8	71	7
-3	63	3	66	4	69	5
-2	61	1	64	2	67	3
-1	60	0	63	1	65	1
+1	60	0	58	-4	64	0

+2	56	-4	55	-7	64	0
+3	54	-6	52	-10	59	-5
+4	50	-10	49	-13	52	-12
Minimum temperature (°C)						
-4	67	7	72	10	73	9
-3	65	5	66	4	67	3
-2	62	2	64	2	65	1
-1	61	1	63	0	65	0
+1	60	0	60	-2	64	0
+2	55	-5	55	-7	60	-4
+3	53	-7	50	-12	57	-7
+4	48	-12	45	-17	51	-13
CO_2 concentration levels (Base value 410 ppm)						
440	63	3	64	2	65	1
470	65	5	67	5	68	4
500	68	8	70	8	71	7
530	70	10	73	11	74	10

Table 3: Effect of maximum temperature, minimum temperature and CO_2 concentration on maturity of pearl millet cultivars.

	Cultivars					
	V_1 – GHB 538		**V_2 – GHB 558**		**V_3 – GHB 732**	
Base maturity	**98 days**		**101 days**		**104 days**	
Change in parameter	**Simulated maturity days**	**Change in maturity days**	**Simulated maturity days**	**Change in maturity days**	**Simulated maturity days**	**Change in maturity days**
Maximum temperature (°C)						
-4	111	13	115	14	116	12
-3	108	10	112	11	113	9
-2	105	7	109	8	107	3
-1	100	2	102	1	105	1
+1	97	-1	99	-2	102	-2
+2	95	-3	95	-6	99	-5
+3	93	-5	90	-11	96	-8
+4	88	-10	88	-13	93	-11
Minimum temperature (°C)						
-4	113	15	117	16	114	10
-3	110	12	114	13	110	6
-2	107	9	112	11	108	4
-1	102	4	102	1	105	1
+1	99	1	98	-3	103	-1
+2	93	-5	95	-6	100	-4
+3	91	-7	92	-9	97	-7
+4	86	-12	87	-14	93	-11
CO_2 concentration levels (Base value 410 ppm)						
440	105	7	106	5	111	7
470	109	11	110	9	113	9
500	112	14	114	13	116	12
530	115	17	117	16	118	14

Effect of maximum temperature

Sensitivity of CERES-millet model simulated yield, anthesis and maturity showed that with increasing in maximum temperature from +1 to +4 °C, a gradual decrease in yield, anthesis and maturity was observed under optimal date of sowing (D_3 – 15th February). While decreasing in maximum temperature from -1 to -4 °C, a gradual increase in yield, anthesis and maturity was observed under optimal date of sowing (D_3 - 15 February). The effect of altered maximum temperature (-4 to +4 °C) on simulated grain yield, anthesis and maturity of three cultivars of pearl millet under optimal date of sowing (D_3 – 15th February) was compared with base yield, base anthesis days and base maturity days. The percentage change from base yield, base anthesis days and base maturity days are presented in Table 1, 2 and 3 and Fig. 1.

The percent change over base yield, base anthesis days and base maturity days was found due to change in maximum temperature. In yield, highest change was obtained in cultivar GHB 558 (+16.9 to -18.2 %) followed by cv. GHB 732 (+13.6 to -19.9 %) and cv. GHB 538 (+14.3 to -11.4 %). In anthesis, highest change was obtained in cultivar GHB 558 (+8 to -13 days) followed by cv. GHB 732 (+7 to -12 days) and cv. GHB 538 (+6 to -10 days). In maturity, highest change was obtained in cultivar GHB 558 (+14 to -13 days) followed by GHB 538 (+13 to -10 days) and cv. GHB 732 (+12 to -11 days). Overall results showed that elevated maximum temperature decreased grain yield, anthesis days and days to maturity in all cultivars significantly and vice - versa.

Effect of minimum temperature

Sensitivity of CERES-millet model simulated yield, anthesis and maturity presented in Table 1, 2 and 3 and Fig. 2. The results showed that with increasing in minimum temperature from +1 to +4 °C, a gradual decrease in yield, anthesis and maturity was observed under optimal date of sowing (D_3 – 15th February). While decreasing in minimum temperature from -1 to -4 °C, a gradual increase in yield, anthesis and maturity was observed under optimal date of sowing (D_3 – 15th February).

The percent change over base yield, base anthesis days and base days to maturity was found due to change in minimum temperature. In yield, highest change was obtained in cultivar GHB 558 (+15.7 to -19.4 %) followed by cv. GHB 732 (+14.8 to -20.2) and cv. GHB 538 (+13.0 to -12.8). In anthesis, highest change was obtained in cultivar GHB 558 (+10 to -17 days) followed by cv. GHB 732 (+9 to -13 days) and cv. GHB 538 (+7 to -12 days). In maturity, highest change was obtained in cultivar GHB 558 (+16 to -14 days) followed by GHB 538.

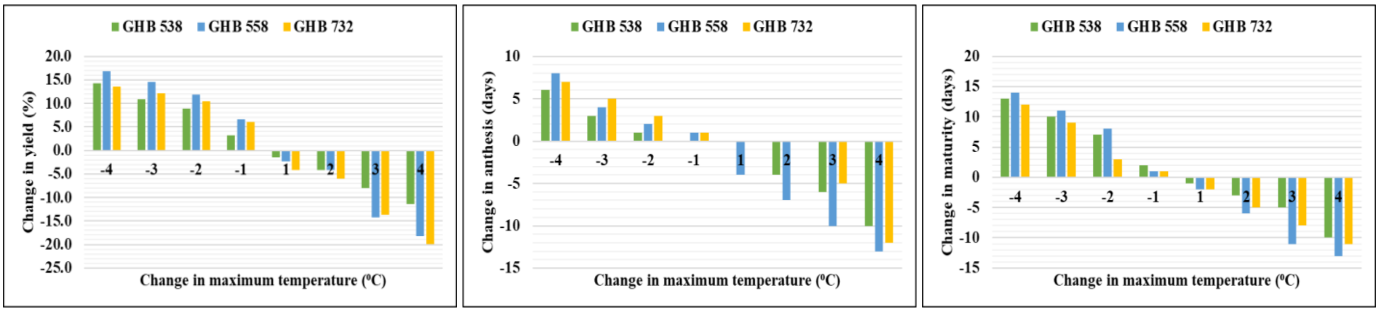

Figure 1: Effect of increased and decreased maximum temperature on grain yield, anthesis and maturity of pearl millet cultivars.

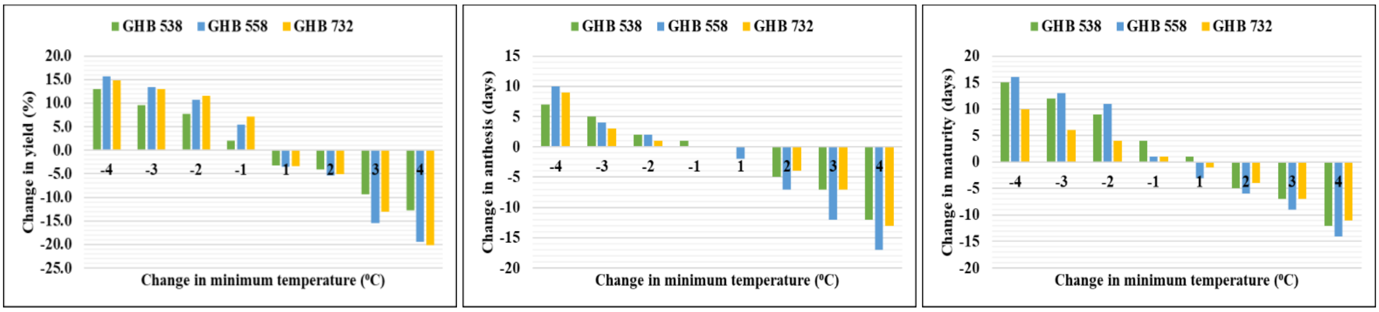

Figure 2: Effect of increased and decreased minimum temperature on grain yield, anthesis and maturity of pearl millet cultivars.

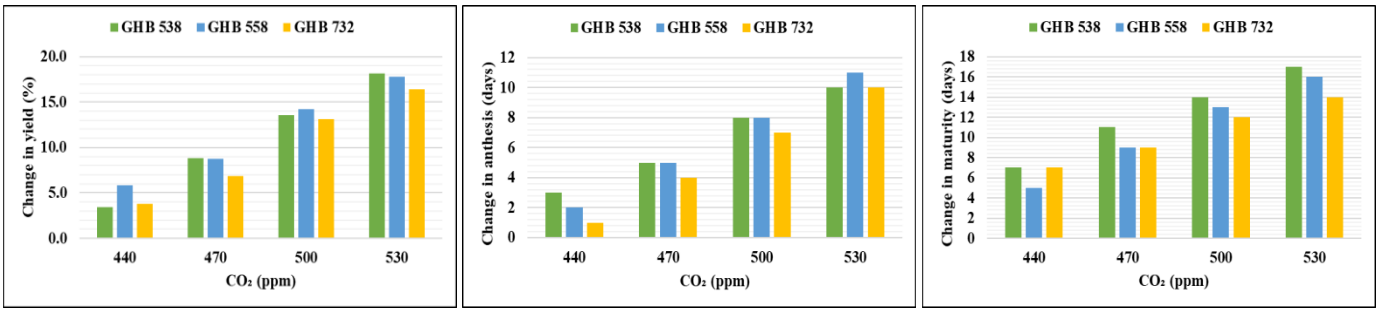

Figure 3: Effect of increased CO2 level on grain yield, anthesis and maturity of pearl millet cultivars.

(+15 to -12 days) and cv. GHB 732 (+10 to -11 days). Overall results showed that elevated minimum temperature decreased grain yield, anthesis days and days to maturity in all cultivars significantly and vice - versa.

Effect of elevated carbon dioxide (CO_2)

The data pertaining to the effect of carbon dioxide (CO_2) on simulated grain yield, anthesis and maturity of pearl millet cultivars presented in Table 1, 2 and 3 and also depicted in Fig. 3. The results showed that with increase in the concentration of carbon dioxide from base value 410 ppm by 30, 60, 90 and 120 ppm resulted in increase in the grain yield, anthesis days and days to maturity. The percent change over base yield, base anthesis days and base days to maturity was found due to elevated concentration of CO_2. In yield, highest change was obtained in cultivar GHB 538 (+3.4 to +18.2 %) followed by cv. GHB 732 (+3.8 to +16.4) and cv. GHB 558 (+5.8 to +17.8). In anthesis, highest change was obtained in cultivar GHB 558 (+2 to +11 days) followed by cv. GHB 732 (+1 to +10 days) and cv. GHB 538 (+3 to +10 days). In maturity, highest change was obtained in cultivar GHB 558 (+5 to +16 days) followed by GHB 538 (+7 to +17 days) and cv. GHB 732 (+7 to +14 days). This clearly showed that elevated concentration of CO_2 had a significant impact on grain yield, anthesis and maturity of various pearl millet cultivars.

CONCLUSION

As per model simulation, the increase in maximum temperature had negative effect and decrease in maximum temperature had positive effect on grain yield, anthesis days and days to maturity. The effect of the minimum temperature was also of the similar order, but the varietal differences were observed. The simulated grain yield, anthesis and maturity with elevated CO_2 concentration, increased the yield, anthesis days and days to maturity in different cultivars.

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