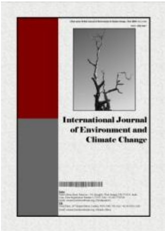

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# Assessment of Projected Climate Change Impact on Green Gram Productivity through DSSAT Model under South Gujarat Environmental Condition

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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

An investigation on climate change impact on green gram was conducted at Agronomy farm, NAU, Navsari, Gujarat during the *rabi* seasons of 2021-22. The calibrated and validated DSSAT CROPGRO simulation model was used to determine the productivity of green grams under various climate change scenarios. In this experiment, the effects of $CO_2$ concentration, solar radiation and maximum and minimum temperatures on green gram productivity were examined individually and in combination. According to the sensitivity of the DSSAT CROPGRO model, under the conditions of projected climate change, the best case scenario for its favourable impact on green gram yield was a rise in $CO_2$ concentration (600 ppm), along with solar radiation up to a certain level (1 unit), which may nullified the adverse effect of increases in temperature on green gram productivity.

*Keywords: DSSAT; crop modeling; sensitivity analysis; climate change; green gram.*

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## 1. INTRODUCTION

In the present century, climatic change has become a serious problem worldwide. IPCC [1] has projected that an increase in global mean temperature of 1.5℃ which will be achieved before 2040 and according to Representative Concentration Pathways (RCP, 8.5), the global mean temperature is reported to increase by about 4.3°C, $CO_2$ concentration is projected to rise to 1200 ppm by the end of the 21$^{st}$ century.

Climate change will have an impact on a weather parameters. Weather parameters such as temperature, solar radiation, and rainfall have determined the crop productivity of a given locality. Looking at the projected climate change scenario, it is necessary to assess the productivity of green gram crops concerning expected climate change conditions. The CROPGRO module of the DSSAT crop simulation model is a very useful tool to evaluate the expected yield of the crop in relation to various projected climate change scenarios because this tool can reduce the expense and time consuming of field experimentation [2].

Dhage and Patil [3] studied the effect of elevated temperature on green gram yield was evaluated by using the CROPGRO model. The result showed that a rise in temperature by 1-2℃ had a negative impact on seed yield (declined by -3.56 %). The sensitivity of CROPGRO model showed that the grain yield reduction due to impact of climate change ranged 7.5 per cent to 21.3 per cent at different treatment [4]. The regression of pigeon pea yield on weather variables show that increase in maximum temperature is harmful for the crop whereas the minimum temperature and rainfall show a positive effect [5]. The sensitivity of the CROPGRO model simulated the chickpea yield to incremental units of $CO_2$ resulting in a gradual increase in seed yield [6]. The objective of this experiment was to evaluate the productivity of the green gram crop in response to anticipated climate change circumstances.

## 2. MATERIALS AND METHODS

### 2.1 General Information

The field experiment was conducted during *rabi* season 2021-22 at Agronomy farm, NAU, Navsari, India situated at latitude 20°57' N, longitude 72°52' E, and an altitude of 12 m above mean sea level. The GBM cultivar of green gram were sown at three different dates (27$^{th}$ October ($D_1$), 11$^{th}$ ($D_2$) and 26$^{th}$ November ($D_3$)). The monthly means of weather data during the crop growing season (October to February) are presented in Table 1.

### 2.2 Calibration and validation of DSSAT CROPGRO model for green gram

The first step in using the CROPGRO model to determine crop productivity under anticipated climatic circumstances is to perform model calibration and validation. The model was calibrated by using the past three years' weather, soil, and yield data of green gram which calculating a genetic coefficient of *cv.* GBM-1 by using GLUE (genetic coefficient estimator) is an inbuilt option in the model, followed by a manual method until the desired agreement between simulated and observed values is reached. The calibrated genetic coefficient of *cv.* GBM-1 is presented in table 2. The model was validated with experimental field data (2021-22) and the model's accuracy was tested with normalized root mean square error (nRMSE), which in our case was 8.02 percent.

### 2.3 Climate change study through DSSAT CROPGRO model

After validating the CROPGRO model, sensitivity analysis (response of the model to change input parameters) of the CROPGRO model was used to study the impact of maximum temperature, minimum temperature, bright sunshine hours, $CO_2$ and solar radiation on the seed yield of green gram. The simulated value of yield under expected climate conditions was compared with a corresponding value of seed yield under normal weather conditions to measure the yield variation (%) under given climatic conditions. After calibration and validation of the model, the following step was used for the climate change study: (1) Open DSSAT model. (2) Open the management file, select environment, and go to the environmental modification option. (3) Add input levels of a climatic parameter that you want to see the actual climatic parameter changes up to this level. (4) Go to the treatments option and assign environmental modification as treatment. (5) Refresh the model and run it.

## 3. RESULTS AND DISCUSSION

### 3.1 Effect of Temperature on Seed Yield

The impact of increased and decreased temperatures (±5℃) on seed yield variation under the different sowing dates is presented in

**Table 1. Monthly mean of weather conditions during the growing season (October to March)**

| Month (SMW number) | Month | Maximum temperature (℃) | Minimum temperature (℃) | Bright sunshine hours (hr.) | Solar radiation (MJ $m^{-2}$ $day^{-1}$) | Relative humidity (%) (morning) |
|---|---|---|---|---|---|---|
| **October (44)** | **October** | 33.6 | 17.1 | 9.0 | 19.13 | 73 |
| **November (44 – 48)** | **November** | 33.7 | 18.2 | 7.4 | 15.98 | 69 |
| **December (49 – 52)** | **December** | 29.2 | 14.7 | 6.2 | 13.55 | 86 |
| **January (52 - 5)** | **January** | 28.9 | 14.0 | 7.2 | 15.37 | 91 |
| **February (5 – 9)** | **February** | 31.1 | 13.7 | 9.3 | 20.03 | 78 |
| **March (9 – 11)** | **March** | 36.3 | 17.3 | 8.5 | 20.70 | 67 |

**Table 2. Calibrated genetic coefficients of GBM-1 cultivar of green gram**

| Parameter | GBM-1 |
|---|---|
| EM-FL (Time between emergence to flower appearance) | 33.8 |
| FL-SD (Time between first flower and first seed (R5)) | 18.1 |
| FL-SH (Time between first flower and first pod (R3)) | 10.5 |
| FL-LF (Time between first flower and end of leaf expansion) | 13.0 |
| SD-PM (Time between first seed and physiological maturity) | 19.77 |
| LFMAX (Maximum leaf photosynthesis rate at 30 ℃, 350 ppm $CO_2$ and high light) | 0.99 |
| WTPSD (Maximum weight per seed (g)) | 0.560 |
| SLAVR (Specific leaf area of cultivar under standard growth conditions ($cm^2$/g) | 130 |
| SDPDV (Average seed per pod under standard growing condition (#[seed]/pod)) | 10.5 |
| SFDUR (Seed filling duration for pod cohort at standard growth condition) | 24.3 |
| PODUR (Time required for cultivar to reach final pod load under optimal condition) | 18.0 |
| XFRT (Maximum fraction of daily growth that is partitioned to seed + shell) | 1.00 |
| THRSH (The maximum ratio of (seed/seed+shell) at maturity) | 78.0 |
| SDPRO (Fraction protein in seed (g[protein]/g [seed])) | 0.240 |
| SDLIP (Fraction oil in seed (g[oil]/g[seed])) | 0.055 |

**Table 3. % change of seed yield due to varying temperature, $CO_2$ and combined effect of $CO_2$ and maximum temperature under different sowing date**

| Change in climatic parameters | % Change yield from base seed yield 27/10/2021 ($D_1$) (1376 kg ha$^{-1}$ base yield) | 11/11/2021 ($D_2$) (1449 kg ha$^{-1}$ base yield) | 26/11/2021 ($D_3$) (1461 kg ha$^{-1}$ base yield) |
|---|---|---|---|
| **Maximum temperature (℃)** | | | |
| **-5** | 35.2 | 24.3 | 18 |
| **-4** | 31 | 28.4 | 22.1 |
| **-3** | 20.3 | 18.2 | 15.5 |
| **-2** | 14.5 | 16.1 | 11.2 |
| **-1** | 5.6 | 8.7 | 4.7 |
| **+1** | -9.4 | -5.1 | -10.0 |
| **+2** | -20.9 | -15.2 | -14.3 |
| **+3** | -28.7 | -22.0 | -26.5 |
| **+4** | -40.7 | -32.9 | -35.5 |
| **+5** | -49.5 | -41.9 | -45.5 |
| **Minimum temperature (℃)** | | | |
| **-5** | -5.6 | -23.8 | -26.2 |
| **-4** | -0.2 | -9.1 | -13.0 |
| **-3** | 1.9 | -6.0 | -7.6 |
| **-2** | 5.4 | 1.3 | -5.0 |
| **-1** | 4.7 | 3.3 | 4.0 |
| **+1** | -2.9 | -1.1 | 1.9 |
| **+2** | -10.0 | -8.8 | -1.9 |
| **+3** | -16.1 | -13.5 | -3.8 |
| **+4** | -19.7 | -22.2 | -9.7 |
| **+5** | -25.1 | -25.9 | -12.8 |
| **$CO_2$ concentration (Base value 380 ppm)** | | | |
| **450** | 19.1 | 17.5 | 17.5 |
| **500** | 30.6 | 27.6 | 27.7 |
| **550** | 40.6 | 36.9 | 36.9 |
| **600** | 49.2 | 44.6 | 44.6 |
| **$CO_2$ (ppm) + Maximum temperature (℃) (Combine effect)** | | | |
| **450 + 1** | 8.5 | 11.8 | 5.3 |
| **500 + 2** | 4.8 | 9.9 | 11.0 |
| **550 + 3** | 2.3 | 8.8 | 2.2 |
| **600 + 4** | -7.7 | 1.3 | -3.4 |

**Table 4. % Change of yield due to interactive effect of solar radiation, temperature and $CO_2$ under different sowing date**

| Change in parameters | % Change yield from base seed yield | | |
|---|---|---|---|
| | 27/10/2021 ($D_1$) (1376 kg ha$^{-1}$ base yield) | 11/11/2021 ($D_2$) (1449 kg ha$^{-1}$ base yield) | 26/11/2021 ($D_3$) (1461 kg ha$^{-1}$ base yield) |
| **450 ppm** | | | |
| **-3** | -29.51 | -28.85 | -22.66 |
| **-2** | -12.06 | -9.25 | -3.70 |
| **-1** | 2.11 | 5.24 | 5.68 |
| **+1** | 25.36 | 29.12 | 20.81 |
| **+2** | 27.11 | 32.23 | 32.92 |
| **+3** | 29.07 | 36.44 | 27.38 |
| **500 ppm** | | | |
| **-3** | -23.04 | -22.64 | -15.74 |
| **-2** | -3.85 | -1.24 | 4.86 |
| **-1** | 12.06 | 14.63 | 15.13 |
| **+1** | 38.44 | 40.79 | 31.83 |
| **+2** | 39.61 | 44.24 | 44.56 |
| **+3** | 42.22 | 49.34 | 38.60 |
| **600 ppm** | | | |
| **-3** | -12.50 | -12.35 | -4.11 |
| **-2** | 9.96 | 11.87 | 18.75 |
| **-1** | 28.20 | 29.88 | 30.60 |
| **+1** | 58.43 | 59.49 | 49.08 |
| **+2** | 59.81 | 63.77 | 62.90 |
| **+3** | 63.66 | 69.77 | 56.13 |

Table 3. The results showed that the increase in maximum temperature positively affected the seed yield (rises from 4.7 to 35.2 %) because a decrease in temperature will increase the duration of different phenological stages, which provides a much larger period for photosynthesis [7].

The sensitivity of the CROPGRO model simulated the seed yield gradually increased when the minimum temperature was decreased up to -3℃ (Table 3) then yield was noticed to be decreased with temperature decline as the minimum temperature goes close to the base temperature of green gram where plant growth not possible. Also seed yield decreased with increase in the minimum temperature up to +5℃ because a higher rate of respiration during the night-time was caused by the higher minimum temperature resulting in comparatively greater loss of photosynthates [8]. The above-presented result was a good confirmation with the findings of Kumar et al. [2], Patil et al. [9] and Yadav et al. [10].

### 3.2 Effect of $CO_2$ on Seed Yield

The sensitivity of the CROPGRO model showed the positive impact of elevated $CO_2$ concentration on seed yield (from 17.52 to 49.27 %) (Table 3). The rise of seed yield under the increase in the concentration of $CO_2$ may be due to the plant assured more entry of $CO_2$ in the plant system, resulting in the plant exhibiting a higher rate of photosynthesis. However, since $CO_2$ is a greenhouse gas, increasing in $CO_2$ concentration is responsible for the rising earth's surface temperature. In this situation, the combined study of $CO_2$ and maximum temperature and its impact on seed yield are necessary. The results of the combined experiments showed that the seed yield dropped (from 11.87 to -7.70%) as both $CO_2$ concentration and maximum temperature increased. It has been concluded that the seed yield rises more with increased $CO_2$ concentration alone but seed yield decreases with both $CO_2$ concentration and temperature rises. Our result was in good confirmation with the finding of Srivastava et al. [11].

### 3.3 Combined Effect of Solar Radiation, Temperature and $CO_2$ on Seed Yield

The seed yield variation (%) due to the combined effect of radiation, $CO_2$ and temperature is presented in table 4. The results showed that at $CO_2$ concentration of 600 ppm, the green gram yield could increase to a maximum of 9.96 to 69.77 per cent by either increasing radiation and temperature by three units or decreasing it by two units. However, at a concentration of 450 and 500 ppm, the yield was found to increase up to 1 unit when radiation and temperature were subtracted, and then it was found to decrease with more units subtracted. The highest benefits are obtained at the level of $CO_2$ concentration combined with 1 unit addition in temperature and radiation. A higher $CO_2$ concentration (600 ppm) to reduce the negative effects of low radiation intensity (up to -2 units) and temperature increase on seed yield. Conversely, a lower level of $CO_2$ (450 and 500 ppm) may be able to nullify the negative effects of low solar radiation (up to -1 units), but yield did not increase as much as it would with a higher $CO_2$ concentration. Our result are in accordance with findings of Pandey et al., [12].

## 4. CONCLUSION

Calibrated and validated model of the DSSAT CROPGRO model is successfully used for simulating the seed yield of green grams under projected climate change scenarios. The model demonstrated that increased $CO_2$ concentration and solar radiation favored crop productivity while rising temperatures had a negative impact. The combined study found that increases in $CO_2$ concentration and maximum temperature affect productivity. In contrast, increases in $CO_2$ concentration along with solar radiation have a beneficial influence because of the nullified negative impact of rises in maximum temperature. Overall, the beneficial effect of projected climate change on crop productivity can be harvested when solar radiation and temperature increase by 1 unit under all levels of $CO_2$ concentration.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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