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# Assessing impacts of projected climate on pigeonpea crop at Gulbarga

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## ABSTRACT

Pigeonpea [*Cajanus cajan*(L.) Millsp] is an important semi-arid legume crop in India. In Karnataka, pigeonpea is largely grown in the northern parts of the state especially in Gulbarga, which is called "Pulse Bowl of Karnataka". Climate change is one of the major challenges being faced by agriculture in the Semi-Arid Tropics (SAT) of the country. Pigeonpea productivity in Gulbarga is affected by large variations in rainfall amount and distribution, increased temperatures, depleting soil productivity and disturbing water balance. Based on daily weather data of 41 years (1969-2009), productivity and water use of pigeonpea under eleven climate scenarios are assessed using the pigeonpea model in Agricultural Production Systems Simulator (APSIM). Simulations are done with automatic sowing based on rainfall and soil moisture availability during the sowing window (15 Jun to 20 Aug) and following recommended crop management practices. Simulations show that increase in temperature by 2°C could reduce pigeonpea yields by about 16%. Rainfall decrease of 10% from present coupled with 2°C increase in temperature could reduce yields further by 4%, making the total reduction to be at 20%. Crop duration was shortened by about 10 days and water use reduced by 25 mm with increase in temperature. Increased rainfall scenarios have considerably reduced the adverse effects of higher temperature. Breeding of varieties tolerant to higher temperature and adoption of better water management (both *in-situ* and *ex-situ*) practices achieved through integrated watershed approach could play a major role in sustaining pigeonpea productivity under future climate scenarios.

***Key words:*** Climate change, Gulbarga, pigeonpea, simulation model, APSIM

Pigeonpea [*Cajanus cajan(*L.) Millsp.] is a major legume crop and rich source of protein for vegetarian population of India, largely grown in semi–arid regions of the country. It is the second most important pulse crop after chickpea. In 2010-11, it was cultivated in about 4.37 Mha (17% of the total area under pulses in the country) and contributed about 16% to the total pulses production with an average productivity of 0.66 t $ha^{-1}$ (DES, 2012). In Karnataka, pigeonpea is largely grown in the northern parts of the state especially in Gulbarga, which is known as "Pulse Bowl of Karnataka". Pigeonpea occupies an area of about 0.38 M ha in Gulbarga with a production of about 0.22 M tonnes and thus the district average productivity is 0.57 t $ha^{-1}$. Major soils of the district are Vertisols and associated intergrades (deep black, medium black, shallow black) and lateritic, with water holding capacity of 200-230 mm, and are suitable for pigeonpea cultivation. Gulbarga district experiences a typical semi-arid climate. Normal annual rainfall for Gulbarga station is 834 mm received in 48 rainy days (IMD, 2010). *Kharif* (Jun-Oct) rainfall is about 720 mm, which is 86 per cent of the annual rainfall. May is the hottest month with an average maximum temperature of 40°C and December is the coldest month with an average minimum temperature of 15.9°C.

Climate change due to global warming is posing a serious threat to agriculture which is one of the major challenges presently faced by agriculture in India, more so in the Semi-Arid Tropics (SAT) of the country. Increased concentration of greenhouse gases (GHGs) in the atmosphere is causing increasing temperatures across the globe (IPCC, 2007). Variability in rainfall is increasing and extreme rainfall events are occurring more often. The annual mean area-averaged surface warming over the Indian subcontinent to range between 3.5 and 5.5 °C over the region during 2080s. During winter, India may experience between 5 and 25% decline in rainfall, which is likely to be significant and may lead to droughts during the dry summer months (Lal *et al*., 2001). A study using long-term gridded weather data sets of IMD revealed that 5.1 M ha have become drier and 5.6 M ha have become wetter during the periods 1971-1990 and 1991-2004 (Wani *et al*., 2012). Largest shifts are seen in Madhya Pradesh where an additional 3.82 Mha became semi-arid. In Karnataka semi-arid area increased by 0.23 M ha. Devappa and Khageshan (2011) reported a decreasing trend in the annual rainfall @ 3.44 mm per year for Gulbarga district, based on data for 1961-2008. Variations in rainfall amount and distribution, increased temperatures, depleting soil productivity and disturbing water balance are affecting pigeonpea productivity in Gulbarga.The objectives of this paper are to study the temporal changes of area and productivity of pigeonpea in Gulbarga district, understand climate variability and change and assess impacts of projected climate change on yield, phenology and water balance of pigeonpea using APSIM pigeonpea simulation model.

## MATERIALS AND METHODS

Daily weather data on maximum temperature, minimum temperature and rainfall were procured from the India Meteorological Department for the period 1969-2009 (41 years). Daily solar radiation was estimated from temperatures using Bristow-Campbell (1984) method. Reference crop evapotranspiration ($ET_0$) was estimated using Hargreaves and Samani (1982) method. Soil water holding capacity was estimated based on the soil map of National Bureau of Soil Survey & Land Use Planning (NBSS&LUP, 1985). Water balance and indices were computed based on the revised water budgeting approach of Thronthwaite and Mather (1955). Pigeonpea data of Gulbarga were collected from 1970 to 2009 (DES, 2012) for assessing the changes in area, production and productivity of the crop.

Crop simulation models provide a more scientific approach to study the potential impacts of climate change and climate variability on agriculture production (Onwonga *et al*., 2010). InfoCrop model for mustard was successfully applied for assessing the impact of climate change by Boomiraj *et al*. (2010). In the present study, pigeonpea simulation model in APSIM 7.4 (McCown *et al*., 1996) version was used to assess the impacts of projected climate change. APSIM pigeonpea crop simulation model was extensively evaluated by Robertson *et al.* (2001) using 38 datasets which include wide range of sowing densities, growing seasons and cultivars on both Alfisols and Vertisols under rainfed and irrigated conditions. APSIM was developed primarily as a research tool to investigate on-farm management practices especially where outcomes are affected by variable climatic conditions (Holzworth *et al.,* 2006). APSIM was used earlier to estimate potential yields and yield gaps of pigeonpea in India (Bhatia *et al*., 2003).

Pigeonpea variety TS-3R was developed by the University of Agricultural Sciences, Raichur and is very popular in Gulbarga region. It is a medium duration (150-160 days) variety and is resistant to wilt and tolerant to fog (Balatkar *et al*., 2012). Field experiments were conducted for generating genetic coefficients of pigeonpea at ICRISAT during 2011-12. Randomised block design (RBD) with four replications and recommended package of practices was followed. Detailed crop data were collected as per the requirement of APSIM model for developing crop genetic coefficients. Weather data from the automatic weather station installed about 200 m away from the experimental field were used in the model. Ten climate change scenarios and the present were considered (Table 1) for assessing impacts of projected climate on pigeonpea using the calibrated APSIM model. The scenarios included 1°C, 2°C increase in both maximum and minimum temperatures and with 10% and 20% decrease and increase in rainfall.

**Table 1 :** Projected climate scenarios

| Sr. No. | Climate scenario description |
|---|---|
| 1. | Present |
| 2. | Present + 1 °C Temp. |
| 3. | Present + 1 °CTemp.-10% Rainfall |
| 4. | Present + 1 °C Temp.-20% Rainfall |
| 5. | Present + 1 °C Temp.+10% Rainfall |
| 6. | Present + 1 °C Temp.+20% Rainfall |
| 7. | Present + 2 °C Temp. |
| 8. | Present + 2 °C Temp.-10% Rainfall |
| 9. | Present + 2 °C Temp.-20% Rainfall |
| 10. | Present + 2 °C Temp.+10% Rainfall |
| 11. | Present + 2 °C Temp.+20% Rainfall |

These climate change scenarios are incorporated in the model by increasing daily maximum and minimum temperatures and multiplying the rainfall by specified change.

## RESULTS AND DISCUSSION

District-wise data of Gulbarga showed that pigeonpea area has increased by three-folds from about 0.14 M ha in 1970 to 0.43 M ha in 2007 (Fig. 1). There has been a sharp and steady increase in area under pigeonpea since 1995. Average pigeonpea productivity was 0.42 t $ha^{-1}$. In 1992, due to severe infestation of pod borer, the lowest productivity of 0.023 t $ha^{-1}$ was recorded (Parma, 2005).

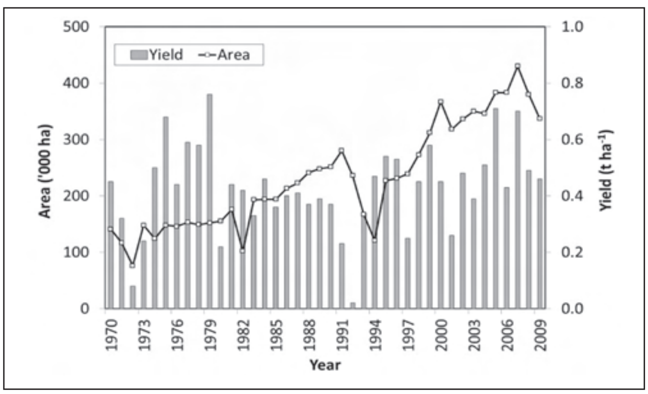


**Fig. 1 :** Area and productivity of pigeonpea of Gulbarga district

The climate of Gulbarga was more or less stable in the semi-arid type except for a few years when it changed to dry sub-humid and arid types of climate (Fig. 2). Analysis of seasonal rainfall indicated that no significant trend exists in southwest monsoon rainfall during the period 1969-2009.

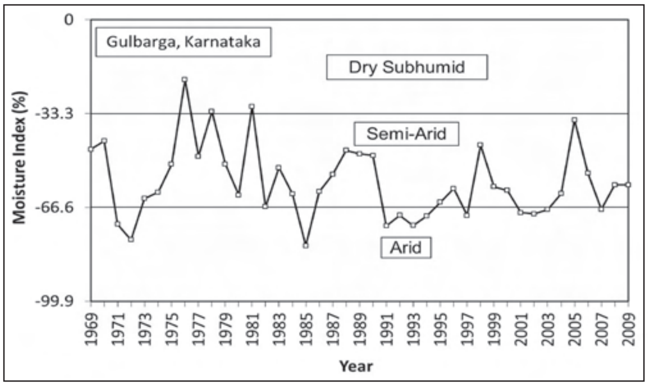


**Fig. 2 :** Climatic shifts at Gulbarga

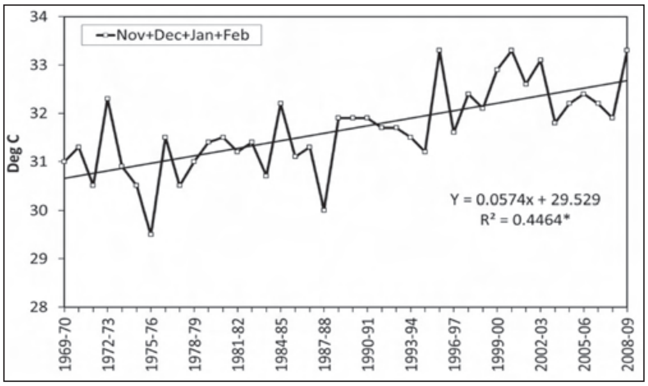


**Fig. 3 :** Maximum temperature during Nov-Feb at Gulbarga

Due to climate change, temperatures have shown an increasing trend, particularly in winter. Maximum temperature during *rabi* season (Nov-Feb) at Gulbarga shown statistically significant increasing trend (Fig. 3).

***Estimation of pigeonpea genetic coefficients***

Genetic coefficients for variety TS-3R were estimated based on observed phenology and crop growth data from the field experiments at ICRISAT, Patancheru during 2011 and shown in Table 2. In APSIM, grain demand for carbohydrate (biomass) is driven using a cultivar-specific daily rate of harvest index (HI) increase (hi_incr). Demand for biomass to be partitioned to grain on any day is calculated using HI i.e., the ratio of grain-biomass to tops-biomass. Each day HI is increased by hi_incr until it reaches a maximum hi_max_pot. Each day, the phenology routines calculate daily thermal time (in degree days) from 3-hourly air temperatures interpolated from the daily maximum and minimum temperatures. These daily thermal time values are accumulated into a thermal time sum which is used to determine the duration of phenological phases like 'floral initiation to flowering', 'flowering to start grain', 'start grain to end grain', etc. Between the stages of emergence and flowering, calculated daily thermal time is reduced by water or nitrogen stresses, resulting in delayed phenology when the plant is under stress. Crop height (cm) is a function of stem weight per plant, as specified for the cultivar.

APSIM simulated growth parameters fairly matched with the observed data. Observed and simulated total biomass shown in the Fig. 4 indicate that the APSIM pigeonpea model could simulate well and can be used for assessing the impacts of climate change on pigeonpea at Gulbarga. Other crop

**Table 2 :** APSIM pigeonpea (TS-3R) cultivar parameters

| Parameter | Description | Units | Value |
|---|---|---|---|
| hi_incr | Daily potential increase in HI | per day | 0.005 |
| hi_max_pot | Maximum HI | | 0.25 |
| tt_emerg_to_endjuv | Thermal time from emergence to end of juvenile | °C day | 272 |
| x_pp_endjuv_to_init | Look up table for photoperiod and | h vs. °C day | 11.4 13.2 13.3 |
| y_tt_endjuv_to_init | thermal time from end of juvenile to floral initiation | | 1 1580 100000 |
| tt_init_to_flower | Thermal time from floral initiation to flowering | °C day | 130 |
| tt_flower_to_start_grain | Thermal time from flowering to start grain fill | °C day | 90 |
| tt_start_to_end_grain | Thermal time from start grain to end grain | °C day | 696 |
| tt_end_grain_to_maturity | Thermal time from end grain to maturity | °C day | 34 |
| tt_maturity_to_ripe | Thermal time from maturity to harvest ripe | °C day | 36 |
| x_stem_wt | Look up table for stem weight per | g vs. cm | 0 4 9 25 85 130 |
| y_height | plant and plant height | | 0 60 100 130 200 210 |

growth parameters like grain yield, pod yield and leaf area index simulated by the model were within acceptable range, when compared with the observed values.The observed and simulated grain yields were 1780 and 1570 kg ha$^{-1}$, respectively. Simulated flowering and maturity days were 89 and 162 days and well compared with the observed values of 88 and 164 days, respectively. As mentioned earlier, the TS-3R genetic coefficients estimated are based on one season data. There is scope for improving these coefficients using more experimental data generated at several locations.

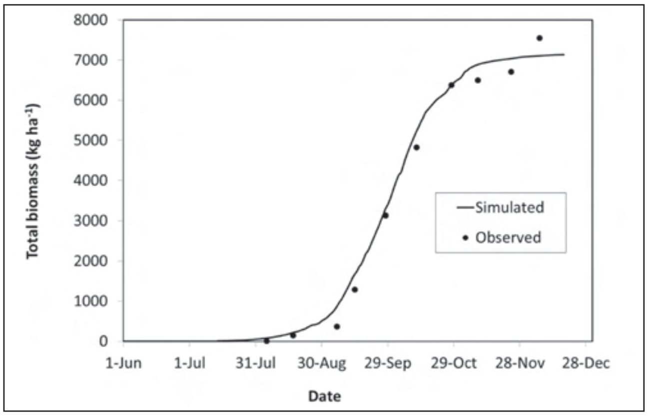


**Fig. 4 :** Observed and simulated total biomass of pigeonpea cv. TS-3R

***Climate change impacts on pigeonpea***

Climate change is likely to alter the growing conditions of crops due to increase in temperature and changes in the rainfall pattern. In semi-arid tropics, the duration of growing period generally decreases and the abiotic and biotic stresses are likely to increase. Such adverse conditions in future climate will impact the crop yields negatively.

Simulated pigeonpea grainyield and total biomass at Gulbarga were 2057 and 8708 kg ha$^{-1}$, respectively under baseline (present) climate. Increase in temperature by 1 and 2 °C could decrease grain yield by 9 and 16%, respectively (Table 3). Similarly, total biomass decreased by 5 and 9% with increase in the temperature by 1 and 2 °C. Decrease in rainfall by 10% coupled with increase in temperatures by 1 and 2 °C could further reduce grain yields by 5 and 4% making the total reduction at14 and 20%. The situation could further worsen with reduction in rainfall by 20%, making the loss of grain yields by 21 and 28% with increase in temperature by 1 and 2 °C, respectively. Increased rainfall scenarios could benefit the crop to some extent, particularly in the low rainfall years, but net effect still remained negative.

Increased temperature could shorten the crop duration. Days to flowering shortened by 2 and 4 and the total crop duration by 5 and 9 days with increase in temperature by 1 and 2 °C, respectively (Table 3). The increase in temperature causes more transpiration per day which results in water stress during the dry periods. Water balance outputs have shown that decrease in rainfall by 10 and 20% resulted in less plant water use by 18 and 45 mm, respectively with increase in temperature by 2 °C (Table 4). Slight reduction in runoff and drainage with increased temperatures is due to shortened crop duration. Increments in rainfall by 10 and 20% will result in more rainfall only for the days having rainfall and will not affect non-rainy days. Thus, additional rainfall has contributed more towards runoff and drainage than evapotranspiration. Simulated water use efficiency of pigeonpea reduced from 7.2 kg ha$^{-1}$ mm$^{-1}$ in the baseline by 6.6 and 6.0 kg ha$^{-1}$ mm$^{-1}$ with temperature increase of 1 and 2 °C, respectively.

**Table 3 :** Effect of projected climate on phenology and productivity of pigeonpea cv. TS-3R

| Climate scenario | Days to flower | Days to maturity | Total biomass (kg ha$^{-1}$) | Grainyield (kg ha$^{-1}$) | Change in yield (%) |
|---|---|---|---|---|---|
| Present (P) | 103 | 157 | 8708 | 2057 | 0 |
| P+1°C | 101 | 151 | 8286 | 1875 | -9 |
| P+1°C-10%RF | 99 | 150 | 7798 | 1771 | -14 |
| P+1°C-20%RF | 99 | 150 | 7090 | 1615 | -21 |
| P+1°C+10%RF | 101 | 151 | 8659 | 1961 | -5 |
| P+1°C+20%RF | 101 | 152 | 8866 | 2005 | -3 |
| P+2°C | 99 | 148 | 7943 | 1734 | -16 |
| P+2°C-10%RF | 98 | 147 | 7465 | 1636 | -20 |
| P+2°C-20%RF | 98 | 147 | 6763 | 1486 | -28 |
| P+2°C+10%RF | 100 | 149 | 8302 | 1809 | -12 |
| P+2°C+20%RF | 99 | 148 | 8525 | 1854 | -10 |

**Table 4 :** Effect of projected climate on water balance of pigeonpea

| Climate Scenario | Rainfall (mm) | Runoff (mm) | Drainage (mm) | Evapo-transpiration (mm) | Soil evaporation (mm) | Plant use (mm) |
|---|---|---|---|---|---|---|
| Present (P) | 594 | 66 | 103 | 475 | 187 | 287 |
| P+1°C | 589 | 65 | 102 | 472 | 186 | 286 |
| P+1°C-10%RF | 522 | 48 | 70 | 449 | 181 | 268 |
| P+1°C-20%RF | 457 | 33 | 45 | 420 | 178 | 242 |
| P+1°C+10%RF | 650 | 84 | 135 | 487 | 188 | 299 |
| P+1°C+20%RF | 710 | 104 | 171 | 498 | 191 | 307 |
| P+2°C | 587 | 64 | 99 | 474 | 187 | 287 |
| P+2°C-10%RF | 520 | 47 | 68 | 450 | 182 | 269 |
| P+2°C-20%RF | 455 | 33 | 43 | 420 | 179 | 242 |
| P+2°C+10%RF | 648 | 82 | 132 | 490 | 190 | 300 |
| P+2°C+20%RF | 709 | 102 | 167 | 501 | 192 | 309 |

## CONCLUSIONS

The simulation results have shown that the selected temperature and rainfall change scenarios could reduce pigeonpea grain yields by 3 to 28%. Days to flowering and maturity reduced by 5-10 days under different climate change scenarios. Increased temperature by 2 °C coupled with 20% reduction in rainfall could reduce water use by 45 mm. Increased rainfall could help to recoup the yield losses in the low rainfall years. Results of study indicated that, better water and nutrient management approach is the key and Integrated Watershed Management plays a major role in sustaining pigeonpea productivity under future climate scenarios. Adoption of varieties tolerant to high temperature could also play a major role in sustainable pigeonpea yields. Water stress during the end of season could be avoided by sowing the short and extra-short duration varieties. Breeding of varieties which can put extra root mass is required for sustainable pigeonpea production in the future.

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