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Vulnerability assessment of *kharif* rainfed sorghum to climate change in SAT regions of India

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ABSTRACT

This paper presents results of Info Crop model evaluation in terms of its validation, sensitivity impact and adaptation of sorghum to climate change in semi arid tropics (SAT) regions of India. The model has reasonably predicted phenology, crop growth yield. Sorghum crop was found to be sensitive to changes in carbon dioxide (CO_2) and temperature. Future climate change scenario analysis showed that sorghum yields are likely to reduce at Akola, Anantpur, Coimbatore and Bijapur. At Kota the sorghum yield is likely to increase at 2020 and no change at 2050 and yield will reduce at 2080. The increase in yield at Gwalior and Kota at 2020 is due to reduction in maximum temperature and increase in rainfall from current. Adoption of adaptation measure like one irrigation (50mm) at 40-45 days after sowing would be better adaptation strategies for rainfed kharif sorghum with existing varieties in the selected location of the SAT regions.

Key words : InfoCrop, simulation, validation, adaptation, dry matter, leaf area index, maturity, India, SAT.

Sorghum is the fifth most important cereal crop grown on 47 million ha in 99 countries in Africa, Asia, Oceania, and the Americas. Major producers are the USA, India, Nigeria, China, Mexico, Sudan and Argentina.

In India sorghum is mainly grown in the Deccan Plateau, Central and Western India apart from a few patches in Northern India as a dryland cereal crop. It is nutritionally superior to other fine cereals such as rice and wheat with high fiber content, minerals and slow digestibility. As sorghum is generally cultivated in nutrient-poor soils in frequently drought prone areas, it offers food and fodder security through risk aversion on sustainable basis. Water stress is one the major constrain in sorghum production in rainfed area. In India the yield gap analysis (Murthy *et al.*, 2007) of sorghum results showed that the total yield gap for all production zone was 2410 kg ha^{-1}. The primary production zone had the lowest gap of 2130 kg ha^{-1}, followed by secondary production zone with the gap of 2530 kg ha^{-1} and tertiary zone with a gap of 2560 kg ha^{-1}. Yield gap I (Simulated minus FLD yield) was 60-65 % and Yield gap II (FLD minus Average farmer yield) was 35-40% . The mid season drought was identified as the most important constraint across the state in India. Apart form this the rise in temperature and rainfall variation due to climate change will further aggravate the problem in SAT regions. The IPCC has already projected a temperature increase of 0.5 to 1.2 °C by 2020, 0.88 to 3.16 °C by 2050 and 1.56 to 5.44 °C by 2080 for the Indian region, depending on the scenario of future development (IPCC, 2007). It is very likely that hot extremes, heat waves, and heavy precipitation events will become more frequent.

The CERES-sorghum simulated results indicated a decrease in yield and biomass of rainy season sorghum at Hyderabad and Akola under all climate change scenarios. The positive effect of increased CO_2 if any, were masked by the adverse effects of predicted increase in temperature, resulting in shortened crop growing seasons (Gangadhar Rao *et al.*, 1995). Crop simulation analysis for *kharif* sorghum at Parbhani showed that a temperature increase of 3.3°C, which is expected to increase by the end of this century, will on average reduce the crop yield under good management by 27%. However, the effect of 11% increase in rainfall will be marginal.

There are limited studies to assess the probable impact of climate change on sorghum productivity in SAT regions of India. The objective of this study was therefore to quantify the impact of future climate change on sorghum crop with an additional objective of the study was to assess the benefits of adaptation strategy like supplemental irrigation.

MATERIALS AND METHODS

Model

InfoCrop considers following processes of growth and development, soil water, nitrogen and carbon, and crop-pest interactions. Each process is described by a set of equations, the parameters of which vary depending upon the crop/cultivar. Aggarwal *et al.* (2006a and b).

Validation of model

Data on phenology, leaf area, dry matter partitioning, and yield were collected in several field experiment from All India Coordinated Research trials conducted at various sorghum growing regions of the country (Palem, Dharwad, Akola, Indore, Coimbatore and Kanpur). Management practices relating to date of sowing, time and amount of application of irrigation and nitrogen as measured in the different treatments were given as inputs for validation of the model. These experiments were conducted over a period of 1992 to 2002. Maximum temperature in these locations varied from 21.0 to 38.6 ºC, whereas minimum temperatures varied from 4.8 to 26.6 ºC during sorghum growing period. Rainfall during the cropping season varied from 212 and 1155 mm. The experiments consisted of several treatments varying on dates of sowing, irrigation and nitrogen dose. Weather data for these locations was collected from the concerned research stations. Database used for calibration and validation of the model is given in Table 1.

Statistical analysis

Model performance using the coefficients developed was evaluated by calculating different statistical parameters viz. Coefficient of determination (R^2), Residual Mean Square Error (RMSE) (Fox, 1981), Coefficient of Residual Mass (CRM), D-index (Willmott, 1982) and Model efficiency (EF) (Kabat *et al.*, 1995 and Singh *et al.*, 2003).

Calibrated change in temperature and CO_2: The validated model was tested for its sensitivity to atmospheric CO_2 and temperature in scenarios of climate change. The effect of change in temperature and CO_2 were studied in rainfed sorghum for gradual increase in CO_2 (369, 450, 550 ppm) and temperature (0, 1, 2, 3, 4, 5°C) during the entire crop growth period.

Climate change scenarios: Impact of projected climate change scenarios was assessed by running the regional validated model for 2020, 2050 and 2080. The functions were from the output of the $HadCM_3$ A2a scenario, which has continuous population rise along with regionally oriented economic development. Projected temperature rise during the sorghum growing season is given in Table 2 for different locations. Projected rainfall also varied in all six regions during *kharif* season (Table 2). Impact of changing climate on sorghum crop yield in A2 scenario was assessed.

Adaptation strategies

One adaptation strategy (50 mm supplemental irrigation at 40-45 DAS) was selected and crop model was run for future climate change scenarios. Yield loss of rainfed sorghum was compared with district average, current rainfed potential as well as with adaptation measures.

RESULTS AND DISCUSSION

Validation of model

Days to 50% flowering : Simulated days to 50% flowering were compared with observed data for both normal and late sown crop. The observed flowering duration varied from 52 – 86 days while simulated one ranged from 54-92 days (Fig. 1). This result showed that the model was able to simulate flowering period reasonably well for all treatments (R^2=0.75). The RMSE was 3.71 against the mean value of 69.4 days. The maximum error between observed and simulated 50% days to flowering was 9 days with the model efficiency of 0.72.

Days to physiological maturity : InfoCrop-Sorghum model satisfactorily simulated days to physiological maturity. The observed and simulated values varied from 83-129 and 85 -131 days respectively. Simulated number for days to physiological maturity in different agro ecological zones was also in satisfactory (R^2=0.81) (Fig 1) agreement with the observed value. RMSE value of 3.94 against a mean value of 106.4 day, D-index value of 0.96, and model efficiency value of 0.81 showed that the model can simulate the days to maturity reasonably in the different sorghum growing region of India. Furthermore the maximum difference between observed and simulated days to physiological maturity was 9 days against the mean growing period of 106.4 days.

Dry matter production : Simulated values of total biomass of sorghum in different treatments was in good agreement

Table 1 : Details of experiments conducted at different locations used for calibration & validation of InfoCrop model

Location	Latitude	Longitude	No. of treatment	Nitrogen (kg ha^{-1})	Sowing date	Maximum temp. (°C)	Minimum temp. (°C)	Rainfall (mm)
Akola	20°42´N	77°02´E	31	40	First wk. July	24.1-38.6	9.4-25.2	621
Coimbatore	11°00´N	77°00´E	28	40	Third wk. June	24.5-34.8	18.8-24.9	212
Dharwad	15°30´N	75°04´E	25	40	Third wk. June	22.8-33.3	10.9-21.2	499
Indore	22°42´N	75°53´E	23	40	Last wk. June	24.0-36.0	9.0-26.5	755
Kanpur	26°28´N	80°20´E	21	40	Last wk. July	21.0-38.8	4.8-26.6	1155
Palem	16°30´N	78°14´E	21	80	Last wk. June	24.6-35.5	18.0-25.5	688

Table 2 : Projected mean temperature rise (°C) and rainfall changes during sorghum growing season in A2a scenarios

Location	Max. Temp. (^{0}C)			Min. Temp. (^{0}C)			Rainfall (%)		
	2020	2050	2080	2020	2050	2080	2020	2050	2080
Akola	0.9	1.9	2.7	0.9	1.9	3.2	-1.9	-10.5	-1.5
Gwalior	-0.2	0.6	1.7	0.8	1.9	3.2	20.9	28.3	15.1
Anantpur	0.7	1.6	2.5	0.8	1.6	2.4	-3.0	-13.3	-6.6
Coimbatore	0.8	1.7	2.7	0.8	1.6	2.6	1.3	3.7	9.3
Bijapur	1.0	2.3	3.5	1.0	1.9	3.5	20.9	28.3	15.1
Kota	-0.2	0.6	1.7	0.8	1.9	3.3	18.9	27.2	17.8

Table 3 : Statistical estimates for the comparison of observed and simulated parameters

Statistical estimates	Days to anthesis (days)	Days to maturity (Days)	Leaf area index	Dry matter production (Mg ha^{-1})	Seed yield (Mg ha^{-1})
Max. Error	9	9	2.77	1.6	9
RMSE	3.71	3.94	0.91	0.52	3.71
D - index	0.93	0.96	0.97	0.77	0.93
CRM	0.00	-0.01	-0.02	-0.02	0.00
EF	0.72	0.81	0.96	0.86	0.72

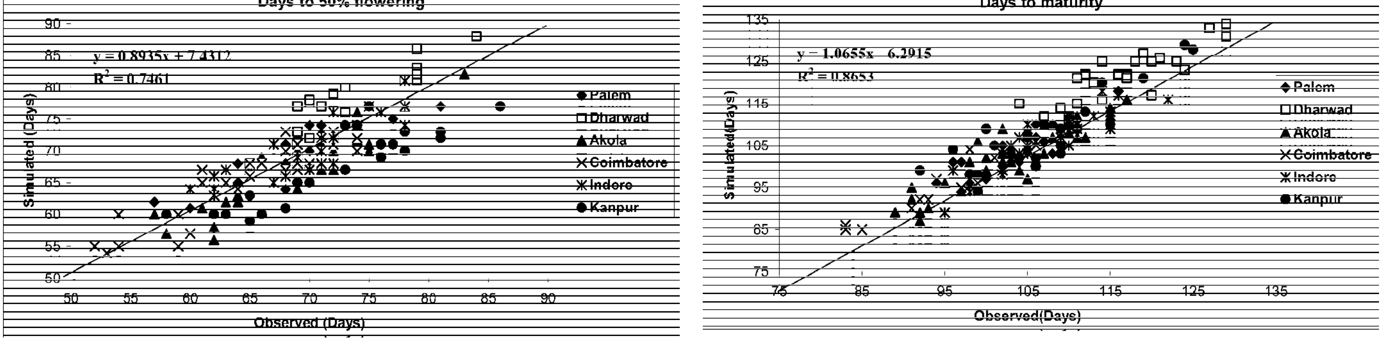

Fig. 1 : Validation of InfoCrop - Sorghum model for days to anthesis and days to maturity

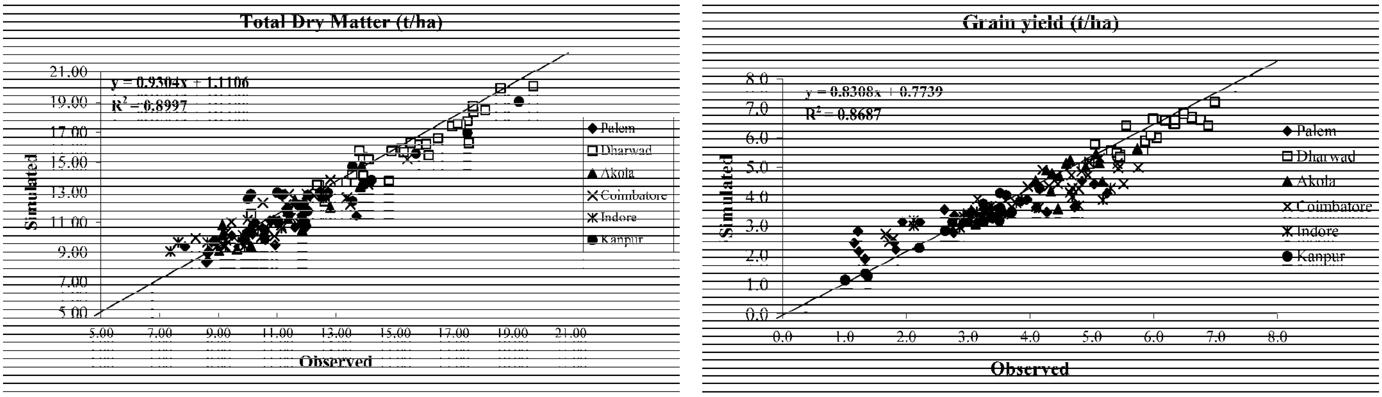

Fig. 2 : Validation of InfoCrop - Sorghum model for total dry matter production and grain yield

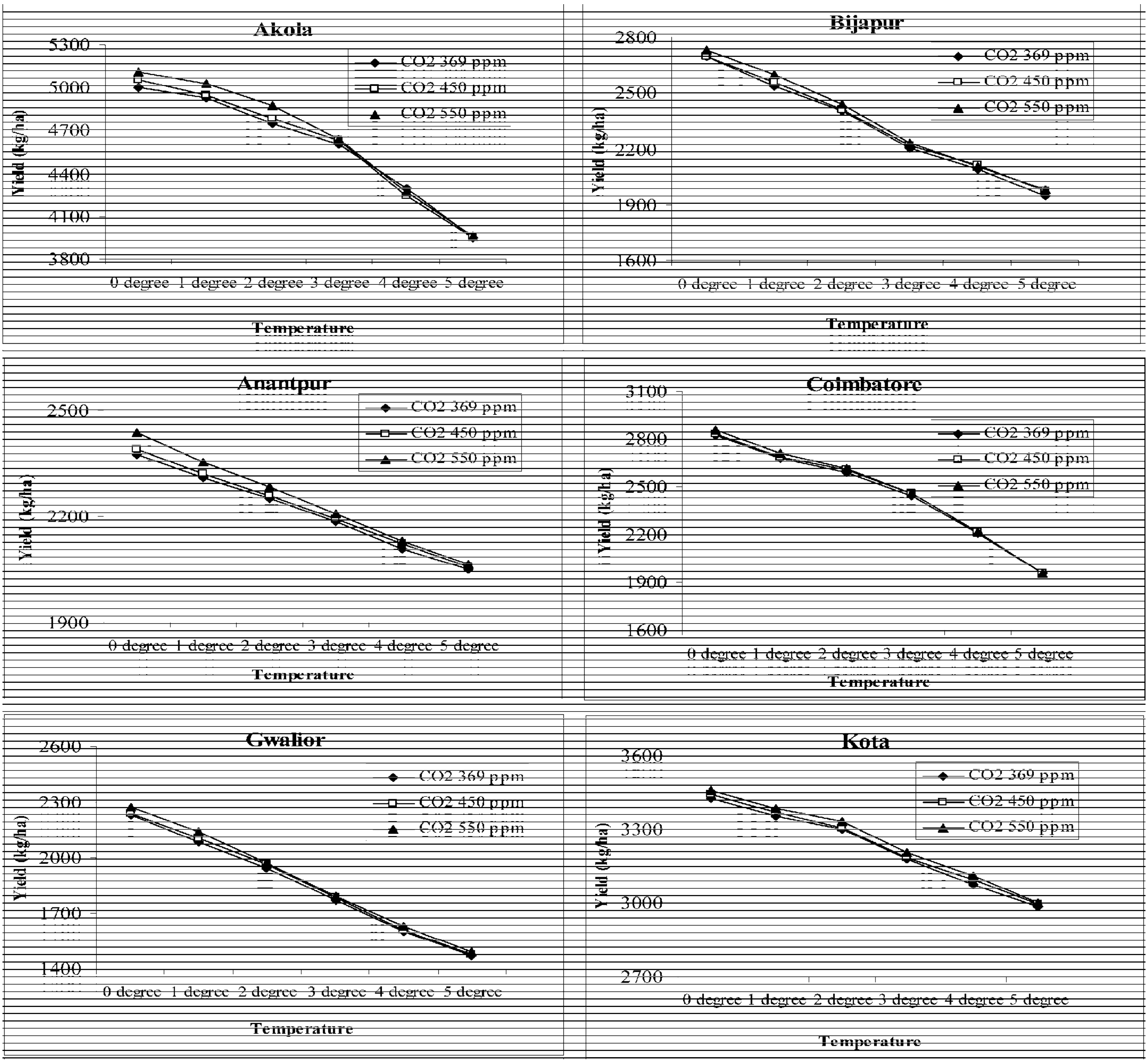

Fig. 3 : Effect of CO_2 and temperature on simulated yield of rainfed sorghum in different locations in India

with the corresponding measured values (R^2=0.96) (Fig. 2). Observed values of total dry matter varied from 4.84 to 19.73 t ha^{-1} in different locations for both irrigated and rainfed crop, while simulated dry matter yield ranged from 6.91 to 20.08 t ha^{-1}. The value of model efficiency (0.91), D-index (0.97), RMSE (0.91) showed that there was a good agreement between observed and simulated dry matter production of sorghum in different parts of India.

Yield: Observed grain yield of sorghum varied from 1.01 to 6.99 Mg ha^{-1} while simulated values ranged from 1.15 to 7.22 Mg ha^{-1}. The simulated and observed values showed a good agreement (R^2=0.85) and the estimation error was within the acceptable limits (Fig.2). Model simulated grain yield satisfactorily in all regions, with some variations.

Statistical evaluation of the model is given in Table 3. High R^2 values (0.75-0.89) indicate good linear agreement between observed and simulated data. In all the cases D-index value was found to be closer to 1. This showed a good simulation by the model. Model efficacy values ranged from 0.75-0.96 (closer to 1) showing good performance of the model. CRM values ranged from -0.02 to 0.00 showing slight error of under estimation. From the statistical estimates it is conformed that InfoCrop-Sorghum model can be used to predict phenology (days to 50% flowering and days to maturity), growth (total dry matter production) and grain yield, effectively after calibration of the model defined cultivar specific co-efficients.

Sensitivity analysis

Simulated yield showed that the sorghum crop is little sensitive to rise in temperature and CO_2. In all five regions, increasing temperature reduced sorghum grain yield while increasing CO_2 concentration increased yield of the crop. Increase in CO_2 from 369 to 550 ppm with no change in temperature has resulted in 0.9-2.7 % increase in yield of rainfed kharif sorghum across different regions. Because the C_4 crops response is low against CO_2 compare to C_3 crops. The positive yield response of sorghum to elevated carbon dioxide was due to, little increase in photosynthetic activity. But the little positive effect of increase in CO_2 concentration was nullified by temperature rise. Under rainfed condition the grain yield dropped steeply with rise in temperature from 1 to 5^0C in Gwalior (5.9 to 34.9%), Coimbatore (5.0 to 31.3%), Bijapur (5.0 to 27.4%), Akola (1.4 to 22.4%) and comparatively less in Anantpur (2.7 to 15.4%), and Kota (2.1 to 13.3%) irrespective of increase in CO_2 concentration (Fig. 3). Sorghum crop would also be vulnerable to temperature rise in all selected SAT location in India. Further rise in temperature in this location would cause substantial yield reduction in this crop. Rise in atmospheric temperature reduced leaf area index, grain number as well as weight of grains which was in turn reflected in yield of the crop. The sensitivity response of the model to CO_2 and temperature changes followed the various experimental results obtained from climate change studies in crops. Similar results were reported by earlier workers (Kimball, 1983, Mishra *et al.,* 1999 and Uprety, 2003) who found that increase in CO_2 concentration leads to changes in crop physiological processes hence affecting crop yield. According to Rotter and Van de Geijn, 1999 and Jacobs and DeBruin, 1992 rise in CO_2 accompanied by temperature increase might decrease plant growth and increase transpiration rate causing crop yield reduction. Aggarwal *et al.*, (2006b) also reported that yield reduction in rice and wheat crop is attributed to reduction in leaf area index and grain number with rise in temperature.

Impact assessment

In future climate change A2a scenarios projected sorghum yield showed a spatial as well as varietal variation among all six regions (Fig 4). The yield is likely to reduce in four regions (8.6% in Coimbatore, 6.3% in Bijapur, 2.6% Akola and 2.5% in Anantpur) and increase in Kota (3.3%) and Gwalior (0.1%) at 2020. But at 2050 onwards the reduction of yield would occur in all six regions. A2050, the more yield reduction would occur at Coimbatore (20.6%) and by Bijapur (17.5%). The least reduction is projected at Kota (0.1%) followed by Anantpur (3.9%), Akola (6.4%) and Gwalior (6.5%). The highest reduction is going to occur in Coimbatore region (31.7%), followed by Bijapur (25.6%), Gwalior (20.9%), Akola (16.3%), Anantpur (9.1%) and Kota (8.0%) by the end of the century.

Yield reduction of sorghum with future climate change scenarios in different locations of India was primarily attributed to reduction in crop growth period (days to anthesis and days to physiological maturity) with rise in temperature. This highest reduction in Coimbatore is because of its low rainfall during kharif season as well as temperature rise (2.6^0C) in 2080. The yield increase at Gwalior and Kota during 2020 is, due reduction maximum in temperature (0.2^0C) from current and little increase in rainfall (Table 2).

Simulation study conducted by Singh *et al.*, (2008)

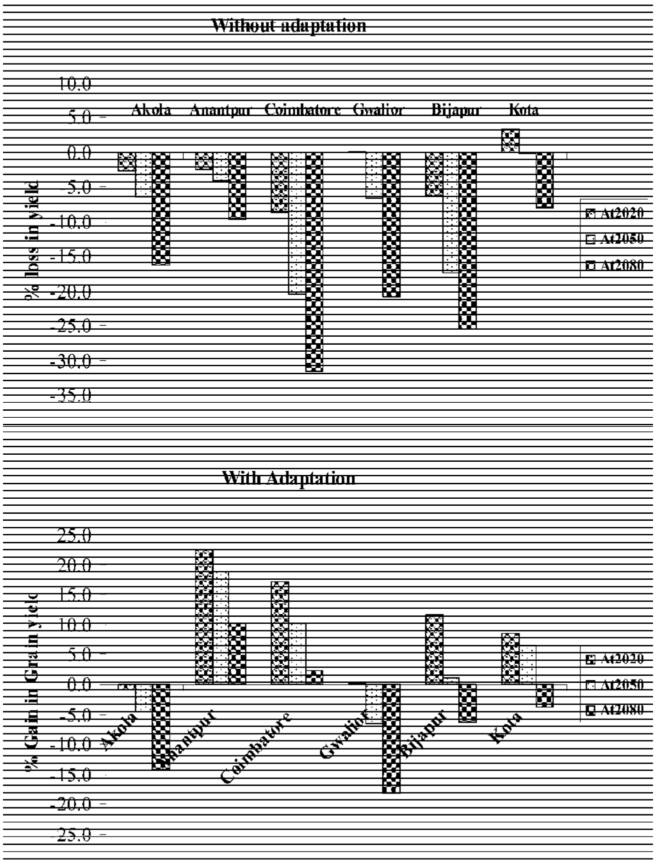

Fig. 4 : Simulated percent change in yields in HadCM3 – A2a scenarios of climate change without and with adaptation.

also revealed that with rise in temperature, rain becomes deciding factor in regulating crop production. It is envisaged that the increase in temperature, if any, may be compensated by increase in rainfall.

Adaptation strategies

There are lot of adaptation strategies highlighted in fourth assessment report of IPCC such as alteration of sowing date, replacement of variety, supplemental irrigation etc. The change of sowing date and changing variety are applicable for assured irrigation condition or irrigated crops; we have taken supplemental as one of the adaptation method in rainfed areas. A supplemental irrigation at 40-45 DAS is found to prevent yield loss to certain extent irrespective of the different SAT regions of India. The supplemental irrigation could improve the yield up to 33.7%, 19.9%, 19%, and 4.2% (Fig. 4) at Coimbatore, Anantpur, Bijapur and Kota respectively. At Gwalior and Akola the simulated yield shows that there will be little improvement (2%) due to a supplemental irrigation.

SUMMARY AND CONCLUSION

Results from this simulation study revealed that InfoCrop model can successfully simulate growth and yield of kharif sorghum crop across different locations of India. Simulated yield of sorghum was found to be sensitive to changes in atmospheric CO_2 and temperature. Yield of sorghum (C_4 crop) increased with elevated CO_2 concentration in some extent, while the positive effect of increased CO_2 was nullified by temperature rise. The above result supports the adverse impacts of future anticipated climate change on sorghum growth and yield. Spatial variation was noticed in terms of its yield loss with all selected SAT regions in India are due to soil type and weather parameters such as temperature and rainfall. Adaptation strategies like a supplemental irrigation would be helpful in preventing yield loss of rainfed sorghum crop in all locations except Gwalior and Akola.

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