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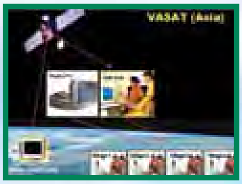


# Use of High Science Tools in Integrated Watershed Management

## Proceedings of the National Symposium

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International Crops Research Institute for the Semi-Arid Tropics

# Impact of Climate Change on Dryland Sorghum in India

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### *Abstract*

*This paper presents results of climate change impacts on sorghum in semi arid tropics (SAT) regions of India and adaptation strategies to overcome the impact. The main objective of the paper is how to use crop simulation model to assess the climate change impact and how best we can reduce the impact through integrated watershed approach. InfoCrop, a generic dynamic crop model, provides integrated assessment of the effect of weather, variety, pests, and soil management practices on crop growth and yield, on soil nitrogen and organic carbon dynamics in aerobic, anaerobic conditions, and also greenhouse gas emissions. 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 (CSH 16 and CSV 15) are likely to reduce at Akola, Anantpur, Coimbatore and Bijapur. But yield of CSH 16 will increase little in Gwalior (0.1%) at 2020 and there after it will reduce. At Kota, the sorghum yield is likely to increase at 2020 (3.3 & 1.7 % in CSH 16 and CSV 15, respectively) and no change at 2050 and yield will reduce at 2080 in both varieties. The increase in yield at Gwalior and Kota at 2020 will be due to reduction in maximum temperature and increase in rainfall from the current. Adoption of adaptation measures like one irrigation (50mm) at 40-45 days after sowing would be better for rain-fed kharif sorghum in the selected location of the SAT regions. The yield gap between district average and simulated rain-fed potential is so wide at Akola, Anantpur, Bijapur and Kota compared with Coimbatore and Gwalior. If we bridge the yield gap, we can overcome the climate change impact. Integrated Genetic and Natural Resource Management (IGNRM) through watershed management would be an appropriate method to bridge the yield gap to sustain the sorghum yield and food security.*

**Key words**: *InfoCrop, Simulation, Watershed, Adaptation, Dry matter, Leaf area index, Maturity, India, SAT.*

## Introduction

Sorghum is the fifth most important cereal crop grown on 47 million ha in 99 countries of Africa, Asia, Oceania, and the Americas. Major producers are the USA, India, Nigeria, China, Mexico, Sudan and Argentina. The crop occupies 25% or more of arable land in Mauritania, Gambia, Mali, Burkina Faso, Ghana, Niger, Somalia and Yemen, and >10% of this area in Nigeria, Chad, Sudan, Tanzania and Mozambique. For direct human use (>55%), grain is mostly consumed in the form of flat breads and porridges (thick or thin); stover is an important source of dry season maintenance rations for livestock, especially in Asia; also an important feed grain (33%), especially in the Americas. India is the second largest sorghum grower in the world after 2005 (area of 8.45 m ha during 2007-08), followed by Nigeria. Sudan is the world largest sorghum grower (area of 8.95 m ha during 2007-08). China topped in productivity (4584 kg ha$^{-1}$) among the nine countries where sorghum is grown in more than 1 m ha. India ranks seventh and Sudan ranks eighth in productivity (Table 1).

**Table 1. Area, production and productivity of sorghum in India compared with rest of the world.**

| | Area (m ha) | | Production ( M t) | | Productivity (kg ha$^{-1}$) | |
|---|---|---|---|---|---|---|
| Countries | 1981 | 2007 | 1981 | 2007 | 1981 | 2007 |
| World | 44.89 | 46.92 | 65.52 | 63.38 | 1458 | 1350 |
| USA | 5.27 | 2.32 | 19.16 | 12.64 | 3618 | 4300 |
| Nigeria | 2.68 | 7.80 | 3.28 | 9.06 | 1461 | 1159 |
| India | 16.36 | 8.45 | 11.38 | 7.15 | 695 | 846 |
| Mexico | 1.49 | 1.78 | 4.99 | 6.20 | 3343 | 3495 |
| Sudan | 3.05 | 8.95 | 2.27 | 5.84 | 725 | 652 |
| China | 2.83 | 0.53 | 7.03 | 2.43 | 2493 | 4584 |
| B. Faso | 1.05 | 1.61 | 0.62 | 1.62 | 589 | 1007 |
| Ethiopia | NA | 1.46 | NA | 2.17 | NA | 1484 |
| Niger | NA | 2.84 | NA | 0.98 | NA | 344 |

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. Traditionally, sorghum is grown for food and fodder purposes. In view of decreasing demand for sorghum (rainy season, (*kharif*) sorghum grain in particular) as a food crop, it is increasingly diverted for various alternative uses such as animal feed, poultry feed, potable alcohol from grain (Dayakar Rao 2008). Water stress is one the major constrain in sorghum production in rain-fed area. In India the yield gap analysis 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. They concluded that the integrated watershed management approaches, encompassing harvesting and storing of excess run off for supplemental irrigation, improved cultivars, integrated nutrient. Pest management practices are required to abridge the yield gaps of *kharif* sorghum. 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.

These changes in the global climate may affect the crop yields, incidence of weeds, pests and plant diseases, and the economic costs of agricultural production. Easterling *et al*. (2007) analyzed modeling results to show that in low-latitude regions, a temperature increase of 1-2°C is likely to have negative yield impacts for major cereals. There is a probability of 10-40% loss in crop production in India with increase in temperature by 2080-2100 (IPCC 2007). There are a few Indian studies (Saseendran *et al*. 2000; Aggarwal 2008) that also confirm decline in the agricultural production with climate change. 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. Despite variable response across seasons to increase in temperature, an average yield reduction of groundnut crop at Anantpur will be about 38% and an increase in rainfall will benefit the crop marginally. Considering the impacts of increase in temperature and $CO_2$ concentration, the yield reduction of rain-fed crops across a few selected locations in India are simulated to be 22 to 50% for *kharif* sorghum, 33 to 51% for pearl millet, 23 to 29% for groundnut, 8-11% for pigeonpea and 7% for chickpea (at Nandyal and Akola). However, the climate change impacts at current low levels of management of crops would be marginal (Piara Singh *et al.* 2009 unpublished data). This means that as we improve the management of crops to achieve higher crop yields to achieve food security the impacts of climate change will become significant. On the other hand, global warming impact was likely offset to some extent by increased $CO_2$ levels in atmosphere, although the magnitude of these effects are uncertain and this needs more debate and research (Long *et al*. 2005, 2006).

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 using crop simulation model 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

Info Crop 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.

- Crop growth and development: phenology, photosynthesis, partitioning, leaf area growth, storage organ numbers, source: sink balance, transpiration, uptake, allocation and redistribution of nitrogen.
- Effects of water, nitrogen, temperature, flooding and frost stresses on crop growth and development.
- Crop-pest interactions: damage mechanisms of insects and diseases.
- Soil water balance: root water uptake, inter-layer movement, drainage, evaporation, run off, ponding.
- Soil nitrogen balance: mineralization, uptake, nitrification, volatilization, inter-layer movement, denitrification, leaching.
- Soil organic carbon dynamics; mineralization and immobilization.
- Emissions of green house gases: carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$).

The basic model is written in Fortran Simulation Translator programing language (FST/FSE; Graduate School of Production Ecology, Wageningen, The Netherlands), a language also adopted by the International Consortium for Agriculture Systems Application (ICSA) as one of the languages for systems simulation (Van Kraalingen, 1995). Another version of the model has been developed to facilitate its greater applications in agricultural research and development by the stakeholders not familiar with programing. The user-interface of this software has been written using Microsoft. Net framework while the back-end has FSE models and databases in MS-Access. More details of the model are provided by Aggarwal *et al*. (2006a and b).

## Climate Change Impact Assessment

***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.

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

| | Max. temp. ($^0$C) | | | Min. temp. ($^0$C) | | | Rainfall (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | 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 |

## Adaptation Strategies

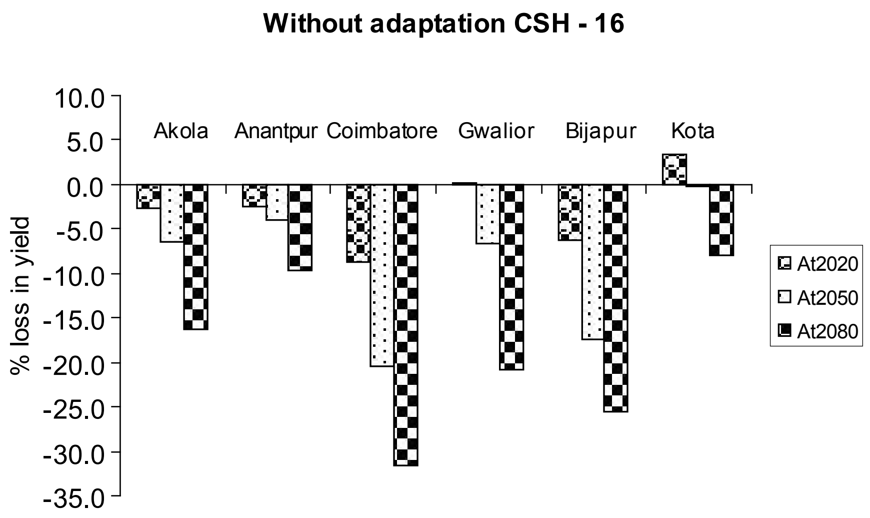
One adaptation strategy (50 mm supplemental irrigation at 40-45 DAS) was selected and crop model was run for future climate change scenarios. Yield loss of rain-fed sorghum was compared with district average, current rain-fed potential as well as with adaptation measures.

# Results and Discussion

## Impact Assessment

### CSH 16 –Sorghum hybrid

In future climate change A2a scenarios projected sorghum yield to show a spatial as well as varietal variation among all six regions (Fig 1). The



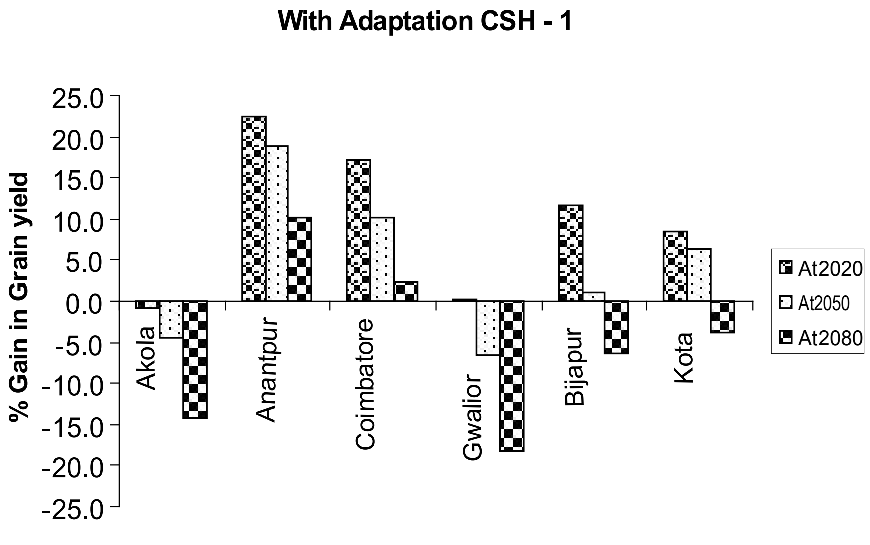




*Figure 1. Simulated per cent change in yields (CSH 16) in HadCM3 – A2a scenarios of climate change without and with adaptation.*

yield of CSH 16 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 from 2050 the reduction of yield would occur in all six regions. A2050, the more yield reduction would occur at Coimbatore (20.6%) and Bijapur (17.5%). The least reduction is projected in 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.

***CSV 15 Sorghum variety:*** The yield reduction of CSV 15 (Fig. 2) would also have spatial variation. In 2020 the yield reduction will occur in all regions except Kota, where there will be 1.7% increase in yield. After 2020, the same trend has been observed like CSH 16, such as the highest yield reduction would occur in Coimbatore (31.3%) and Bijapur (24.8%), followed by Gwalior (16.5%), Anantpur (14.6%) and Akola (11.3%). The less reduction is observed in Kota (8.4%) by 2080.

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 will be because of its low rainfall during *kharif* season as well as temperature rise (2.6°C) in 2080. The yield increase at Gwalior and Kota during 2020 will be, due to reduction in maximum temperature (0.2°C) from current temperature and little increase in rainfall (Table 2).

Increasing temperature lowered days to flowering and days to maturity, which in turn lowered total crop duration. In plants warmer temperature accelerates growth and development leading to less time for carbon fixation and biomass accumulation before seed set, resulting in poor yield (Rawson, 1992; Morison, 1996). Simulated results also confirmed reduction in leaf area index with climate change which in turn lowered the

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

| | Max. temp. (°C) | | | Min. temp. (°C) | | | Rainfall (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | 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 |

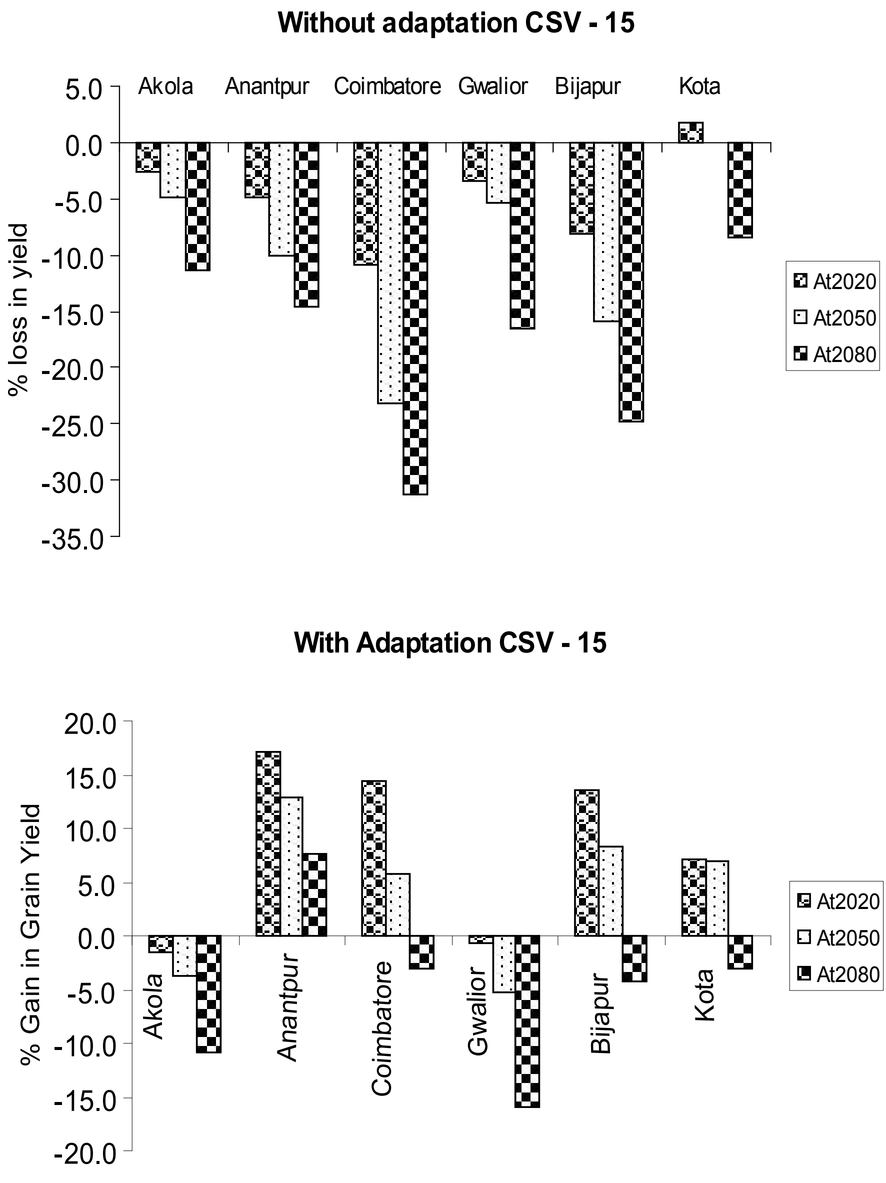



*Figure 2. Simulated per cent change in yields (CSV 15) in HadCM3- A2a scenarios of climate change without and with adaptation.*

radiation use efficiency (RUE) of the crop. Less leaf area together with low RUE has lowered net photosynthesis and finally reducing total dry matter production of sorghum crop. Pidgeon et al., (2001) also reported that changes in climate affect crop radiation use efficiency (RUE). Spatial variation in temperature as well as rainfall and its distribution led to spatial variation in yield reduction. This study supports the recent report of the IPCC and a few other global studies that indicate a probability of 10-40% loss in crop production in India with increase in temperature by 2080-2100 (IPCC, 2007). Simulation study conducted by Singh *et al*., (2008) 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 many 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 rain-fed areas. Also Government of India is promoting micro-watersheds in rain-fed areas, which can store the excess water collected during peak rainfall and can be utilized for supplemental irrigation. 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 (CSH 16) up to 33.7%, 19.9%, 19%, and 4.2% (Fig. 1) in Coimbatore, Anantpur, Bijapur and Kota, respectively. At Gwalior and Akola, the simulated yields show that there will be little improvement (2%) due to a supplemental irrigation.The same way the simulated results showed that there could be better improvement in yield of sorghum variety CSV 15 (Fig. 2) in Coimbatore (28%), Bijapur (20%), Anantpur (17%), and Kota (5%). There is not much improvement at Gwalior (0.5%) and Akola (0.9%) because at Akola and Gwalior the average rain fall during the crop growth period (600 mm and 720 mm respectively) is higher than that of other selected SAT regions which receive low average rainfall (480 mm at Kota, 372 mm at Bijapur, 368 mm at Anantpur and 196 mm at Coimbatore) during crop growth period. So in these two regions, the variety of longer duration than present variety might be a better adaptation strategy.

### Yield Gap

But on the other hand the comparison of district average yield with water stress potential yield, shows wide gap at Akola (3.45 Mg $ha^{-1}$), Kota (2.78 Mg $ha^{-1}$), Bijapur (1.56 Mg $ha^{-1}$) and Anantpur (1.48 Mg $ha^{-1}$). At Coimbatore, the yield is also low due to less average rainfall (196 mm), thus causing fewer gaps between water stress potential and district average yield in both hybrid and variety. On the other hand, the average rainfall (720 mm) is sufficient for growth and development of sorghum at Gwalior, which shows very narrow yield gap between water stress potential and district average. Bridging the gap by using IGNRM techniques through watershed development program (Wani *et al*., 2009), will be a better adaptation strategies against climate change as well as for sustainable production of sorghum to ensure food security.

## Summary and Conclusion

Results from this simulation study revealed that the 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 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 rain-fed sorghum crop in all locations except Gwalior and Akola. But on the other hand, the comparison of district average yield with water stress potential yield, shows wide gap. Bridging the gap by using IGNRM techniques through watershed development program will be a better adaptation strategy against climate change as well as for sustainable production of sorghum to ensure food security in India.

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