Climate change impact assessment and adaptation strategies to sustain rice production in Cauvery basin of Tamil Nadu

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The results of the projected climate change over Cauvery basin of Tamil Nadu for A1B scenario using regional climate models showed an increasing trend for maximum, minimum temperatures and rainfall. The yields of ADT 43 rice simulated by decision support system for agricultural technology transfer with CO_2 fertilization effect had shown a reduction of 135 kg ha^{-1} decade^{-1} for providing regional climates for impact studies (PRECIS) output, while there was an increase in yield by 24 kg ha^{-1} decade^{-1} for regional climate model system 3 (RegCM3) output. Suggested adaptation strategies include system of rice intensification, using temperature tolerant cultivars and using green manures/biofertilizers for economizing water and increasing the rice productivity under warmer climate.

Keywords: Adaptation strategies, agriculture, climate change, impact, rice production.

Introduction

IMPACTS of climate change pose a serious threat to food security and need to be much better understood[1]. In the recent past, changes in timing and amount of precipitation, extremes in temperature and widespread drought are becoming quite common in most parts of the world. The last decade, that ended with 2010, was the warmest in the past. Climate models are the main tools available for developing projections of climate change in the future[2,3]. However, the presence of large uncertainties in climate models and future emission scenarios predicting long-term changes in certain climate variables, in particular in regional scales, is a challenging task that climate modellers face today[4,5]. Future temperature projections using global circulation models (GCM) indicate an increase of 2.5–4°C from the current levels over the Indian subcontinent. However, GCM results are available for a very coarse resolution of 2.5° lat. and 3.75° long., which will have high uncertainty[6]. As climate change projections form the basis for assessing the impact on crop production and developing adaptation strategies, reliable future changes with reduced level of uncertainty are increasingly important. Regional climate models (RCM) run at high resolution of 25 km × 25 km grid taking into consideration the orography, coasts, vegetation and internal regional climate variability would predict the future climate with high confidence[7].

Rice is one of the most important staple food crops which is predominantly grown in the Cauvery river basin, which is also known as the rice bowl of Tamil Nadu. The research results indicate that the productivity of rice crop declines by 41% for 4°C increase in temperature[8]. Well-calibrated and validated crop weather models could be used as an effective tool for assessing the impacts of future changes in climate[9]. It is important to develop suitable adaptation strategies for sustaining the rice productivity to meet the demand of a growing population[10]. In this article, two regional climate model outputs have been used to understand the climate change trends in the Cauvery river basin of Tamil Nadu for assessing the impact on rice productivity and designing suitable adaptation strategies to reduce the impacts of climate change.

Methods

Description of the study area

The Cauvery river basin located in the southern part of India covers an area of 81,155 sq. km. About 44,000 sq. km of the basin lies in Tamil Nadu from 10.00°N to 11.30°N lat. and 78.15°E to 79.45°E long., and the rest is in Karnataka. The Tamil Nadu part of the Cauvery basin receives an annual average rainfall of 956 mm and employs over 4.4 million people in the agricultural sector. Most of the upstream areas and catchment areas of the Cauvery river basin receive rainfall during the southwest monsoon season, filling up the Mettur reservoir on the Cauvery

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river that supplies water to Tamil Nadu. However, the Cauvery delta area of Tamil Nadu receives major share of its rainfall during the northeast monsoon season. Since this river basin receives rainfall from both the monsoons, rice crop is cultivated in both kharif (southwest monsoon: June–September) and Rabi (northeast monsoon: October–January) seasons.

Development of future climate projections

The future climate change scenario was developed using two RCMs, viz. Providing REgional climates for Impact Studies (PRECIS) and Regional Climate Model System 3 (RegCM3). PRECIS was developed by the Hadley Centre, UK Met Office that can be used over any part of the globe[11–14]. For the present study, PRECIS was received from the Hadley Centre by the Tamil Nadu Agricultural University, Coimbatore with the required boundary conditions and the GCM output used was HadCM3Q0: A1B.

RegCM3 was developed by the Abdus Salam International Centre for Theoretical Physics (ICTP), Italy, and has been mostly applied to study the regional climate and seasonal predictability around the world. It is an open-source RCM available on the public domain (http://www.ictp.trieste.it/pubregcm/RegCM3) which can be used for climate simulation over different areas of interest using EH5OM GCM output as a boundary condition. In addition, some of the experiments carried out by Dash *et al.*[15], using RegCM3 for developing future scenario have shown the usability of the model over the Indian subcontinent.

Both the RCMs were run for the Cauvery Delta Zone (CDZ) of Tamil Nadu with horizontal resolution of $0.22° \times 0.22°$ or 25 km × 25 km, with a sufficient buffer zone. We have selected the moderate CO_2 emissions scenario, A1B, for future climate projections. From the large number of outputs generated from the models, only maximum temperature, minimum temperature and rainfall were retrieved. Models were run for 129 years from 1971 to 2099.

Impact assessment

The decision support system for agrotechnology transfer (DSSAT) modelling system is an advanced physiologically based crop growth simulation model and has been widely applied to understanding the relationship between rice and its environment. In this study, the DSSAT model was employed for assessing the impact of climate change on rice productivity. ADT 43 rice variety which is commonly grown in the Cauvery basin was used as a test variety and the simulations were made with and without CO_2 fertilization effect.

Development of adaptation strategies

Future climate over the Cauvery basin mainly indicates steady increase in temperature and variation in rainfall pattern. Though rainfall is expected to increase, water shortage/intermittent drought during critical growth phases of the crop might occur due to more extreme conditions in future. Selected adaptation technologies were tested in the farmer's field, such as varietal screening to withstand the high temperature and changing the method of cultivation for economizing water during summer 2008.

A trial was conducted at the farmer's field in the Cauvery basin to evaluate the performance of different systems of rice cultivation that are traditionally followed by the farmers in the Cauvery Delta Zone of Tamil Nadu. Details of rice cultivation systems are explained in Table 1. Water productivity and grain yield were compared among the different systems of cultivation.

Results

Future climate projections using regional climate models

The results of the projected climate change over the Cauvery basin of Tamil Nadu for A1B scenario using PRECIS and RegCM3 RCMs showed an increasing trend for maximum temperature, minimum temperature and rainfall (Figure 1 *a*–*c*). Decadal means of maximum and minimum temperatures were generated to understand the variation more clearly and the results (Table 2) revealed that the increase in maximum temperature in PRECIS was 3.7°C and in RegCM3 it was 3.1°C. The increase in minimum temperature in PRECIS was 4.2°C and in RegCM3 it was 3.7°C during the same period. The increase in minimum temperatures is higher than that in maximum temperatures in both models.

Impact of projected climate on rice production

The yields of ADT 43 rice over CDZ simulated by DSSAT without considering the CO_2 fertilization effect showed a reduction of 356 kg ha^{-1} $decade^{-1}$ for PRECIS output, whereas the decline was 217 kg ha^{-1} $decade^{-1}$ for RegCM3 output (Figure 2). However, when CO_2 fertilization effect was considered in DSSAT, the PRECISE output showed decreasing trend at the rate of 135 kg ha^{-1} $decade^{-1}$, whereas RegCM3 projected increased yield (24 kg ha^{-1} $decade^{-1}$).

Development of adaptation strategies

Future climate scenarios and their possible impact on rice production were presented to the stakeholders, including

Table 1. Agronomical practices followed in different rice cultivation systems

System of cultivation	Abbreviation used	Practices followed
Transplanted rice cultivation	TRC	Transplanted 24-day-old seedlings with a spacing of 20 × 15 cm. Hand weeding was done twice at 20 and 35 days after transplanting. Field was irrigated to maintain the water level at 5 cm from transplanting to 10 days before harvest.
Direct sown rice	DSR	Wet seeded rice was sown using eight row paddy drum seeder in a puddled soil maintaining a spacing of 20 × 15 cm. Hand weeding was done at 15, 30 and 45 days after sowing. A thin film of water was maintained till seedling establishment and gradually the water level was raised to maintain 5 cm in the field just like TRC.
Alternate wetting and drying	AWD	Transplanted 24-day-old seedlings with a spacing of 20 × 15 cm. Initially, water was impounded to 5 cm depth in the main field and subsequent irrigations were given 3 days after complete disappearance of water. Hand weeding was done twice at 20 and 35 days after transplanting.
System of rice intensification	SRI	Fourteen-day-old seedlings were transplanted with a spacing of 22.5 × 22.5 cm. Weeding was done thrice using conoweeder at 10 days interval from the tenth day after transplanting. Irrigation was done after the disappearance of water and formation of hairline cracks in the soil.
Aerobic rice cultivation	ARC	Pre-germinated seeds were sown in rows of 20 × 10 cm by using aerobic rice drum seeder in thoroughly prepared dry soil. Hand weeding was done at 15, 30 and 45 days after sowing. Field was irrigated once in 5 days without impounding water.

Table 2. Projection of decadal mean maximum and minimum temperatures over the Cauvery basin

	Maximum temperature (°C)		Minimum temperature (°C)	
Decade	PRECIS	RegCM3	PRECIS	RegCM3
1971–1980	34.0	31.9	24.2	21.6
1981–1990	34.5	31.9	24.5	21.7
1991–2000	34.1	32.0	24.3	21.9
2001–2010	35.0	32.1	25.3	22.0
2011–2020	35.0	32.5	25.3	22.3
2021–2030	35.8	32.4	26.1	22.4
2031–2040	35.5	32.7	26.0	22.8
2041–2050	36.6	33.1	26.9	23.2
2051–2060	36.3	33.3	26.8	23.6
2061–2070	37.0	34.1	27.4	24.2
2071–2080	37.6	34.2	28.2	24.5
2081–2090	37.3	34.6	28.0	24.9
2091–2099	37.7	35.0	28.3	25.3
Difference	3.7	3.1	4.2	3.7

farmers of the Cauvery river basin, officials from the Department of Agriculture and Water Resource and members of the Water Users Association. Possible adaptation technologies were discussed and documented. Some of the adaptation strategies suggested by the farming community are: changing cultivation method to improve the water-use efficiency and rice productivity, varietal screening for tolerating higher temperatures, altering the sowing window to grow the crops in favourable environment, growing green manure crops and incorporation, use of biofertilizers and growing azolla as dual crop in paddy to reduce the fertilizer bill as well as improve the soil productivity, crop rotation with short-duration legume crops for fixing atmospheric nitrogen in the soil and growing alternate crops for managing extreme weather conditions such as continuous flooding or drought, for enriching the soil organic matter content. The selected adaptation technologies such as screening the temperature-tolerant varieties and changing the cultivation method were pilot tested in the farmer's field. The results are presented below.

Screening of temperature-tolerant varieties: Popular rice varieties of Cauvery basin were grown during summer 2010 with the objective of assessing the performance under higher temperature. Six short-duration varieties (ADT 48, ADT 37, ADT 36, ADT(R) 45, ADT 42 and ADT 43), seven medium-duration varieties (ADT 38, CO 49, CO 50, CO 48, ADT (R) 46, CO 43, BPT 5204) and one long-duration variety (CR1009) were screened.

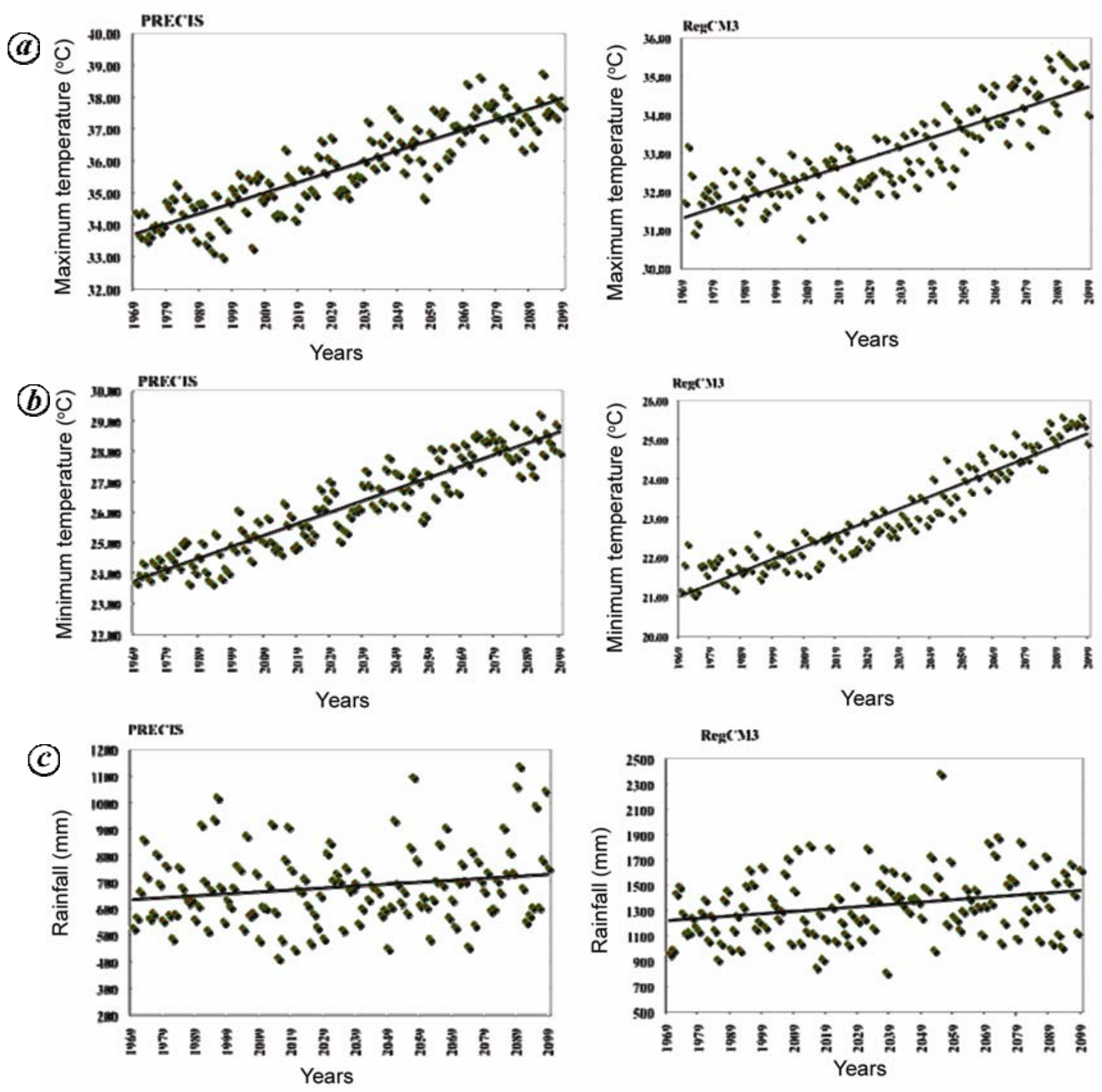

Figure 1. Temperature and rainfall projections for A1B scenario using PRECIS and RegCM3 models. ***a***, Mean annual maximum temperature (°C). ***b***, Mean annual minimum temperature (°C). ***c***, Mean annual rainfall (mm/yr).

Summer season experienced 3–4°C higher temperatures than the normal growing season. Among the varieties tested, ADT 38, ADT 48, CO 43, ADT 36, ADT 37 and BPT 5204 withstood higher temperature and gave higher yields compared to the other varieties. This indicates that these varieties can be recommended for the future warmer climate. CR 1009 variety could not withstand higher temperatures and the grain formation was also less (Figure 3).

Changing cultivation method

In the Cauvery basin, during kharif season, normally the crop experiences intermittent drought due to less water availability and more evapotranspiration losses from the field. Moreover, the crops cultivated at the tail end of the river basin face water scarcity quite frequently due to low water availability compared to the head end and middle region, where farmers use more water. Under changing climatic conditions, more water scarcity is expected. The results of the field experiment conducted in the farmer's field of the Cauvery basin with different cultivation methods indicated that under the system of rice intensification (SRI) method, 22% increase in grain yield and 24.5% water saving were noticed compared to transplanted rice. Water productivity was also maximum under SRI method of rice cultivation (0.58 kg/m^3), followed by alternate wetting and drying method, and aerobic rice cultivation. The conventional rice cultivation (0.36 kg/m^3), and direct sown rice produced lower grain yield per unit of water used (Table 3). SRI method of cultivation will suit better under future warmer climate in terms of economizing water and increasing the productivity.

Table 3. Grain yield and water productivity in different rice cultivation systems

System of cultivation	Grain yield (kg/ha)	Percentage change in grain yield from TRC	Total water used (m^3/ha)	Percentage water saving over TRC	Water productivity (kg/m^3)
TRC	6032^{b}	–	$16,802^{a}$	–	0.36^{c}
DSR	5175^{c}	–14.2	$15,763^{a}$	6.2	0.33^{d}
AWD	5111^{c}	–15.3	$12,488^{a}$	25.7	0.41^{b}
SRI	7359^{a}	22.0	$12,685^{a}$	24.5	0.58^{a}
ARC	3582^{d}	–40.6	$9,687^{a}$	42.3	0.37^{c}

Means within the columns followed by the same letter are not significantly different (LSD at $P = 0.05$).

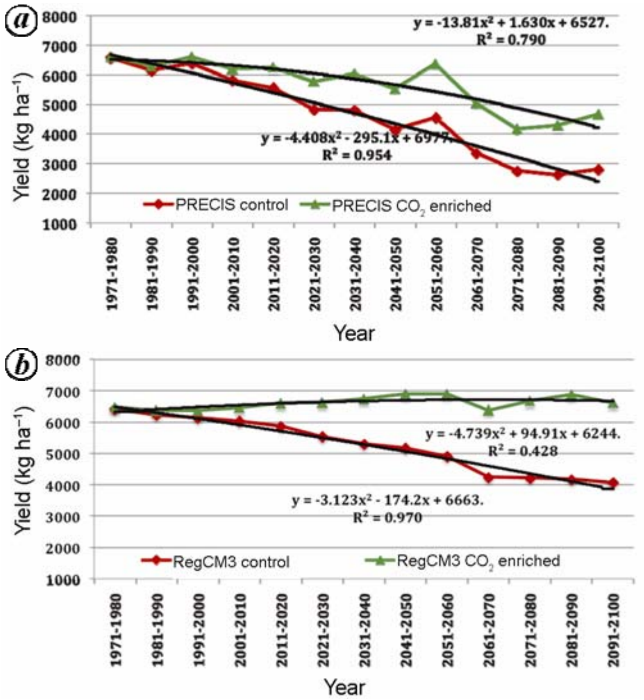

Figure 2. Response of rice yield to climate change. Rice yield predicted using PRECIS (***a***) and RegCM3 (***b***).

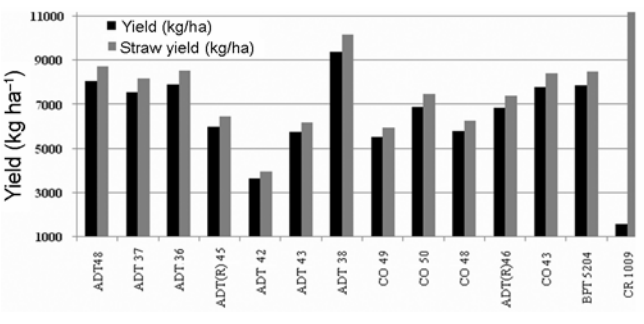

Figure 3. Performance of different varieties under the system of rice intensification method of cultivation during summer 2010.

Discussion

The impact of climate change is likely to have a great influence on the agriculture and water sectors, and eventually on the food security and livelihoods of a large section of the rural population in developing countries[7]. Droughts, floods, tropical cyclones, heavy precipitation events, hot extremes, and heat waves are known to negatively impact agricultural production and the livelihood of the farmers. As climate change projections form the basis for assessing the impact on crop production and developing adaptation strategies, reliable future changes with reduced level of uncertainty are increasingly important.

The results of the projected climate change over the Cauvery basin of Tamil Nadu for A1B scenario using PRECIS and RegCM3 regional climate models showed an increasing trend for maximum temperature, minimum temperature and rainfall. Climate scientists depend on models that incorporate sophisticated understanding of the coupled behaviour of the climate system. However, estimates of radiative forcing reveal that gases like CO_2 contribute to warming, whereas aerosol and clouds tend to cool the surface leading to the global warming controversy. It is known that climate models do a reasonable job of capturing the large-scale aspects of current climate, but still contain systemic model errors adding uncertainty to the future projection[16]. Hence, the regional model outputs on temperature and rainfall variations have to be handled with caution while using them for impact assessment.

Crop simulation models are used to estimate the impacts of climate change on agricultural production. While most models used for this purpose have been validated at the plot level, few studies have evaluated them for multiple years at a regional level[17]. In the present study, ADT 43 rice variety was used and there are reports indicating that the choice of the variety makes a difference between increase and decrease in the yield while being exposing to climate change scenarios[18]. The yields of rice over CDZ simulated by DSSAT for ADT 43 rice variety have shown a reduction of 356 and 217 kg ha^{-1} $decade^{-1}$ for PRECIS and RegCM3 outputs respectively, without considering the CO_2 fertilization effect. This reduction in yield might be mainly due to increase in both maximum and minimum temperatures as well as variation in rainfall. Agarwal and Mall[19] have also reported that 2°C increase in mean temperature has resulted in considerable decrease in grain yield of rice, if there is no adaptation measure taken. However, when the CO_2 fertilization effect was considered, the yield reduction was minimized while using PRECIS output and there was a projected yield increase by 24 kg ha^{-1} $decade^{-1}$ while using RegCM3 outputs. The increase in yield might be due to the positive effect of CO_2 fertilization that might have reduced the impact of increased temperature. Similar results were also reported by Mohandass *et al*.[20].

To sustain crop productivity during climate change, farmers need different adaptation options. The adaptation tool box for agriculture should include measures that farmers can practice now, together with a long-term strategy to suit the different extreme weather patterns. Proactive measures for adaptation to climate variability and change can substantially reduce many of the adverse impacts, and thus contribute to livelihood security of the vulnerable rural population. To sum up, regional models for the Indian subcontinent should be developed for downscaling the climate change scenarios of smaller regions for the near future, and the sensitivity analysis for all possible scenarios of climate change using crop weather model should be taken up for assessing the impact of future climate and for developing adaptation strategies.

1. Allen, L. H., Plant response to raising CO_2 and potential interaction with air pollutants. *J. Environ. Qual*., 1990, **19**, 15–34.
2. Houghton, J. T., Meira Filho, L. G., Callander, B. A., Harris, N., Kattenberg, A. and Maskell, K., *Climate Change, Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 1995.
3. Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., Van Der Linden, P. J. and Xioaosu, D., *Climate Change: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 2001.
4. New, M. and Hulme, M., Representing uncertainty in climate change scenarios: a Monte Carlo approach. *Integr. Assess.*, 2000, **1**(3).
5. Ghosh, S. and Mujumdar, P. P., Climate change impact assessment – uncertainty modeling with imprecise probability. *J. Geophys. Res. Atmos.*, 2009, **114**, D18113.
6. Manabe, S. and Hahn, D. G., Simulation of atmospheric variability. *Mon. Weather Rev*., 1981, **109**, 2260–2286.
7. IPCC, Summary for policymakers. *Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 2007.
8. Lal, M., Singh, K. K., Rathore, L. S., Srinivasan, G. and Saseendran, S. A., Vulnerability of rice and wheat yields in NW India to future changes in climate. *Agric. For. Meteorol*., 1998, **89**, 101–114.
9. Saseendaran, S. A., Singh, K. K., Rathore, L. S., Singh, S. V. and Sinha, S. K., Effects of climate charge on rice production in the tropical humid climate of Kerala, India. *Climate Change*, 2000, **44**, 495–514.
10. Hoanh, C. T., Guttman, H., Droogers, P. and Aerts, J., Water, climate, food and environment in the Mekong Basin in Southeast Asia. Final Report ADAPT Project, Adaptation Strategies to Changing Environment, Amsterdam, 2003, p. 52.
11. Hudson, D. A. and Jones, R. G., Regional climate model simulations of present-day and future climates of southern Africa. Technical Notes No. 39, Hadley Centre, UK Met Office, Bracknell, 2002.
12. Rupakumar, K. *et al*., High-resolution climate change scenarios for India for the 21st century. *Curr. Sci*., 2006, **90**, 334–345.
13. Taylor, M. A. *et al*., *Glimpses of the Future: A Briefing from the PRECIS Caribbean Climate Change Project*, Caribbean Community Climate Change Centre, Belmopan, Belize, 2007, pp. 1–24.
14. Akhtar, M., Ahmad, N. and Booij, M. J., The impact of climate change on the water resources of Hindukush–Karakorum–Himalaya region under different glacier coverage scenarios. *J. Hydrol.*, 2008, **355**(1–4), 148–163.
15. Dash, S. K., Shekhar, M. S. and Singh, G. P., Simulation of Indian summer monsoon circulation and rainfall using RegCM3. *Theor. Appl. Climatol.*, 2006, **86**, 161–172.
16. Annamalai, H., Prasanna, V., Hafner, J., Nagothu, U. and Kitterod, N. O., Modeling the current and future climate over the Cauvery river basin. In *Sustainable Rice Production in a Warmer Planet*, Macmillan Publishers, New Delhi, 2011, pp. 59–81.
17. Carbone, J. Gregory, Linda O. Mearns, Theodoros Mavromatis, John Sadler, E. and David Stooksbury, Evaluating CROPGRO-soybean performance for use in climate impact studies. *Agron. J*., 2003, **95**, 537–544.
18. Challinor, A. J., Wheeler, T. R., Craufurd, P. Q., Ferro, C. A. T. and Stephenson, D. B., Adaptation of crops to climate change through genotypic responses to mean and extreme temperatures. *Agric. Ecosyst. Environ*., 2008, **119**(1–2), 190–204.
19. Agarwal, P. K. and Mall, R. K., Climate change and rice yields in diverse agro-environments of India. II. Effect of uncertainties in scenarios and crop models on impact assessment. *Climate Change*, 2002, **52**(3), 331–343.
20. Mohandass, S., Kareem, A. A., Ranganathan, T. B. and Jeyaraman, S., Rice production in India under current and future climates. In *Modeling the Impact of Climate Change on Rice Production in Asia*, CAB International, UK, 1995, pp. 165–181.

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