Simulating the impact of projected climate change on rice (Oryza sativa L.) yield and adaptation strategies in major rice growing regions of India

RANI SAXENA¹ and S. NARESH KUMAR²

¹Division of Agronomy, Rajasthan Agricultural Research Institute, Durgapura, Jaipur-302018
²Centre for Environment Science and Climate Resilient Agriculture, Indian Agricultural Research Institute, New Delhi-110012

E-mail address: mathurrani@rediffmail.com

ABSTRACT

Global mean air temperatures are projected to increase by 1.8 to 4.0 °C by the end of this century (IPCC, 2007). Climate change exerts both positive and negative impact on crop yield, though its magnitude may differ from location to location. According to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007a, b), in arid and semi-arid regions, warming beyond a certain limit may adversely affect the crop growth, development and finally the crop productivity. Among the climatic factors, temperature and CO₂ are important factors that significantly influence crop growth, development and yield. Cardinal temperatures influences crop physiological process and reproduction, thereby influencing grain yield. Not only different crops respond differently to increase in temperature, but also different genotypes show differential response in yield (Prasad et al, 2006). Increase in CO₂ concentrations further from current 393 ppm (NOAA, 2012), benefit the yield of C₃ plants due increase in photosynthetic rates. However, due to green-house effect, the increase in CO₂ concentration in atmosphere causes rise in temperature.

Rice is one of the main staple food crop in India and grown in about 42.56 million hectare area with a production of about 95.33 million tonnes (Agricultural Statistics at a Glance, 2012). Rice is reported to be influenced by temperature, especially during grain filling phase (Cao Yun-Ying, 2009). As it is a C₃ crop, CO₂ fertilization effects on growth yield have been reported by Baker and Allen (1993). Several studies have reported the impact of climate change on rice in India (Mall et al., 2004, Aggarwal and Mall, 2002, Attri and Rathore, 2003, Hundal, et al., 1993 and Krishnan, et. al., 2007). However, they did not attempt to provide the adaptation gains. In the present study, an attempt has been made to assess the impact of elevated CO₂ and temperature alone and in combination on rice crop using 35 years (1970-2005) weather data from locations representing major rice-growing agro- ecological regions. Apart from quantifying the impacts, the adaptation gains by changing planting time and change in variety was also assessed.

MATERIALS AND METHODS

For this study, eight locations viz. Ludhiana, Patna, Cuttack, Raipur, Akola, Lucknow, Barrackpore, Rajamundry, differing in climatological and geographical features were selected.
The point data on daily weather for 1970-2005 (Coordinating centers of the project, Central Research Institute for Dryland Agriculture, Hyderabad and Indian Meteorological Department, Pune), soil and data crop/variety of these locations was collected. InfoCrop, a generic crop simulation model was used to carry out the present study. The temperatures were raised by 1°C, 2°C, 3°C, 4°C and 5°C over ambient and CO₂ concentrations used were 369 ppm, 450 ppm, 550 ppm and 650 ppm. These two factors were used in all possible combinations to get 20 combinations (5 x 4). Simulations were carried out for rainfed and irrigated conditions and at all locations. To cope with the yield losses due to rise in temperature, change in duration of crop (±15 days to medium duration crop) and planting time (±10 days to date of transplanting) was used as an adaptive measure as a part for adaptation strategy suggested by Attri and Rathore (2003) to reduce the climate change effects.

Model description

InfoCrop (Aggarwal et al., 2006) is a generic crop growth model that can simulate the effects of weather, soil, agronomic managements, nitrogen, and water on crop growth and yield. The model simulations are based on crop growth and development processes such as phenology, photosynthesis, partitioning, leaf area growth, source-sink balance, radiation use efficiency, transpiration, uptake, allocation and redistribution of nitrogen. The process like effects of temperature, CO₂, water stress, nitrogen stress, flooding and frost stresses on crop growth and development are also considered in the model.

Model inputs

Varietal characteristics: InfoCrop distinguishes varieties of a crop by their differences in phenology, growth and source-sink balance. In most cases, thermal times of three phenological phases, the sensitivity to photoperiod, early vigour (defined in the model as relative LAI growth rate during initial stages), index of storage organs formation, and the potential weight of the grain are sufficient to adequately characterize the varieties. Based on previous published studies (DRR 2009) and considering days to flowering and maturity (120-140 days), dominant variety of a region were selected for analysis assuming that farmers have optimized their variety (Table 1).

Table 1: Model inputs of physical and chemical properties of soil and rice varieties at different locations.

| Parameters               | Rajamundry | Cuttack | Akola | Raipur | Barrakpur | Patna | Lucknow | Ludhiana |
|--------------------------|------------|---------|-------|--------|-----------|-------|---------|----------|
| Latitude °N              | 16.9       | 20.3    | 20.99 | 22     | 22.45     | 25    | 25      | 30.9     |
| Longitude °E             | 81.7       | 85      | 77.8  | 77     | 88.26     | 85    | 85      | 75.8     |
| SAND (%)                 | 16         | 79      | 17    | 16     | 47        | 38    | 42      | 40       |
| CLAY (%)                 | 56         | 10      | 55    | 55     | 21        | 21    | 22      | 23       |
| BD (Cg/cc)               | 1.21       | 1.59    | 1.21  | 1.21   | 1.41      | 1.4   | 1.4     | 1.39     |
| SOC (%)                  | 0.75       | 0.53    | 0.75  | 0.75   | 0.82      | 0.63  | 1       | 0.56     |
| pH (1:2.5 soil water suspension) | 7.9 | 6.3 | 7.9 | 7.9 | 6.2 | 8 | 6.6 | 7.9 |
| EC (ds mm⁻¹)             | 0.2        | 0.1     | 0.2   | 0.2    | 0.1       | 0.3   | 0.1     | 0.8      |
| KSAT (mm h⁻¹)            | 48         | 237     | 48    | 48     | 141       | 114   | 126     | 120      |
| WCST (%)                 | 0.54       | 0.4     | 0.54  | 0.54   | 0.47      | 0.47  | 0.47    | 0.48     |
| WCFC (%)                 | 0.44       | 0.17    | 0.44  | 0.44   | 0.33      | 0.38  | 0.36    | 0.37     |
| WCWP (%)                 | 0.22       | 0.07    | 0.22  | 0.22   | 0.16      | 0.19  | 0.18    | 0.18     |
| WCAD (%)                 | 0.13       | 0.04    | 0.13  | 0.13   | 0.09      | 0.11  | 0.1     | 0.1      |
| Rice Varieties           | Samba Mashuri | Karjat 5 | Vijeta | Shatabdi | Pant Dhan | Pant Dhan | PR-120 |
| Location    | Temp. | Irrigated 450 ppm | Irrigated 550 ppm | Irrigated 650 ppm | Rainfed 450 ppm | Rainfed 550 ppm | Rainfed 650 ppm |
|-------------|-------|-------------------|-------------------|-------------------|----------------|----------------|----------------|
| Rajamundry  | 1     | 5.2               | 10.5              | 13.8              | 9.4            | 16.6           | 22.6           |
|             | 2     | -2.4              | 4.6               | 8.4               | 0.6            | 10.5           | 17.8           |
|             | 3     | -16.4             | -8.5              | -2.6              | -6.4           | 0.0            | 8.7            |
|             | 4     | -33.3             | -25.9             | -19.3             | -19.4          | -13.4          | -4.6           |
|             | 5     | -48.4             | -40.4             | -34.8             | -31.6          | -23.8          | -18.5          |
| Cuttak      | 1     | 7.0               | 15.3              | 19.6              | 10.0           | 19.3           | 28.0           |
|             | 2     | -1.8              | 6.7               | 11.4              | -3.3           | 6.6            | 15.3           |
|             | 3     | -16.1             | -6.4              | -0.4              | -14.2          | -5.1           | 2.8            |
|             | 4     | -30.4             | -22.6             | -16.2             | -28.5          | -20.4          | -12.4          |
|             | 5     | -46.4             | -38.1             | -32.5             | -42.4          | -35.0          | -28.5          |
| Akola       | 1     | 7.2               | 13.2              | 18.0              | 14.1           | 28.2           | 43.3           |
|             | 2     | -0.1              | 7.7               | 12.4              | 4.8            | 18.7           | 32.6           |
|             | 3     | -13.1             | -3.3              | 3.2               | -1.0           | 10.4           | 23.4           |
|             | 4     | -24.2             | -15.3             | -9.1              | -5.4           | 4.0            | 16.6           |
|             | 5     | -35.5             | -28.2             | -22.0             | -14.8          | -5.5           | 2.3            |
| Raipur      | 1     | 7.5               | 14.4              | 19.6              | 9.9            | 17.5           | 23.4           |
|             | 2     | -2.4              | 4.8               | 9.3               | 3.7            | 11.0           | 17.2           |
|             | 3     | -13.5             | -5.1              | -0.4              | -4.4           | 3.8            | 10.9           |
|             | 4     | -26.2             | -17.8             | -12.3             | -15.3          | -6.7           | 0.6            |
|             | 5     | -41.6             | -34.0             | -28.4             | -27.5          | -18.9          | -11.5          |
| Barrackpore | 1     | 10.9              | 19.6              | 24.4              | 9.1            | 21.8           | 30.3           |
|             | 2     | -2.4              | 7.5               | 12.4              | 1.0            | 10.8           | 19.5           |
|             | 3     | -15.4             | -5.9              | 1.2               | -8.9           | 1.5            | 8.9            |
|             | 4     | -29.3             | -19.7             | -12.8             | -22.0          | -11.0          | -3.5           |
|             | 5     | -44.0             | -35.8             | -29.2             | -32.2          | -25.3          | -16.9          |
| Patna       | 1     | 8.0               | 13.9              | -19.9             | 5.5            | 15.4           | 23.2           |
|             | 2     | -3.5              | 4.8               | 9.8               | -1.5           | 6.2            | 14.0           |
|             | 3     | -19.6             | -10.5             | -4.8              | -13.9          | -4.6           | 1.3            |
|             | 4     | -35.6             | -27.7             | -21.8             | -24.5          | -17.3          | -11.6          |
|             | 5     | -49.6             | -42.1             | -36.7             | -37.0          | -28.6          | -21.5          |
| Lucknow     | 1     | 1.7               | 3.0               | 2.1               | NA             | NA             | NA             |
|             | 2     | -3.6              | 1.4               | 2.9               | NA             | NA             | NA             |
|             | 3     | -17.7             | -9.5              | -4.8              | NA             | NA             | NA             |
|             | 4     | -32.9             | -25.6             | -20.3             | NA             | NA             | NA             |
|             | 5     | -46.6             | -38.4             | -32.9             | NA             | NA             | NA             |
| Ludhiana    | 1     | -0.1              | 1.1               | 0.4               | NA             | NA             | NA             |
|             | 2     | -3.4              | -1.6              | 0.2               | NA             | NA             | NA             |
|             | 3     | -15.0             | -9.3              | -4.7              | NA             | NA             | NA             |
|             | 4     | -27.6             | -20.8             | -16.2             | NA             | NA             | NA             |
|             | 5     | -45.6             | -40.4             | -34.9             | NA             | NA             | NA             |

NA- Not applicable
**Soil parameters:** The location-wise soil parameters used in InfoCrop are thickness of 3 soil layers, layer-wise sand, clay, bulk density, soil organic carbon and soil hydraulic characters. The soil pH, EC and slope also are required as inputs for different locations (Table 1).

**Management:** Rice was transplanted on the recommended time for each location during kharif season in irrigated conditions, while the rainfed crop transplanting was soil moisture dependent during kharif season. Irrigated crop received irrigation whenever the soil moisture went below 80%. The irrigated crop was supplied with 100 kg N ha\(^{-1}\) while rainfed crop received 50 kg N ha\(^{-1}\). Crop was assumed to be free of pests and diseases.

**RESULTS AND DISCUSSION**

**Impact of elevated CO\(_2\) on rice yield.**

The analysis indicated that the rice yields are sensitive to changes in CO\(_2\) concentrations. The CO\(_2\) increase was found to have significant effect on yield under both irrigated and rainfed conditions at all locations. Increasing yield trend was observed at all CO\(_2\) concentrations (450 ppm, 550 ppm and 650 ppm) at current temperatures. In irrigated condition, at 450 ppm CO\(_2\) level, the range of per cent change varied from 2.8% (Ludhiana) to 20.8% (Barrackpore), while the mean per cent change across all the locations was 13.4%. In rainfed condition, the increase in yield ranged from 10.1% (Lucknow) to 21.2% (Barrackpore) with a mean per cent change of 17.6% across all the locations. In irrigated condition, mean per cent change across all the locations was 17.8% at 550 ppm and 19.6% at 650 ppm, while in rainfed condition it was 27.9% at 550 ppm and 35.9% at 650 ppm. The increasing yield with increase in CO\(_2\) levels was attributed to greater LAI and net photosynthetic rates. Elevated CO\(_2\) is reported to increase the rice yields (De Costa et al., 2006, Uprety et al., 2003 and Cheng et al., 2009).

**Impact of temperature increase on rice yield**

Rice yield decreased with each degree increase in temperature. However, the rate of decrease differed with location. The reduction rate in yield was low in rainfed than in irrigated condition. Increase in 1°C in temperature (at 369 ppm CO\(_2\) concentration) may reduce irrigated rice yields by -6.6% at Ludhiana, -8.6% at Patna, 9.4% at Cuttack, -9.4% at Barrackpore and -11.1% at Rajhmundry. On the other hand, in rainfed condition reduction was -4.6% at Akola, -7.1% at Patna, -8.6% at Cuttack, -8.9% at Barrackpore and -9.4% at Rajhmundry. In irrigated condition, mean per cent change across all locations was between -8.9% (at 1°C rise) to -58.7% (at 5°C rise). In rainfed condition, corresponding decrease was between -1.6% to -43.6%. Decrease in crop duration is found to be the major factor for reduction in grain yield with increase in temperature. Rice yields are reported to be adversely affected by increase in atmospheric temperature (Aggarwal and Mall, 2002, Mathews et al., 1998, Lal et al., 1998 and Krishnan et al., 2007).

**Combined impact of temperature increase and elevated CO\(_2\) on rice yield**

The integrated effect of increased temperature and elevated CO\(_2\) resulted in decline in yield in spite of the beneficial effects of high CO\(_2\) concentrations (Table 2). For instance, in Ludhiana, across the temperature rise (1°C to 5°C) conditions, the range of per cent reduction in yield was between -0.1% to -45.6% (at 450 ppm CO\(_2\)), 1.1% to -40.4% (at 550 ppm CO\(_2\)) and 0.4% to -34.9% (at 650 ppm CO\(_2\)) in irrigated condition. Since in Lucknow and Ludhiana, currently farmers do not go for rainfed rice, hence the simulation results are not showed. The results showed that, yield declined with increase in temperature, however at the same time the yield loss got reduced in elevated CO\(_2\) condition. In rainfed situations, similar trends were observed at all the locations but the extent of yield loss was lesser. The irrigated crop showed significant decrease than the rainfed crop (Bouman, 2001). In rainfed rice, low rate of yield reduction may be due to rainfall changes and also because of the fact that the yields are already less due to low management and stress condition (Kumar et al., 2006 and Pantuwan et al., 2002).

**Adaptation to temperature and CO\(_2\) increase for irrigated condition**

Change in crop duration (±15 days to medium duration crop) and planting time (±10 days to date of transplanting) was used as an adaptive measure to offset increase in temperatures and to harness the benefits of elevated CO\(_2\). The adaptation gains were in comparison to the yields obtained at current climate with 369 ppm CO\(_2\) at respective locations. The results (Fig. 1) showed that at Ludhiana, for an across the temperature rise (0°C to 5°C), the range of change in yield was 6714 kg ha\(^{-1}\) to 5871 kg ha\(^{-1}\) (at 369 ppm CO\(_2\)), 6905 kg ha\(^{-1}\) to 6242 kg ha\(^{-1}\) (at 450 ppm CO\(_2\)), 7040 kg ha\(^{-1}\) to 6274 kg ha\(^{-1}\) (at 550 ppm CO\(_2\)).
Fig 1: Current and adapted (change in duration of crop (± 15 days to medium duration crop) and planting time (± 10 days to date of transplanting) was used as an adaptive measure | irrigated yields at different temperatures and CO₂ levels for different locations.
Fig 2: Current and adapted [change in duration of crop (± 15 days to medium duration crop) and planting time (± 10 days to date of transplanting)] was used as an adaptive measure | rainfed yields at different temperatures and CO₂ levels for different locations
CO$_2$) and 7113 kg ha$^{-1}$ to 6364 kg ha$^{-1}$ (at 650 ppm CO$_2$). On the other hand in Cuttack, this ranged from 5840 kg ha$^{-1}$ to 3982 kg ha$^{-1}$ (at 369 ppm CO$_2$), 6049 kg ha$^{-1}$ to 4830 kg ha$^{-1}$ (at 450 ppm CO$_2$), 6189 kg ha$^{-1}$ to 5187 kg ha$^{-1}$ (at 550 ppm CO$_2$) and 6382 kg ha$^{-1}$ to 5427 kg ha$^{-1}$ (at 650 ppm CO$_2$). Least amount of adaptation gains were likely in Ludhiana at 1°C rise in temperature, since in Ludhiana, currently most of the farmers manage crop to maximize their yields. The results clearly proved that adaptation strategies reduced the yield loss. By changing the planting date from normal to early and by adopting long duration cultivar, yields can be improved in most of the rice producing areas. This increase in yield is attributed to high radiation use efficiency.

Adaptation to temperature and CO$_2$ increase for rainfed condition

The results (Fig. 2) showed that at Barrackpore, for an across the temperature rise (0° to 5°C), the range of change in yield was 4736 kg ha$^{-1}$ to 3308 kg ha$^{-1}$ (at 369 ppm CO$_2$), 5273 kg ha$^{-1}$ to 3905 kg ha$^{-1}$ (at 450 ppm CO$_2$), 5514 kg ha$^{-1}$ to 4343 kg ha$^{-1}$ (at 550 ppm CO$_2$) and 5707 kg ha$^{-1}$ to 4548 kg ha$^{-1}$ (at 650 ppm CO$_2$). At Cuttack, this range was 5044 kg ha$^{-1}$ to 3028 kg ha$^{-1}$ (at 369 ppm CO$_2$), 5450 kg ha$^{-1}$ to 3689 kg ha$^{-1}$ (at 450 ppm CO$_2$), 5653 kg ha$^{-1}$ to 4066 kg ha$^{-1}$ (at 550 ppm CO$_2$) and 5902 kg ha$^{-1}$ to 4390 kg ha$^{-1}$ (at 650 ppm CO$_2$). Change in planting date and long duration cultivar was found to produce more yield than the normal practice. Recent analysis indicated that adaptation to climate change can significantly improve the irrigated and rainfed rice yield in India in future climates (Naresh Kumar et al., 2013).

CONCLUSION

Among all the atmospheric factors, the increased temperature and CO$_2$ are the key factors of climate change, which are supposed to have immense influence on rice yield. In climate change, the higher temperature plays an important role than CO$_2$ in tropics. A significant increase in yield may be expected because of increase in CO$_2$ as rice is a C$_3$ plant. However, this impact study projects an overall reduction in productivity of both irrigated and rainfed crop in all the main producing states in India due to rise in temperature. However, adaptation options provide an opportunity to minimize the yield loss.

ACKNOWLEDGEMENT

We are grateful to the project “ICAR Network programme on Impact, Adaptation and Vulnerability of Indian Agriculture to Global Climate Change” for funding.

REFERENCES

Aggarwal, P. K. and Mall, R. K. (2002). ‘Climate change and rice yields in diverse agro-environments of India. II. Effect of uncertainties in scenarios and crop models on impact assessment’. Climatic Change, 52(3), 331–343.

Aggarwal, P. K., N. Kalra, S. Chander, and H. Pathak. (2006). InfoCrop: A dynamic simulation model for the assessment of crop yield losses due to pests, and environmental impact of agro-ecosystems in tropical environments. I. Model description. Agric. Sys., 89:1–25.

Agricultural Statistics at a Glance, (2012). Directorate of Economics and Statistics, department of agriculture and cooperation, ministry of agriculture, government of India.

Attri, S. D. and L. S. Rathore (2003). Simulation of impact of projected climate change on wheat in India. Intern. Climatol., 693-705.

Baker, J. T. and Allen Jr. L. H. (1993). Effect of CO$_2$ and temperature on rice: a summary of five growing seasons. J. Agric. Meteorol., 48 (5): 575-582.

Bouman, B. A. M., Kropff, M. J., Tuong, T. P., Wopereis, M. C. S., Ten Berge, H. F. M., Van Laar, G. G. (2001). “Oryza 2000: Modelling Lowland Rice”. International Rice Research Institute, Philippines, pp. 235.

Cao Yun-Ying, HuaDuan, Li-Nian Yang, Zhi-Qing Wang, Li-Yun Liu and Jian-Chang Yang (2009). Effect of High Temperature during Heading and Early Filling on Grain Yield and Physiological Characteristics in Indica Rice. Acta Agronomica Sinica, 35(3):512-521

Cheng, W., Sakai, H., Yagi, K., and Hasegawa, T. (2009). Interactions of elevated CO2 and night temperature on rice growth and yield. Agric. Forest Meteorol., 149(1): 51-58.

De Costa, W. A. J. M., Weerakoon, W. M. W., Herath, H. M. L. K., Amaratunga K. S. P., and Abeywardena, R. M. I. (2006). Physiology of yield determination of rice under elevated carbon dioxide at high temperatures in a subhumid tropical climate. Field Crops Res., 96(2-3): 336-347.
DRR, (2009). Annual reports (2001-09). All India Coordinated Rice Improvement Programme (ICAR), Directorate of Rice Research, Hyderabad, India

Hundal, S. S., P. Kaur, G. Singh and R. Singh. (1993). Simulated rice and wheat yields in Punjab (India) under changing climate scenarios. Proceedings of the Indo-German Conference on Impact of Global Climatic Changes on Photosynthesis and Plant Productivity held at HAU, Hisar on Dec. 1-3, 1993.

IPCC., (2007b). Summary for policymakers. In: Parry M, Canziani O, Palutikof J, Van Der Linden P, Hanson C, eds. Climate change 2007. Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, 7–22.

IPCC., (2007a.), Climate change (2007). The physical science basis. Summary for policymakers. Paris: WMO/UNEP, 21.

Kalra, Naveen, Chakraborty, D., Sharma, Anil, Rai, H. K., Jolly, Monica, Chander, Subhash, Ramesh Kumar, P., Bhadraray, S., Barman, D., Mittal, R. B., Mohan Lal, Sehgal, Mukesh. (2008). Effect of increasing temperature on yield of some winter crops in northwest India, Current Science, 94 (1), 82-91.

Krishnan, P. and Surya Rao, A.V. (2005). Effects of genotypic and environmental on seed yield and quality of rice. J. Agric. Sci., 143: 283–292.

Krishnan, P., Swain, D. K., Bhaskar, B. Chandra, Nayak, S. K., Dash, R. N. (2007). Impact of elevated CO₂ and temperature on rice yield and methods of adaptation as evaluated by crop simulation studies. Agric. Ecosys. Environ., 122, 233–242.

Kumar, R., Sarawgi, A. K., Ramos, C., Amarante, S. T., Ismail, A. M. and Wade, L. J. (2006). Partitioning of dry matter during drought stress in rainfed lowland rice. Field Crops Res., 96(2-3):455-465

Lal, M., Singh, K. K., Rathore, L. S., Srinivasan, G. and Saseendran, S. A. (1998). Vulnerability of rice and wheat yields in NW India to future changes in climate. Agric. Forest Meteorol., 89: 101–114.

Mall, R. K., M. Lal, V. S. Bhatia, L. S. Rathore, and R. Singh (2004). Mitigating climate change impact on Soybean productivity in India: A Simulation study. Agric. Forest Meteorol, 113-125.

Mathews, R. B., Kropff, M. J., Horie, T. and Bachelet, D. (1997). Simulating the impact of climate change on rice production in Asia and evaluating options for adaptations. Agric. Sys., 54: 399–425.

Naresh Kumar, S., Aggarwal, P. K., Rani Saxena, Swaroopa Rani, Surabhi Jain and Nitin Chauhan. 2013. An assessment of regional vulnerability of rice to climate change in India. Climatic Change, DOI 10.1007/s10584-013-0698-3.

NOAA, (2010). Atmospheric CO₂. In: Dave Keeling. CO₂ Now.org

Pantuwan, G., Fukai, S., Cooper, M., Rajatasereekul, S. and O’Toole, J. C. (2002). Yield response of rice (Oryza Sativa L.) genotypes to drought under rainfed lowland 3. Plant factors contributing to drought resistance. Field Crops Res., 73: 181-200.

Prasad, P. V. V., Boote, K. J., Allen, L. H., Sheehy, J. E and Thomas, J. M. G. (2006). Species, ecotype and cultivar differences in spikelet fertility and harvest index of rice in response to high temperature stress. Field Crops Res., 95: 398–411.

Uprety, D. C., Dwivedi, N., Jain, V., Mohan, R., Saxena, Jolly, M. and Paswan, G. (2003). Response of rice cultivars to the elevated CO₂. Biologia Plantarum, 46(1): 35–39.