# VARIATION OF IRRIGATED RICE YIELD UNDER THE CLIMATE CHANGE SCENARIOS

**W.R.S.S. Dharmarathna[1], S.B. Weerakoon[2*], U.R. Rathnayake[3], Srikantha Herath[4]**

[1]Department of Civil Engineering, Faculty of Engineering, University of Peradeniya, Peradeniya, Sri Lanka.
[2*] Corresponding Author, Department of Civil Engineering, Faculty of Engineering, University of Peradeniya, Peradeniya, Sri Lanka, Email: sbweera@pdn.ac.lk
[3]Department of Civil Engineering, Faculty of Engineering, University of Peradeniya, Peradeniya, Sri Lanka.
[4]United Nations University – Institute for Sustainability and Peace (UNU-ISP), Shibuya-ku, Tokyo, Japan.

**ABSTRACT**

Atmospheric Carbon Dioxide ($CO_2$) concentration and average daily maximum temperature in Sri Lanka show an increasing trend owing to global climate change, and they are two critical parameters for the rice production. During this study, variations of future rice yield in Kurunegala District were simulated under three conditions together with emission scenarios A2 and B2; viz. a) Present level of $CO_2$ concentration with future temperatures, b) Present level of temperature with future $CO_2$ concentrations, and c) Future $CO_2$ concentrations with future temperatures. The model predicted that the average rice yield would decrease by 8% and 3.4% with the condition (a) under the emission scenarios A2 and B2 respectively. The condition (b) showed that the average rice yield would increase by 3.5% and 4.4% under the A2 and B2 scenarios respectively. The condition (c) which represents the future conditions more closely, showed that the average rice yield would increase by 1.7% and 2.4% under the A2 and B2 scenarios respectively.

***Key words:*** Rice yield, Climate change, $CO_2$ concentration, Temperature

## 1. INTRODUCTION

Studying the rice yield variability under the climate change scenarios has become very important for Sri Lankans, as rice is their staple food. The average daily maximum temperature and atmospheric $CO_2$ concentration are increasing as a result of global climate change and have become the most important considerations for Sri Lankan rice production. The increasing trend of daily maximum temperature could decrease the rice spikelet fertility and will reduce the yield while the increasing trend of atmospheric $CO_2$ concentration could increase the rice yield.

The study was set up to examine the both temperature and $CO_2$ effects on four rice varieties that are cultivated in Kurunegala District, Sri Lanka, under the emission scenarios, A2 and B2 published by the Intergovernmental Panel on Climate Change (IPCC, 2007). Kurunegala District is located in the Northwestern Province of Sri Lanka and there are 25 major irrigation schemes and about 2500 small village tanks and diversions based storage irrigation systems for paddy cultivation [1]. The rice varieties, namely Bg 250 (2 ½ months), At 307 (3 months), Bg 357 (3 ½ months) and Bg 379-2 (4 months) were selected for the study, to represent both short term and long term rice varieties.

## 2. METHODOLOGY

The daily weather variables, rainfall, maximum temperature and minimum temperature were forecasted up to year 2090 by using Global Climate Models (GCMs) data under the Hadley Centre experiments (HadCM3) for A2 (medium–high emissions) and B2 (medium–low emissions) scenarios.

The GCMs data were downscaled into regional level by using Statistical Downscaling Model (SDSM 4.2) [2]. The model was calibrated and validated by using 40 years of observed daily weather data collected from the Department of Meteorology, Colombo for the periods from 1961 to 1980 and 1981 to 2000 respectively.

The rice varieties were modeled in the cereals-rice model of Decision Support System for Agro technology Transfer (DSSAT 4.5) software [3]. DSSAT is a popular crop growth model that is used worldwide for modeling phenology, growth and yield of 30 different crops including rice under given soil nutrient and daily weather conditions. For this study, rice model of DSSAT was calibrated and validated using the observed crop and their management data collected from the Rice Research Development Institute (RRDI) farm, Batalagoda for the Yala (dry) seasons of years 2010 and 2006 respectively.

In order to analyze the future rice yield trends, the respective rice varieties were simulated in DSSAT with future weather conditions that downscaled by using SDSM. Atmospheric $CO_2$ concentrations for future conditions were derived from the scenario curves of Special Report on Emission Scenarios (SRES) published by the IPCC under A2 and B2 scenarios [4].

## 3. RESULTS

As $CO_2$ is an essential component in the production of plant biomass through the interplay between photosynthesis and respiration, increase of ambient $CO_2$ concentration will have direct effects on the photosynthetic and respiratory processes. Since the rates of physiological and biochemical reactions of plants are primarily determined by the temperature, rising global temperatures will also have a significant influence on all processes leading to crop yield formation [5].

Therefore in order to examine the effects of $CO_2$ and temperature on the rice yield, future simulations were carried out under three conditions as (a) Present level of $CO_2$ concentration with future temperatures; (b) Present level of temperature with future $CO_2$ concentrations; and (c) Future $CO_2$ concentrations with future temperatures.

### 3.1 Present level of $CO_2$ concentration with future temperatures

When rice is exposed to temperatures higher than 35°C, damages occur according to growth stages. Furthermore, clear varietal differences affect high temperature tolerance at different growth stages. A variety may be very tolerant of high temperatures at one growth stage but susceptible at another. Rice is most sensitive to high temperatures at heading and next most sensitive at about 9 days before heading. One or two hours of high temperature at anthesis has a decisive effect on the incidence of sterility [6].

Present level of $CO_2$ concentration was kept in 370 ppm as observed value in the RRDI farm and rice varieties were simulated with forecasted future temperature conditions under the A2 and B2 scenarios. The results showed decreasing trends for all four rice varieties where short term varieties with higher decreasing trends especially under the A2 scenario as it has the higher temperature increasing trend. The rice yield variations under A2 and B2 scenarios are shown in Figure 1 and 2 respectively.

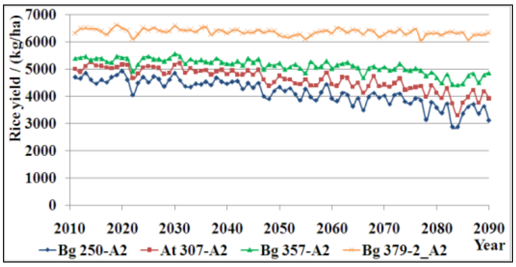


**Figure 1: Variation of rice yield with A2 scenario under condition (a)**

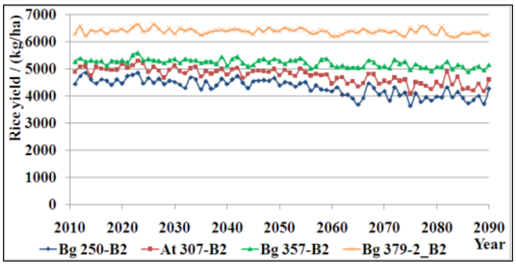


**Figure 2: Variation of rice yield with B2 scenario under condition (a)**

### 3.2 Present temperature with future $CO_2$ concentrations

Most plants growing in atmospheric $CO_2$ higher than ambient exhibit increased rates of photosynthesis. Extremely high level of $CO_2$ also reduces the stomatal openings of some crop plants. From that, $CO_2$ reduces transpiration per unit leaf area while enhancing photosynthesis. Thus it may lead to improve water-use efficiency (the ratio of crop biomass to amount of water used in evapotranspiration). As a result of these interactions, elevated $CO_2$ alone tends to increase growth and yield of most agricultural plants [7].

The temperature conditions during the period from 01/01/2011 to 31/12/2020 were kept as the current temperature level under both A2 and B2 scenarios and the rice varieties were simulated with future $CO_2$ concentrations. The results showed an increasing trend for all four rice varieties under both A2 and B2 scenarios. The Figure 3 and 4 show the respective rice yield variations under A2 and B2 scenarios respectively.

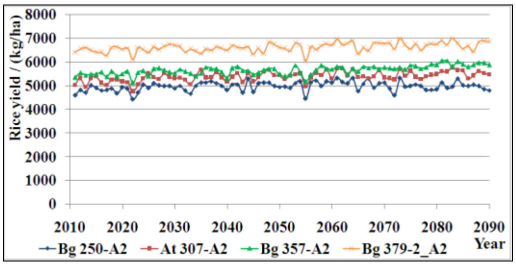


**Figure 3: Variation of rice yield with A2 scenario under condition (b)**

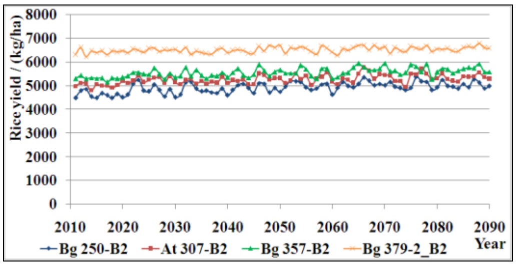


**Figure 4: Variation of rice yield with B2 scenario under condition (b)**

### 3.3 Future $CO_2$ concentrations with future temperatures

The studies by Desiraju and fellow researchers, [8] reported that, when it compared with ambient conditions, the combination of increased $CO_2$ and increased temperature resulted in a small increase in biomass and yield in the dry season. In addition, the International Rice Research Institute (IRRI) crop modeler John Sheehy and fellow researchers determined that, as a general rule, for every 75 ppm increase in $CO_2$ concentration, rice yields will increase by 0.5 t/ha, but yield will decrease by 0.6 t/ha for every 1 °C increase in temperature [9].

In this case, the rice varieties were simulated in DSSAT with future $CO_2$ and temperature conditions. The results showed small increasing trends (lesser than the trends of condition [b] in three varieties) under both A2 and B2 scenarios. The Figure 5 and 6 show the respective variations under A2 and B2 scenarios.

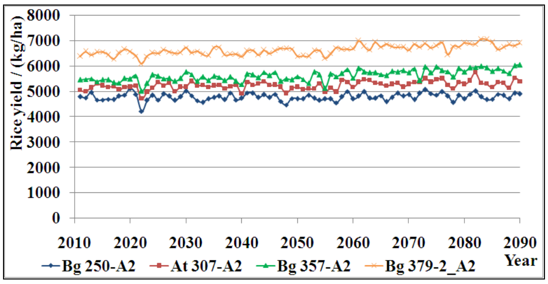


**Figure 5: Variation of rice yield with A2 scenario under condition (c)**

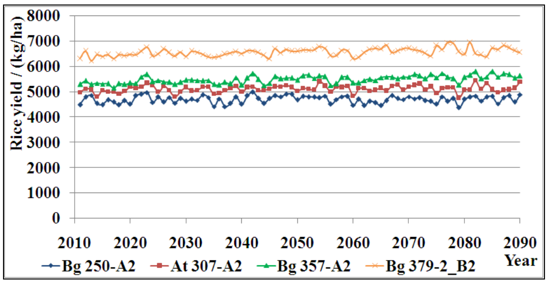


**Figure 6: Variation of rice yield with B2 scenario under condition (c)**

The yield variations under three conditions are shown in the Table 1 as percentages of base values. Average rice yields for the period from 2011 to 2020 were considered as the base values. The minus value indicates decreasing trend.

**Table 1: Rice yield variations under three conditions as percentages of the base values**

| Condition | A2 Scenario | | | |
|---|---|---|---|---|
| | Bg 250 | At 307 | Bg 357 | Bg 379-2 |
| (a) | -13.6 | -10.3 | -6.0 | -2.1 |
| (b) | 3.5 | 4.5 | 4.0 | 1.9 |
| (c) | -0.4 | 1.7 | 3.4 | 2.2 |
| | B2 Scenario | | | |
| (a) | -6.2 | -5.1 | -1.8 | -0.5 |
| (b) | 6.5 | 4.9 | 4.5 | 1.5 |
| (c) | 1.9 | 2.0 | 3.3 | 2.4 |

## 4. CONCLUSION

SDSM 4.2 was used to downscale the future weather conditions in Kurunegala District, Sri Lanka, up to 2090 under the emission scenarios A2 and B2 published by the IPCC.

DSSAT 4.5 was used to model four rice varieties (including both short term and long term rice varieties) that are cultivated in Kurunegala district, Sri Lanka.

Simulations were carried out under three different conditions to examine the effect of atmospheric $CO_2$ concentration and daily maximum temperature on the dry season rice yield as,

a. Present level of $CO_2$ concentration with future temperatures
b. Present temperature with future $CO_2$ concentrations
c. Future $CO_2$ concentrations with future temperatures

The results under condition (a) indicate that the rice yields would decrease due to expected trend of temperature increase in the future. The condition (b) shows that future rice yields would increase due to the high concentration of atmospheric $CO_2$. The condition (c), under the effect of both $CO_2$ concentration and daily maximum temperature, shows that rice yields would increase at a lesser rate than the condition (b) except the rice variety Bg 379-2.

Therefore in order to meet the future rice requirement of the country, it is timely need to introduce suitable adaption measures. The following potential adaptation measures against climate change impacts could be suggested however, there effect need to be verified.

- Adjustments in planting date
- Introduce temperature tolerant rice varieties

## 5. REFERENCES

[1]. S. Sriyananda, “Drought attack - lives and livelihood in peril”, SUNDAY OBSERVER, 28 March 2004, http://www.sundayobserver.lk/2004/03/28/fea06.html

[2]. R.L. Wilby and C.W. Dawson, User manual of Statistical Downscaling Model, 2007.

[3]. G. Hoogenboom, J.W. Jones, P.W. Wilkens, C.H. Porter, K.J. Boote, L.A. Hunt, U. Singh, J.L. Lizaso, J.W. White, O. Uryasev, F.S. Royce, R. Ogoshi, A.J. Gijsman, and G.Y. Tsuji, Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.5, University of Hawaii, Honolulu, Hawaii, 2010.

[4]. IPCC, Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp., 2001.

[5]. W.A.J.M. De Costa, “Prediction of the effects of elevated $CO_2$ and temperature on irrigated rice yields in the low-country dry zone of Sri Lanka using a process-based simulation model”, Journal of the National Science Foundation of Sri Lanka, 165-184 pp, Vol. 28(3), 2000.

[6]. S. Yoshida, Fundamentals of Rice Crop Science, The International Rice Research Institute, Manila, 1981.

[7]. M.L. Parry, C. Rosenzweig, A. Iglesias, M. Livermore and G. Fischer, “Effects of climate change on global food production under SRES emissions and socio-economic scenarios”, Global Environmental Change, Vol. 14., 2004.

[8]. D. Subrahmanyam, R. Rao, P.M.V. Reddy and S.R. Voleti, “Climate Change and its Impact on Rice”, Rice Knowledge Management Portal (RKMP), Hyderabad, 2010.

[9]. J.E. Sheehy, F.P.L. Mitchell and B. Anaida, “Decline in rice grain yields with temperature: Models and correlations can give different estimates” Field Crops Research, Vol. 98, Manila, 2006.