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IMPACT OF CLIMATE CHANGE ON RICE YIELDS IN SRI LANKA: A CROP MODELLING APPROACH USING DECISION SUPPORT SYSTEM FOR AGRO TECHNOLOGY TRANSFER (DSSAT4.5)

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ABSTRACT

Future climate changes will have an adverse effect on the whole world. Global warming will lead to losses in crop productivity in most of the crops. The objective of this study was to assess the yield reduction using Decision Support System for Agro-technology Transfer (DSSAT) crop model, with climate change predictions given by the Intergovernmental Panel on Climate Change (IPCC), 2013. Experimental data at Rice Research and Development Institute (RRDI), Batalagoda were used to develop genetic coefficients for rice varieties to calibrate the model. Using Coordinated Rice Varietal Trial (CRVT) data at Batalagoda and Field Crops Research and Development Institute, Mahailluppallama, rice yields were simulated with increasing temperature and CO_2 concentration. It was found that increase in temperature (maximum and minimum) by 2 ^{0}C will reduce the yields by about 12% and increase in CO_2 concentration has a positive impact and yields increases by about 2% with increasing 50 ppm than actual. However, combined effect of temperature and CO_2 concentration will lead to reduce rice yields. Therefore, adaptation measures to overcome yield reduction of rice in future are important to meet the future changes of climate to ensure the national food security.

KEYWORDS: **Climate change, Crop Growth Model, Rice yield, Temperature, Rice varieties.**

INTRODUCTION

The recent fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2013) provides clear evidences of changes in the climate in the coming decades. It is certain that Global Mean Surface Temperature (GMST) has increased since the late 19th century. Each of the past three decades has been successively warmer at the earth's surface than any other previous decades in the instrumental record, and the decade of the 21st century has been the warmest. The globally averaged combined land and ocean temperature data as calculated by a linear trend, show a warming of 0.85 °C (0.65 to 1.06 °C), over the period 1880-2012 (IPCC, 2013). The rate of increase in maximum and minimum air temperatures in Sri Lanka varies between locations and seasons. There was an increase in both maximum and minimum temperatures in all major agricultural areas over the last century (Weerakoon, 2013). A recent study conducted with time series of annual and seasonal average temperature during 1961-2010 has shown that warming trend is faster during recent years with an increase of 0.01 to 0.03 °C per year depending on the location (Nissanka *et al.*, 2011).

Crop production is inherently sensitive to variability in climate. Some of the early studies have shown that there is a greater impact of warmer temperatures on crop yields. Increased temperatures have hastened the phenology and reduced biomass production. The suitable air temperature range for vegetative growth of rice is generally from 12 to 38 °C with an optimum between 25 °C and 30 °C. Temperatures above optimum threshold shorten the grain filling period and reduce final yield (Reddy and Hodges, 2000). Temperature above 32 °C has decreased pollen fertility, increased spikelet sterility and empty grains (Abeysiriwardena *et al.*, 2002; Weerakoon, 2013). However, other factors such as enhanced net photosynthetic rate at elevated CO_2 concentration will offset to some extent of such decreases in yield due to temperature warming. Changes in precipitation patterns and frequency of extreme weather events will further complicate the impacts on crop yields (Craufurd and Wheeler, 2009).

Rice being the staple food in Sri Lanka, impact of climate change on its production is very important to ensure the national food security. Therefore, estimating yields of different rice varieties under changing climatic conditions and various management practices have become important (Dharmarathna *et al.*, 2011). Rice is the climatically most adaptable cereal grown over a large spatial domain and wide range of landscape types (Kumar *et al.*, 2014). In addition, simulation analysis for adapting rice to climate change scenarios emphasized low cost adaptation strategies, which includes improved crop varieties, improved crop management practices, efficient utilization of irrigation and fertilizer application (Aggarwal *et al.*, 2010). Until the 1960's agricultural research almost completely relied upon experimental and empirical work, combined with statistical analysis, though progress had been impressive despite some constraints and limitations. In the next generation, various kinds of models based on statistical, mechanistic, deterministic, dynamic, static approaches used in assessing and predicting crop growth and yield. Crop growth model is an effective tool for predicting possible impacts of climate change on growth and yield (Dharmarathna *et al.*, 2011).

Crop models are designed to use a minimum set of soil, weather, genetic and management information, to assess the crop phase and morphological development using temperature, day length, genetic characteristics and vernalization where appropriate. Leaf expansion, growth and plant population provide information for determining the amount of light intercepted, which is assumed to be proportional to biomass production (Amien *et al.*, 1999). By changing the environmental conditions, crop production variations can be simulated. Therefore, this study was carried out to assess the impact of climate change on rice production in Sri Lanka using popular rice varieties grown in the country through a modelling study using DSSAT 4.5 model.

MATERIAL AND METHODS

Data for DSSAT model calibration

Decision Support System for Agro Technology Transfer (DSSAT) 4.5 (Hoogenboom *et al.*, 2010) was used for simulating rice production. Growth and yield data were collected from experiments conducted at Rice Research and Development Institute (RRDI), Batalagoda (Lat. $7^0 52'$ N and Long. $80^0 43'$ E) in 2000, 2001, 2006 and 2007 for Bg 250, Bg 300, Bg 357 and Bg 358 varieties. Experiments have conducted in a plot size of 6 x 3 m with three replications. The required crop varietal data such as leaf area index, dry weights of above ground biomass, dry weights of plant parts (leaf, stem, root), harvest yield, panicle number and number of tillers were used to develop varietal genetic coefficients. Dates of panicle initiation, heading and physiological maturity were used to develop phenology parameters. Field management conditions and fertilizer applied levels were used to develop crop management data files of the DSSAT model.

Soil physical and chemical properties were collected from the factsheets of bench mark soils of the Intermediate Zone and soils of the Dry Zone of Sri Lanka published by the Soil Science Society of Sri Lanka. Soil samples were collected from RRDI, Batalagoda and Field Crops Research and Development Institute (FCRDI), Mahailluppallama fields and tested, and used in management files. Weather data on rainfall, maximum and minimum temperatures and solar radiation collected for the past 30 years at Batalagoda and Mahailluppallama meteorological stations were used. Using experimental data from Batalagoda the genetic coefficients were calculated and calibrated first to adjust phenological dates and then to yield parameters.

Validation of the model and predict yields under changing climates

Coordinated Rice Varietal Trial (CRVT) data in 2000 to 2010 were collected from RRDI, Batalagoda and FCRDI, Mahailluppallama. Phenological data and yield data were used for comparisons. Management data such as planting dates, flowering dates and fertilizer rates were used to develop crop model files. Past 30 year weather data at Batalagoda and Mahailluppallama were also used. Using the above data, crop management files were developed for the respective years and predictions were done for the past 30 years. Average yields of those experiments were taken to assess climate change impacts. Climate change impacts were simulated by increasing maximum and minimum temperatures by 2 °C and CO_2 concentration by 50 ppm and 100 ppm than actual (381 ppm).

RESULTS AND DISCUSSION

Model Calibration

The genetic coefficients used in the DSSAT model after calibration are given in Table 1.

Table 1. Genetic coefficients that calibrated and used for yield perdictions.

Variety	P1	P2R	P5	P2O	G1	G2	G3	G4
Bg 250	266.5	143.0	369.7	12.4	50.2	0.0280	0.84	1.11
Bg 300	407.9	134.7	396.2	12.6	50.7	0.0260	0.95	1.10
Bg 358	435.6	72.5	500.1	10.7	50.3	0.0190	0.69	1.10
Bg 357	382.0	122.5	393.8	11.5	55.5	0.0250	0.95	1.14

Notes: **P1** is the time period (expressed as growing degree days [GDD] in °C above a base temperature of 9 °C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod. Short duration varieties show lower values than long duration varieties.

P2R is the extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O.

P5 means the time period in GDD °C from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9 °C. It varies with the duration of the variety.

P2O is the critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate.

G1 is the potential spikelet number coefficient as estimated from the number of spikelets per gram of main culm dry weight at anthesis. A typical value is 55 used in the model.

G2 is the single grain weight (g) under ideal growing conditions.

G3 is the tillering coefficient relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.0.

G4 is the temperature tolerance coefficient. This is usually 1.0 for varieties grown in normal environments.

The comparisons of date of panicle initiation, anthesis, and physiological maturity of observed based on experimental data and simulated values based on DSSAT model are given Figures 1, 2 and 3, respectively. These figures indicated that DSSAT model calibrated values are well fitted in to the observed growth parameters.

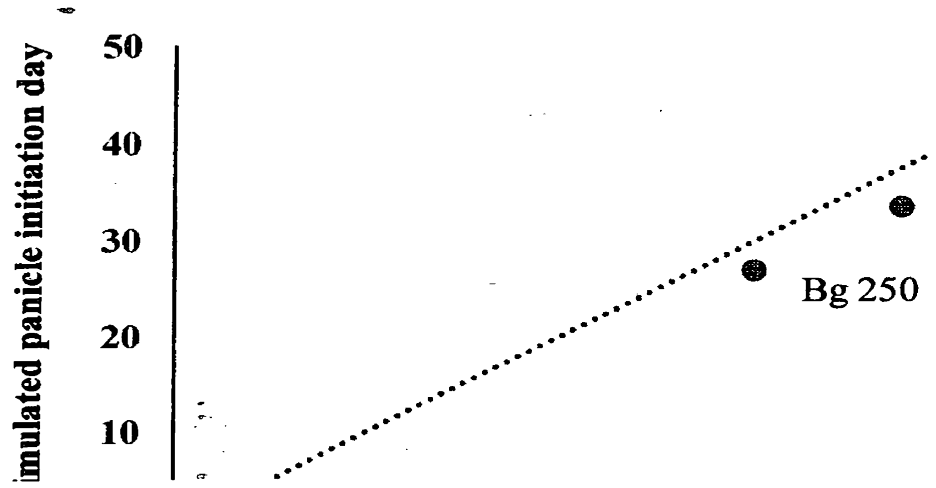

Figure 1. **Comparison of observed and simulated day of panicle initiation in four rice varieties.**

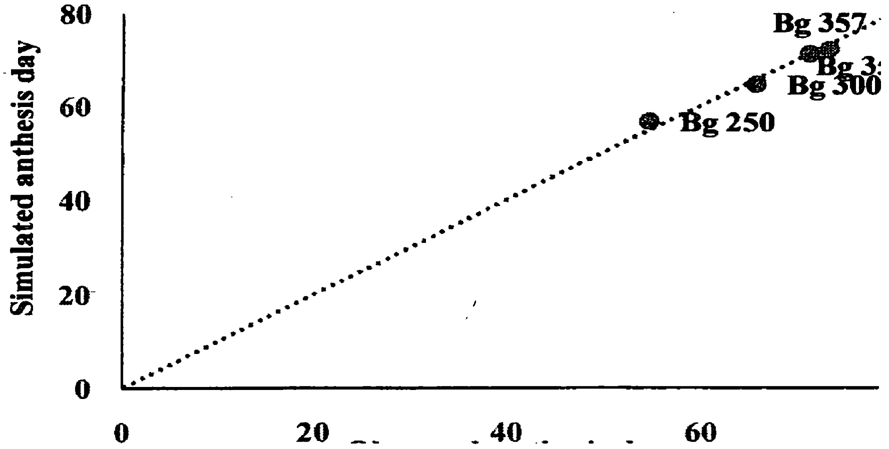

Figure 2. **Comparison of observed and simulated day of anthesis of four rice varieties.**

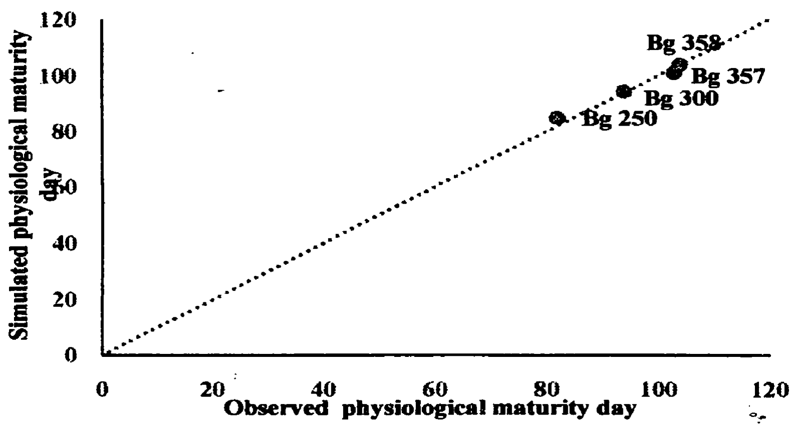

Figure 3. **Comparison of observed and simulated day of physiological maturity of 4 rice varieties.**

After comparison of phenological dates of the varieties, genetic coefficients related to growth were fixed, then calibration was done for coefficients related to yield parameters. Figure 4 shows the observed and simulated yields after the calibration. According to that figure simulated yields are acceptable to the observed yields. Further predictions were done using the calibrated genetic coefficients. Table 2 gives the corresponding Root Mean Square Error (RMSE) values.

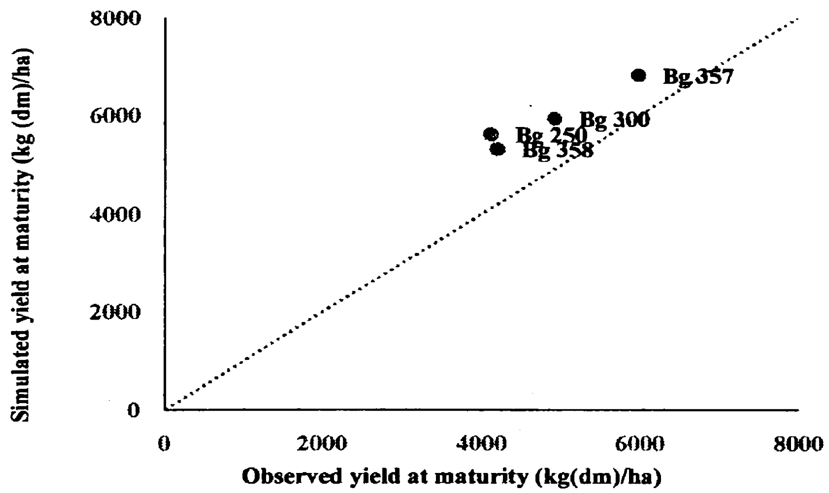

Figure 4. **Comparison of observed and simulated yields of four rice varieties.**

Table 2. **RMSE values correspond to the results.**

Variety	RMSE value
Bg 250	1,526
Bg 300	1,326
Bg 357	827
Bg 358	1,243

Validation and climate change impacts

Yields were simulated for rice varieties for last 30 years (1980 to 2010) using the collected CRVT data and average values of 30 years were used to comparisons. Figures 5, 6, 7 and 8 shows yield predictions for CRVT data in some seasons as average values of 30 years. According to figures, it can be observed that lower observed yields are over estimated in the model. It may be due to pest, disease problem or a soil specific problem to that site and observed yields in the fields can be lower than the potentials. In the model such factors are not considered and give the potential yields. When observed yields are high the simulated yields are under estimated at some points which may be due to some site specific soil conditions than general soil conditions used in simulating.

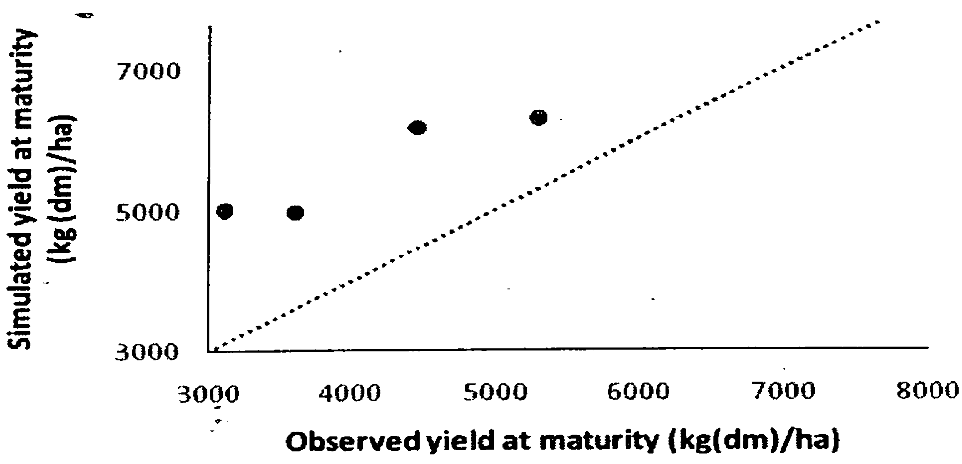

Figure 5. **Comparison of observed and simulated rice yields of 30 year average for variety Bg 250.**

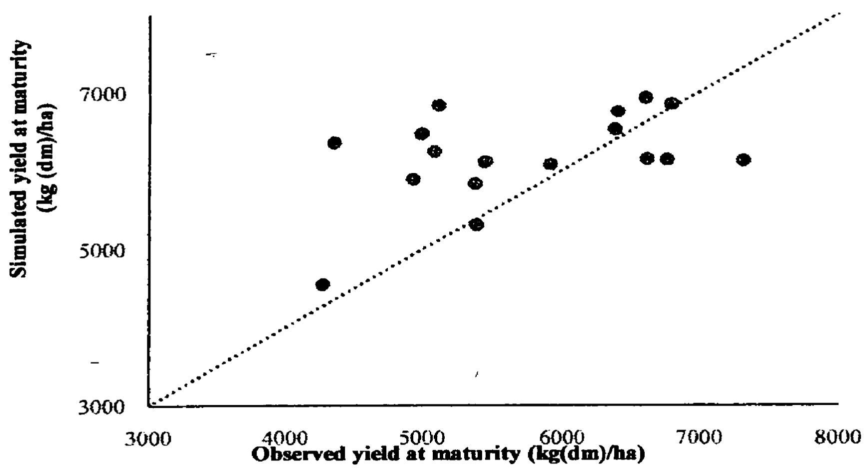

Figure 6. **Comparison of observed and simulated rice yields of 30 year average for variety Bg 300.**

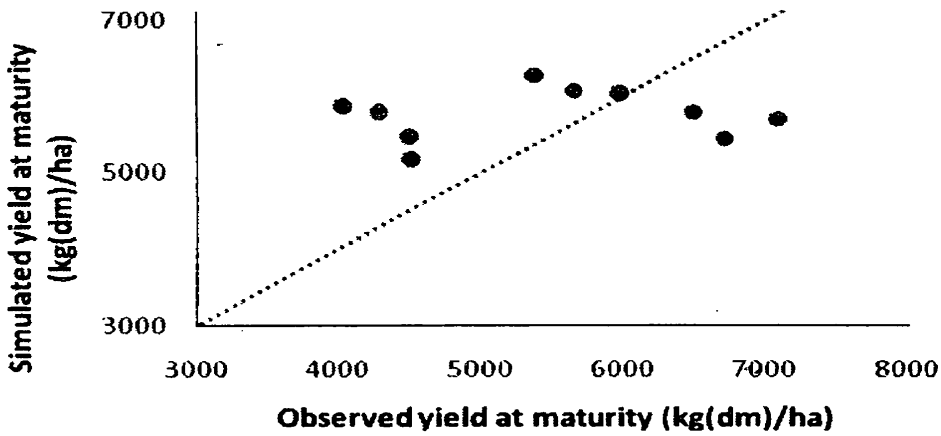

Figure 7. **Comparison of observed and simulated rice yields of variety Bg 358.**

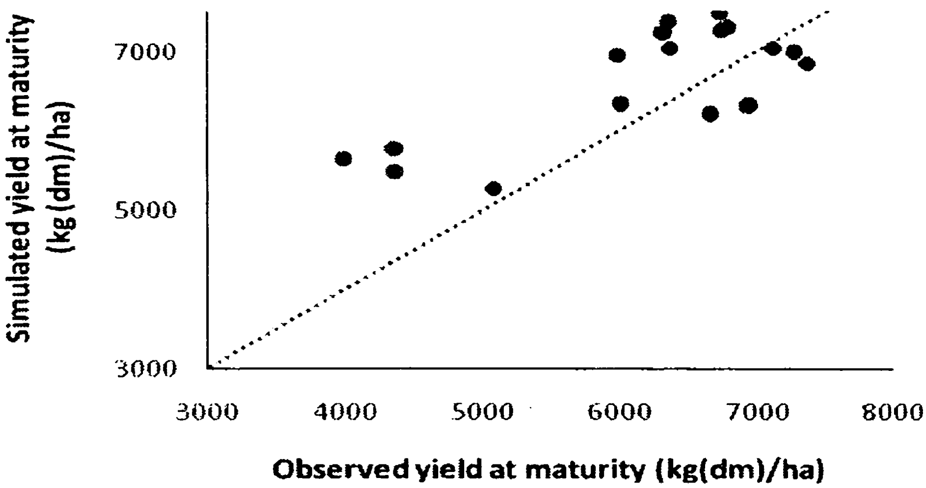

Figure 8. Comparison of observed and simulated rice yields of variety Bg 357.

Impact of climate changes on rice yields

The average values of yield increases and reductions for four varieties used in the study are given in Table 3. The model results show that the effect of temperature would drastically reduce rice yield at RRDI, Batalagoda and FCRDI, Mahailluppallama. Increase in maximum temperature has significant negative impacts on rice yields in all varieties. Rice yields were reducing by about 6% in varieties with increasing the maximum temperature by 2 °C. When increasing both maximum and minimum temperatures by 2 °C the reduction of yields was as higher as 12% on average.

Table 3. Average yield reductions in rice varieties with changes of climate.

Climate change phenomena	Change in rice yield (%)			
	Bg 250	**Bg 300**	**Bg 358**	**Bg 357**
a) Temperature effect				
Increased Maximum Temperature by 2 °C	-4.5	-7.2	-4.4	-7.3
Increased Max. Tem. by 2 °C + Min. Tem. by 2 °C	-8.8	-11.7	-8.4	-15.7
b) Carbon dioxide effect				
Increased CO_2 50 ppm	1.9	1.6	1.6	1.7
Increased CO_2 100 ppm	3.8	3.4	3.1	3.2
c) Temperature and CO_2 effect				
Increased T max, T min 2 °C + CO_2 50 ppm	-6.4	-10.7	-6.7	-14.3
Increased T max, T min 2 °C + CO_2 100 ppm	-4.0	-9.6	-4.7	-12.7

In all major crop growing systems in Sri Lanka, both maximum and minimum air temperature has increased over years (Premalal, 2009). These increases in temperature had already showed profound negative impacts on the productivity. A recent study done on the impact of climate change on productivity of rice varieties available in major rice growing district of Kurunegala suggests that there will be a reduction in grain yield by over 20% due to changes in climate as predicted by GCM's using RCP 8.5 scenario in the mid century (Weerakoon, 2013).

The growth and yield of crops are directly related to the rate of photosynthesis and phenology, and their response to temperature. Photosynthesis rate also directly influence by the CO_2 concentration in the air. According to the IPCC, 2013 the global mean surface temperature change for the period 2016–2035 relative to 1986–2005 base period will likely to be in the range of 0.3 °C to 0.7 °C (medium confidence). Increase of global mean surface temperatures for 2081–2100 relative to 1986–2005 base period is projected to be in the ranges of 0.3 °C to 1.7 °C (RCP2.6), 1.1 °C to 2.6 °C (RCP4.5), 1.4 °C to 3.1 °C (RCP 6.0), 2.6 °C to 4.8 °C (RCP 8.5).

According to the results given from the DSSAT model (Table 3), increasing atmospheric CO_2 concentration has a positive effect on rice yield. If the CO_2 concentration increased by 50 ppm than the actual prevailing CO_2 (381 ppm) the yields increase by 1.3% on average and increase in CO_2 concentration by100 ppm will increase rice yields by about 3.3%. Results showing that increase in temperature have negative impacts and increase in CO_2 concentration has a positive impact on rice yields. Therefore, to understand the impact of climate change should consider the interactive effect of air temperature and CO_2 concentration.

Past experiments have shown that increased atmospheric CO_2 concentration will have a positive direct impact on all agricultural crops in Sri Lanka. Weerakoon (2013) has showed the grain yield could be as high as 30% with increase in CO_2. However, the impact varied between crops and the rice growing ecosystems. For, example in the irrigated rice system, the increase in grain yield per unit increase in atmospheric CO_2 over the past 40 years was 0.042 t/μmol of CO_2 while in the rainfed system it was 0.019 t/μmol of CO_2 (Weerakoon, 2013). CO_2 is vital for photosynthesis, and thus increases in CO_2 concentration would increase the rate of plant growth. Photosynthesis is the net accumulation of carbohydrates formed by the uptake of CO_2, so it increases with increasing CO_2. A doubling of CO_2 may increase the photosynthetic rate by 30% to 100%, depending on other environmental conditions such as temperature and available moisture (Parry, 1990).

Several recent simulation studies have estimated the effects of global climate change on regional rice production using different climate change scenarios. More specially, research is needed to quantify the interactive effects of CO_2, air temperature and other environmental variables on rice growth and yield formation processes (Reddy and Hodges, 2000). The combined effect of increase in temperature and CO_2 concentration had a negative impact on rice yields. Increase of maximum temperature and minimum temperature by 2 °C and increase of CO_2 concentration by 50 ppm than the actual concentration has decreased rice yields by about 11% on average. Increase of maximum temperature and minimum temperature by 2 °C and increase of CO_2 concentration by 100 ppm than the actual concentration decrease average rice yields by about 9%. According to results, Bg 357 is more sensitive compared to other varieties and Bg 358 and Bg 250 has the comparatively lower effect. Therefore, adaptation measures such as new varieties suitable to drought tolerant, changes of planting days to overcome the yield reduction will important to face the future climate changes.

CONCLUSIONS

By using DSSAT crop model genetic coefficients can be calibrated using experimental data for local rice varieties with comparing observed and simulated characters of the crop. According to the results temperature increase has a negative impact on yield whereas increase of CO_2 concentration has a positive impact on yield of all four varieties selected. The combined effect of temperature and CO_2 has a negative effect on rice yield. Bg 357 is more sensitive compare to other varieties to the changes in temperature and CO_2 concentration.

REFERENCES

Abeysiriwardena, D.S.D.Z., K. Ohba and A. Maruyama. (2002). Influence of temperature and relative humidity on grain sterility in rice. Journal of National Science Foundation Sri Lanka, 30 (1&2): 33-41.

Aggarwal, P.K., S.N. Kumar and H. Pathak. (2010). Impacts of climate change on growth and yield of rice and wheat in the Upper Ganga Basin. WWF Report, Indian Agricultural Research Institute (IARI), India.

Amien, I., P. Redjekiningrum, B. Kartiwa and W. Estiningtyas. (1999). Simulated rice yields as affected by inter annual climate variability and possible climate change in Java. Climate Research, 12: 145-152.

Craufurd, P.Q. and T.R. Wheeler. (2009). Climate change and the flowering time on annual crops. Journal of Experimental Botany, 60: 2529-2539.

Dharmarathna, W.R.S.S., S.B. Weerakoon, S. Herath, U.R. Rathnayaka and W.M.W. Weerakoon. (2011). Application for Decision Support System for Agrotechnology Transfer (DSSAT) model to optimize irrigated paddy cultivation under changing hydro climate. Annual Transactions of IESL, 207-211.

IPCC (2013). Climate change. The physical science basis. IPCC report 2013. Accessed on 2014.03.20 from https://www.ipcc.ch/report/ar5/wg1/.

Hoogenboom, G., 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. (2010). Decision Support System for Agrotechnology Transfer (DSSAT) version 4.5 (CD-ROM). University of Hawaii, Honolulu, Hawaii.

Kumar, R.N., B. Sailaja and S.R.Voleti. (2014). Crop Modelling with Special Reference to Rice Crop. Accessed on 2014.03.20 from http://www.rkmp.co.in/sites/default/files/ris/research-themes /Crop %20Modelling %20with%20Special%20Reference%20to%20Rice%20Crop.pdf

Nissanka, S.P., B.V.R. Punyawardena, K.M.S. Premalal and R.O. Thattil. (2011). Recent trends of climate in Sri Lanka. Faculty of Agriculture, University of Peradeniya, Sri Lanka (Unpublished).

Parry, M. (1990). Climate change and world agriculture. Earthscan Publications Limited, London.

Premalal, K.H.M.S. (2009). Observed climate change in Sri Lanka. Proceedings of a Symposium on Impact of Climate Change and Agriculture on 10-11th May, Hotel Topaz, Kandy, Sri Lanka.

Reddy, K.R. and H.F. Hodges. (2000). Climate change and global crop productivity. CABI publishing. CAB International, Oxon, UK. Pp. 81-100.

Weerakoon, W.M.W. (2013). Impact of climate change on food security in Sri Lanka. Proceedings of the International conference on climate change: impacts and adaptations. Proceedings of the workshop held in Coconut Research Institute of Sri Lanka.