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Research Paper

Impact of climate change on rice yield in Sri Lanka: A crop modelling approach using Agriculture Production System Simulator (APSIM)

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Abstract: Climate change will have adverse effects on global food production. Potential reduction in crop productivity will be one of the biggest challenges. The objective of this study was to assess the yield fluctuation using Agriculture Production Systems Simulator (APSIM), based on climate change predictions given by the Intergovernmental Panel on Climate Change (IPCC) in 2014. Rice (*Oryza sativa* L.) yields were simulated with increasing temperature, CO_2 concentration and rainfall for three time periods; 2017 (current), 2050 and 2100. The simulations were run for medium (Bg359) and short (Bg300) duration rice varieties for 9 locations representing Wet Zone, Intermediate Zone and Dry Zone and for both *Yala* (March to September) and *Maha* (October to February) seasons. Simulation results revealed that the Wet Zone rice yield of Bg300 decreased in *Maha* season by 18% and 31% and the Dry Zone rice yield of Bg359 decreased in *Yala* season by 17%, and 42% for 2050 and 2100, respectively. Therefore, adaptation measures to overcome climate change-induced rice yield reduction in the future are essential to ensure the national food security.

Keywords: APSIM, Climate change, Rice, Sri Lanka

Introduction

Climate change is considered as the biggest environmental problem of the 21st century, and research has increasingly focused on estimating the impacts that may occur under changing climate. Agriculture is a key focus because of its direct connection to the climate (Schlenker and Roberts, 2009). Rice (*Oryza sativa* L.) being the staple food in Sri Lanka, the impact of climate change on its production is of high importance in ensuring national level food security. Therefore, estimating yields of commonly grown rice varieties under changing climatic conditions and various management practices have become important (Dharmarathna *et al.*, 2011). A number of crop models is available in the literature (DSSAT, CropSyst, APSIM) to study the impacts of climate change, and these models estimate crop growth, yield, water balance, and nutrient balance on a daily basis. In the present study, Agricultural Production Systems Simulator (APSIM) was used to simulate the rice yield as affected by the changes in climate. This model was used in different countries (*i.e.* China, Australia, Canada) to evaluate the impact of climate change for different crops (rice, maize, wheat, sugarcane, cotton; Yang *et al*., 2015; Yang *et al.*, 2014; Kouadio *et al*., 2015; Marin *et al*., 2015).

The *APSIM-Oryza* module was developed by incorporating the ORYZA2000 rice growth model (Bouman and van Laar, 2006) to the APSIM modelling framework (Keating *et al*., 2003; Gaydon *et al*., 2012a,b). In the literature, *APSIM-Oryza* has been used to evaluate the impacts of management practices on rice yield and soil resources (Boling *et al*., 2010; Gaydon *et al*., 2012a,b; Lijun *et al*., 2013; Liu *et al*., 2013a), irrigation management (Feng *et al*.,2007; Malone *et al*., 2007; Paydar *et al*., 2009; Soundharajan and Sudheer, 2009; Yadav *et al*., 2011a,b; Katerji *et al.,* 2013; Liu *et al*., 2013b; Phung *et al*., 2013), and fertilizer management (Bouman and van Laar, 2006; Zhang *et al*., 2007; Micheni *et al*., 2008). In Sri Lanka, it has been used to evaluate the nitrogen response in lowland rice (Suriyagoda and Peiris, 2013), find optimum planting date for rainfed rice (Rathnayake and Malaviarachchi, 2013) and assess the yield advantage and water productivity when aligning planting date with the onset of rainfall (Amarasingha *et al*., 2014).

In a previous study, *APSIM-Oryza* was parameterized and evaluated for short (Bg300) and medium (Bg359) duration rice varieties grown under standard management conditions in Sri Lanka. The validated model performed well in different agro-climatic zones in Sri Lanka under water-limited farmer-field conditions, predicting the grain yield with a strong model skill (R^2>0.97, RMSE=484 kg ha^{-1}; Amarasingha *et al*., 2014). Hence, we assumed that the parameterized model is robust enough to be used in testing the performance of rice under possible hypothetical climatic scenarios. The objective of this study was to assess the impacts of climate change on crop productivity of medium and short duration rice varieties in Sri Lanka during to cultivating seasons.

Materials and Methods

<u>Study area:</u>
Ambalantota, Aralaganwila and Maha-Illuppallama located in the Dry Zone (DZ), Batalagoda and Kundasale located in the Intermediate Zone (IZ), and Labuduwa and Ratnapura located in the Wet Zone (WZ) of Sri Lanka (Table1) were selected as the study sites. These locations were selected as they represent major rice growing areas in the country and also due to availability of long-term climate data (*i.e.* daily data of more than 30 years).

Table 1. Description of the locations used in the study.

Climatic Zone	Location	Latitude (DMS)	Longitude (DMS)	Elevation (m above mean sea level)
Dry Zone	Ambalantota	7°46′57″ N	81°10′58″ E	65
	Aralaganwila	7°06′53″ N	81°17′47″ E	64
	Maha-Illuppallama	8°06′00″ N	80°27′00″ E	113
Intermediate Zone	Batalagoda	7°31′26″ N	80°25′57″ E	115
	Kundasale	7°30′01″ N	80°71′04″ E	110
Wet Zone	Labuduwa	6°04′39″ N	80°13′57″ E	51
	Ratnapura	6°42′20″ N	80°23′05″ E	128

<u>APSIM model:</u>
The APSIM version 7.5 and *APSIM-Oryza* module that was well-parameterised and validated for Bg300 and Bg359 was used to this study. The phenological parameters for Bg300 and Bg359 were used from the published literature

(Amarasingha *et al.*, 2014), *i.e.* (i) development rate in juvenile phase - DVRJ (°Cd^{-1}), (ii) development rate in photoperiod-sensitive phase - DVRI (°Cd^{-1}), (iii) development rate in panicle development phase - DVRP (°Cd^{-1}), and (iv) development rate in reproductive phase - DVRR (°Cd^{-1}).

Input data for *APSIM-Oryza* module:
The input data required to run the *APSIM-Oryza* were; daily weather information, soil characteristics and crop management information as described below.

Weather data: Daily weather data, namely, maximum (T_{MAX}) and minimum (T_{MIN}) temperatures, amount of rainfall and number of sunshine hours, for all locations were obtained from the Natural Resource Management Center (NRMC) of the Department of Agriculture, Sri Lanka. The daily incoming radiation (MJ m^{-2}d^{-1}) was calculated using the sunshine hours and location specific information, *i.e.* latitude and longitude, and angstrom coefficients (Samuel, 1991).

Soil data: Soil characteristics of the study sites were obtained from Mapa *et al.* (2010). Layer-wise soil data were incorporated into the model when available and default values from the model were used for sub soil layers.

Crop and management: Fertilizer application and management practices were identified according to the recommendations of the Department of Agriculture, Sri Lanka (DOA, 2014). Planting dates and planting method (direct seeding), and fertilizer management strategies were adjusted in the model simulations as collected from the respective locations. Irrigation amount was decided according to the difference between the water content at saturation and plant available water content.

Definition of scenarios modelled:
The T_{MAX} and T_{MIN}, rainfall and CO_2 concentration were changed as predicted by the climate change models. The Representative Concentration Pathways (RCP) 8.5 in IPCC (2014) synthesis report were used to adjust to climate scenarios against the year 2017 (current), 2050 (mid of the century) and 2100 (end of the century) (Table 2).

Table 2. Climatic factor values for different scenarios

Climatic factor	**Scenario**		
	2017 (Current)	**2050**	**2100**
Rainfall (Increased)	0	10%	20%
T_{MAX} (Increased)	0	1.85	3.7
T_{MIN} (Increased)	0	1.85	3.7
CO_2 Concentration	410 ppm	550 ppm	1100 ppm

The simulations were run for both *Yala* (March-September) and *Maha* (October-February) seasons. The *oryza.ini* file in *APSIM-Oryza* was modified as per the published literature (Rathnayake and Malaviarachchi, 2013; Suriyagoda and Peiris, 2013; Amarasingha *et al*., 2014).

Results and Discussion

In the DZ, the average simulated rice yield of Bg300 for the *Maha* season was projected to increase by 4% in 2050 and by 15% in 2100 (Fig. 1) compared to the current (2017) value of 6.1 tons ha^{-1}. Similar changes were projected for Bg359 in the DZ in *Maha* season, with 5% and 14% increase in the average simulated rice yields by 2050 and 2100, respectively, from the current value of 6.7 tons ha^{-1} (Fig. 1). The simulated yields for *Yala* season, however, for both varieties decreased in the DZ, *i.e.*11% and 28% in 2050 and 2100, respectively, for Bg300 from its current value of 6.7 tons ha^{-1}, and by 17% in 2050 and 42% in 2100 for Bg359 from its current value of 7.8 tons ha^{-1}. The average simulated rice yields for Bg300 and Bg359 in the WZ during the *Maha* season decreased below the baseline (2017) by 18% and 3% in 2050, and by 31% and 5 % in 2100, respectively, while in the *Yala* season, it was increased by 4% and 2% in 2050 and by 12% and 7% in 2100, respectively. There fluctuation of the simulated yield with climate change in 2050 and 2100 in comparison to 2017 was low for both the varieties and seasons in the IZ. In all locations, the variability of simulated rice yield was higher for Bg300. Prediction made for 2100 showed a higher variability compared to that of 2050. However, it was difficult to explain the variation in rice yields between 2017-2050 and 2050-2100. There could be cyclic effects of climate change on rice yield, which is beyond the scope of this analysis.

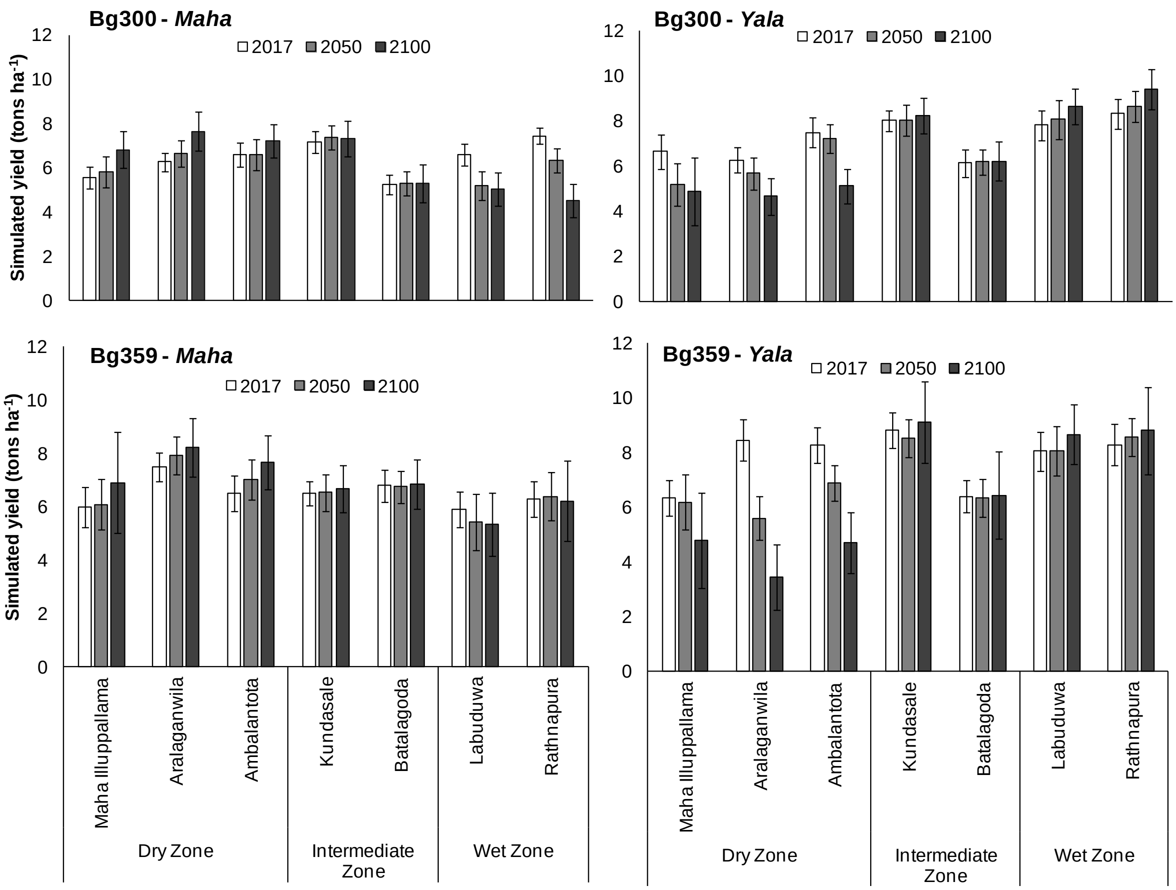

Figure 1. Simulated rice yields of Bg300 and Bg359 in three scenarios (2017, 2050 and 2100) during *Yala* and *Maha* seasons at the locations in Dry Zone, Intermediate Zone and Wet Zone. Vertical lines indicate standard error of the means.

Conclusion

The medium duration rice variety (Bg359) are at a higher risk than the short duration rice variety (Bg300) under the predicted climatic scenarios. Impacts of climate change varied depending on the location and the season. In the *Maha* season, DZ showed a positive impact on rice yield and it was negative in the WZ, while an opposite response was reported in the *Yala* season. The climate change impacts on the future rice yields in the IZ during both *Yala* and *Maha* seasons were predicted as negligible.

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