Validation of APSIM for long duration rice varieties in different agro-climatic zones of Sri Lanka

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Abstract
Rice (*Oryza sativa* L.) is the staple food for many Asians. In Sri Lanka, rice production is heavily dependent on the rainfall distribution pattern, and would be adversely affected by climate change. Prediction and estimation of yield and resource-use efficiency of commonly grown rice varieties is of immense importance under a variable and changing climate. Agricultural system simulation models are useful tools to assess the performance of agricultural systems under scenarios of changing rainfall patterns. The present study was conducted to validate the Oryza module of the Agricultural Production Systems Simulator (APSIM) model for two long duration rice varieties, Bg403 and Bg379-2 (4 months maturity). Model evaluation was done using secondary data. APSIM simulated the observed rice yields for Bg403 and Bg379-2 with a strong fit (R^2 of 0.88 and 0.77, respectively, and CV of 9.9% and 14.4%, respectively). Yield was less when grown under rainfed condition than under irrigation for both the varieties. The highest simulated yield loss was observed at Aralaganwila (Dry-Zone Low Country), where a 10% reduction in the seasonal rainfall was simulated. The validated APSIM-Oryza module can be used in evaluating the potential areas for rice cultivation in Sri Lanka under current and predicted climate change scenarios.

Key words
Low-land rice, Productivity, Water scarcity

Introduction
Rice (*Oryza sativa* L.) is the staple food for Sri Lankans. Total land devoted to rice is estimated to be about 805,647 ha (Agstat, 2013). Rice varieties are categorized into three types according to the time taken for maturity: short duration (up to 3 months), medium duration (3-4 months months), and long duration (4-4.5 months). Rice varieties in the short and medium duration age classes collectively comprise over 93% of the rice production of Sri Lanka and the balance is long duration varieties (Agstat, 2013). Due to heavy and longer duration rainfall during *Maha* season (major rainy season from October to February), farmers cultivate long and medium duration rice varieties. Short duration rice varieties are cultivated during the *Yala* season (minor rainy season from March to September) when the availability of water is limited. Long duration rice varieties are reported to give higher yields than other types. The total land area devoted to rice is not usually cultivated due to a shortage of water during the season (DCS, 2011). Global climate change projections have raised concerns about the negative impacts on crop production in Sri Lanka (Weerakoon and De Costa, 2009). Therefore, it is important to identify the ways of improving national rice production to meet the rising demand of an increasing population.

Estimation of rice yields are needed for different management conditions, and one approach to achieve this is by using crop models. The APSIM-Oryza was developed by incorporating the ORYZA2000 rice growth model (Bouman and van Laar, 2006) into the APSIM modelling framework. The model has been used in Sri Lanka, to evaluate the nitrogen response in lowland rice (Suriyagoda and Peiris, 2011), and for assessing the yield advantage and water productivity when aligning planting date with the onset of rainfall using short and medium duration rice varieties (Amarasingha *et al.*, 2014). The objectives of this study were to (i) validate APSIM-Oryza module for two long duration rice varieties widely grown in Sri Lanka (Bg379-2 and Bg403), (ii) estimate the rice yield in the Dry and Intermediate Zones with and without irrigation water availability during the *Maha* season and, (iii) estimate the rice yield of long duration rice varieties when rainfall is reduced by 5 % and 10 % during the *Maha* season.

Materials and Methods

APSIM model

The Agricultural Production Systems Simulator (APSIM) version 7.4 was used to validate the phenology and growth of long duration rice varieties Bg379-2 and Bg403 in four locations in different agro-climatic zones in Sri Lanka namely, Maha-Illuppallama (MI; Dry Zone, Low-Country), Bathalagoda (BG; Intermediate Zone, Low-Country), Bombuwela (BW; Wet Zone, Low-Country), and Aralaganwila (AG; Dry Zone, Low-Country). APSIM was previously parameterised for the above rice varieties (Fernando, 2014)

Data for model calibration and evaluation

Secondary data collected for over twenty years from both *Yala* and *Maha* seasons included planting date, time taken for flowering, 50% heading and maturity, and yield. These data were sourced from the Rice Research and Development Institute (RRDI) at BG and its regional station at BW, and the Field Crop Research and Development Institute (FCRDI) at MI and its regional station at AG under the National Coordinated Rice Variety Trials (NCRVT). Daily weather data (maximum and minimum temperatures, rainfall, and solar radiation) from 1976 to 2011 for MI, 1993 to 2013 for BG, 2002 to 2012 for BW, and 2001 to 2012 for AG were obtained for both *Yala* and *Maha* seasons from the Natural Resource Management Centre (NRMC) of the Department of Agriculture (DOA). Soil characteristics of the study sites were obtained from Mapa *et al*. (2010).

Management practices

All crop management practices were conducted according to the recommendations of the DOA (DOA, 2014). Planting dates and planting methods (direct seeding), irrigation, and fertilizer management strategies were parameterised in the model simulations as recorded from the sites. In the simulation process, a maximum ponding depth of 8.0 cm of water was maintained in the field either through rainfall or irrigation. Irrigation water was available only at the MI, BG, and AG and therefore, model simulations were run with supplementary irrigation for those sites. At the BW site, irrigation water is not available and hence simulations were run as a rainfed system.

Definition of the scenario modelled

Rainfall distribution may change as predicted by the climate change models. Specifically, the reduction in amount of rainfall received during *Maha* season may affect rice production. The simulated scenarios were:

> *Scenario A: With and without irrigation*
> Simulations were run with supplementary irrigation and without (*i.e.* rainfed).
>
> *Scenario B: Reduced rainfall in the Maha season*
> The weather files of the BG, MI, AG and BW sites were changed to reduce the daily rainfall by 5% and 10%. The *Maha* season is the major rice cultivating season in the Dry and Intermediate Zones.

Results and Discussion

The model could simulate the time taken for 50% flowering of Bg403 and Bg379-2 varieties in different locations. The CV values for Bg403 and Bg379-2 were 2.6% and 3.2%, respectively. The RMSE values for Bg403 and Bg379-2 varieties were 2.2 and 3.0 days and the R^2 values were 0.71 and 0.70, respectively (Fig. 1).

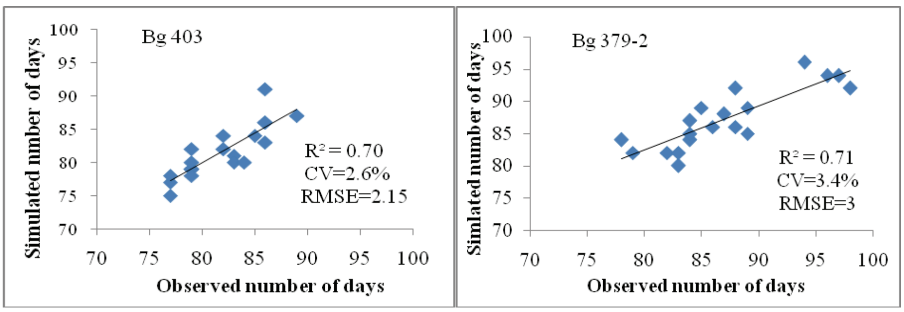

Figure 1. Observed and simulated days required for 50% flowering of Bg403 and Bg379-2 rice varieties grown during *Yala* and *Maha* seasons at Maha-Illuppallama, Bathalagoda, Aralaganwila and Bombuwela, in Sri Lanka.

The model estimated the rice yield at different locations with a strong fit. For Bg403 and Bg379-2, R^2 values were 0.89 and 0.77, respectively while the CV values were less than 15 % (Fig. 2). Therefore, this model can be used to predict the grain yield of Bg403 and Bg379-2 with high accuracy.

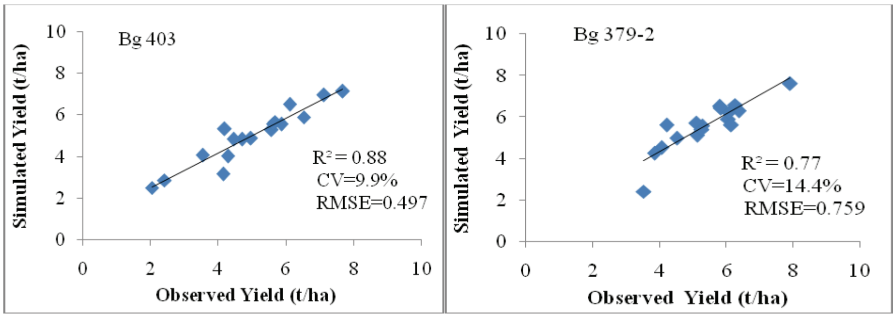

Figure 2. Observed and simulated grain yield of Bg403 and Bg379-2 rice varieties grown during *Yala* and *Maha* seasons at Maha-Illuppallama, Bathalagoda, Aralaganwila and Bombuwela, Sri Lanka.

There was a wide variability in soil physical and chemical properties among different locations (Mapa *et al*., 2010). Even under such variable conditions the parameterized APSIM-Oryza model could estimate the grain yield of rice with a high accuracy. The average expected grain yield of long duration rice varieties is higher than the short and medium duration rice varieties. However, due to various reasons, the yield potential of those varieties has not been achieved under field conditions. As APSIM-Oryza can incorporate the changes in soil moisture, nutritional aspects, and agronomic management decisions, the validated model can effectively be used in exploring yield-limiting factors. In these simulations supplementary irrigation was available when estimating the yields at MI, BG, and AG if the rainfall was not adequate; whereas at BW rice yield was simulated as a rainfed crop. Therefore, the different sites and years represented varying levels of soil moisture stresses which was a major factor affecting low observed yields across locations and years. Even under such diverse soil moisture availabilities, APSIM-Oryza could simulate the grain yield with a strong fit.

The highest observed yields were recorded at AG (Bg 379-2: 5.9 t/ha and Bg 403: 6.1 t/ha). The model can be used to estimate the expected yield under different management conditions such as a reduction in irrigation water availability. At BW, the observed yield recorded was lower than other locations tested (Bg 379-2: 4.5 t/ha and Bg 403: 3.2 t/ha). Possible agronomic interventions can be tested using simulation models to understand whether rice productivity can be improved through different management decisions. The precision achieved for the long duration rice varieties in this study is comparable with or even better than the level of precision reached by Amarasinghe *et al*. (2014) for short and medium duration rice varieties grown in in Sri Lanka.

Scenario analyses

The validated model was used to simulate yield performances under different scenarios. In the simulation of Scenario A (with and without irrigation), the yield was reduced at all the sites, with the greatest reduction at BG (69 % reduction) (Fig. 3A). At AG the yield reduction was less (15 %) than that observed at MI (50 %).

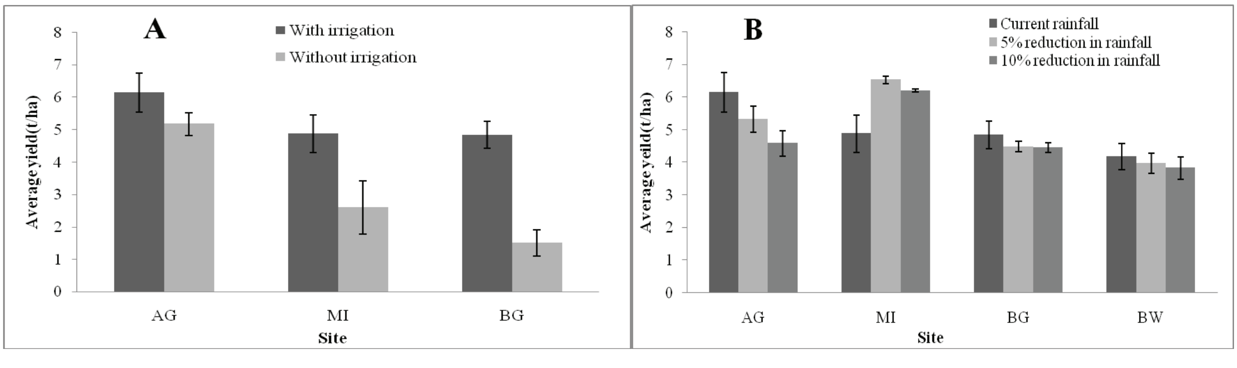

Figure 3. Average yield of rice with and without access to irrigation water supply (A), and under different levels of rainfall (B) during *Maha* season at Aralaganwila (AG), Maha-Illuppallama (MI), Bathalagoda (BG) and Bombuwela (BW) in Sri Lanka. Vertical lines indicate the standard error of the means, n=10.

The reason for the greater dependency of irrigation water at BG is due to the lower amount of rainfall received during the *Maha* season (average rainfall of 587 mm, n=10) than that received at AG (average rainfall of 1346 mm, n=10). The dependency of irrigation water can be reduced at least partly if the planting date is adjusted with the onset of rainfall season (Amarasinghe *et al*., 2014).

The average rice yield was reduced at all the sites except at MI when the simulated amount of rainfall was reduced by 5 % and 10 % below recorded data. The AG site experienced the greatest reduction in grain yield with the reduction in rainfall (Fig. 3B) and thus would be more affected by a possible reduction in rainfall in the future. At BG and BW sites, the reduction in grain yield was less than 8 % and 10 % when rainfall was reduced by 5 % and 10 %, respectively. Rice productivity increased at MI, and the exact reason for this response is not known and needs to be assessed further.

Conclusion

The APSIM-Oryza model was evaluated with high precision for two long-duration rice varieties (4 months to maturity; Bg403 and Bg379-2) for different agro-climatic zones in Sri Lanka. The capability of the model to simulate the time required for 50 % flowering, physiological maturity, and grain yield for both rice varieties was satisfactory

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