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Modelling the Impact of Changes in Rainfall Distribution on the Irrigation Water Requirement and Yield of Short and Medium Duration Rice Varieties Using APSIM During *Maha* Season in the Dry Zone of Sri Lanka

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ABSTRACT: *Rice (Oryza sativa L.) production in Sri Lanka is heavily dependent on the rainfall distribution pattern of the cultivating season. Estimation of the variation in yield and resource use efficiency of commonly grown rice varieties will be of immense importance when predicting yields under variable and changing climate. In this context, a modelling approach was used to predict the yield and water productivity of commonly grown short and medium–duration rice varieties under different climate scenarios using APSIM-Oryza module, which was previously parameterised and tested with a strong model skill. Maha-Illuppallama (DL_{1B}) and Thabbowa (DL_3) in the Dry zone of Sri Lanka were selected as the study areas. Daily rainfall data for the past 35 years (1976-2011) were analysed and the normal onset time period of Maha rains was identified in terms of a two-week period for each year, separately. The onset of rain before and after the identified weeks was considered as an early or late onset, respectively. Yield of rice varieties Bg300 (short duration; 3 months age class) and Bg359 (medium duration; 3.5 months age class) was simulated under the rainfed condition. The yield of rice varieties BG300 and Bg359 and the irrigation water requirement were simulated under two scenarios namely, (1) Normal Rainfall Distribution (NRD), and (2) Intense Rainfall Distribution (IRD). The results revealed that the amount of rainfall received during the Maha season was higher when an early onset occurred (63 % to 94 %) than that observed with a late onset. Rainy season ceased by late February at both locations irrespective of the time of onset of rainfall. The simulated yield of Bg359 under the two scenarios tested (i.e. NRD and IRD) were similar. However, delayed onset would increase the irrigation water requirement by 10 -17 %. Furthermore, a yield advantage of 14 -51% under IRD was observed only during an early onset compared to the NRD. The results also revealed that under the IRD condition, the variability of rice yield of Bg300 was lesser irrespective of the onset compared to that of Bg359 indicating that a climate forecast for IRD during the Maha season would assist farmers to opt for short duration rice varieties compared to medium duration varieties due to lower estimated yield losses in the former.*

Keywords*: APSIM, intense rainfall distribution, onset of rainfall, rainfall regime*

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INTRODUCTION

Climate change is defined as a statistically significant variation in either the mean state of climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may result from natural internal earth system processes or external forcing or to persistent anthropogenic changes in the composition of the atmosphere or land use (IPCC, 2013). At present, the level of atmospheric CO_2 is over 400 ppm and as per the Bern Climate Change Model, it is projected to reach a level of 700 ppm under climate change scenarios (Jalota ***et al.***, 2013).The average global surface temperature has also risen by 0.74 ± 0.18 ° C over the past 100 years (Trenberth and Jones, 2007). Climate change is expected to alter water resources and their distributions in time and space.

Global climate change has increased concerns on its negative and positive impacts on agricultural crops in Sri Lanka (Weerakoon and De Costa, 2009). Long term studies have shown changes in rainfall intensities with long dry spells, increasing maximum and minimum air temperatures along with increased atmospheric CO_2 concentrations (IPCC, 2013). Despite these challenges, the national rice production in Sri Lanka needs to be increased to meet the increasing demand both from increasing population and changing dietary patterns.

There are two major cropping seasons in Sri Lanka, namely, *Maha* (Second Inter-monsoon from October to November and the North-East monsoon from December to February) and *Yala* (First Inter-monsoon from March to April and the South-West monsoon from May to September). Most of the rice cultivation in Sri Lanka is practiced in the Dry Zone under rainfed conditions with supplementary irrigation during the *Maha* season when and where necessary and mainly with supplementary irrigation during the *Yala* season. Previous studies have shown a significant decline in water balance (***i.e.*** the difference between rainfall and evapotranspiration) during the *Yala* season in most of the climatic zones of Sri Lanka (De Costa, 2009). Analyses have also shown indications of declining water balances during the *Maha* season although the impact on crops may be less due to the smaller magnitudes of declines during the second inter-monsoon and the north-east monsoon. It is possible that climate change in coming decades may accelerate the declining water balances in the *Maha* season (De Costa, 2009). Hence, appropriate agronomic practices and proper water management techniques are imperative together with the cultivation of suitable rice varieties with greater capacity to conserve irrigation water in order to sustain production and productivity of the rice crop.

The Dry zone in Sri Lanka contributes to over 60 % of the rice production in the country. The rice varieties in the short (3 months to mature) and medium (3.5 months to mature) duration age class collectively contribute to over 93 % of the rice production of Sri Lanka (Agstat, 2013). Due to heavy and longer duration rainfall during the *Maha* season, farmers usually cultivate long and medium duration rice varieties while short duration rice varieties are cultivated during the *Yala* season as the availability of water is limited. The variations in onset, duration and the total amount of rainfall received during the season are important in rainfed and supplementary irrigated systems (Ayoni and Dharamasena, 2009) such as in rice cultivated during the *Maha* season of Sri Lanka.

In order to study the impact of changing climate, number of crop models are available in the literature (DSSAT, CropSyst, APSIM) and these models estimate crop growth, yield, water balance, and nutrient balance on daily basis. In the present study, Agricultural Production System Simulator (APSIM) is used to simulate the rice yield as affected by the changes in climate, soil nutrients, variety and management practices. 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 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 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 with 14 % Co-efficient of Variation (CV) for Bg300 and 8 % for Bg359 (Amarasingha *et al.*, 2014). A CV less than 20 % is generally considered as a good model fit (Gaydon, 2012a, b). The validated model performed well in different agro-climatic zones in Sri Lanka under water-limited farmer-field conditions, and predicting the grain yield with a strong model skill (R^2>0.97, RMSE=484 kg ha^{-1}; Amarasingha *et al.*, 2014). Hence, the parameterized model is robust enough to be used in the testing of performance of rice crop under possible hypothetical climatic scenarios. The objectives of this study were to (i) identify the rainfall distribution pattern and the amount of rainfall received with the changes in onset of the *Maha* season at two rice growing locations in Sri Lanka, (ii) evaluate the crop productivity and irrigation water requirement for a widely grown medium duration rice variety during the *Maha* season and (iii) use the APSIM model to assess crop productivity of medium and short duration rice varieties in a rainfed system if the rainfall distribution during the *Maha* season reduces and the variability increases in comparison to the present rainfall distribution pattern.

METHODOLOGY

Study area

Maha-Illuppallama (DL_{1b}, latitude 8º 08’ 50’’N and longitude 80° 25’ 50’’ E, 137 m above msl) and Thabbowa (DL_3, latitude 08˚05’ 10” N and longitude 79˚ 56’ 20’’E, 32 m above msl), located in the Dry zone of Sri Lanka were selected as the study sites. The Dry zone receives a mean annual rainfall of less than 1750 mm with a relatively dry season from May to September. The two sites were selected as they represent major rice growing areas in the country and highly dependent on irrigation and based on availability of long-term climate data (i.e. daily data of more than 30 years).

Input data for APSIM-Oryza model

The input data required to run the APSIM-Oryza were daily weather information, soil characteristics and crop management information, which are described below.

Weather data

Daily weather data (maximum and minimum temperatures, rainfall amount and number of sunshine hours) from January 1976 to May 2011 for Maha-Illuppallama and Thabbowa 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 (a = 0.29 and b = 0.39) (Samuel, 1991).

Soil data

Soil characteristics of the study sites were obtained from Mapa *et al.* (2010; Tables 1 and 2). Layer-wise soil data were incorporated to the model where available and default values present in the model were used for sub soil layers.

Table 1. Soil physical and chemical characteristics and volumetric soil water dynamics at Maha-Illuppallama

Depth (cm)	BD* (g cm^{-3})	LL15 (mm mm^{-1})	DUL (mm mm^{-1})	SAT (mm mm^{-1})	OC (%)	EC (1:5 dS m^{-1})	pH (1:5 H_2O)	CEC (cmol kg^{-1})
0-10	1.7	0.19	0.31	0.33	0.91	0.17	7.6	10.1
10-20	1.7	0.20	0.31	0.33	0.91	0.17	7.6	10.1
20-30	1.7	0.25	0.32	0.33	0.91	0.17	7.6	10.1
30-40	1.5	0.27	0.35	0.37	0.20	0.16	7.8	11.0
40-50	1.5	0.27	0.35	0.37	0.20	0.16	7.8	11.0
50-60	1.5	0.27	0.35	0.37	0.20	0.16	7.8	11.0

*BD-Bulk Density, LL-Lower Limit, DUL- Drainage Upper Limit, SAT- Saturation Water Content, OC- Organic Carbon, EC- Electrical Conductivity, CEC- Cation Exchange Capacity

Table 2. Soil physical and chemical characteristics and volumetric soil water dynamics at Thabbowa

Depth (cm)	BD* (g cm^{-3})	LL15 (mm mm^{-1})	DUL (mm mm^{-1})	SAT (mm mm^{-1})	OC (%)	EC (1:5 dS m^{-1})	pH (1:5 H_2O)	CEC (cmol kg^{-1})
0-10	1.7	0.19	0.310	0.330	1.52	0.18	6.7	16.2
10-20	1.5	0.20	0.310	0.330	1.40	0.17	6.8	13.0
20-30	1.5	0.25	0.320	0.330	1.40	0.17	6.8	13.0
30-40	1.5	0.27	0.350	0.370	1.40	0.17	6.8	13.0
40-50	1.5	0.27	0.350	0.370	1.40	0.17	6.8	13.0
50-60	1.5	0.27	0.350	0.370	1.40	0.17	6.8	13.0

BD-Bulk Density, LL-Lower Limit, DUL- Drainage Upper Limit, SAT- Saturation Water Content, OC- Organic Carbon, EC- Electrical Conductivity, CEC- Cation Exchange Capacity

Crop and management

Fertilizer 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), irrigation and fertilizer management strategies were adjusted in the model simulations as collected from the sites.

Rainfall distribution pattern

Rainfall data for the past 35 years (1976-2011) were analysed and the onset date of *Maha* rains was identified for each year separately. The onset of rainfall was defined as a spell of at least 20 mm of rain per week in three consecutive weeks after a pre-specified week for the *Maha* (standard week 35) and *Yala* (standard week 9) seasons. Once this requirement is fulfilled, the starting day of the rainfall is considered as the date of onset (Punyawardena, 2002; Chitranayana and Punyawardena, 2010). According to the onset dates, the average weekly rainfall was calculated for both sites. The onset was categorized into six time periods on weekly basis for the period starting from 1st and 2nd week of September (Sep 1-2wk) up to 1st and 2nd weeks of November (Nov 1-2 wk).

Definition of the scenario modelled

The rainfall distribution may change as predicted by the climate change models. One condition that would greatly affect the crop performance would be the reduction in the length of the rainfall season coupled with an increase in the intensity of rainfall (*i.e.* IRD: Intense Rainfall Distribution), which was considered as the first likely scenario in the modelling exercise. Continuation of the present, normal rainfall distribution (NRD) was considered as the second likely scenario in the simulation.

The IRD was defined as a 10 % reduction in the total amount of rainfall towards the latter part (tail end) of the rainfall season, and the amount of arrested rainfall was proportionally incorporated to the rainy days occurred early in the season in the simulations thus, increasing the variability while keeping the total quantum of rainfall intact. Accordingly, the weather file of the APSIM model was changed. To simulate situations where supplementary irrigation was practiced, 50 mm irrigation was supplied in the model if the soil water content decreased below 25 % of the plant available water content.

In order to evaluate the effect of supplementary irrigation on rice crop production, simulations were run with and without (*i.e.* rainfed) supplementary irrigated conditions. The growth of different varieties were tested (*i.e.* instead of the decisions on growing short or medium duration rice varieties) to be used in making management decisions to improve, maintain or minimise the reduction in yield per crop and/or water productivity under the scenarios modelled.

The calibrated APSIM version 7.4 (*i.e. APSIM-ORYZA* module) for Sri Lankan rice varieties (Bg300 and Bg359) was used in this study. During *Maha* season farmers normally cultivate the medium duration rice varieties. However, if the onset is delayed the risk of establishing medium age rice varieties increases. Therefore, in such a situation establishment of short duration rice variety may be advantageous and hence, a short duration rice variety was also used in the scenario analysis. The *oryza.ini* file in APSIM was modified as per the published literature (Rathnayake and Malaviarachchi, 2013; Suriyagoda and Peiris, 2013; Amarasingha *et al*., 2014).

RESULTS AND DISCUSSION

Rainfall distribution pattern

The rainfall distribution pattern for the 35 year period tested (1976-2011) with the onset for Maha-Illuppallama and Thabbowa study sites are illustrated in Fig. 1.

Maha-Illuppallama received 35-40% higher rainfall during the *Maha* season than that at Thabbowa. At Maha-Illuppallama, the onset occurred from early September in certain years while at Thabbowa the onset occurred from mid to late September. The number of rainy weeks in both sites was greater in years with an early onset than that in years with a late onset. At Maha-Illuppallama an early onset increased the amount of rainfall received by 94%

during the season than that occurred with a late onset, and the corresponding increment at Thabbowa was 63 %. The rainy season eased by the late February at both locations irrespective of the time of rainfall onset.

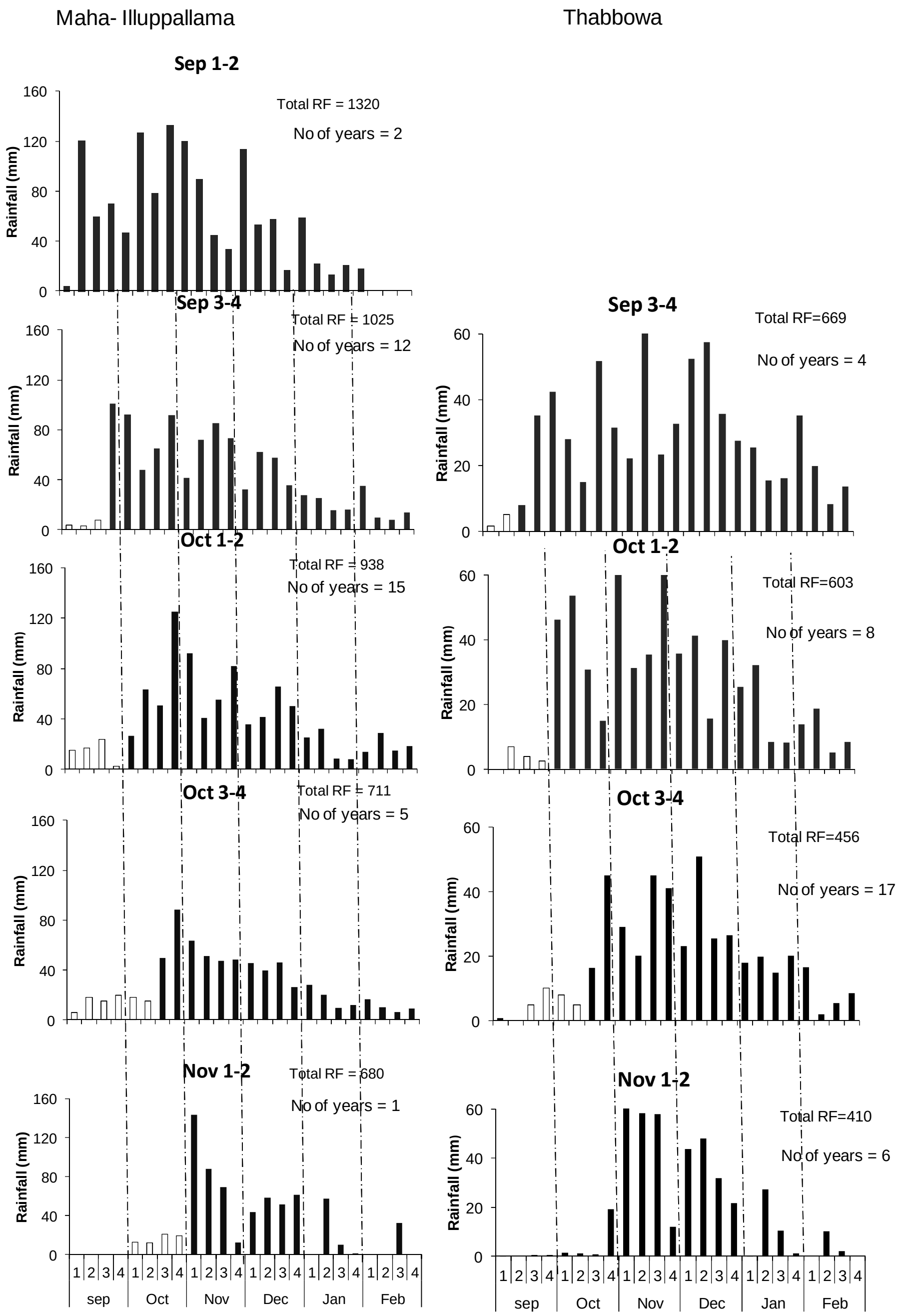

Fig.1. Distribution of rainfall during *Maha* with the onset at Maha-Illuppallama and Thabbowa for the last 35 years (1976-2011)

Crop productivity and irrigation water requirement for medium duration rice variety (Bg359) during the *Maha* season

Fig. 2 illustrates the yield and irrigation water requirement for Bg359 (medium duration rice variety) during the *Maha* season as affected by different onset times with NRD and IRD towards the end of the season. Simulated rice yield of Bg359 was similar between the NRD and IRD scenarios when having access to supplementary irrigation, irrespective of the location and onset (Fig. 2A). Even if the rainfall distribution was reduced by 10% towards the tail with a higher intensity end (IRD scenario), having access to irrigation water ensured the crop productivity as observed under NRD scenario. However, the requirement and dependency on irrigation water differed between the two scenarios and onset. For example, in years when an early onset occurred, the amount of irrigation water required was similar between the NRD and IRD (Fig. 2B). However, when the onset was late, the amount of irrigation water required increased compared to an early onset for both the scenarios and for both sites (Fig. 2B).

The simulated results indicated that the percentage increments of irrigation water requirement at Maha-Illuppallama and Thabbowa under NRD were 88 %, and 53 %, respectively, and under IRD condition were 126 % and 90 %, respectively. Therefore, the amount of irrigation water required under IRD scenario was higher for the medium duration rice variety Bg359 than that required under NRD scenario under each onset duration, ***i.e.*** at Maha-Illuppallama the increment was 10-20 % and at Thabbowa 9-25 %.

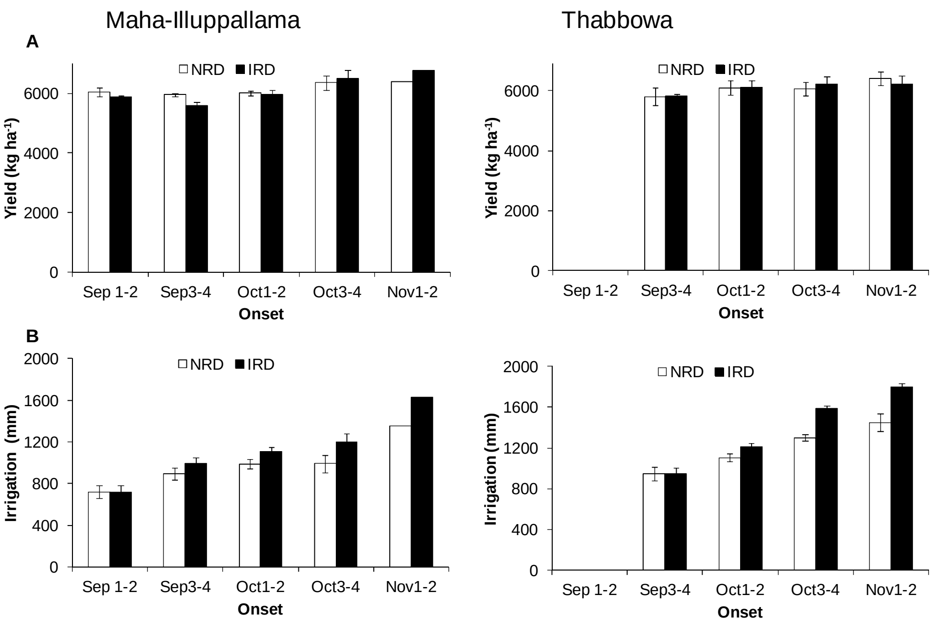

Fig. 2. (A) **Yield, and (B) irrigation water requirement of Bg359 during *Maha* season as affected by different onset times with Normal Rainfall Distribution (NRD) and Intense Rainfall Distribution (IRD) conditions towards the end of the season when having access to supplementary irrigation at Maha-Illuppallama and Thabbowa. Vertical bars represent standard error of simulated yield and irrigation**

The simulated results indicate that the Thabbowa study site required 5-12 % more irrigation water than that at Maha-Illuppallama under both NRD and IRD scenarios. This was due to the lower amount of rainfall received at Thabbowa compared to that at Maha-Illuppallama (Fig. 1) and prevailing high evapotranspiration regime of the area. As the amount of rainfall received with an early onset was higher, the irrigation water requirement was simulated to be lower than that at a late onset at both study sites. Therefore, the dependency of supplementary irrigation water requirement increased as the onset delayed.

Productivity of medium (Bg359) and short (Bg300) duration rice varieties in *Maha* season without the access to supplementary irrigation

Fig. 3 illustrates the simulated yield of rice varieties Bg359 and Bg300 with the different onset times under the NRD and IRD scenarios when grown under rainfed condition at the two study sites Maha-Illuppallama and Thabbowa. With an early onset and IRD scenario, 40 % and 51 % higher yield was simulated for Bg359 at Maha-Illuppallama for Sep 1-2 wk and Sep 3-4 wk onsets, respectively, compared with the NRD, which was 23 % and 14 % at Thabbowa in Sep 3-4 wk and Oct 1wk, respectively (Fig. 3). However, with a late onset, yield of Bg359 reduced by 28-82 % under IRD scenario than that with the NRD at Maha-Illuppallama and the corresponding values at Thabbowa were 15-19 %. Even under IRD with an early onset, as the rainfall season was relatively longer (than that at an late onset), the number of days with soil moisture less than the amount that can create stress (***i.e.*** below the plant available water content- 15 bars) to the rice crop was minimum while the higher amount of rainfall received during the early growth stages of Bg309 minimised soil water stresses (data not shown). These resulted in a higher yield with an early onset with IRD scenario than that with NRD rainfall scenario (Fig. 3).

Moreover, the simulated yield variation of Bg300 at Maha-Illuppallama and Thabbowa, between the NRD and IRD was 1-20 % and 1 - 6%, respectively (Fig. 3). The corresponding values for Bg359 at Maha-Illuppallama and Thabbowa were 28-82 % and 15-19 %, respectively. Therefore, Bg300 had a lesser variability in the simulated yield both at NRD and IRD scenarios in both study sites. This response was due to the adequate soil water content maintained during the short growth of Bg300 than that for Bg359.

The present study was conducted using a well-parameterised APSIM model (Amarasingha *et al*., 2014; Amarasinghe and Suriyagoda 2013, 2014). Therefore, the resource requirements such as time taken to estimate the productivity was minimum for such an analysis, and the simulated results generated thorough this study are with a higher accuracy and thus, would be a valuable decision making tool at policy and practitioner levels.

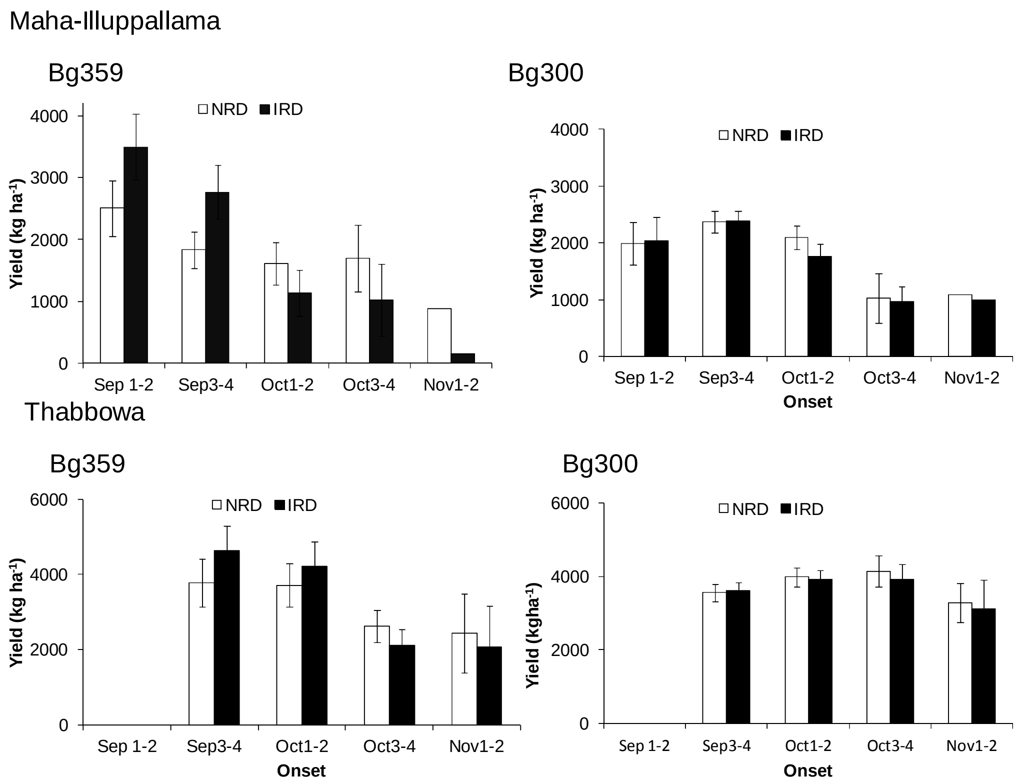

Fig. 3. Rice yield of Bg359 and Bg300 with the different onset times under the Normal Rainfall Distribution (NRD) and Intense Rain Distribution (IRD) patterns without supplementary irrigation at Maha-Illuppallama and Thabbowa. Vertical bars represent the standard error of the simulated yields.

CONCLUSIONS

An early onset resulted in a longer *Maha* season (*i.e.* early or mid-September to late February) and a higher rainfall (63 % and 94 % higher at Thabbowa and Maha-Illuppallama, respectively) compared to a late onset. The well-parameterized APSIM module simulated the yield of the medium duration rice variety Bg359 as similar between the normal and intense rainfall distribution (IRD) scenarios when the supplementary irrigation was available. However, the irrigation water requirement increased (90 - 126%) with a late onset under IRD than that with an early onset and normal rainfall distribution (NRD). The variability in rice yield of Bg300 was less during the *Maha* season even with IRD than that of Bg359. Availability of a seasonal climate forecast for situations such as IRD during the Maha season would assist farmers to opt for short duration rice varieties compared to medium duration varieties due to lower estimated yield losses in the former.

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