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Shifting Planting Dates and Fertilizer Application Rates as Climate Change Adaptation Strategies for Two Rice Cultivars in Cambodia

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ABSTRACT

We attempted to assess the impact of climate change on rice yields in Cambodia and to investigate adaptation strategies to climate change including more drastically shifting the planting dates and considering more fertilizer application levels. The potential yields of two wet season rice cultivars (Sen Pidao and Phka Rumduol) under two climate change scenarios in Cambodia were simulated using the CERES-Rice model. Field experiments conducted at the Cambodian Agricultural Research and Development Institute (CARDI), in 2010, 2011, and 2013 and climate variables from the HadGEM3-RA model were collected for this study. Compared with the baseline (1991-2000), yields of Sen Pidao rice will decrease under climate change and yields of Phka Rumduol rice could increase or decrease depending on fertilizer rates and the periods (2040s, 2050s, and 2080s). In general, the variations in the simulated effects of climate change on yields were more sensitive at fertilizer N100-N200 and less sensitive at fertilizer N0-N50. It is likely that forward shifts of planting date from the baseline plating date for the two cultivars in the future can be more benefitted than backward shifts. It is concluded that the CERES-Rice model can be useful to provide efficacious adaptation strategies in Cambodia.

Key words: *Adaptation, CERES-Rice, Climate Change, Fertilizer, Rice Cultivars*

1. INTRODUCTION

Rice (*Oryza sativa* L.), the overwhelmingly predominant food crop and principal source of employment and income in rural areas of Cambodia, is grown on nearly 85% of the country's total cultivated land. According to the 2008 census, more than 80% of the households in Cambodia live in rural areas and most families are highly dependent on agriculture (Royal Government of Cambodia, 2008). Cambodia is located in the southern portion of the Indochinese Peninsula with a tropical monsoon climate and distinct wet and dry seasons. Rice can be cultivated year-round, with one crop grown in the dry season, and three crops in the wet season. The majority (about 81% of national production or 86% of the cultivated rice area) of rice crops are cultivated during the summer monsoon or wet season (USDA, 2013). Cambodian rice yields are low compared with its neighboring countries, such as Thailand and Vietnam. There are many factors that affect Cambodian rice yields, such as climate, inadequate fertilizer, underdeveloped irrigation facilities, poor farming practices, and the use of low-yield cultivars.

Mechanistic rice models are useful tools for simulating rice growth, development, and yield. The DSSAT/CERES-Rice model, included in the Decision Support System for Agrotechnology Transfer (DSSAT), developed by the International Benchmark Systems Network for Agrotechnology Transfer, is widely used as a decision support system (Jones *et al.*, 2003; Timsina and Humphreys, 2006) to assess the potential impacts of climate change and the efficacy of adaptation options. A considerable number of studies based on the CERES-Rice model have been conducted in different regions: Australia (Timsina and Humphreys, 2006), China (Jiang and Jin, 2009), India (Sarkar and Kar, 2008), Indochinese peninsula (Chun *et al.*, 2016; Li *et al.*, 2017) and South Korea (Kim *et al.*, 2002; Lee *et al.*, 2012). CERES-Rice has also been used to study climate change over a wide range of environments. Aggarwal and Mall (2002) used

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CERES-Rice as the primary impact assessment model to assess the impacts of climate change on rice yields in India. They reported that rice yields increased by 6.0~24% in the scenarios run for 2070, depending upon the level of fertilizer application. The responses to climate change were smaller at low N (nitrogenous fertilizer) management compared with optimal management. Kim *et al.* (2013) simulated rice yield responses to climate change for the temperate climate regions under the East Asian monsoon system for years 2050 and 2100 compared with the baseline (1997~2008). Their results showed that the yield increases were generally greater (+24% in 2050 and +29% in 2100 in Harbin, China) with increasing latitude, with yield decreases at lower latitudes (e.g. Hiroshima, Japan). Yao *et al.* (2007) simulated rice yields in 2071~2090 compared with the baseline (1961~1990) in China. They reported that rice yields increased by 5~20%, depending on the geographic location. Thomas *et al.* (2013) evaluated rice yields for the 1950~2000 baseline period and the future climate conditions given by four General Circulation Models (GCMs) for 2050 in Cambodia. They found that for the country as a whole, at low levels of fertilizer use, there was a potential decrease in yields of 2.3%. With high fertilizer use, the potential losses could be 9.9% of the total yield.

Adjusting the planting dates for rice cultivation have been studied to offset the negative impacts of climate change on crop yield (Chun *et al.*, 2016; Li *et al.*, 2017; Azdawiyah *et al.*, 2015; Dharmarathna *et al.*, 2014; Waongo *et al.*, 2015). Waongo *et al.* (2015) derived location-specific planting dates for maize cropping in Sub-Saharan Africa. They reported that approximately 15% higher potential maize yield was simulated with the derived optimized planting dates compared with conventional planting dates for West Africa. Li *et al.* (2017) reported that shifting the planting date to 20 days later relative to baseline planting date would slightly increase rice yields (0~4.7%) in Cambodia. However, to the best of our knowledge, few studies have been conducted on with field experiments for model calibration and validation in Cambodia. There has been no comprehensive study assessing different cultivars, fertilizer use and management practices in Cambodia.

In this study, we examined the potential yields of two different wet season rice cultivars under two climate change scenarios in Cambodia. This study made a more detailed assessment of the impact of climate change on rice yields in Cambodia, including more drastically shifting the planting dates and considering more fertilizer application levels.

2. MATERIALS AND METHODS

2.1 Study Site and Data Collections

Soil and phenological characteristics were collected at an experimental plot conducted by the Cambodian Agricultural Research and Development Institute (CARDI), located at E 11°28'34.4", N 104°48'36.5, in 2010, 2011 and 2013. Two aromatic milled rice cultivars were analyzed: (1) short duration, early maturity, a short non-photosensitive rice, cv. Sen Pidao and (2) medium duration, medium maturity, a taller photosensitive wet season rice, cv. Phka Rumduol (Kamoshita *et al.*, 2016). The two varieties (Phka Rumduol in 1999 and Sen Pidao in 2002) were released by the CARDI to improve food security (Trak, 2009).

The future climate data for this study were collected from CORDEX-East Asia. We selected the HadGEM3-RA model, a regional climate model, to investigate the effects of climate change on rice yields in Cambodia, because the model provides the longest period. More detailed information on these models is given on the CORDEX-East Asia webpage (https://cordex-ea.climate.go.kr/). The projected data were based on two IPCC greenhouse gas concentration scenarios (RCP4.5 and RCP8.5) for this study. The yearly average changes in the projections for total daily radiation and maximum and minimum temperature are listed in Table 1. For both emission scenarios, the projected radiation and temperatures were higher than the baseline. The increase in the minimum temperature was generally greater than the increase in the maximum temperature. Compared with baseline weather conditions, the mean daily maximum temperature was projected to increase by 1.9℃ in the 2040s and 2.5℃ in the 2080s under the RCP4.5 scenario and by 2.1℃ and 4.8℃ for the respective decades under the RCP8.5 scenario.

2.2 Model Calibration and Validation

The baseline years were the years 1991 to 2000 and the simulation years were 2041~2050 (the 2040s), 2051~2060 (the

Table 1. Average changes in total solar radiation and maximum and minimum temperature for the 2040s, 2050s, and 2080s, simulated with the HadGEM3 model based on the RCP4.5 and RCP8.5 emission scenarios.

Scenario	Year	Radiation (Mj $m^{-2}day^{-1}$)	Tmax (℃)	Tmin (℃)
RCP4.5	2040s	+0.4	+1.9	+2.0
	2050s	+0.3	+2.5	+2.5
	2080s	+0.3	+2.5	+2.7
RCP8.5	2040s	+0.2	+2.1	+2.4
	2050s	+0.0	+2.4	+2.7
	2080s	+0.5	+4.8	+4.8
Baseline (mean)	1990s	20.1	33.5	25.3

The values for the baseline are the 10-year average from 1991 to 2000.

2050s) and 2081~2090 (the 2080s). The CO_2 concentrations for all the periods used for this study were 362, (499 and 571 for RCP4.5 and RCP8.5, respectively), (499 and 571 for RCP 4.5 and RCP8.5, respectively), and (532 and 801 for RCP4.5 and RCP8.5, respectively) μmol mol^{-1} for the baseline, the 2040s, the 2050s, and the 2080s, respectively. However, the question on howthese CO_2 concentration scan impact on rice productivity is not addressed in this study. It is recommended that this question be addressed in a further study. Daily weather data included total solar radiation, maximum and minimum temperature, and precipitation. Cultivar coefficients should be calibrated to achieve the observed yield and biomass under no-stress growing conditions (Boote, 1999). In this study, the experiments conducted in 2011 were selected for the calibration of the cultivar coefficients, while those in 2010 (Sen Pidao and Phka Rumduol) and 2013 (Phka Rumduol only) were selected for the validation of the CERES-Rice model. Genotype coefficients were determined by the "trial and error" method to compare the best match. The estimates of genotype coefficients are summarized in Table 2. The genotype coefficients P20, G1, G2, G3, and G4 for both cultivars were similar to each other, while P1, P2R, and P5 for both cultivars are quite different to each other. However, a further study is recommended on the calibration using longer period of the experiments. The GenCalc program in DSSAT was employed to estimate cultivar coefficients (Hunt *et al.*, 1993). The simulated yields of both cultivars were nearly same as the observed yields in the calibration year, while 1.2 to 3.1% of rice yields were higher for the simulated than observed values in the validation years. More detailed information on the calibration and vali- dation of the CERES-Rice model can be found in Chun *et al.* (2016).

2.3 Planting Date Adjustment and Fertilizer Rates

Simulations of the effect of adjusting the planting date under the RCP4.5 and RCP8.5 future climate change scenarios were conducted using the CERES-Rice model to investigate a suitable agronomic option for adaptation. Cambodia's accommodated fertilizer rate was 50 N kg ha^{-1} (CARDI, 2012) which is much lower than the other countries in Southeast Asia. According to the FAO (2010), farmers in Vietnam applied 221 kg of fertilizer on average and 108 kg on average in Thailand. For this study, considering the possible increase in fertilizer usage in the future, we simulated rice growth and yields with six fertilizer rates (N:P:K, kg ha^{-1}): N0 (0:0:0), N33 (33:23:30), N50 (50:23:30), N100 (100:23:30), N150 (150:23:30), and N200 (200:23:30). In this study, we focused on adaption strategies in accordance with the changing climate, considering 6 different fertilization rates. A wide range of adaptive actions can be implemented to reduce or overcome the negative effects of climate change on rice yields. For this study, the adaption measures that were investigated in this study were a combination of changing of planting dates, along with fertilization. Farmers can strategically shift the time of planting to control the plant growth-rate. To determine the optimum planting dates for the greatest yields, the planting dates were shifted from the actual planting date in 2011 (day-of-year, DOY 195) to DOY

Table 2. Genotype coefficients developed for the rice cultivars Sen Pidao and Phka Rumduol

No.	Genotype coefficient	Sen Pidao	Phka Rumduol
1	P1: Time period (expressed as growing degree days [GDD] at ℃ above a base temperature of 9℃) from emergence to the end of the juvenile phase.	554.400	435.100
2	P20: Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate.	13.000	11.280
3	P2R: Photoperiod sensitivity coefficient, extent to which the phase development leading to panicle initiation is delayed (expressed as GDD in ℃).	87.700	295.100
4	P5: Time period (expressed as GDD in ℃) from the beginning of grain filling to physiological maturity with a base temperature of 9 ℃.	251.100	388.000
5	G1: Potential spikelet number coefficient as estimated from the number of spikelets per g of the main culm + spike dry weight at anthesis.	68.670	58.960
6	G2: Single grain weight (g) under nonlimiting growing conditions, i.e., nonlimiting light, water, nutrients, and absence of pests and diseases.	0.021	0.0260
7	G3: Tillering coefficient (scalar value) relative to IR64 cultivar under nonlimiting conditions.	1.000	1.000
8	G4: Temperature tolerance coefficient.	1.150	1.200

147 and to DOY 245, a shift of 48 days before and 50 days after, respectively, at an interval of 1 day. Changes in rice yields were then compared with the rice yield in the baseline. Since the effects of planting density on changes in rice yields were not investigated, a further study on the planting density is recommended.

3. RESULTS AND DISCUSSION

3.1 Effects of Climate Projections on Yields

The yield variations of both cultivars at six different fertilizer rates for the baseline years (1991~2000) are shown in Fig. 1. Generally, rice yields increased with more fertilizer but

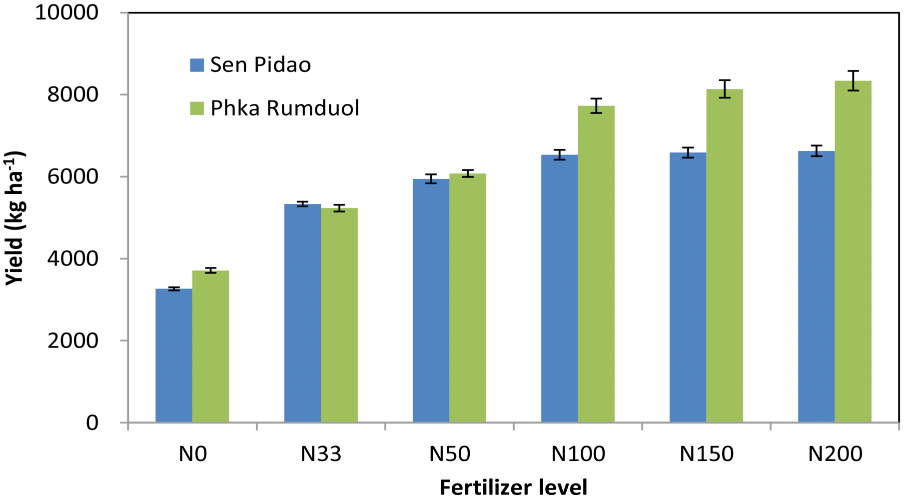

Fig. 1. Average simulated rice yields of Sen Pidao and Phka Rumduol at 6 different fertilizer rates for the baseline years (1991~2000). The vertical bars represent±SE (standard errors). The fertilizer rates (N:P:K, kg ha^{-1}) are: N0 for 0:0:0, N33 for 33:23:30, N50 for 50:23:30, N100 for 100:23:30, N150 for 150:23:30, N200 for 200:23:30.

reached a plateau if more than 100 kg N ha^{-1} of fertilizer was applied. This result implies that 100 kg N ha^{-1} of fertilizer rate can be economically better and is in good agreement with that of Chun *et al.* (2016). They reported that 100 kg N ha^{-1} of fertilizer rate would be cost-effective in Cambodia through a benefit-cost ratio analysis. For Sen Pidao, the rice yield was 3,264 kg ha^{-1} without any fertilizer (N0), increasing to 5,334 kg ha^{-1} with applied nitrogen at 33 kg N ha^{-1} (N33), and reaching the yield of 6,533 kg ha^{-1} with applied nitrogen at 100 kg N ha^{-1} (N100). For the Phka Rumduol cultivar, rice yield increased from 3,713 kg ha^{-1} without fertilizer application (N0) to 7,725 kg ha^{-1} with nitrogen fertilizer at 100 kg N ha^{-1} (N100).

To assess the impacts of climate change on rice yields, we simulated the rice yields for two cultivars with the projected future climate variables, i.e. a combination of temperature, precipitation, and solar radiation for each year from 2041~2050, 2051~2060 and 2081~2090 (Fig. 2 and Fig. 3). For the Sen Pidao cultivar under the RCP4.5 scenario, yields decreased under the effects of climate change (Fig. 2a). The yields were projected to decrease by 15~27%, and 21~34% in the 2040s and 2080s, respectively. For the Phka Rmuduol cultivar under the RCP4.5 scenario, the yields decreased much less than for Sen Pidao, starting with a 7% decrease in the 2020s at fer-

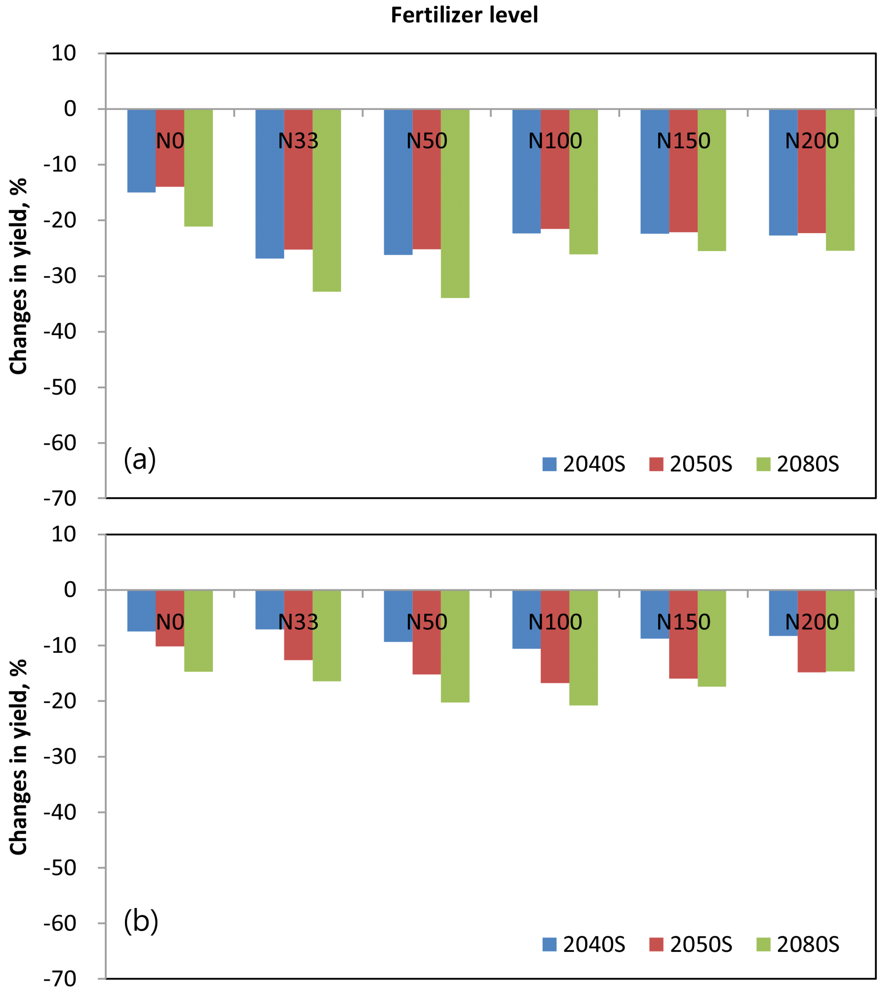

Fig. 2. The projected rice yield change (%) relative to the simulated yield for the baseline years (1991~2000) for Sen Pidao (a) and Phka Rumduol (b) at 6 different fertilizer rates under the RCP4.5 scenario for the 2040s, 2050s and 2080s. The fertilizer rates (N:P:K, kg ha^{-1}) are: N0 for 0:0:0, N33 for 33:23:30, N50 for 50:23:30, N100 for 100:23:30, N150 for 150:23:30, N200 for 200:23:30.

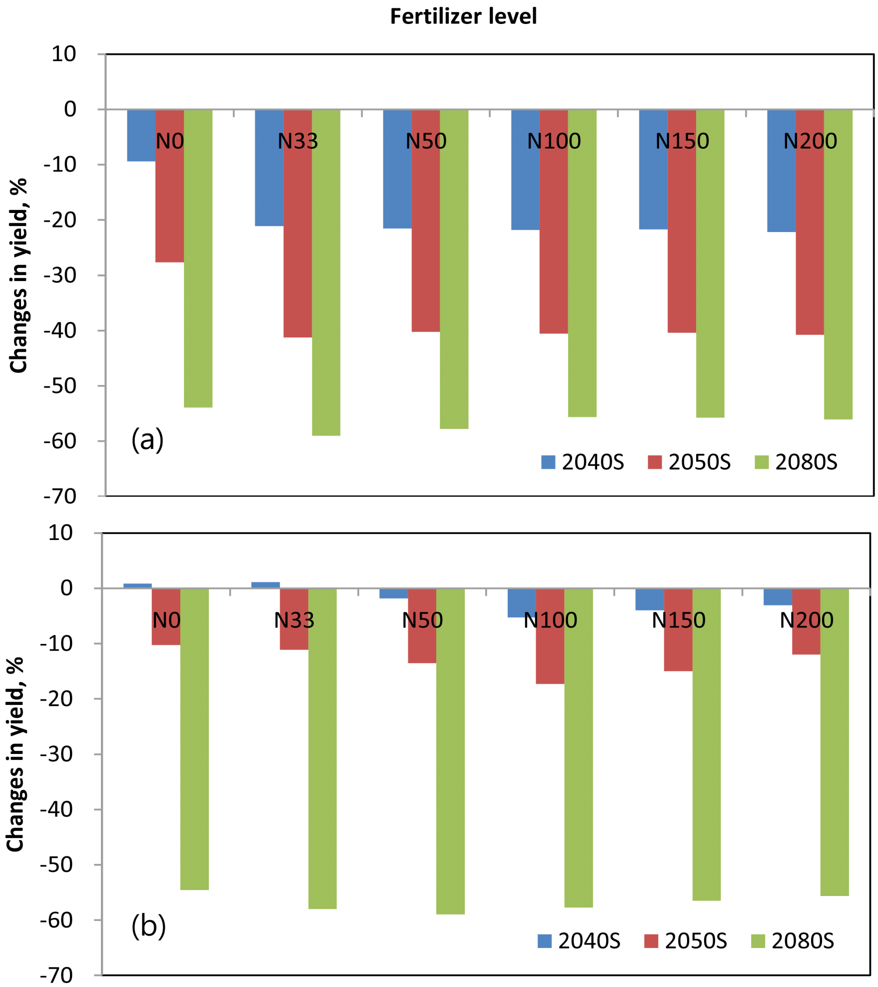

Fig. 3. The projected rice yield change (%) relative to the simulated yield for the baseline years (1991～2000) for Sen Pidao (a) and Phka Rumduol (b) at 6 different fertilizer rates under the RCP8.5 scenario for the 2040s, 2050s and 2080s. The fertilizer rates (N:P:K, kg ha^{-1}) are: N0 for 0:0:0, N33 for 33:23:30, N50 for 50:23:30, N100 for 100:23:30, N150 for 150:23:30, N200 for 200:23:30.

tilizer F2 to a 21% decrease in the 2080s at fertilizer N100 (Fig. 2b).

Under the RCP8.5 scenario, rice yields for Sen Pidao decreased with climate change for all combinations of variables (Fig. 3a). The simulated declines in yields were up to 59% in the 2080s (N33). The yields in the 2080s were generally much lower than the baseline. For the Phka Romduol cultivar, the relative changes in yields in the 2040s and 2050s were much less than for Sen Pidao, while the changes in yields in the 2080s were much larger than in other years (Fig. 3b). These results can be explained by considering that temperature was the largest contribution to decreases in rice yields in Cambodia (Li *et al.*, 2017). Li *et al.* (2017) reported that the contribution of temperature to rice yield changes account for approximately 64.7%. Chun *et al.* (2016) reported that approximately 4.5℃ of temperature was projected to increase in the 2080s. The ADB (2009) projected that temperature would increase by 4.8 ℃ by 2100 for the Southeast Asia region. In some cases, yields were projected to slightly increase in the 2040s at N0 and N33 fertilizer levels.

3.2 Changing Planting Date

Under the RCP4.5 scenario, yields decreased as the planting date was moved to earlier in the year and increased for a planting date somewhat later, depending on the fertilization rate, cultivar and simulated year (Fig. 4). For example, in the 2040s at fertilizer N0, the highest yields for Sen Pidao were achieved by planting on DOY 229, resulting in a 12.7% increase relative to the baseline years (1991~2000), while at fertilizer N200, the highest yields were achieved by planting on DOY 242, with a 41.4% increase (Fig. 4a). However, for Phka Rumduol, the highest yields in the 2040s at fertilizer N0 were achieved by planting on DOY 198, which is an increase of only 3.9%; the highest yield for fertilizer N200 was at DOY 228, which represents a yield increase of 13.3% (Fig. 4d).

Under the RCP8.5 scenario, yields increase as the planting

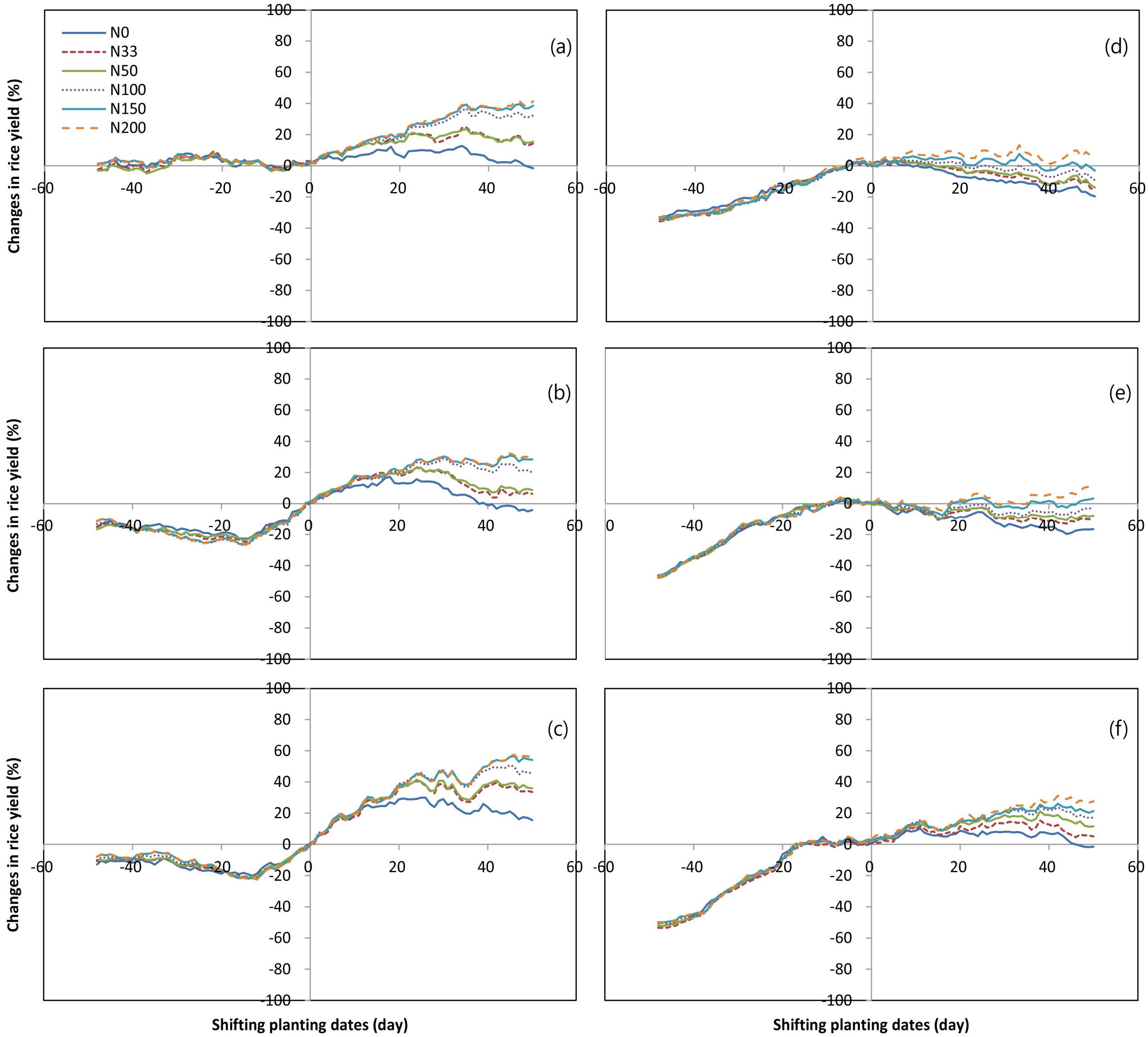

Fig. 4. Changes in simulated mean rice yields (%) for the Sen Pidao (a~c) and Phka Rumduol (d~f) cultivars under the RCP4.5 climate scenario at 6 different fertilizer rates with shifting planting date (a shift from the actual planting date in 2011 of 48 days before and 50 days after, respectively, at an interval of 1 day). (a) and (d): the 2040s, (b) and (e): the 2050s, and (c) and (f): the 2080s. The fertilizer rates (N:P:K, kg ha^{-1}) are: N0 for 0:0:0, N33 for 33:23:30, N50 for 50:23:30, N100 for 100:23:30, N150 for 150:23:30, N200 for 200:23:30.

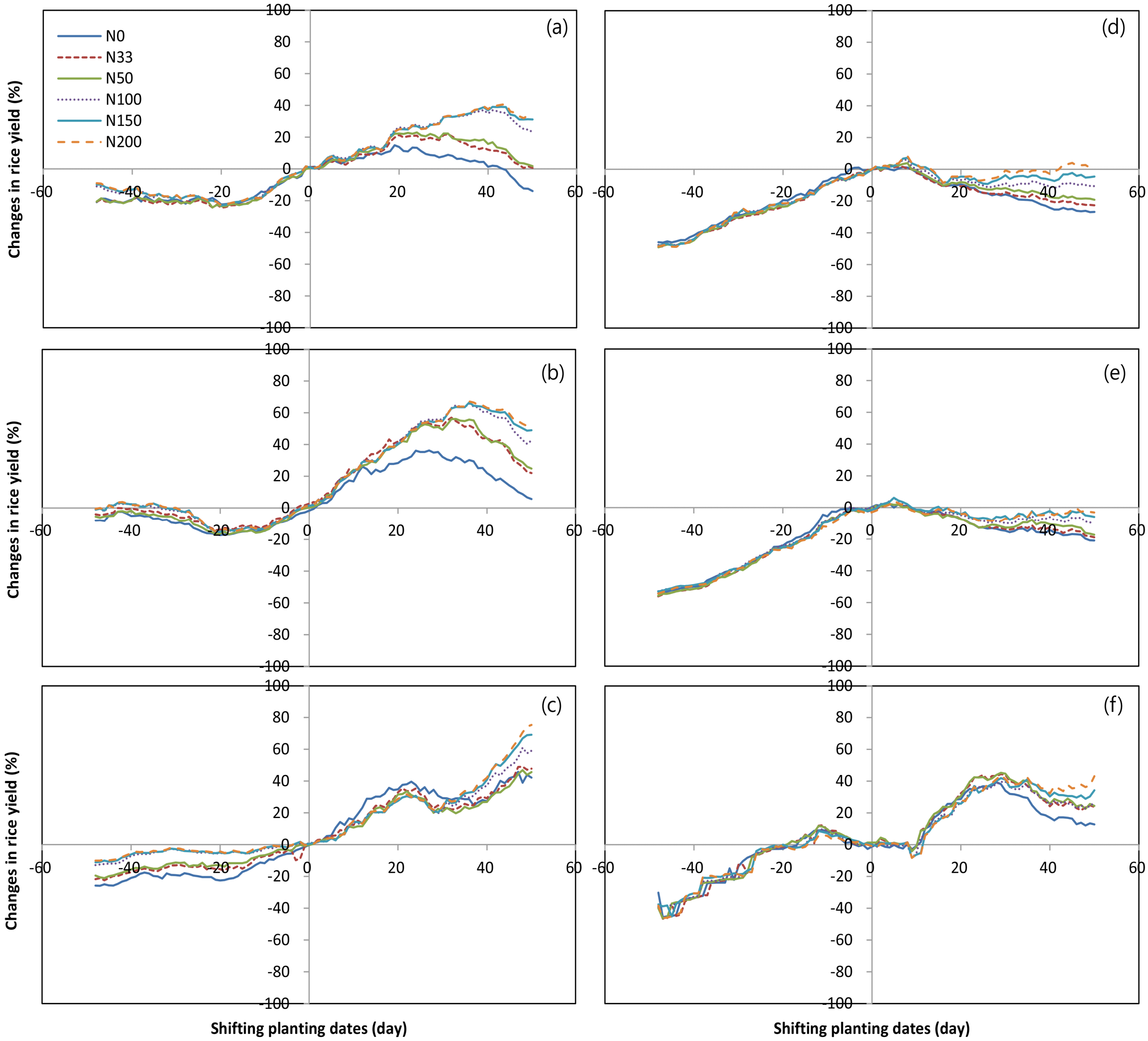

Fig. 5. Changes in simulated mean rice yields (%) for the Sen Pidao (a~c) and Phka Rumduol (d~f) cultivars under the RCP8.5 climate scenario at 6 different fertilizer rates rates with shifting planting date (a shift from the actual planting date in 2011 of 48 days before and 50 days after, respectively, at an interval of 1 day). (a) and (d): the 2040s, (b) and (e): the 2050s, and (c) and (f): the 2080s. The fertilizer rates (N:P:K, kg ha^{-1}) are: N0 for 0:0:0, N33 for 33:23:30, N50 for 50:23:30, N100 for 100:23:30, N150 for 150:23:30, N200 for 200:23:30.

date is shifted to later in the season (Fig. 5). Yields for Sen Pidao under the RCP8.5 scenario varied with planting dates and had more clear peaks except for the 2080S than under the RCP4.5 scenario. At the highest fertilization levels, yields were the more sensitive to the planting date. In the 2040s, yields increased by 15% when the planting date was shifted to DOY 214 at fertilizer N0, and increased to 40.9% when the planting date was shifted to DOY 239 at fertilizer N200 (Fig. 5a). In the 2080s (Fig. 5c), the trends of changes in rice yields were different from the other two (i.e., the 2040s and 2050s). Changes in rice yields showed a tendency to increase as a result of shifting the planting date. For Phka Rumduol, the variations in yields were less sensitive to shifting the planting date compared with Sen Pidao (Fig. 5a to c). In the 2040s, the highest yields for Phka Rumduol only increased by 1.3% at fertilizer N0 and by 8.4% at fertilizer N200 (Fig. 5d).

Many studies have shown that adjusting the planting dates for rice cultivation will be helpful for improving rice yields under the effects of climate change (e.g., Azdawiyah *et al.*, 2015; Chun *et al.*, 2016; Dharmarathna *et al.*, 2014; Li *et al.*, 2017). By changing the planting date, plant development stages are shifted, which suggests that rice plants may grow under a more appropriate temperature range and/or sufficient solar radiation for grain-filling; therefore, shifting the rice planting date following climate change can allow for rice plants to be subjected to more optimal conditions during the plant development stages.

3.3 Combination of Planting Date and Nitrogen Fertilizer Level

We investigated the effects of the combinations of nitrogen fertilizer level and planting date on rice yields under climate change. We assumed that the managements in the baseline years (i.e., the recommended nitrogen fertilizer, 50 kg N ha^{-1} and the planting date, DOY 195) were applied in the future periods. The simulated rice yields under the two emission scenarios at 6 different fertilizer rates with shifting planting date (a shift from the actual planting date in 2011 of 48 days before and 50 days after, respectively, at an interval of 1 day) were then compared with those under climate change at N50 (50 kg N ha^{-1}, there commended nitrogen fertilizer application rate in Cambodia) (Seng *et al.*, 2001) and the planting date in the base line years (i.e., DOY 195). Changes in rice yields (%) are presented in Fig. 6 and Fig. 7 under RCP4.5 and RCP8.5, respectively.

For the Sen Pidao under RCP 4.5 at N100 (the cost-effective fertilizer rate, 100 kg N ha^{-1}), the highest increases were simulated when rice plants would be planted 30 to 45 days after the baseline planting date. However, for the Phka Rumduol cultivar under RCP 4.5 at N100, the highest increases were simulated when short shifts (7 days before and after) of planting date were made than for the Sen Pidao. For the Sen Pidao under RCP 4.5 at N100, the highest increase in rice yields (58.1%) was simulated on DOY 230 (i.e., 35 days after the baseline planting date) in the 2040s, while the highest increase (85.4%) was simulated on DOY 240 in the 2080s (Fig. 6a and c). For the Phka Rumduol cultivar under RCP 4.5 at N100, rice yields in the 2040s were simulated to increase by 30.2% when rice plants would be planted 7 days after the baseline planting date, while the highest increase in the 2050s was simulated when rice plants would be planted 7 days before the baseline planting date. Similar results were found in those under RCP 8.5 at N100 (Fig. 7). The highest increases for San Pidao were simulated when longer than a month shifts (36 to 48 days) of planting date were made (Fig. 7a to c). In contrast, for Phka Rumduol, about a week shifts of planting date were found to highest increase rice yields in the 2040s and 2050s. These results indicate that forward shifts of planting date from the baseline plating date for the Cambodian rice cultivars in the future can be more benefitted than backward shifts. These results are in good agreement with those of Li *et al.* (2017) and Dharmarathna *et al.* (2014). They reported that the CERES-Rice model simulated to increase rice yields in Sri Lanka under both A2 and B2 scenarios with advancing the rice planting date by 1 month. Jalota *et al.* (2013) reported that several climate variables including temperature, CO_2, rainfall, solar radiation, relative humidity, etc. compositionally contribute to the determination of the crop yield. Therefore, substantial investigation and analysis might be required to explain the yield response to climate variability. A further study on this is recommended.

4. CONCLUSIONS

Compared with the baseline, the effects of climate change on the yields of two cultivars (Sen Pidao and Phka Rumduol) under the RCP4.5 and RCP8.5 climate scenarios for the periods 2041~2060, and 2081~2090, suggested that the yields of Sen Pidao rice will decrease, while the yields of Phka Rumduol rice could increase or decrease, depending on fertilization rates, and period that was simulated. The simulations of various adaptation strategies showed that changing the planting date may increase yields and reduce the negative impacts of climate change, depending on the cultivar and fertilization rates. In general, the variations in the simulated effects of climate change on yields were more sensitive at fertilizer N100, N150, and N200 and less sensitive at fertilizer N0, N33, and N50. These

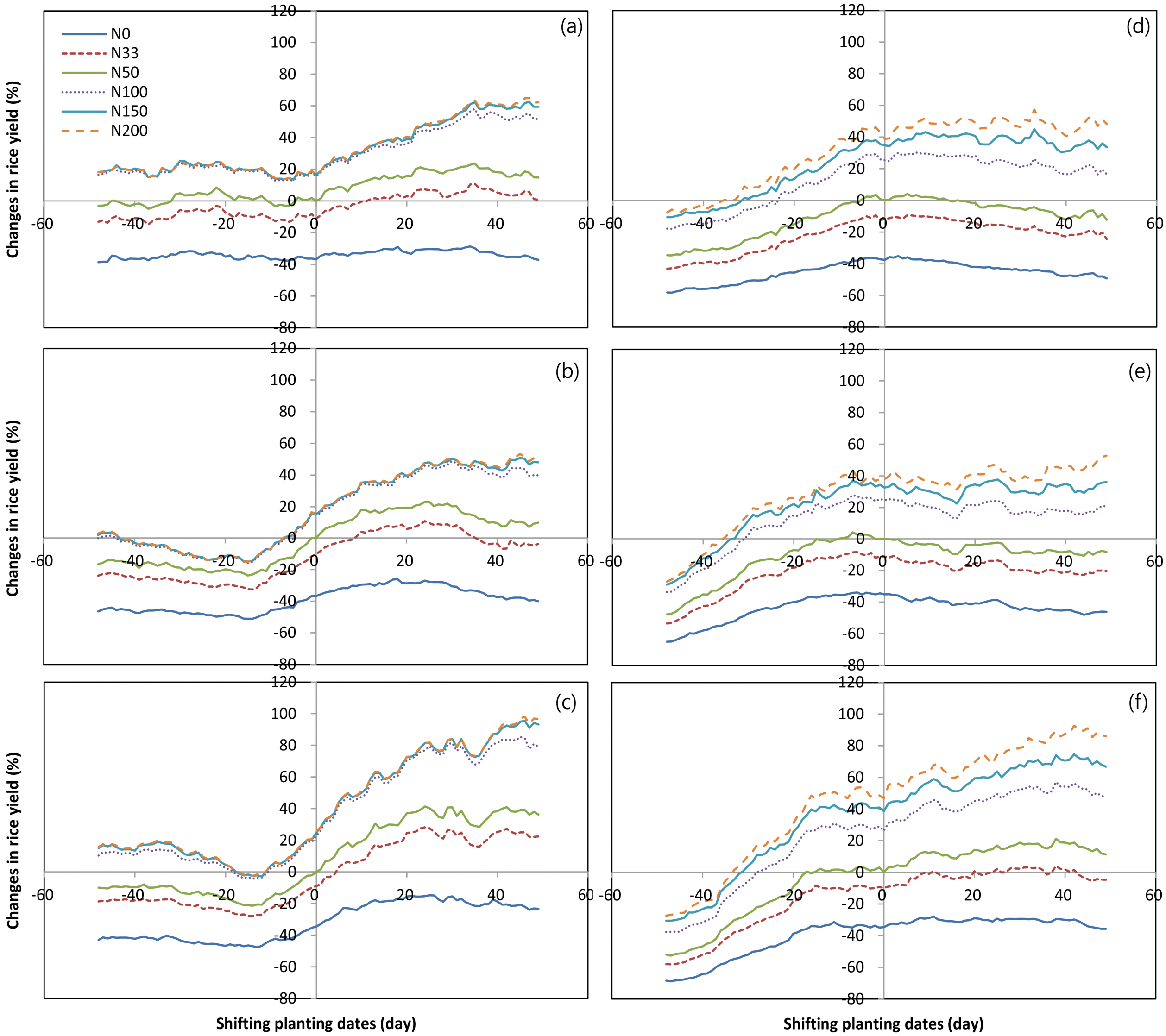

Fig. 6. Changes in simulated mean rice yields (%) relative to yields with no shifting the planning date and N50 for the Sen Pidao (a~c) and Phka Rumduol (d~f) cultivars under the RCP4.5 climate scenario at 6 different fertilizer rates with shifting planting date (a shift from the actual planting date in 2011 of 48 days before and 50 days after, respectively, at an interval of 1 day). (a) and (d): the 2040s, (b) and (e): the 2050s, and (c) and (f): the 2080s. The fertilizer rates (N:P:K, kg ha^{-1}) are: N0 for 0:0:0, N33 for 33:23:30, N50 for 50:23:30, N100 for 100:23:30, N150 for 150:23:30, N200 for 200:23:30.

simulation results are expected to help the Cambodian agricultural sector properly anticipate the effects of climate change and adopt appropriate management practices to maximize rice production. Forward shifts of planting date from the baseline plating date for the two rice cultivars are recommended in the future. However, it should be noted that even though the planting date adjustment is a low-cost adaptation strategy to climate change, training or educational programs may be required for farmers to adopt this strategy because they generally may prefer the conventional planting dates. It is also concluded that the DSSAT/CERES-Rice model can be useful as a decision-supporting tool for rice production in Cambodia. However, it should be noted that the adaptive options simulated for a specific rice cultivar under a specific future climate scenario in

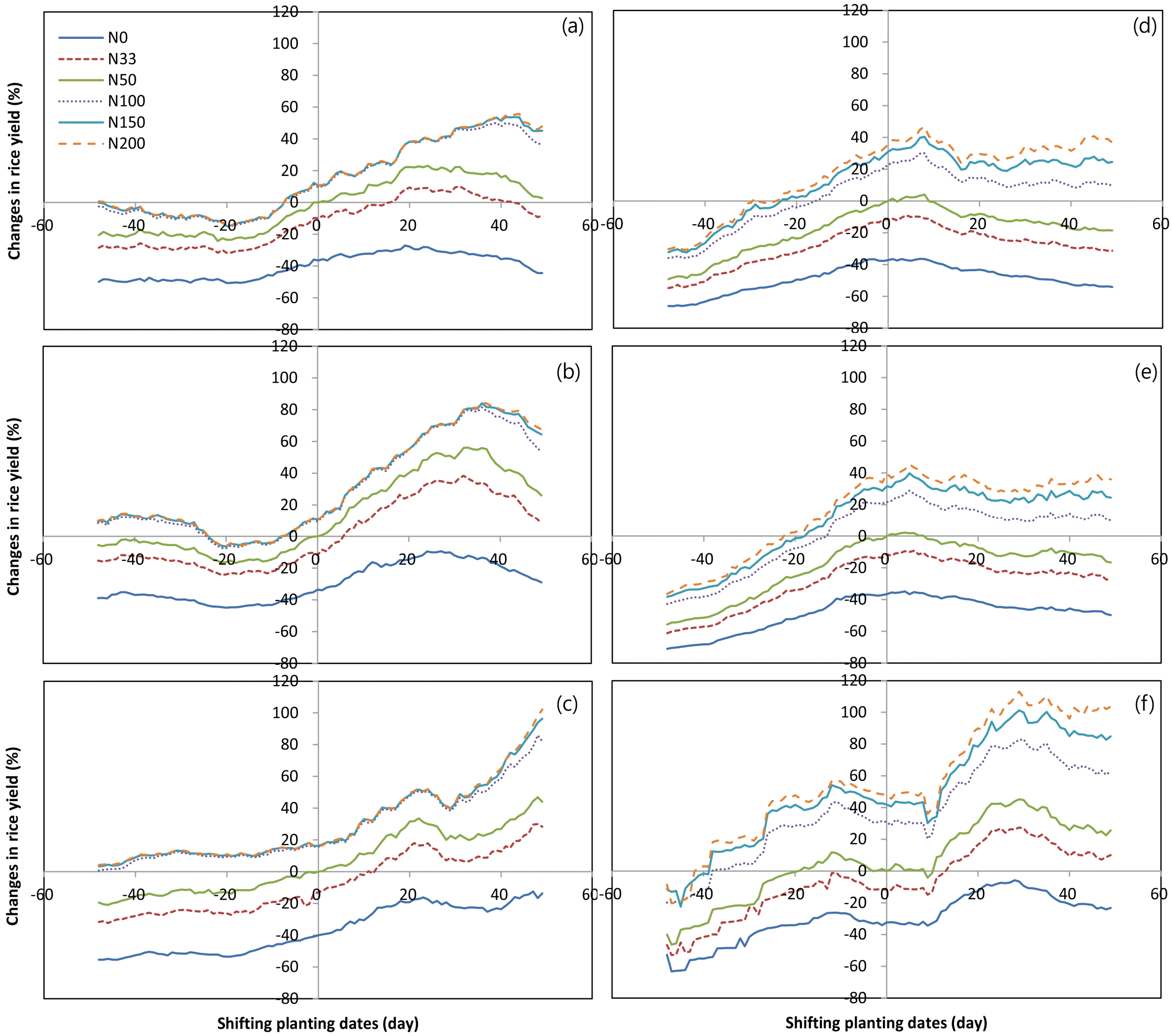

Fig. 7. Changes in simulated mean rice yields (%) relative to yields with no shifting the planning date and N50 for the Sen Pidao (a~c) and Phka Rumduol (d~f) cultivars under the RCP8.5 climate scenario at 6 different fertilizer rates with shifting planting date (a shift from the actual planting date in 2011 of 48 days before and 50 days after, respectively, at an interval of 1 day). (a) and (d): the 2040s, (b) and (e): the 2050s, and (c) and (f): the 2080s. The fertilizer rates (N:P:K, kg ha^{-1}) are: N0 for 0:0:0, N33 for 33:23:30, N50 for 50:23:30, N100 for 100:23:30, N150 for 150:23:30, N200 for 200:23:30.

a specific location may not be suitable for other future climate scenarios and/or other cultivars at a different location.

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