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Irrigation water requirement of rice in Long Xuyen Quadrangle area, Vietnam in the context of climate change

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ABSTRACT

Climate variability is deeply affecting all aspects of human life including agricultural sector.In the present study the CROPWAT model was used to estimate reference evapotranspiration (ETo), crop evapotranspiration (ETc), effective rainfall (ER) and crop water requirement (CWR) of summer-autumn rice crop and its yield during baseline period (2002-2017) and also under representative concentration pathways (RCPs) 4.5 scenario for 2020s, 2055s and 2090s-time scales for Long Xuyen Quadrangle (LXQ) area of Vietnam. It was found that the ER significantly increased by 6.2, 16.9 and 15.4 per cent, respectively in 2020, 2055 and 2090; ETo and ETc increased by 2.1 and 2.3 per cent, respectively in 2020s; 4.4 and 5.8 in 2055; and 5.8 and 7.7 per cent in 2090 compared to baseline. The CWR also increased approximately 4.6, 4.4 and 3.5 per cent, respectively in 2020, 2055 and 2090 and consequent decrease in rice yield by 6.5, 7.9 and 10.4 per cent, respectively. Results showed that if the crop planting date is delayed by 20 days, the rice yield would increase approximately 4.9, 7.9 and 9.9 per cent, respectively in three-time scales of RCP 4.5 scenario, compared to base line period.

Keywords : Irrigation, crop calendar, climate change, rice yield, water requirement

Long Xuyen Quadrangle is known as a key agricultural area of the Mekong Delta of Vietnam (MDV) with total annual rice production of about 5 million tons and contributes significantly to helping Vietnam maintain its position among the world's top rice exporters. However, in recent years, rice production is a growing challenge with salinity intrusion and drought due to the impact of climate change (Deb *et al.* 2015). MNRE (2016) reported that the temperature in the MDV can increase approximately 1.3-1.4°C and precipitation will also increase by 4.7-14.1 per cent corresponding to RCP4.5 scenario. Studies on reference evapotranspiration (ETo), crop evapotranspiration (ETc), effective rainfall (ER) and CWR have been conducted different regions of the world. The crop simulation models have been used to integrate ETo, ETc, and CWR with growth and yield of different crops (Pramod *et al.* 2018; Mehta and Pandey 2016). Kim *et al.* (2013) used the CERES model to estimate rice yield under the climate change scenario for east Asian area.Deb *et al.* (2015) used Aquacrop model to study effect of brackish irrigation water on rice productivity in Ca Mau province, Vietnam. The results pointed out that a decline in rice yield of approximately 1.6 to 23.7 per cent by 2085s relative to baseline climate condition for A2 emissions scenario in the case of the summer-autumn cropping season. Shifting of planting dates were found to be beneficial to enhance the rice yield under climate change. Dharmarathna *et al.* (2014) also suggested shifting of planting date as a climate change adaptation strategy for rice production in Kurunegala district of Sri Lanka.Candradijaya *et al.* (2014) used CROPWAT model to assess the effect of climate change on rice yield and suggested the adaptation strategies as shifting planting dates and irrigating schedule. They reported that the yield reduction is sensitive to variation in the planting date and irrigation scheduling.

MATERIALS AND METHODS

Study area

The study area is concentrated to coastal plains of Long Xuyen Quadrangle (LXQ) area of Vietnam stretching from 09°57'-10°42'N and 104°29'-105°29'E (Fig.1) with 85 per cent of rice cultivation area (MNRE 2016). The terrain is lowered from east to west and north to south with an average elevation of approximately 0.25-2.0 m above sea level. The

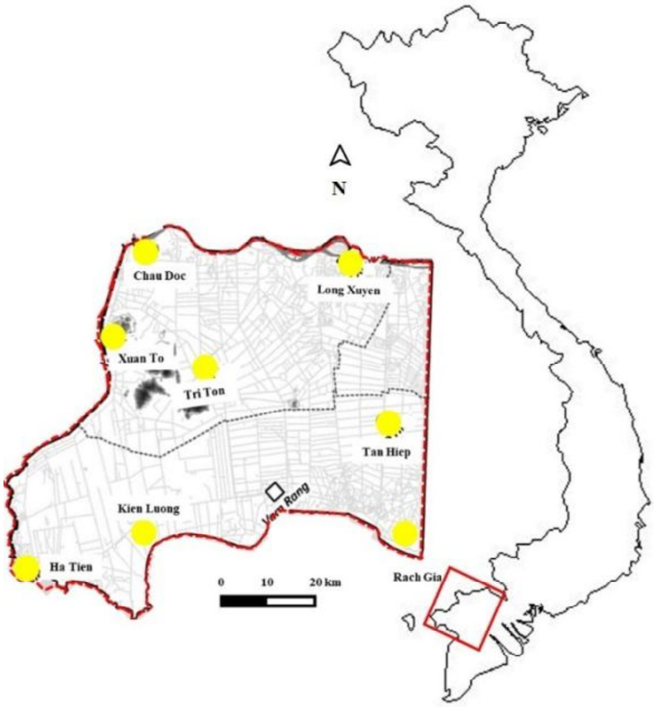

Fig. 1: The Long Xuyen Quadrangle (LXQ) area of Vietnam with rain gauge stations marked by the yellow circles

study area is covered by an irrigation canals system that brought fresh water from the Hauriver which is one of the two major tributaries of the Mekong Delta of Vietnam (MDV). The area lies in the tropical monsoon climate with two rainy and dry seasons with air temperature varying in the range of 25 to 29°C. Mean annual precipitation is in the range of 1268.5 to 2643.5 mm (Table 1) with 85 per cent of precipitation concentrated in rainy season (May-November) and rest 15 per cent distributed in the dry season (December-April).

Estimation of crop water requirement

CROPWAT model (Version 8.0) FAO (2016) was used for calculating the ETo as,

$$ET_O = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s -}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

Where: R_n is the net radiation at the soil surface ($MJm^{-2}day^{-1}$); G is soil heat flux density ($MJm^{-2}day^{-1}$); T is mean daily air temperature (°C); u_2 is wind speed at 2.0 m height (ms^{-1}); e_s is the saturation vapor pressure (kPa); e_a is actual vapor pressure (kPa); Δ is the slope of the vapor pressure curve (kPa°C^{-1}); γ is psychrometric constant (kPa°C^{-1})

The crop water requirement (CWR)was determined as the product of ETo and the crop coefficient (Kc):

$$ET_C = ET_O * K_C \qquad (2)$$

The effective rainfall (ER) is defined as the precipitation which is effectively consumed by the plants after subtracted percolation and flow surface and calculated following (Deb *et al.* 2015).

$$ER = \text{Pmonth}\ \frac{125 - 0.2 \times \text{Pmonth}}{125}\ \ for\ Pmonth \le \frac{250}{m} \qquad (3)$$

$$ER = 125 + 0.1 \times \text{Pmonth} \qquad for\ Pmonth > \frac{250}{m} \qquad (4)$$

Where P *month* is the total monthly rainfall (mm)

Crop water requirement (CWR) has close relationship with the amount of water that needs to be supplied to crops, while ETc relates to the amount of water that is lost through the process of evapotranspiration (APN 2010). CWR was calculated as;

$$CWR_i = \sum_{i=0}^{n} (K_{Ci} \times ET_O - E \qquad (5)$$

The irrigation water deficiency was estimated by changing the relative yield or the relative evapotranspiration (ETa/ETm) through a yield response factor (Ky).

$$Ky = \frac{(1 - \frac{Ya}{Ym})}{(1 - \frac{ETa}{ETm})} \qquad (6)$$

Where: Ya is the actual yield, Ym is the maximum yield, ETa is the actual evapotranspiration and ETm is the maximum evapotranspiration

Climatic data

The input climatic data on temperature, humidity, wind speed, solar radiation, sunshine duration and precipitation were obtained from the Southern Regional Hydro-meteorological Center of Vietnam (SRHCV) for the period of 11 years (2007-2017). The mean monthly climatic data are presented in Fig.2.

Future precipitation and temperature data corresponding to time scales 2016-2035 (2020s), 2046-2065 (2055s) and 2080-2099 (2090s) of RCP4.5 scenario (constructed by Vietnam's Ministry of Natural Resources and Environment) were used to estimate the rice yield in the future. Under RCP 4.5 scenario, the temperature and precipitation increased up to a maximum value of 0.7°C-1.9°C and 4.7-14.1 per cent, respectively during future time scales (Fig.3 and Table 2).

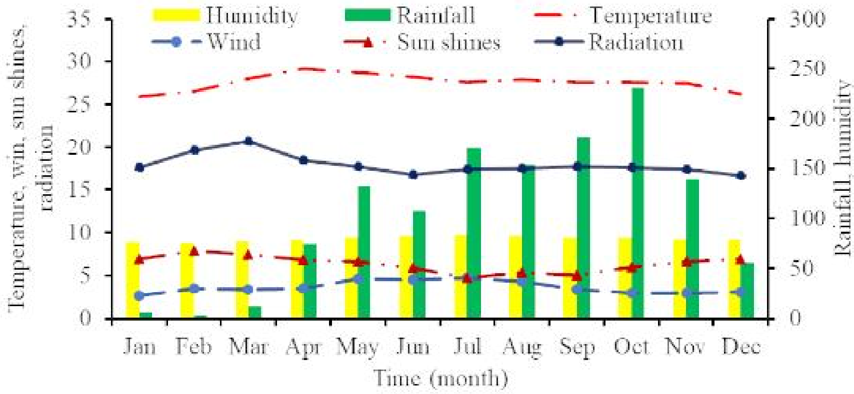

Fig. 2: The mean climatic data of Mekong delta of Vietnam for the period 2007-2017

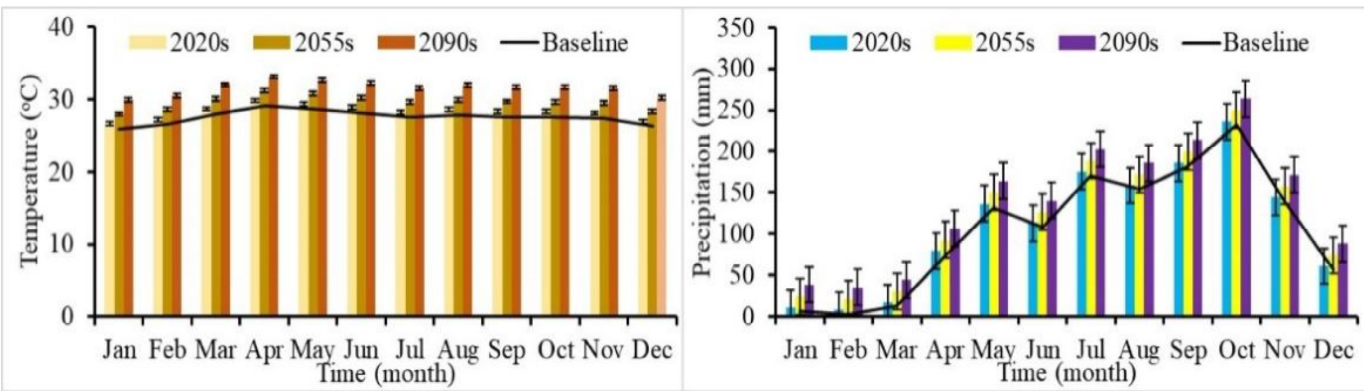

Fig. 3: Changes in temperature and precipitation for time scales of RCP4.5 scenario and standard error bars

Table 1: Description of mean annual precipitation and standard deviation (SD)

Station	Annual precipitation (mm)	SD (mm)	Latitude (N)	Longitude (E)
Chau Doc	1268.5	72.2	10°42’	105°08’
Tri Ton	1421.9	85.0	10°23'	104°59
Xuan To	1467.9	84.7	10°35'	104°56
Long Xuyen	1536.2	93.8	10°22’	105°25'
Tan Hiep	1568.7	93.0	10°06'	105°16'
Ha Tien	2643.5	133.4	10°23’	104°29’
Kien Luong	2172.8	133.8	10°18’	104°38'
RachGia	2144.9	122.8	10° 01'	105° 05'

Table 2: Future change scenarios of temperature and precipitation in the study area

Baseline (2007-2017)	Future time	RCP4.5 scenario	Change
Mean temperature 27.6°C	2020s	28.3±0.8	0.7°C
	2055s	29.1±1.5	1.4°C
	2090s	29.5±2.0	1.9°C
Precipitation 1268.5mm	2020s	1326.2±4.5	4.7%
	2055s	1440.4±13.5	13.1%
	2090s	1447.4±13.8	14.1%

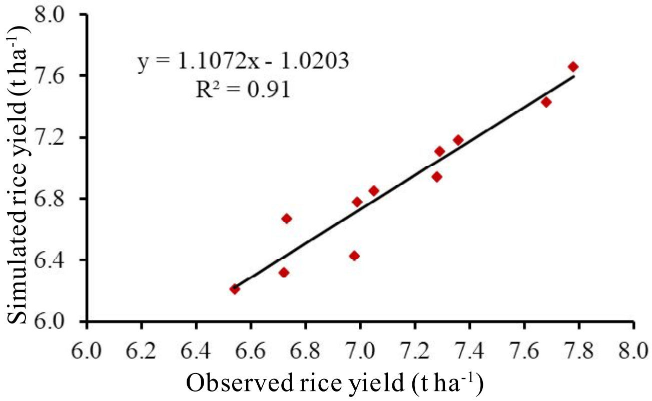

Fig. 4: Simulated and observed rice yield from CROPWAT model

Table 3: Characteristics of IR6976 rice cultivated in the study area

Parameter	Value / description
Days to maturity	90–105
Plant height (cm)	80–95
Length of panicle (cm)	6.8
Grain type	Long-grain rice
Grain form	Regular-milled white rice
Yield (t ha^{-1})	5.5-8.0

Crop data

The farmers grow IR6976 variety of rice in 93 per cent of the area while in 7 per cent other rice varieties such as IR50404, OM4900 and OM9582 are grown (Deb *et al.* 2015). This IR6976 variety has a mean growing cycle of 100 days from sowing till harvesting depending on the specific cropping season. Its general characteristics are provided in Table 3. The length of growth stages, crop coefficient (Kc) and yield response coefficient (Ky) are presented in Table 4.

The soil characteristics show that soil is mostly silly-clay mix clay which is predominantly acidic (pH = 4.0) and hence, has high potentials for retaining plant nutrients (Table 5).

Calibration of the model

Calibration and performance estimation are very necessary for crop models when they are applied to a new area. In this work, simulation was run in CROPWAT model by changing the parameters default based on the historical climate data obtained from 2007-2017 to obtain the most suitable parameters. The model performance was evaluated by statistical methods namely coefficient of determination (R^2) and root mean square error (RMSE). The statistical indices R^2 and RMSE are widely applied to evaluate the model performance based on the agreement of the simulated results and observed data (Deb *et al.* 2015).

The model calibration showed that the simulated results are in good agreement with observed data (Fig.4) (R^2 0.91 and RMSE is less than 0.23) and the magnitude of R^2 and RMSE confirmed the satisfaction of evaluation criteria.

RESULTS AND DISCUSSION

ETo, ETc, ER, CWR and rice yield

The results showed that under RCP4 .5 scenario the ER increased by 6.2 per cent, 16.9 per cent and 15.4 per cent, respectively during 2020s, 2055s and 2090s while the ETo increased by 2.1, 4.4 and 5.8 per cent and the ETc increased by 3.3, 5.8 and 7.7 per cent,respectively(Table 6). The CWR also increased approximately by 4.6, 1.4 and 2.5 per cent corresponding to time scales of RCP 4.5 scenario.

The evaluation of rice yield under RCP 4.5 scenario compared to baseline condition showed a decrease by 6.5 per cent for 2020s, by 7.9 per cent for 2055s and by10.4 per cent for 2090s (Table 6). A similar study carried out by Soora *et al.* (2013) showed that climate change is likely to reduce rice yields by approximately 4.0, 7.0 and 10.0 per cent, respectively for time scales 2020s, 2050s and 2080s of climate scenarios. The rice yield reduction in the other area of MDV reported by Deb *et al.* (2015) showed that the decline in rice yield of summer-autumn crop was ranging from 1.6 to 23.7 per cent for 2085s compared to baseline.

Mitigation strategies: Shifting crop planting date

In this regard, it is necessary to find the solution to improve the current water conditions for summer-autumn crop to adapt to the changed patterns of precipitation and temperature in the future and optimally improve crop yield by shifting the planting dates.

The variation of CWR and rice yield under the impact of climate change was assessed through the shift of the planting date under different time scales of RCP 4.5 scenario (Table 7).

Simulation results showed that crop water requirement decreased significantly after planting date is late shifted 20 days and results observed that crop water requirement decreased by 8.2 per cent (2020s), 9.0 per cent (2055s) and 9.0 per cent for 2090s.

Similarly, simulation results showed that rice yield

Table 4: Length of crop growth stage and emp. coefficient of rice.

Indicators	Land Preparation	Initial Stage	Developmental Stage	Late Stage
Length of growth stage (day)	10	10	60	25
Crop coefficient (K_C)	1.05	1.24	1.72	1.13
Yield response coefficient (Ky)	1.00	1.09	1.32	0.50

Table 5: Relevant soil characteristics

Soil description	Values
Maximum rain infiltration rate (mm/day)	40
Plowing depth (cm)	20
Maximum water depth (cm)	20
Water availability at planting (mm)	1.5
Maximum rooting depth (cm)	90
Maximum percolation rate after puddling (mm/day)	40
Critical depletion for puddle cracking (mm)	10.4
Drainable porosity	13
Initial soil moisture depletion (%)	50
Initial available soil moisture (mm/m)	130
Total available soil moisture (mm/m)	120

Table 6: Change of ETo, ETc, ER, CWR and rice yield under the impacts of climate change

Factors	Baseline	2020s	Change (%)	2055s	Change (%)	2090s	Change (%)
ETo (mm)	420.5	429.4	+2.1	437.6	+4.4	442.7	5.8
ETc (mm)	709.8	733.3	+3.3	750.8	+5.8	764.6	+7.7
ER (mm)	318.7	338.6	+6.2	372.8	+16.9	367.7	+15.4
CWR (mm)	571.3	608.9	+6.6	596.2	+4.4	591.4	+3.5
Rice yield (t ha^{-1})	7.1	6.6	-6.5	6.5	-7.9	6.4	-10.4

Table 7: Change in crop water requirement and rice yield after the shifted planting dates

Change in planting date	Change in crop water requirement (%)			Change in rice yield (%)		
(days)	2020s	2055s	2090s	2020s	2055s	2090s
Early						
-20	16.1	17.3	17.2	-2.7	-3.7	-6.9
-15	13.1	14.2	14.1	-2.0	-2.7	-5.3
-10	8.0	8.8	8.8	-1.3	-1.8	-3.7
-5	5.1	5.4	5.4	-0.7	-0.9	-1.9
Late						
5	-0.4	-0.7	-0.7	0.9	1.9	2.1
10	-4.5	-5.4	-5.4	2.4	4.7	6.1
15	-7.9	-8.8	-8.9	3.6	6.3	8.0
20	-8.2	-9.0	-9.0	4.9	7.9	9.9

changed considerably after the planting date is changed. Specifically, a late shift of the crop planting is also observed to enhance the rice yield and the maximum rice yield is achieved when the planting date is late shifted by 20 days compared to current planting date, rice yield increased approximately by 4.9, 7.9 and 9.9 per cent, respectively for 2020s, 2055s and 2090s.

Research limitations

In this work, only precipitation and temperature data are changed corresponding to time scales of RCP 4.5 scenario. Other input data namely solar radiation, sunshine, wind speed and soil characteristics were assumed to be the same as that of the current climate condition. In addition, fertilizer application rate, soil data and other nutrients were also assumed to be unchanged. They, therefore, are not guaranteed to represent the real status of the study area for the future climate conditions.

CONCLUSION

It was found that under the impact of climate change ETo and ETc were increased leading to increase in crop water requirement, which ultimately resulted in rice yield reduction for time scales of RCP 4.5 scenario. The results show that rice yield is very sensitive to the shift of planting date and crop water requirement. The study on the shift of the planting date can help to reduce the risk of crop failure and offset the crop yield reduction caused by climate change. However, the rice yield increases by shifting planting date under climate change scenario need to combine withthe other solutions such as fertilizer application rate and crop protection to enable realization of potential yield increases. This study further strengthens our knowledge for the impact of global climate changes on local agricultural activities to better adapt to climate change challenges.

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Competing interests

The authors declare that they have no competing interests.

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