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Research article

Utilizing rainfed supply and irrigation as a climate variability adaptation solution for coastal lowland areas in Vietnam

Dang Truong An[a], Nguyen Van Hong[b,*], Mai Phuong Ngoc[c]

[a] *University of Science, Vietnam National University, Ho Chi Minh 70000, Vietnam*
[b] *Sub-Institute of Hydrometeorology and climate change,* Ho Chi Minh *70000, Vietnam*
[c] *School of Social Sciences Education, Vinh University, Nghe An 70000, Vietnam*

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Abstract

Globally, the agricultural sector continues to be affected by the impacts of climate variability. Lowland regions have frequent drought and saline intrusion, leading to irrigation water deficits as a part of climate variability. This study focused on determining the rainfed use efficiency (RUE) and further establishing a crop cultivation calendar (CCC) for rice paddies across Kien Giang province, Vietnam. The crop yield was simulated in response to the relevant environmental factors based on a crop model. The model performance was appraised using calibration and validation procedures and was considered suitable based on good values for statistical indicators (index of agreement = 0.74–0.89, coefficient of determination = 0.73–0.92 and root mean square error approximately 11–20%). The results indicated that the rainfed use efficiency and crop yield of rice planting seasons notably improved when the CPC (baseline) was altered, specifically, when the first cropping season was around the first week of November, which increased RUE (14.2–17.9%) and the crop yield (1.5–5.9%) at three experimental locations, while the second cropping season in the fourth week of March decreased RUE by 8.8–10.9% and increased the crop yield by up to 6.9 t/ha. An alteration in the CCC of rice paddies across the study area accounted for relevant environmental factors and produced an effective adaptation solution.

Introduction

In recent decades, agricultural production around the world has been facing challenges from adverse cultivation conditions such as drought, heatwaves and saline intrusion as a consequence of climate variability, leading to irrigation water deficits (IWDs) (Abbas and Mayo, 2020). Climate variability increases the frequency and intensity of drought and saline intrusions and has seriously affected all aspects of people's lives, especially in the agricultural sector (Intergovernmental Panel on Climate Change, 2014). Research Centers in Southeast Asia (2016) reported that climate variability is one of

* Corresponding author.
E-mail address: nguyenvanhong79@gmail.com (N.V. Hong)

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the main challenges to human well-being in the 21st century. A report by the Vietnamese Ministry of Natural Resources and Environment showed that Kien Giang province is faced a lack of IWDs in lowland farming areas due to saline intrusion and drought events in 2016 (Dang, 2021; Lee and Dang, 2018). Approximately 86,200 ha of the rice area in Kien Giang province was affected by drought and salinity with total damage of approximately VND 2.35 billion during the drought stages of 2014–2016 (Asia Pacific Network, 2010).

In the context of IWDs for lowland agriculture due to the impacts of climate variability (ICV), studies on rainfed use efficiency (RUE) have been widely deployed around the world (Deryng et al., 2014; Bai and Xiao, 2020). For example, in South and Southeast Asia, Zeigler and Puckridge (1995) conducted a study on improving sustainable productivity in rainfed lowland rice. They reported that rice cultivation regions are suitable for the application of water-saving solutions (WSSs). In central-northern India, Bouman and Tuong (2001) deployed a study on WSSs for irrigating lowland rice and reported that irrigation water input reduced approximately 23% with a crop yield decrease of 6%. Belder et al. (2004) assessed the effectiveness of WSSs on lowland rice and indicated that using irrigation water could be reduced by up to 15% without affecting crop yield. Yang et al. (2007) established a WSS to increase crop yield in lowland paddies and their results identified a WSS with savings of 24.5% to 29.2% and increased rice yield of 7.4–11.3%. In the lower Mekong Basin, Mainuddin et al. (2013) implemented a study on the rainfed rice yield under future climate scenarios. Their results suggested that altering the CCC could lead to increased crop yield. In Vietnam, Deb et al. (2015) investigated the ICV on rice yield in the lowland paddies of Ca Mau province and their results indicated that altering the CCC enhanced the crop yield in the context of climate variability.

In recent years, the lowland rice paddies in Kien Giang province have been exposed regularly to the potential risks of climate change, leading to a decline in crop yield (Trang, 2016; Vu et al., 2018). Agricultural production has been strongly affected by climatic variables because the growth phases of rice cultivation crops are closely involved with meteorological factors (Asia Pacific Network, 2010; Nhan et al., 2011). Kien Giang is a coastal cultivation area where agricultural production is vulnerable to climate variability due to saline intrusion and drought, leading to a lack of IWDs.

In the context of water scarcity for lowland agriculture, applying short-duration rice varieties (Kima et al., 2014; Won et al., 2020), altering the CCC (Sacks et al., 2010; Ding, 2020) as well as WSS (Belder et al., 2004; Pascual and Wang, 2017; Hasan et al., 2019) are considered effective adaptation solutions and are broadly ongoing in many parts of the world (Arimi, 2014; Bai and Xiao, 2020). These practice solutions can help to reduce the negative ICV as well as contributing to maintaining crop yield and increasing profits.

Thus, the main objective of the current research focused on determining the RUE as well as establishing the CCC for lowland rice paddies across Kien Giang province based on the Aquacrop model of the Food and Agriculture Organization of the United Nations (FAO). This model was applied to detect the interactions between environmental factors for a typical case to highlight the role of environmental factors for irrigation activities as well as providing insight on links between CCC, RUE and crop yield.

Materials and Methods

Study area

Kien Giang province is located southwestern Vietnam, (9°23’50”N–10°32’30”N and 104°26’40”E–105°32’40”E), as shown in Fig. 1. Kien Giang province has diverse terrain with a long coastline and many islands, mountains and rivers, with the costal territory being relatively flat, with elevations in the range 0.5–2.5 m above mean sea level (Nhan et al., 2011; Son et al., 2014). The province has approximately 575.7 ha of agricultural land of which 354.0 ha is in rice production, accounting for 61.5% of the total agricultural land area (Trang, 2016). Rice production is commonly based on irrigation from the rivers combined with abundant rainfed supply (Mainuddin et al., 2013), where the rainfed use efficiency is considered as that part of the rainfall which is effectively utilized by the plants after subtracting lost rainfed volume due to runoff and percolation (Inthavong et al., 2014).

The climate in the province is affected from November to April by the northeast monsoon circulation in the dry season and from May to October by the southwest monsoon circulation in the wet season (Auffhammer et al., 2011; Nguyen et al., 2015). The area has a tropical monsoon climate, being hot and humid with an average annual rainfall up to 2,146 mm and an average annual temperature varying from 26.4°C to 28.0°C. In general, the climate has basic advantages as there are few natural disasters such as tropical depressions and abundant sunshine radiation, heat and rainfall (Table 1), so it is very favorable for many kinds of plants (Food and Agriculture Organization of the United Nations, 2016; Kontgis et al., 2019).

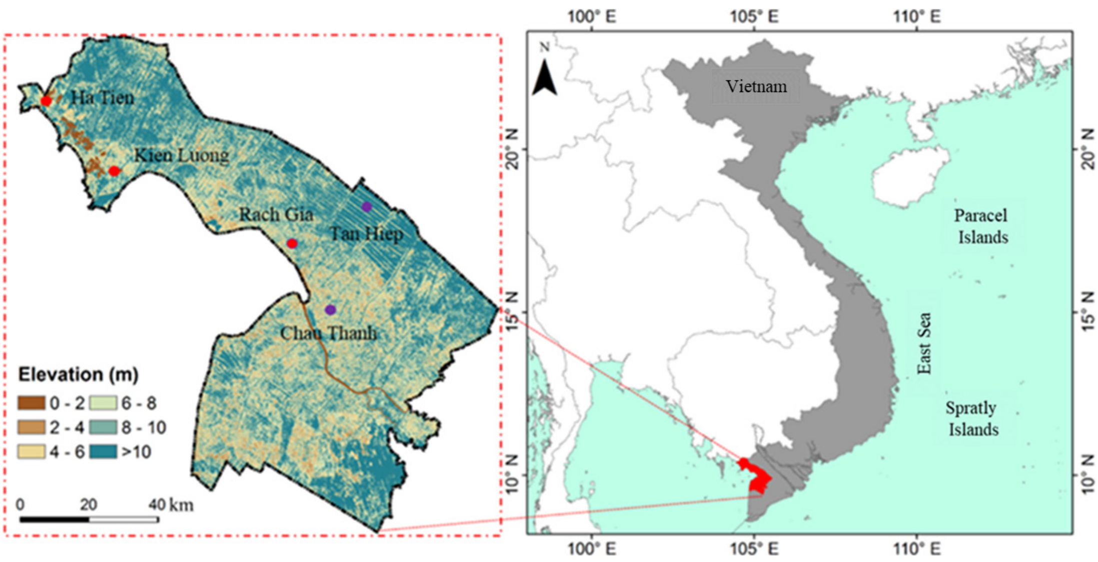

Fig. 1 Location of study area in southwestern Vietnam

Table 1 Features of annual average rainfall (AAR) and standard deviation (SD) at rainfall observation stations in study area

Station	AAR (mm)	SD (mm)	Latitude (N)	Longitude (E)
Ha Tien	2677	608.2	10°22’00	105°30’14”
Kien Luong	2687	118.6	10°18'12”	104°38'18”
Rach Gia	2127	356.2	10°01´18”	105°05´26”
Chau Thanh	2481	281.5	09°53’00”	105°11’17”
Tan Hiep	2835	776.8	10°06’55”	105°17’00”

Agricultural production activities

In the province, farmers commonly plant single, double or sometimes triple-cropped rice (Fig. 2A) depending on the topographical characteristics and the supply of irrigation water from the rivers to supplement the abundant local rainfed supply (Kontgis et al., 2019). Growing and harvesting periods of crops depend on local weather conditions and forecasts of saltwater intrusion (Fig. 2B). In general, the CCC of the first cropping season begins from the second week of November and the second cropping season starts from the third week of March, while the total cultivation area in the third cropping season is not substantial (Nguyen et al., 2015) and was not considered in this study.

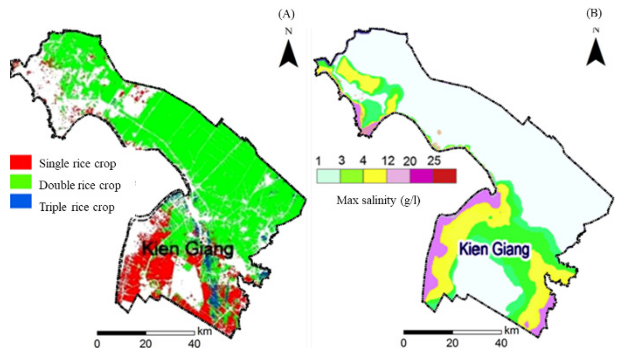

Fig. 2 Rice cultivation regions in the study area: (A) rice cultivation systems (Nguyen et al., 2015); (B) saline intrusion levels (Tran et al., 2019)

Model description

The AquaCrop model was developed by FAO for simulating attainable crop yield under different irrigation conditions based on full irrigation and rainfed, supplemental and deficit irrigation (Deb et al., 2015). The advantage of the AquaCrop model is that it requires a comparatively small number of parameters and intuitive input variables compared with other crop models (Ding et al., 2020) but still balances simplicity, accuracy and robustness (Shrestha et al., 2016). The model is easy to apply to practical problems based on integrating four modules based on climate, soil, crop and management (Greaves et al., 2016).

In the AquaCrop model, the yield response to water expresses the relationship between crop yield and water stress because of insufficient irrigation water (rainfed or irrigation) during the crop growing phases. Yield response to irrigation water is defined by Equation 1:

$$\left(1-\frac{Y}{Y_x}\right)=K_y\left(1-\frac{ET}{ET_x}\right) \quad (1)$$

where Y_x and Y are the maximum and actual crop yields, respectively, ETx and ET are the maximum and actual evapotranspiration levels, respectively, and K_y is the proportionality factor between relative crop yield decline and relative reduction in evapotranspiration. ET in Equation 1 is defined by Equation 2:

$$ET = E + Tr \quad (2)$$

where E is the soil evaporation and Tr is the crop transpiration and Tr is obtained by multiplying the evaporating power of the atmosphere by the crop transpiration coefficient (KcTr), water stress (Ks) and temperature stress (KsTr) as shown in Equation 3:

$$Tr = Ks * Ks_{Tr}(Kc_{Tr,x}CC^*)ET_o \quad (3)$$

where, Kc_{Tr} is calculated as shown in Equation 4:

$$Kc_{Tr} = Kc_{Tr,x}\,CC^* \quad (4)$$

where $Kc_{Tr,x}$ is the proportional factor that integrates all the effects of characteristics that distinguish the crop transpiration from the grass reference surface and CC* is the fractional canopy cover that is continuously adjusted to the simulated canopy development.

In Equation 3, reference evapotranspiration (ET_o) is defined using the FAO Penman-Monteith equation (Greaves et al., 2016) as shown in Equation 5:

$$ET_O = \frac{0.408\,\Delta\,(R_n-G)+\gamma\frac{900}{T+273}u_2(e_s-e_a)}{\Delta+\gamma(1+0.34u_2)} \quad (5)$$

where R_n is the radiation at the soil surface, G is the soil heat flux density, T is the average daily temperature, u_2 is the wind speed at 2.0 m height, e_s is the saturation vapour pressure, e_a is the actual vapour pressure, Δ is the slope of the vapour pressure curve and γ is the psychrometric constant.

The aboveground biomass production (B) of the crop cycle is defined by multiplying WP* by $\sum_i \frac{Tr_i}{ETo_i}$ fo for that day, as shown in Equation 6:

$$B = \mathrm{WP}^* \sum_i \frac{Tr_i}{ETo_i} \quad (6)$$

The crop yield (Y) is estimated as shown in Equation 7:

$$Y = f_{HI}\mathrm{HI} * \mathrm{B} \quad (7)$$

where fHI is a multiplier which considers the stresses that adjust the HI from its reference value. The adjustment of the HI to irrigation water deficits depends on the timing and extent of stress during the crop cycle (Steduto et al., 2012).

In the AquaCrop model, water use efficiency (WUE) is based on the relationship between crop yield and evapotranspiration (Steduto et al., 2012), as shown in Equation 8:

$$WUE = \frac{Yield}{Water\ evapotranspiration} \quad (8)$$

WUE is considered as an indicator to assess the performance of a system and it is applied to identify the management strategies. According to Steduto et al. (2012), WUE is useful under conditions of scarcity of water resources.

The procedure for simulating WUE and crop yield are illustrated in Fig. 3.

Meteorological and soil data collection

Semiautomatic weather stations (Fig. 1) belonging to the Southern Regional Hydrometeorological Center, Vietnam collected input data for the climate module based on: daily values of maximum (Tx) and minimum (Tn) air temperature, sunshine duration (SD), wind speed (WS) at 2 m height and relative humidity (RH) during 2011–2019 (Table 2). Daily reference evapotranspiration (ETo) was obtained by applying the Penman-Monteith equation.

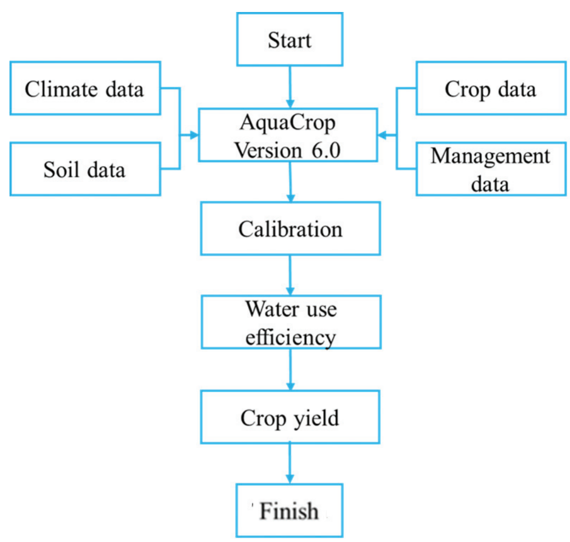

Fig. 3 Flow chart of AquaCrop model simulation

Table 2 Meteorological variables observed in study area for planting crop seasons

Year	Tn (°C)	Tx (°C)	TR (mm)	RH (%)	SD (hr/d)	WS (m/s)	ETo (mm/d)
2011	20.3	33.4	2418.8	83	6.5	2.8	5.3
2012	20.7	33.6	1941.5	80	6.3	2.9	5.8
2013	20.2	33.1	2299.2	81	6.4	3.1	5.6
2014	21.1	33.7	1941.7	79	6.9	2.8	5.7
2015	19.5	33.2	1528.6	78	7.1	2.6	5.9
2016	19.4	32.7	2268.4	80	7.2	2.5	5.5
2017	19.0	32.9	2499.5	82	6.7	2.9	5.4
2018	20.7	32.7	2561.3	82	6.5	2.7	5.1
2019	18.0	32.9	2434.6	81	6.9	3.1	5.2
Average	19.9	33.2	2210.4	80	6.7	2.8	5.3

Tn, Tx = minimum and maximum air temperature, respectively; TR = total rainfall; RH = relative humidity; SD = sunshine duration, WS = wind speed; ETo = reference evapotranspiration

The soil properties at the experimental locations were collected from field surveys and analyzed based on United States Department of Agriculture software (Gerakis and Baer, 2000; Saxton and Rawls, 2006). The results from the standard laboratory procedures for soil sample analysis were classified as silty clay loam to silt loam and the percentages of each soil are provided in Table 3. The average volumetric water content for a 0.6 m soil profile depth at saturation, field capacity (FC), total available soil moisture (FC-WP), total available water (TAW), permanent wilting points (PWP), hydraulic conductivity (K) and physicochemical properties (K^+, Na^+, Ca^{2+}, Mg^{2+} and pH) are presented in Table 3.

With the subtropical climate in the study area, rice was grown annually based on single-crop, double-crop rice paddies and a few areas of triple-crop rice paddies (Fig. 2A). In general, the CCC of the first cropping season was around 18–30 November and was harvested 20–28 February, while the second cropping season started 20–31 March and was harvested 20–25 June. The short-duration variety OM2517 was grown with 85 d to 95 d length for the growth cycle with the planting density varying from 160 kg/ha to 180 kg/ha, respectively. In addition, OM2517 is known as a high yielding variety, with good pest resistance and is planted widely in the area. Detailed information about the amount of irrigation, observed rainfed supply and fertilizer rates (N, P, K) are provided in Table 4.

Results and Discussion

Model performance assessment

Most studies apply calibration and validation procedures to appraise the performance of a model (Greaves and Wang, 2016; Dang, 2021). In the current study, as a first step, the calibration procedure was conducted to compare the simulated model and observed crop yield during the period 2000–2010 and the second step for validation was also carried out in the same way as the calibration procedure for the period 2011–2019. The calibration and validation procedures were evaluated based on the indication of the index of agreement (d), the coefficient of determination (R^2) and the root mean square error (RMSE), as presented in Dang (2021).

Table 3 Soil profile characteristic of soil samples in 0.6 m depth in the study area

Determination	Three investigated locations		
	Ha Tien	Kien Luong	Rach Gia
Sand (%)	22	28	24
Silt (%)	61	54	51
Clay (%)	27	18	25
Soil features	Silty clay loam	Silt loam	Silty clay loam
FC (% vol)	39	41	43
PWP (% vol)	24	15	17
K (mm/d)	15	2.0	2.7
K^+(ppm)	19	17	21
Na^+(ppm)	28	16	31
Ca^{2+}(ppm)	45	38	29
Mg^{2+}(ppm)	25	28	34
pH	5.6	5.8	5.4

FC = field capacity; PWP = permanent wilting point; K = hydraulic conductivity

Table 4 Collected information on irrigation, rainfed supply and fertilizer rates for growth and development stages of rice plants across the study area

Location	Crop	Total observed rainfed supply (mm)				Total irrigated water (mm)				Fertilizer rate applied (kg/ha)			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
Ha Tien	First	30.8	202.8	34.9	23.4	50	20	60	50	40	60	50	30
	Second	47.9	70.5	189.2	302.8	40	40	0	0	50	65	50	35
Kien Luong	First	38.9	198.6	45.9	33.7	40	20	50	40	50	45	45	40
	Second	53.2	85.4	177.5	287.6	40	40	10	0	60	60	50	40
Rach Gia	First	27.5	193.2	16.3	16.9	60	10	70	60	40	50	50	30
	Second	41.2	68.3	209.7	334.1	45	55	10	0	50	50	40	50

First = winter-spring crop season; Second = summer-autumn crop season; I = initial stage of rice crop; II = developmental stage of rice crop; III = middle stage of rice crop; IV = late stage of rice crop.

Model calibration

The AquaCrop model was calibrated based on the simulated results for observed crop yield during two planting crop seasons at three different locations, covering the study area during the period 2000–2010. The results produced high correlations with values for d, R^2 and RMSE in the ranges 0.77–0.89, 0.81–0.92 and 11–20%, respectively, for the two planting crop seasons at the experimental locations across the study area (Figs. 4A–4B).

Specifically, at Ha Tien station, the values for R^2, d and RMSE between the simulated model and observed crop yield were d = 0.83–0.86, R^2 = 0.85–0.87 and RMSE = 11–17%, while at Kien Luong station, the corresponding values were 0.77–0.83, 0.81–0.85 and 13–19% and at Rach Gia station, the corresponding values were 0.85–0.89, 0.87–0.92 and 12–20% (Table 5).

The index of agreement (d) is a measure of relative error in the simulated results of the model and is a dimensionless quantity, with the model being considered a more perfect simulation as the value approaches 1 (Heng et al., 2009; Zeleke et al., 2011). The coefficient of determination (R^2) is a measure of the mean square to the observed variance. The coefficient of determination designates the overall deviation between observed data and simulated results from the overall deviation between observed data with its average value. The simulated results are considered good if the value of R^2 is close to 1 (Heng et al., 2009; Babel et al., 2018). The RMSE represents a measure of the overall deviation between observed data and simulated results. It also is considered as a synthetic indicator of absolute model uncertainty and the performance of a model is considered good if the value of RMSE approaches zero (Dang, 2021). The calibrated results of the high d and R^2 values and the low percentage of RMSE of the models for the three observed locations across the study area supported the model calibration was acceptable.

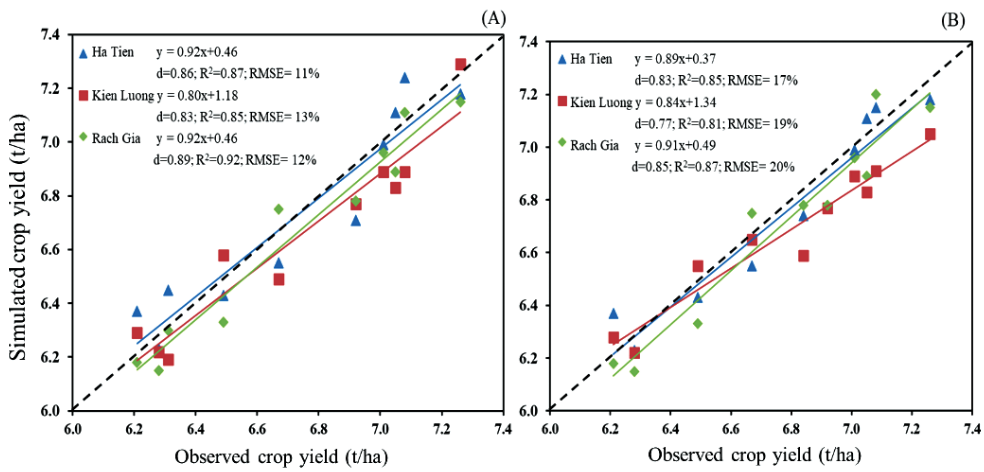

Fig. 4 Relationship between simulated model and observed crop yield at three experimental locations across study area: (A) first cropping season; (B) second cropping season, where dotted lines are plots of y = x, d is the index of agreement, R^2 is the coefficient of determination and RMSE is the relative root mean squared error.

Table 5 Performance results of AquaCrop model in calibration and validation processes based on statistical analysis

Location	Crop	Calibration			Validation		
		d	R^2	RMSE	d	R^2	RMSE
Ha Tien	First	0.86	0.87	11%	0.84	0.82	13%
	Second	0.83	0.85	17%	0.78	0.78	18%
Kien Luong	First	0.83	0.85	13%	0.82	0.74	15%
	Second	0.77	0.81	19%	0.75	0.80	19%
Rach Gia	First	0.89	0.92	12%	0.79	0.76	14%
	Second	0.85	0.87	20%	0.74	0.73	17%

First = winter-spring crop; Second = summer-autumn crop; d = index of agreement; R^2 = coefficient of determination; RMSE = relative root mean squared error

Model validation

Model validation was also deployed by comparing the simulated results and observed crop yields for two planting crop seasons at three experimental locations covering the study area in the period 2011–2019. The validation process of the AquaCrop model run with the calibrated parameters produced good results with averages of d = 0.78, R^2 = 0.77 and RMSE = 15% (Table 5). Specifically, the statistical indicators between the simulated results and observed crop yields for both planting crop seasons had values of d = 0.78–0.84, R^2 = 0.78–0.82 and RMSE = 13–18% at Ha Tien station, values of d = 0.75–0.82, R^2 = 0.74–0.80 and RMSE = 15–19% at Kien Luong station and values of d = 0.74–0.79, R^2 = 0.73–0.76 and RMSE = 14–17% at Rach Gia station (Table 5). The goodness of fit between the simulated results and observed crop yield based on the validation process confirmed the applicability of the AquaCrop model for determining RUE and crop yields across the study area.

Crop cultivation periods and rainfed use efficiency

For years, the rice paddies have been sown without considering adverse environmental conditions such as the effects of irrigation water salinity, drought during the growth stage and high intensity rainfall during flowering, grain filling stages and the harvesting stage, resulting in reduced crop yield. According to Deb et al. (2015), increasing salinity in irrigation water during the growing and developing stages of rice can lead to decreased crop yield.

The results indicated that the RUE would notably improve if the CCC of both the first and second cropping seasons were altered compared to the CCC (Figs. 5A–5B). In the first cropping season, the total RUE would increase on average 16.6%, 17.9% and 14.2% at Ha Tien, Kien Luong and Rach Gia stations, respectively, (Table 6) when the CCC is commences in the first week of November while the corresponding values for the second cropping season would decrease by 8.8%, 10.8% and 8.9% (Table 6) when the CCC commences in the fourth week of March.

Specifically, the RUE increased steadily in the initial, development, middle and late stages of the first cropping season with increases in the ranges at the three experimental locations being 10.6%–14.4%, 12.8%–17.5%, 17.0–23.1% and 29.0%–35.0%, respectively, (Table 6). This is essential for the normal growth of rice plants because the regular distribution of rainfed supply for the growth and development stages of rice plants will help to avoid a lack of supply of irrigation water during the crop's growth cycle, especially during the grain filling or harvesting stages, as this would seriously affect crop yield.

In the second cropping season, when the CCC was adjusted forward 1 wk hydrologically, there were only minor changes in RUE compared to the corresponding baseline values with 6.8–9.7% and 10.0–11.0% for initial and middle stages, respectively, while there were major increases in RUE in the development stage and a major decrease in the late stage of the rice plants (Figs. 6A–6B). This was most suitable for the grain filling process as well as harvesting activities, by avoiding a high concentration of rainfed supply during the harvest stage, which could easily result in crop losses. According to Dang (2021), the crop yield would significantly reduce if the rice plants were subjected to daily high intensity rainfed supply during the flowering and harvesting phases.

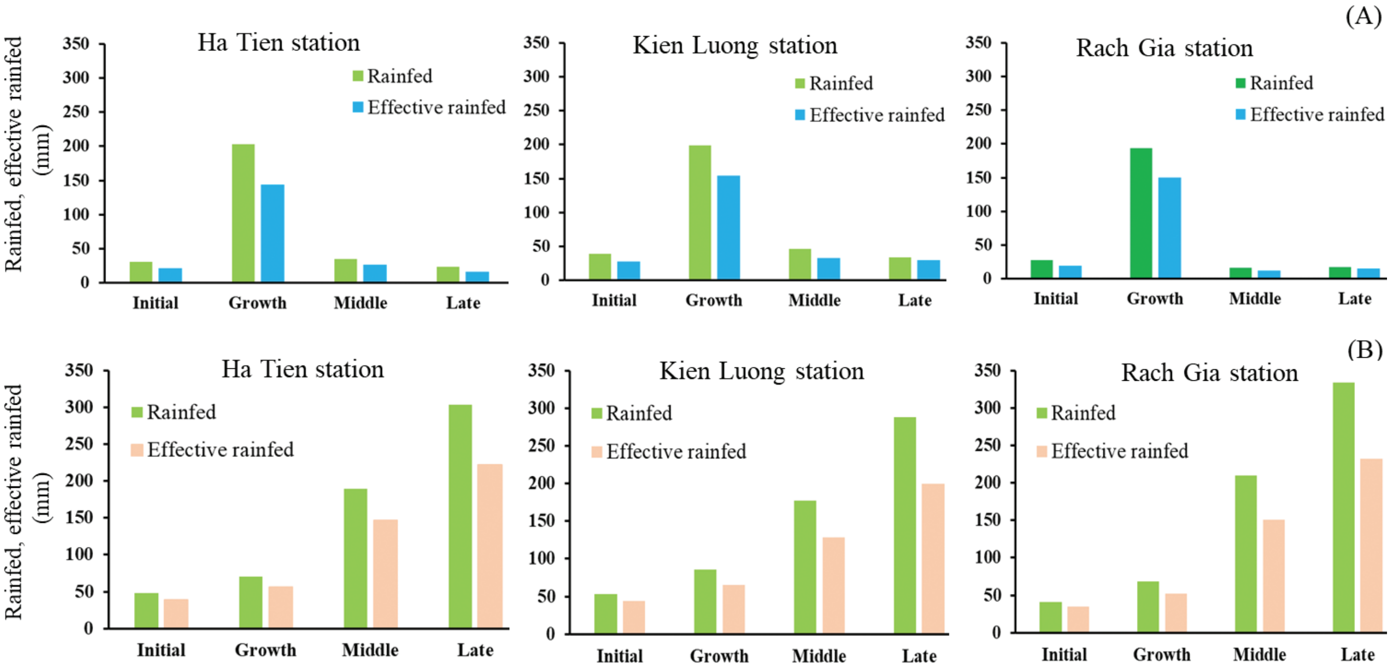

Fig. 5 Comparison of rainfed and rainfed use efficiency at three experimental locations after adjusting crop cultivation calendar: (A) in first cropping season; (B) in second cropping season

Table 6 Comparison of rainfed use efficiency before and after adjusted crop cultivation calendar corresponding to growth and development stages of rice planting crops across study area

Stage	First cropping season			Second cropping season		
	Ha Tien	Kien Luong	Rach Gia	Ha Tien	Kien Luong	Rach Gia
Rainfed use efficiency before adjusting crop cultivation calendar						
Initial	21.6	27.7	19.6	39.1	44.2	35.3
Growth	144.1	154.3	150.1	56.6	65.5	52.4
Middle	26.6	33.0	11.7	146.3	128.0	151.2
Late	15.7	29.3	14.7	222.0	199.9	232.2
Total	208.0	244.3	196.1	464.0	437.6	471.1
Rainfed use efficiency after adjusting crop cultivation calendar						
Initial	23.8	31.0	22.3	45.7	49.5	40.5
Growth	165.7	180.5	168.1	63.4	69.6	56.3
Middle	31.9	38.6	14.4	160.9	139.5	167.8
Late	21.2	37.8	19.1	151.0	125.9	155.6
Total	242.6	288.0	224.0	421.0	399.5	441.3
I (%)	10.6	12.7	14.4	6.8	9.7	9.2
II (%)	15.3	17.5	12.8	22.6	16.9	28.5
III (%)	20.4	17.0	23.1	10.0	9.0	11.0
IV (%)	35.0	29.0	30.0	-32.0	-37.0	-33.0
Change in total RUE (%)	+16.6	+17.9	+14.2	-8.8	-10.8	-8.9

I, II, II and IV = percentage change in initial, growth, middle and late stages, respectively, of rainfed use efficiency (RUE) before and after adjusted crop cultivation calendar; change in total RUE = change in total rainfed use efficiency

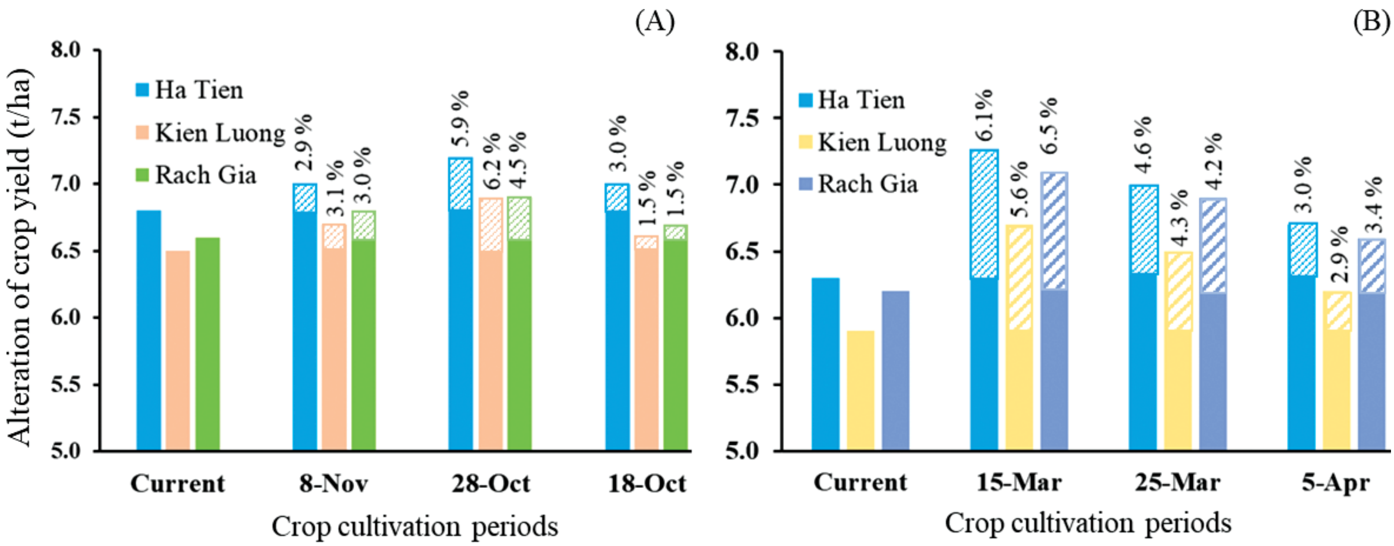

Fig. 6 Trend in crop yield increase at three experimental locations (Ha Tien, Kien Luong and Rach Gia) across study area corresponding to appropriate crop cultivation calendars for (A) first cropping season and (B) second cropping season

Crop cultivation periods and crop yield

The results showed that the crop yield of rice cultivation paddies improved substantially if the flowering and harvesting stages of rice crops receive an appropriate amount of daily rainfed supply. Specifically, for the first cropping season, a shift to two hydrological weeks earlier resulted in the rice cultivation paddies receiving an average daily rainfed supply of approximately 1.3 mm, 5.7 mm, 0.9 mm and 1.7 mm for the initial, growth, middle and late stages, respectively, and a maximum increase in crop yield of approximately 5.9% (Fig. 6A). The results showed that a shift to two hydrological weeks earlier in the CCC was consistent with actual environmental factors in the study area. Similarly, for the second cropping season, a delay of one hydrological week resulted in the rice cultivation paddies receiving an average daily rainfed supply of approximately 1.6 mm, 4.6 mm, 2.4 mm and 4.6 mm for the initial, growth, middle and late stages, respectively, and enhanced the optimal crop yield by up to 7.1 t/ha at the Ha Tien, Kien Luong and Rach Gia experiment stations (Table 7).

When the CCC was delayed by one hydrological week, the rice paddies received high daily rainfed supply during the development and middle stages but received lower daily rainfed supply in the late stage, which suited harvest activities as well as reducing yield losses due to flooding and rice plants falling over due to high intensity rainfed supply.

Studies on crop yield optimization solutions in the Plain of Reeds and Ca Mau Peninsula regions of Vietnam by Dang (2021) and Deb et al. (2015) reported that the crop yield of the second cropping season declined if the grain filling and harvesting stages were subjected to high intensity rainfed supply.

Table 7 Crop yield corresponding to different crop cultivation times for two planting crop seasons at three experimental locations

Period	Ha Tien		Kien Luong		Rach Gia	
	Crop yield (t/ha)	Increased rate (%)	Crop yield (t/ha)	Increased rate (%)	Crop yield (t/ha)	Increased rate (%)
First crop season						
Current	6.8	-	6.5	-	6.6	-
280	7.0	2.9	6.7	3.1	6.8	3.0
270	7.3	5.9	6.9	6.2	6.9	4.5
260	7.0	2.9	6.6	1.5	6.7	1.5
Second crop season						
Current	6.3		5.9		6.2	
85	6.7	6.1	6.2	5.6	6.6	6.5
95	6.9	4.6	6.5	4.3	6.9	4.2
105	7.1	3.0	6.7	2.9	7.1	3.4

Current = current crop yield, where 280, 270, 260, 85, 95 and 105 d are crop planting times according to calendar dates.

The current research assessed the impacts of relevant environmental factors on rice cultivation paddies in Kien Giang province. The results indicated that the crop yield of two planting crops can be considerably affected by environmental factors as a part of climate variability. The applicability of the AquaCrop model for simulating the crop features was confirmed through the good statistical test results supporting its robustness. The study revealed that a shift to two hydrological weeks earlier in the crop cultivation calendar of the first cropping season enhanced rainfed use efficiency as well as the optimal crop yield while both rainfed use efficiency and the crop yield of the second cropping season achieved optimal values if the crop cultivation calendar of the second cropping season was delayed by about one hydrological week. The crop cultivation calendar of the two rice cropping seasons needed to be altered to adapt to adverse cultivation conditions as well as contributing to optimizing crop yields for rice cultivation paddies in the study area.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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