ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.25, n.9, p.591-596, 2021
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v25n9p591-596

Grain yield optimisation in the Plain of Reeds in the context of climate variability[1]

Otimização da produtividade de grãos na Planície de Reeds no contexto da variabilidade climática

T. A. Dang[2*]

[1] Research developed at University of Science
[2] Vietnam National University-HCM City, Vietnam-0700000

HIGHLIGHTS:

- *Crop yield areas expected to decline under the adverse effects of climate factors.*
- *Applying suitable cultivation periods (SCPs) may help improve crop yields.*
- *SCPs create higher potential grain yields compared to the baseline.*

ABSTRACT: The Plain of Reeds is a large floodplain in the Mekong Delta, where natural disasters such as droughts, off-season rainfall and floods have dramatically increased, leading to declining in crop yields. The objective of this study was to evaluate the adverse impacts of climate factors (ICF) on grain yield of the main growing crops in the Plain of Reeds to define the suitable cultivation period (SCP) for rice-growing areas as an adaptation solution to minimise the adverse impacts of climate factors. To conduct this research, a crop model was applied to define the suitable cultivation periods based on simulating the grain yields of each rice-growing season. When the suitable cultivation periods were deployed, the grain yield of all simulated growing crops improved significantly compared to the current cultivation periods (baseline), which, for the main growing crops in the Plain of Reeds, are no longer suitable for the current weather conditions that have been deeply affected by climate variability in recent years.

Key words: *Oryza sativa*, crop model, grain yield, cultivation

RESUMO: A Planície de Reeds é uma grande planície de inundação no Delta do Mekong, onde os desastres naturais aumentaram drasticamente, como secas, chuvas fora de temporada e inundações, levando ao declínio na produtividade das colheitas. O objetivo deste estudo foi avaliar os impactos adversos dos fatores climáticos (ICF) na produtividade de grãos das principais culturas na Planície de Reeds para definir o período de cultivo adequado (SCP) para áreas de cultivo de arroz, como uma solução de adaptação para minimizar os impactos adversos dos fatores climáticos. Para realizar esta pesquisa, um modelo de cultura foi aplicado para definir os períodos de cultivo adequados com base na simulação da produtividade de grãos de cada cultura de arroz. Quando os períodos de cultivo adequados foram implantados, a produtividade de grãos de todas as safras simuladas melhorou significativamente em comparação com os períodos de cultivo atuais (linha de base), os quais, para os principais cultivos na Planície de Reeds, não são mais adequados para as atuais condições climáticas, que foram profundamente afetadas pela variabilidade climática nos últimos anos.

Palavras-chave: *Oryza sativa*, modelo de cultivo, produtividade de grão, plantio

• Ref. 242624 – Received 23 Aug, 2020
* Corresponding author - E-mail: dtan@hcmus.edu.vn
• Accepted 30 Mar, 2021 • Published 03 May, 2021
Edited by: Walter Esfrain Pereira

INTRODUCTION

In recent decades, global climate variability has changed climate factors in most parts of the world (Shrestha et al., 2016). Among climatic factors, precipitation is assessed to change significantly under the impacts of climate factors (ICF) (Kontgis et al., 2019). Variation in precipitation results in water shortages for irrigation in the dry growing crops whereas flooding of the wet growing crops causing a decline in grain yield (Dang, 2020). According to Kotir (2011), one of the main human concerns in the 21st century is the ICF on agricultural activities. Climate variability has affected approximately 7.0% of the total agricultural land area of Vietnam due to drought, extreme precipitation and flooding. Shah et al. (2011) indicated that precipitation is one of the major climate factors that directly affect agricultural activities as well as crop yields.

In the context of climate variability (CCV), the evaluation of the suitable cultivation period (SCP) for rice crops is considered an effective solution to minimise the ICF (Adnan et al., 2017; Dharmarathna et al., 2014). In recent years, rice cultivation paddies in the Plain of Reeds often face adverse weather conditions such as drought, off-seasonal rainfall and flooding as a part of climate variability (Deb et al., 2015). Farmers in the area have to occasionally replant their crops due to drought leading to the lack of irrigation water or heavy rainfall resulting in floods after sowing (Lee & Dang, 2019). In the context of an increasing frequency and intensity of adverse weather events, studies on the ICV of crop growing seasons to define the SCP for rice cultivation paddies in the Plain of Reeds is considered as an optimal solution for limiting the impacts of climate factors and increasing crop yields. Therefore, the objective of this study is to determine the SCP for rice cultivation crops in the Plain of Reeds by applying the AquaCrop model to capture weather variability as a climate variability adaptation solution.

MATERIAL AND METHODS

Thap Muoi Plain, also called the Plain of Reeds, is a floodplain belonging to the Mekong Delta (10º 04’ 56” to 11º 00’ N latitude and 105° 03’ 15” to 106° 09’ 33” E longitude) with an altitude of 2.5 m (Vu et al., 2018), encompassing the parts of Dong Thap, Tien Giang and Long An Provinces (Figure 1).

In most of the rice cultivation paddies in the Plain of Reeds, there are two to three rice crops sown each year, including the winter-spring crop called “Vu Xuan”, the summer-autumn crop called “Vu He” and the autumn-winter crop called “Vu Thu”. The growing and harvesting periods can be modified depending on each crop season. The Plain of Reeds is dominated by the East Asian monsoon in the wet season (May to November) with main features of heat and humidity and abundant precipitation, whereas the dry season in the area (October to April) is dominated by the northeast monsoon that brings dry air and hot from the Siberian centre of high-pressure, creating little precipitation. Temperatures oscillate between 26.0 and 28.2 °C, with mean annual precipitation varying from 1287 mm at Hong Ngu station to 1643 mm at Moc Hoa station and 85% of which falls in the wet season (Table 1).

The study area is divided into two sub-areas based on topographical conditions and irrigation water channel systems (Figure 1).

In the AquaCrop model, ET_o is defined as Eq. 1.

Table 1. Mean annual precipitation (MAP) and standard deviation (SD) at observation stations in the Plain of Reeds

No.	Station name	MAP	SD	Latitude (N)	Longitude (E)
		(mm)			
1	Hong Ngu	1287.5	82.32	10° 51’	105° 21’
2	Cao Lanh	1473.4	88.70	10° 28’	105° 38’
3	Ben Luc	1620.1	95.80	10° 38’	106° 28’
4	Moc Hoa	1643.3	102.20	10° 46’	105° 56’
5	Cay Lay	1448.8	92.10	10° 21’	106° 23’
6	Cai Be	1457.9	87.20	10° 20’	106° 02’

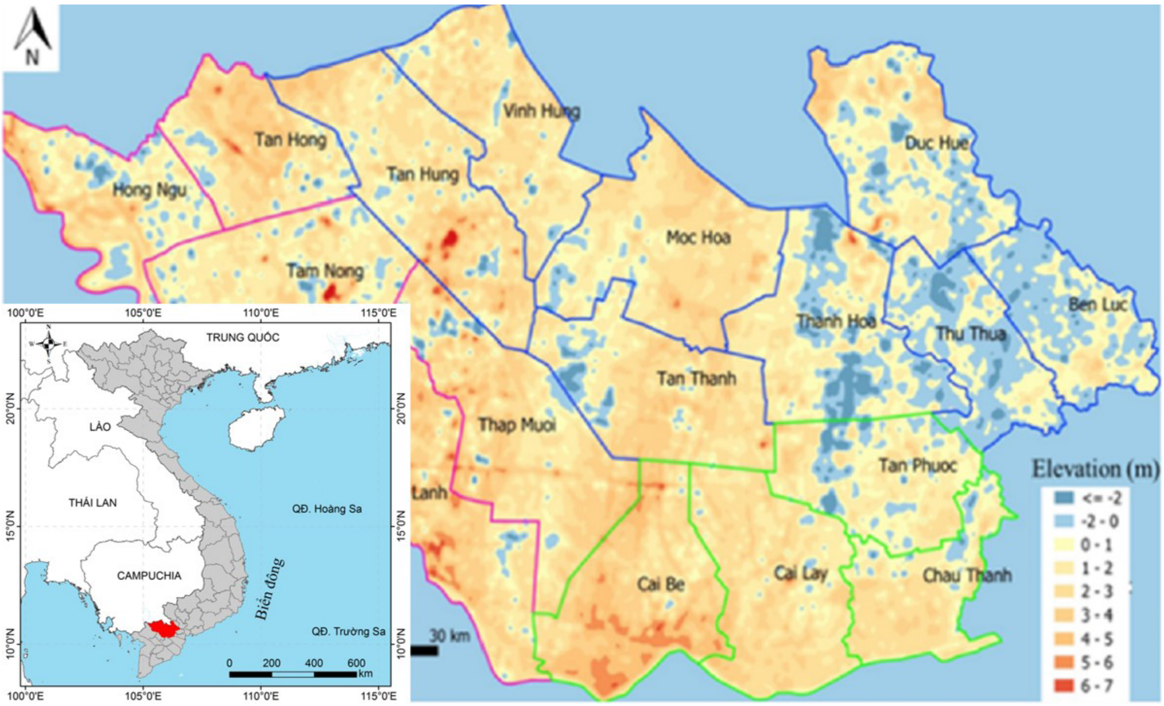


Figure 1. Illustration of the study area

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where:

R_n - radiation at the soil surface, MJ m^{-2} day^{-1};
G - soil heat flux density, MJ m^{-2} day^{-1};
T - average daily temperature, °C,
u_2 - wind speed measured in 2.0 m height, m s^{-1};
e_s - saturation vapour pressure, kPa;
e_a - the actual vapour pressure, kPa;
Δ - the slope of the vapour pressure curve, kPa $°C^{-1}$; and,
γ - psychrometric constant, kPa $°C^{-1}$.

Crop evapotranspiration (ETc) is calculated based on multiplying the crop coefficient (K_c) with ET_o (Steduto et al., 2009; Shah et al., 2015) by Eq. 2.

$$ET_c = ET_o \ K_c \quad (2)$$

Grain yield (Y) is obtained by multiplying the total aboveground biomass (B_i) with a harvest index (Boudhina et al., 2019). Crop yield is defined by Eq. 3.

$$Y = B_i \ HI \quad (3)$$

where:

Y - crop yield, kg ha^{-1}; and,
B_i - aboveground biomass production, kg ha^{-1}.

In Eq. 3, HI is considered as a conservative parameter, and its values are constantly adjusted in the crop module during yield formation in response to water/temperature stresses (Steduto et al., 2009; Greaves & Wang, 2016). The B_i is defined based on Eq. 4:

$$B_i = WP \sum \frac{Tr_i}{ET_{oi}} \quad (4)$$

where:

Tr_i - daily crop transpiration in, mm;
ET_{oi} - daily reference evapotranspiration, mm; and,
WP* - the normalised biomass water productivity, g m^{-2}.

Climate data in the period 2000-2019 were collected from the Southern Regional Hydrometeorological Centre, Vietnam, except the ET_o data that were calculated based on the Penman-Monteith equation. Specifically, weather data in the period of 2000-2010 (Figure 2A) was applied for validating the AquaCrop model, while weather data in the period of 2011-2018 (Figure 2B) was used for calibrating, and weather data in 2019 was applied for running the model.

The soil module requires soil characteristics that were obtained from the field surveys at the locations in the area and analysed following standard international procedures (Silvestro et al., 2017; Oyeogbe & Oluwasemire, 2013). The results showed that the sandy loam to loamy sand dominated in the soil samples, whose features are presented in Table 2.

For crop and management modules, the AquaCrop model requires information about the growth phases of the plant, the length and growing density, the amounts of fertilisers provided and irrigation application depth as well as the timing of the water applications. Crop characteristics were obtained from the Department of Agriculture and Rural Development of provinces such as Dong Thap, Tien Giang and Long An, and detailed information is presented in Table 3.

Assessment of the performance of the AquaCrop model was conducted comparing the simulated and field measurements

Table 2. Soil characteristics of the study area

Soil characteristics	Values	Unit
Calcium	7.45-13.38	mg kg^{-1}
Magnesium	2.57-4.68	mg kg^{-1}
pH	4.90-5.50	-
Volumetric water content at saturation	47	%
Field capacity	32	%
Permanent wilting point	20	%
Saturated hydraulic conductivity	120	mm m^{-1}
Total available soil water	225	mm day^{-1}

Table 3. Characteristics of three rice crop seasons in the study area

Agronomic practices	Rice crop seasons		
	Vu Xuan	Vu He	Vu Thu
Sowing date	12-Dec	15-Apr	17-Aug
Harvesting date	22-Mar	01-Aug	29-Nov
Seeding density (kg ha^{-1})	160	180	150
Emergence (DAP)	6	7	7
Anthesis (DAP)	55	52	51
Maturity (DAP)	102	99	101
Fertilisation dose (kg ha^{-1})	80 U, 70N, 50K	100 U, 60N, 50K	100 U, 60N, 50K

K - Potassium fertiliser; U - Urea fertiliser; N - NPK fertiliser; Vu Xuan - Spring crop season; Vu He - Summer crop season; Vu Thu - Winter-autumn crop season; DAP - Days after planting

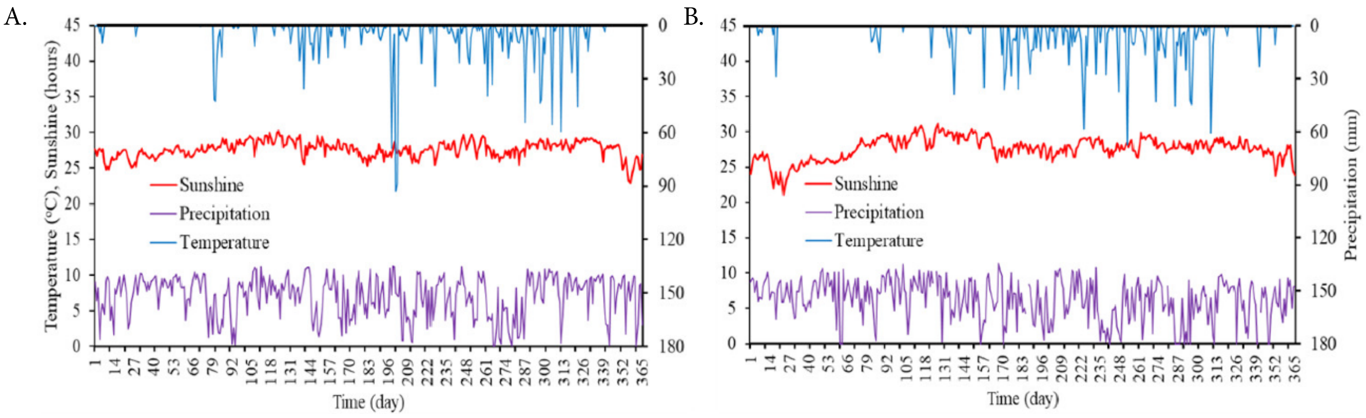


Figure 2. Data for model validation (A) in the period 2000-2010 and model calibration (B) in the period 2011-2018

of grain yield. Specifically, the validation procedure was performed comparing the simulated and measured grain yield in the period 2000-2010. The model calibration was then conducted based on a comparison between the simulated model and harvested grain yield in the period 2011-2019. The deployment was an iterative process of adjusting sensitive parameters in the AquaCrop model. For each adjustment in the input data, simulations were iterated running the calibrated climate and crop file. To assess the relevance of the applied model, error statistics such as the coefficient of determination (R^2), the index of agreement (E), and the root mean square error (RMSE) (Eqs. 5, 6 and 7) were used in this study (Khov et al., 2017; Kamara et al., 2009).

$$R^2=\frac{\sum_{i=1}^{n}S_iO_i-\sum_{i=1}^{n}S_i\sum_{i=1}^{n}O_i}{\sqrt{\sum_{i=1}^{n}S_i^2-\left(\sum_{i=1}^{n}S_i\right)^2}\sqrt{\sum_{i=1}^{n}O_i^2-\left(\sum_{i=1}^{n}O_i\right)^2}} \tag{5}$$

The E index is as follows:

$$E=1-\frac{\sum_{i=1}^{n}\left(S_i-O_i\right)^2}{\sum_{i=1}^{n}\left(S_i-\bar{O}_i\right)^2} \tag{6}$$

where:

S_i and O_i - simulated and harvested results, respectively;

$\bar{O}_i$ - mean value of O_i; and,

n - number of data points.

The RMSE can be used as a measure of absolute error between the simulated and harvested results. The RMSE is described as follows:

$$RMSE=\sqrt{\frac{\sum_{i=1}^{n}\left(S_i-O_i\right)^2}{n}} \tag{7}$$

Sensitivity analysis was performed by increasing or decreasing the value of parameters in the crop model to seek the optimal values. In this study, the key parameters of the AquaCrop model were defined by changing the value of parameters to optimise the simulation run time of the applied AquaCrop model.

RESULTS AND DISCUSSION

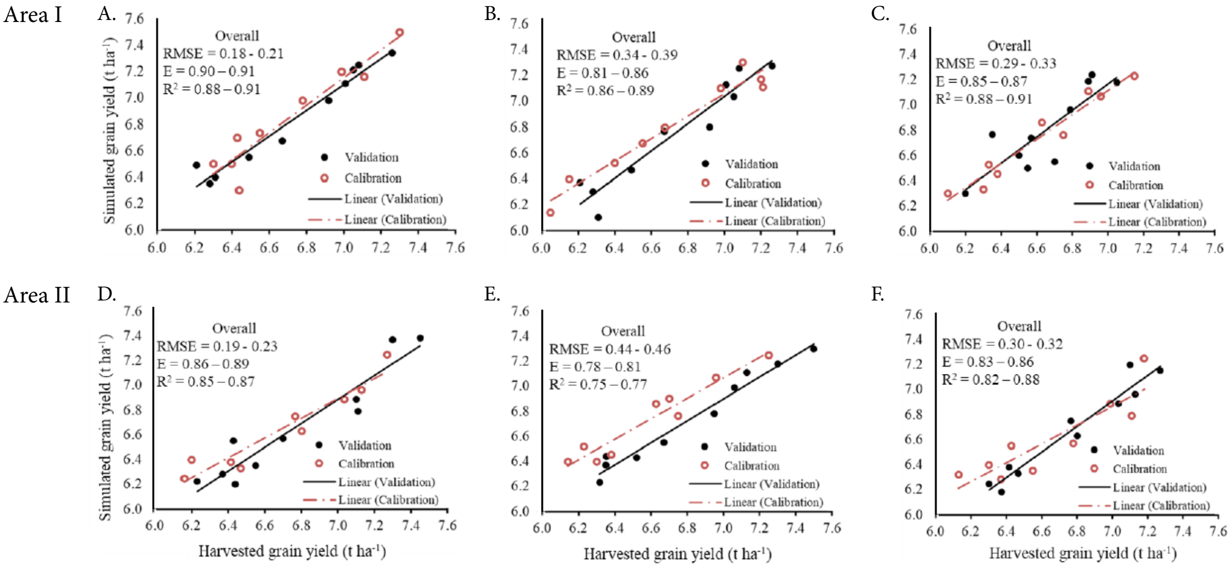
Sensitivity analysis of the key parameters of the AquaCrop model is presented in Table 4.

The validated results point out the goodness of fit between the simulated model and harvested rice yield through the high correlation (Figures 3A, B, C, D, E, F) of the statistical variables (E = 0.81-0.91, R^2 = 0.86-0.91 and RMSE = 0.18-0.39) for both sub-area I and the sub-area II. Based on the results, the AquaCrop model satisfies the model validation criteria.

The calibrated results indicate that an acceptable fit between the simulated model and harvested rice yield for all

Table 4. Sensitivity analysis of the key parameters in the AquaCrop model

Parameters	Sensitivity level	
	High	Moderate
Base temperature (°C)		X
Length of the flowering stage (d)	X	
Canopy growth coefficient		X
Canopy decline coefficient	X	
Upper threshold water stress coefficient		X
Lower threshold water stress coefficient	X	
Upper threshold of canopy senescence		X
Upper threshold stomatal stress coefficient		X
Harvest index of leaf growth before and after flowering	X	



Vu Xuan - Spring crop season; Vu He - Summer crop season; Vu Thu - Winter-autumn crop season

Figure 3. The model validation and calibration for (A) Vu Xuan spring, (B) Vu He summer and (C) Vu Thu winter-autumn crop seasons in the sub-area I and for (D) Vu Xuan spring (E), Vu He summer (F) and Vu Thu winter-autumn crop seasons in the sub-area II

Table 5. Performance of the AquaCrop model through the validation and calibration procedures based on the RMSE, E and R^2

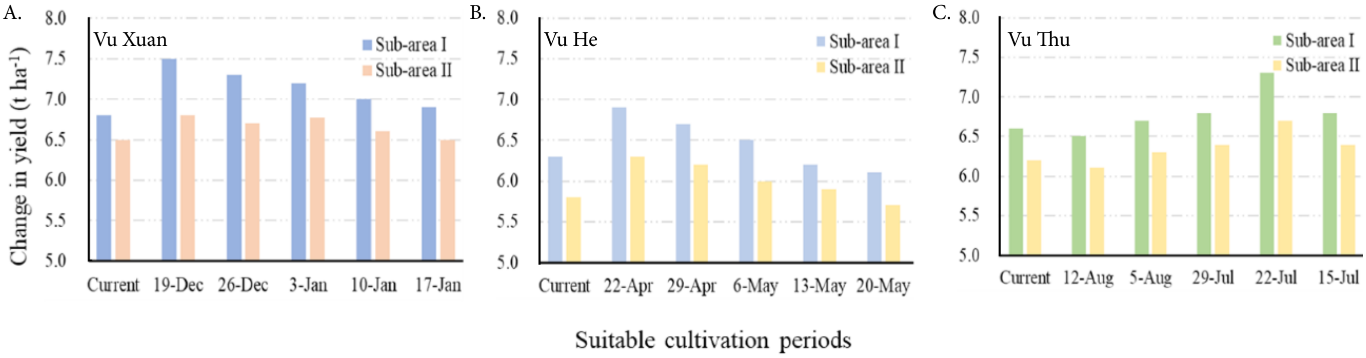
Location	Crop season	Validation (2000-2010)			Calibration (2011-2018)		
		E	RMSE	R^2	E	RMSE	R^2
Sub-area I	Vu Xuan	0.91	0.18	0.91	0.89	0.23	0.87
	Vu He	0.86	0.34	0.89	0.81	0.44	0.77
	Vu Thu	0.86	0.29	0.91	0.86	0.30	0.88
Sub-area II	Vu Xuan	0.87	0.29	0.88	0.86	0.19	0.75
	Vu He	0.81	0.39	0.86	0.78	0.46	0.76
	Vu Thu	0.85	0.33	0.88	0.83	0.32	0.82

E - Index of agreement; RMSE - Root mean square error; R^2 - Coefficient of determination; Vu Xuan - Spring crop season; Vu He - Summer crop season; Vu Thu - Winter-autumn crop season

Table 6. Grain yield of the main growing crops under the suitable cultivation periods

	Vu Xuan					Vu He					Vu Thu			
	Sub-area I		Sub-area II			Sub-area I		Sub-area II			Sub-area I		Sub-area II	
Period	Grain yield (t ha^{-1})	Rate of change (%)	Grain yield (t ha^{-1})	Rate of change (%)	Period	Grain yield (t ha^{-1})	Rate of change (%)	Grain yield (t ha^{-1})	Rate of change (%)	Period	Grain yield (t ha^{-1})	Rate of change (%)	Grain yield (t ha^{-1})	Rate of change (%)
Current	6.7		6.5		Current	6.3		5.8		Current	6.6		6.2	
19-Dec	7.5	+ 10.3	6.8	+ 4.6	22-Apr	6.9	+ 9.5	6.3	+ 8.6	12-Aug	6.5	-1.6	6.1	-1.6
26-Dec	7.3	+ 5.9	6.7	+ 3.1	29-Apr	6.7	+ 6.3	6.2	+ 6.8	05-Aug	6.7	+ 1.5	6.3	+ 3.1
03-Jan	7.2	+ 4.4	6.7	+ 4.2	06-May	6.5	+ 1.6	6.0	+ 3.4	29-Jul	6.8	+ 3.0	6.4	+ 3.3
10-Jan	7.0	+ 2.9	6.6	+ 1.5	13-May	6.2	-3.2	5.9	+ 1.7	22-Jul	7.3	+ 6.2	6.7	+ 8.1
17-Jan	6.9	+ 1.5	6.5	+ 0.7	20-May	6.1	-4.7	5.7	-1.6	15-Jul	6.8	+ 3.3	6.4	+ 3.4

Vu Xuan - Spring crop season; Vu He - Summer crop season; Vu Thu - Winter-autumn crop season



Vu Xuan - Spring crop season; Vu He - Summer crop season; Vu Thu - Winter-autumn crop season

Figure 4. Suitable cultivation periods in three seasons simulated based on the AquaCrop model to obtain the optimal crop yields for the rice-growing crops in the Plain of Reeds

rice growing seasons based on the statistical variables with E = 0.78-0.89, R^2 = 0.75-0.88 and RMSE = 0.19-0.46 (Table 5). One of the major causes creating a difference between the simulation results and harvested data is that in 2014-2016, the Plain of Reeds suffered the worst drought event in the history of 90 years, resulting in the lack of irrigation water and salinity intrusion almost occurring in the rice paddies.

In the Plain of Reeds, farmers are accustomed to traditional cultivation activities that have not yet adapted to change in climate factors under the ICV. The crop yield has, therefore, strongly decreased due to the inappropriate cultivation periods. The analysis of the relationship between the cultivation periods and grain yield of the main growing crops in the Plain of Reeds is illustrated in Figure 4. Specifically, the rice yield of the Vu Xuan crop season can achieve from 6.9 to 7.5 t ha^{-1} for both the sub-area I and II (Table 6) when the SCP was fixed on December 2 to 14. This means that the grain yield of the Vu Xuan crop season increases approximately 1.4 to 10.3%, respectively, compared to the baseline (Figure 4A). For the Vu He crop season, the results indicated that grain yield can achieve from 6.5 to 6.9 t ha^{-1} (increase from 1.6 to 6.3%) for the sub-area I and 5.9 to 6.3 t ha^{-1} for the sub-area II (Table 6) when the SCP is established from April 29th to May 6th (Figure 4B).

For the Vu Thu crop season, the SCP is defined as varying from July 15 to August 05 (Figure 4C) when grain yield can reach from 6.7 to 7.3 t ha^{-1} (an increase from 1.5 to 6.3%) for the sub-area I and from 6.3 to 6.7 t ha^{-1} (increase from 3.1 to 8.1%) for the sub-area II (Table 6).

In general, the grain yield of the growing crops in the Plain of Reeds can be improved positively if the rice-growing crop area is sown within the SCPs. The seasonal variation due to the ICV has negatively affected the growth phases of rice crops in the Plain of Reeds. Therefore, it is recommended that farmers in the rice cultivation areas of the Plain of Reeds soon need to alter the cultivation habits to adapt to change in the current weather conditions.

Conclusions

1. The rice yield of three rice-planting crops significantly improved after applying the suitable cultivation periods.

2. The AquaCrop model is suitable to define the suitable cultivation periods for paddies in the Plain of Reeds through the validation and calibration procedures.

3. The cultivation periods of all rice-growing crops in the Plain of Reeds are not suitable, and farmers are being exposed to the high risks of crop failure because of the unfavourable weather factors during the grain-filling and harvesting stages.

Acknowledgements

Sincere gratitude is expressed to Prof. Lee Seungkyu for his valuable help in conducting this research and reading and commenting on the draft.

Literature Cited

Adnan, A. A.; Jibrin, J. M.; Kamara, A. Y.; Abdulrahman, B. L.; Shaibu, A. S.; Garba, I. I. CERES-Maize model for determining the optimum Kontgis dates of early maturing maize varieties in Northern Nigeria. Frontiers in Plant Science, v.8, p.1-14, 2017. https://doi.org/10.3389/fpls.2017.01118

Boudhina, N.; Masmoudi, M. M.; Alaya, I.; Jacob, F.; Mechlia, N. B. Use of AquaCrop model for estimating crop evapotranspiration and biomass production in hilly topography. Arabian Journal Geosciences, v.12, 259, 2019. https://doi.org/10.1007/s12517-019-4434-9

Dang, T. A. Establishing rainfall intensity-duration-frequency for flood warnings in the Ca Mau coastal area under the impacts of climate variability. International Journal of Climate Change Strategies and Management, v.12, p.705-715, 2020. https://doi.org/10.1108/IJCCSM-06-2020-0067

Deb, P.; Tran, D. A.; Udmale, P. D. Assessment of the impacts of climate change and brackish irrigation water on rice productivity and evaluation of adaptation measures in Ca Mau province, Vietnam. Theoretical Applied Climatology, v.125, p.641-656, 2015. https://doi.org/10.1007/s00704-015-1525-8

Dharmarathna, W. R. S. S.; Herath, S.; Weerakoon. S. B. Changing the planting date as a climate change adaptation strategy for rice production in Kurunegala district, Sri Lanka. Sustainability Science, v.9, p.103-111, 2014. https://doi.org/10.1007/s11625-012-0192-2

Greaves, G. E.; Wang, Y. M. Assessment of FAO AquaCrop model for simulating maize growth and productivity under deficit irrigation in a tropical environment. Water, v.8, p.1-18, 2016. https://doi.org/10.3390/w8120557

Kamara, A. Y.; Friday, E.; David, C.; Lucky, O. Planting date and cultivar effects on dryland corn production. Agronomy Journal, v.101, p.91-98, 2009. https://doi.org/10.2134/agronj2008.0090

Khov, S.; Vote, C.; Hornbuckle, J.; Inthavong, I.; Oeurng, C.; Sengxua, P.; Sihathep, V.; Song, L.; Eberbach, P. Calibration and validation of AquaCrop for irrigated peanut in lowland rice systems of Southern Laos. International Congress on Modelling and Simulation, 22, Hobart, Tasmania, Australia, 3 to 8 December 2017.

Kontgis, C.; Schneider, A.; Ozdogan, M.; Kucharik, C.; Pham, V. D. T.; Nguyen, H. D.; Schatz, Z. Climate change impacts on rice productivity in the Mekong River Delta. Applied Geography, v.102, p.71-83, 2019. https://doi.org/10.1016/j.apgeog.2018.12.004

Kotir, J. H. Climate change and variability in sub-Saharan Africa: A review of current and future trends and impacts on agriculture and food security. Environment Development and Sustainability, v.13, p.587-605, 2011. https://doi.org/10.1007/s10668-010-9278-0

Lee, S. K.; Dang, T. A. Predicting the water use-demand as a climate change adaptation strategy for rice planting crops in the Long Xuyen Quadrangle Delta. Paddy and Water Environment, v.17, p.561-570, 2019. https://doi.org/10.1007/s10333-018-00686-y

Oyeogbe, I. A.; Oluwasemire, K. O. Evaluation of SO model for predicting soil water characteristics in South-western Nigeria. International Journal of Soil Science, v.8, p.8-67, 2013. https://doi.org/10.3923/ijss.2013.58.67

Shah, F.; Huang, J; Cui, K.; Nie, L.; Shah, T.; Chen, C.; Wang, K. Impact of high-temperature stress on rice plants and its traits related to tolerance. Journal of Agricultural Science, v.149, p.545-556, 2011. https://doi.org/10.1017/S0021859611000360

Shrestha, S.; Deb, P.; Bui, T. T. T. Adaptation strategies for rice cultivation under climate change in Central Vietnam. Mitigation Adaptation Strategies Global Change, v.21, p.15-37, 2016. https://doi.org/10.1007/s11027-014-9567-2

Silvestro, P. C.; Pignatti, S.; Yang, H.; Yang, G.; Pascucci, S.; Castaldi, F.; Casa, R. Sensitivity analysis of the Aquacrop and SAFYE crop models for the assessment of water limited winter wheat yield in regional scale applications. PLoS ONE, v.12, e0187485, 2017. https://doi.org/10.1371/journal.pone.0187485

Steduto, P.; Hsiao, T. C.; Raes, D.; Fereres, E. AquaCrop-the FAO crop model to simulate yield response to water. Agronomy Journal, v.101, p.426-437, 2009. https://doi.org/10.2134/agronj2008.0139s

Vu, D. T.; Yamada, T.; Ishidaira, H. Assessing the impact of sea level rise due to climate change on seawater intrusion in Mekong Delta, Vietnam. Water Science Technology, v.77, p.1632-1639, 2018. https://doi.org/10.2166/wst.2018.038