Emirates Journal of Food and Agriculture. 2023. 35(12): 1-7
doi: 10.9755/ejfa.2023.3172
http://www.ejfa.me/

RESEARCH ARTICLE

Delineation of rice yield and production in combination of crop model and remote sensing

Minh Vo Quang[1]*, Hien Tran Thi[2]

[1]Land Resources Department, Environment and Natural Resources College, Cantho University, CanTho, 900000, Vietnam, [2]Natural Resources and Environment Department, BenTre, 930000, VietNam

ABSTRACT

The study was to simulate rice yield in various places and outline a rice yield map for the study area using GIS, remote sensing, and a rice model. As a case study, the data were collected on the climate, soil characteristics, and rice cropping status in the AnGiang province (Southern of the Mekong River Delta in Viet Nam). The AquaCrop model was used to predict rice yield. The MODIS image delineated the rice cropping status based on spatial and temporal NDVI values. The results of the yield simulation are then put together with information about where the rice was planted, the weather, and the properties of the soil to make a map of the yield distribution. Finally, the outcomes are verified and contrasted with the statistical findings in the last step. The rice yield was predicted and compared with actual 1 and 6 percent rice yields. The anticipated rice yield map was established for the Winter-Spring cropping season 2012-2013 and the Summer-Autumn and Autumn–Winter cropping seasons 2013. Rice production and yield distribution can be divided into two major areas. The alluvial soil area produces significantly more rice than the LongXuyen quadrangle area because of the difference in soil and weather conditions. Rice yield simulation and delineation combining remote sensing and crop models is a good approach for yield prediction and better agricultural management strategy development in a country or region. The accuracy of the results depends on the quality of the input data, such as soil weather and remote sensing.

Keywords: GIS; MODIS; Cropping season; Rice yield

INTRODUCTION

The anticipated 2-4°C mean temperature rise by the end of the twenty-first century will impact global agricultural productivity. Under higher atmospheric CO_2 concentrations, the existing cultivars of annual determinate crops in temperate zones will mature earlier, yields will drop, and crop growth will accelerate. However, it should at least partially offset this adverse effect of warmer temperatures when enough water is available. The annual seed crop production may be more affected by shifts in the frequency of hot (or cold) conditions (Wheeler et al., 2000). Otherwise, accurate and timely information about agricultural yields is necessary for import and export planning and pricing. Several mathematical models were proposed for farming yields (Hansen et al., 2004; Wheeler et al., 2000).

AquaCrop uses a unidirectional flow and multi-layered structure, making it a reasonably simple water balance model (Raes et al., 2009). Crop yields in various conditions were simulated using the AquaCrop model (Steduto et al., 2009). FAO created AquaCrop, modeling software that estimates irrigation requirements and simulates potential crop yields using water efficiency (Raes et al., 2009). The simulation principle of the model is quite intuitive about the relationship of components in the soil-water-crop-climate system. Besides, the model's design is also simple and easy to use, with relatively easy input data requirements (Steduto et al., 2009). AquaCrop has been applied to simulate the productivity and evaluate the water use efficiency of crops grown on specialized land, such as 3-crop rice on alluvial soil (Vanuytrecht et al., 2014), soybeans in the conditions of using heavenly water (Thu et al., 2015), and maize in the alluvial soil surrounded by dikes (Tuyen et al., 2017).

Additionally, there have been numerous uses in agricultural productivity due to the development of remote sensing technologies. Several studies have shown that we can use remote sensing data to track changes in crop growth and the result of seeding (Hien & Minh, 2010; Kham et al.,

***Corresponding author:**
Vo Quang, Land Resources Department, Environment and Natural Resources College, Cantho University, CanTho, 900000, Vietnam.
E-mail: vqminh@ctu.edu.vn

Received: 23 June 2023; **Accepted:** 17 November 2023

2007; Rouse et al., 1973). With moderate quality, the study uses no-cost MODIS satellite images to suit the planning needs and to monitor rice crop development. Connecting the yield simulation model to geographic information systems (GIS) and remote sensing has been talked about for a long time as a way to predict and track crop growth (Dente et al., 2008; Jongschaap, 2006; Qin et al., 2008; Setiyono et al., 2018). Besides, Thailand has recently introduced agricultural policies to promote large-scale rice farming by supporting and integrating small-scale farmers. These policies require farming tools that can assist farmers in rice farming planning and management. Crop models and remote sensing technologies can help farmers and field managers. They used the AquaCrop model and moderate-resolution satellite images (30 m) to simulate the rice yield for small-scale farmers. The study used data from rice cultivation techniques, leaf area index (LAI), canopy cover (CC), and agricultural practices to calibrate the model.

Based on this, research was conducted to create a remote sensing, GIS, and Aquacrop model combination to (1) simulate yield response to soil and water conditions to predict the yield of rice by using the Aquacrop model in selected sites in the AnGiang province, and (2) to delineate (3) to combine the results of simulated rice yield and production with rice growing status from remote sensing to delineate the distribution of rice yield and production for the study area.

MATERIALS AND METHODS

Flow of the process

The strategies generally included obtaining reports, secondary information about the climate, soil characteristics, the state of rice agriculture, and methods and procedures for growing rice. We checked the rice plants' health and planting progress by looking at a time series of NDVI data that was gathered and processed from MODIS images. Then, rice yield was simulated using the AquaCrop model. Results are confirmed and compared to statistical conclusions. The date of rice sowing, weather, and soil characteristics are all used to create a spatial yield distribution map. A flowchart of the processes is shown in Fig. 1.

The study location

Two tested areas were conducted in LuongAnTra village (TriTon district) and DinhThanh village (ThoaiSon district) in the AnGiang province, VietNam, from 2012 to 2013.

Remotely sensed data

Images were gathered from NASA with MOD09Q1 coding at 250m spatial resolution and 8-day temporal resolution between 2012 and 2013. The rice cropping schedule was determined from the NDVI images, which reveal stages. For the NDVI computation, the red and near-infrared bands were utilized.

Field observation data

Field observations were made to track the progress of the rice sowing, the crop calendar, and the rice yield. Fifty field observation locations are available to monitor and validate rice planting and the crop calendar from image interpretation (Fig. 2a), and two field measurement sites are available to gather actual production data (Fig. 2b).

Processing the Aquacrop model for rice yield simulation

The AquaCrop-FAO, or crop-water productivity model, simulated rice yield using input variables and required data on crop cultivar characteristics, weather conditions, and soil properties (Raes et al., 2011).

Table 1 shows crop data, including some essential traits of locally grown rice varieties. It shows the time the plants took to grow, the weight of the seeds, the day they sowed their first sprouts, and the date when they had the most leaves.

The Hydrometeorological Center of the AnGiang province gathered weather data from 2012 to 2013, including the temperature T min and max (^{o}C); precipitation (mm); hours of sunshine (hours); the speed of wind (m/s); relative air humidity (%) (Fig. 3); other variables. In addition, the study used the program's ETo calculator to compute the evaporation of the reference ETo (mm).

Soil properties are gathered and analyzed, including soil's texture, water holding capacity, moisture at Permanent Wilting Point (PWP), Field Capacity (FC), Saturated Humidity (SAT), and coefficient of permeability (Ksat) (Fig. 4a). Soil texture used to simulate rice yields changes from clay to silty clay (Fig. 4b), which is suitable for root development.

The results are validated and compared with the statistical data. The yield simulation results are linked with spatial data on rice sowing time to create a map of yield distribution.

Mapping the progress of rice sowing and rice yield

The Normalized Different Vegetation Index (NDVI)

The time series MODIS remote sensing images analyze the current rice crop status and sowing progress based on spatial and temporal NDVI values. The NDVI combines the visible, near-infrared (NIR), and red (R) spectrum bands.

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \qquad (1)$$

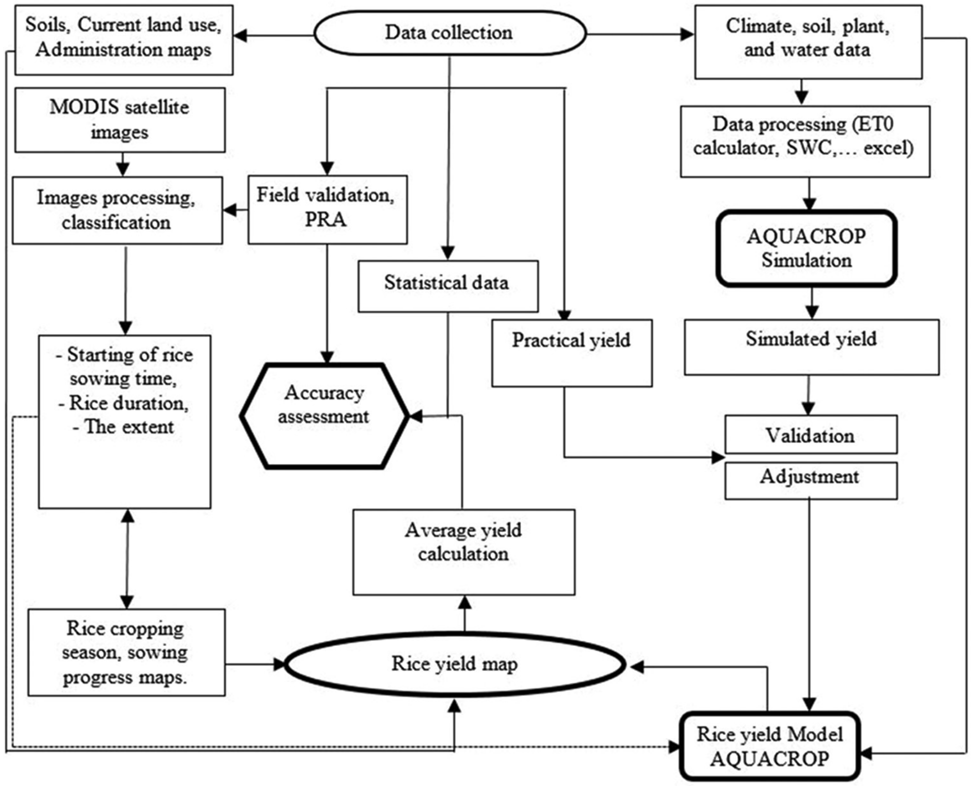

Fig 1. A flowchart of the processes in the procedure.

Fig 2. (a) Fiel data validation. (b) Rice growing measurements.

In which:
+ NIR is the reflection spectrum of the near-infrared band
+ R is the reflection spectrum of the red channel
+ $-1 < NDVI < 1$

Table 1: Characteristics of locally cultivated rice cultivars

Characteristics	Information	Characteristics	Information
Growing duration	90-100 days	Flowering days	65-70 DAS
Germination days	4-5 DAS	Flowering duration	4-5 days
The maximum coverage days	42-50 DAS	Mature days	90-100 DAS
Average seed weight used	120-150 kg/ha	Ripening days	70-77 DAS

DAS Days After Seedling/Sowing (Source: Research Institute of the Mekong Delta, 2010).

Delineation of the rice growing stages and rice yield

The time series NDVI values were generated and defined to determine the relationship between NDVI indices and rice growing phases (Son et al., 2014). NDVI values were low early on, steadily increasing until they peaked at the tillering stage and then beginning to decline as rice grew and was harvested (Fig. 5). Finally, the rice growing stages map was combined with the simulated rice yield to create the rice yield map.

RESULTS

Rice yield simulation

The AquaCrop model was used to simulate rice yield. The Harvest Index (HI_0) is calibrated based on the combination

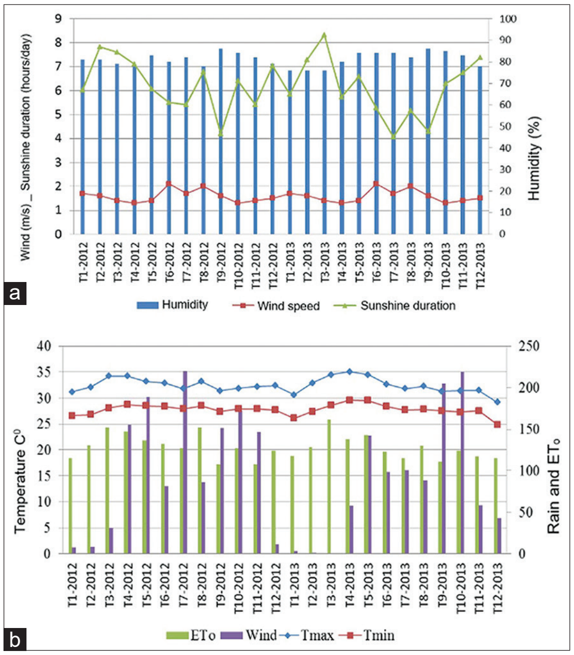

Fig 3. (a and b) The province of An Giang's weather characteristics of 2013. (An Giang Statistical Office, 2013).

of output and data collected to use the model to simulate approximate reality. The practical field data interest was collected at two points on the acid sulfate and alluvial soils to calibrate the harvest index (HI_0) and produce a model that closely corresponds to reality; predicted and statistical yields are combined with field data acquired at two sites. Soils belong to acidic and alluvial groups. These corrected data are employed to simulate yield and create rice yield maps.

Fig. 6 depicts the two research locations' predicted rice yield for the 2013 cropping season. In the DinhThanh village of ThoaiSon district, the Winter-Spring crop yield was 7.6 tons/ha, more significant than the rice crop yields of about 1 ton/ha in the Autumn-Winter and Summer-Autumn seasons. Otherwise, the rice yields are lower than in alluvial areas in LuongAnTra, TriTon district, and other acid-sulfate soils in the LongXuyen Quadrangle. As a result, the harvest yield is roughly 1 ton/ha lower than rice productivity in the ThoaiSon district's DinhThanh village. Hence, the variance between expected and actual

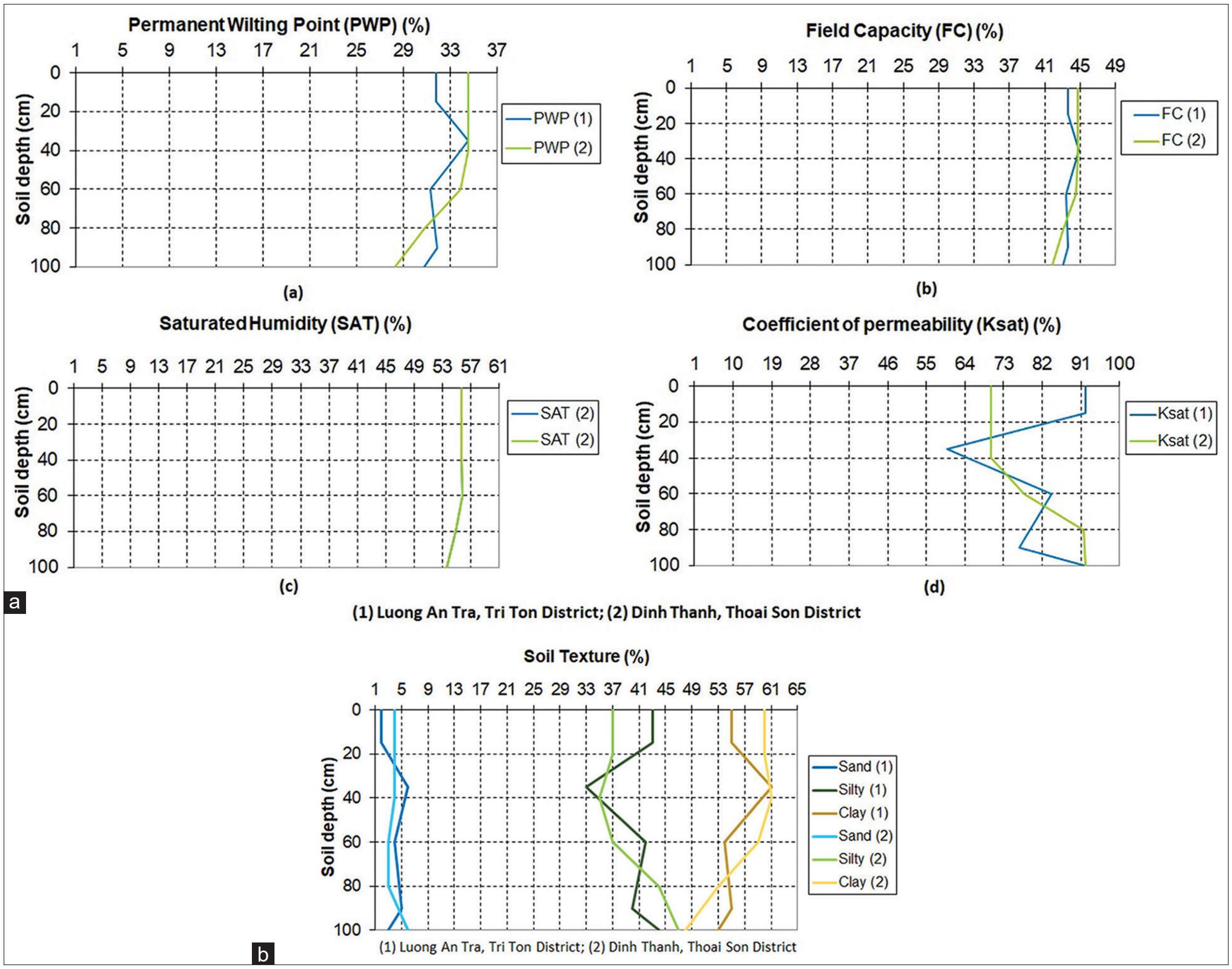

Fig 4. (a) Permanent wilting point (PWP), Filed capacity (FC), Saturated humidity (SAT), and coefficient of permeability of two location soil profiles, (1) Luong An Tra and (2) Dinh Thanh villages. (b) Soil texture at different soil depths of two locations. (1) Luong An Tra, and (2) Dinh Thanh villages.

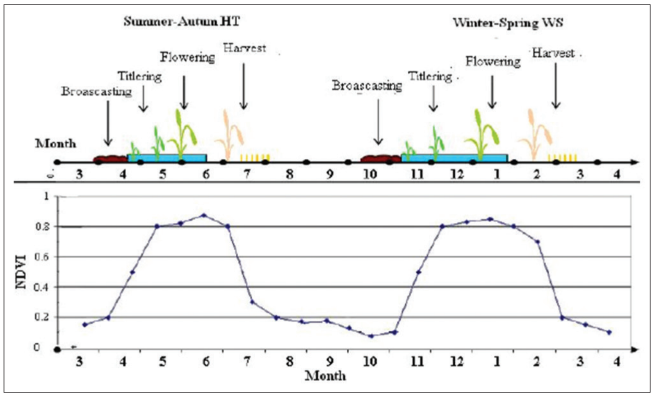

Fig 5. NDVI change at different rice growing stages of double two rice cropping seasons Tran Thi Hien and Vo Quang Minh, 2010.

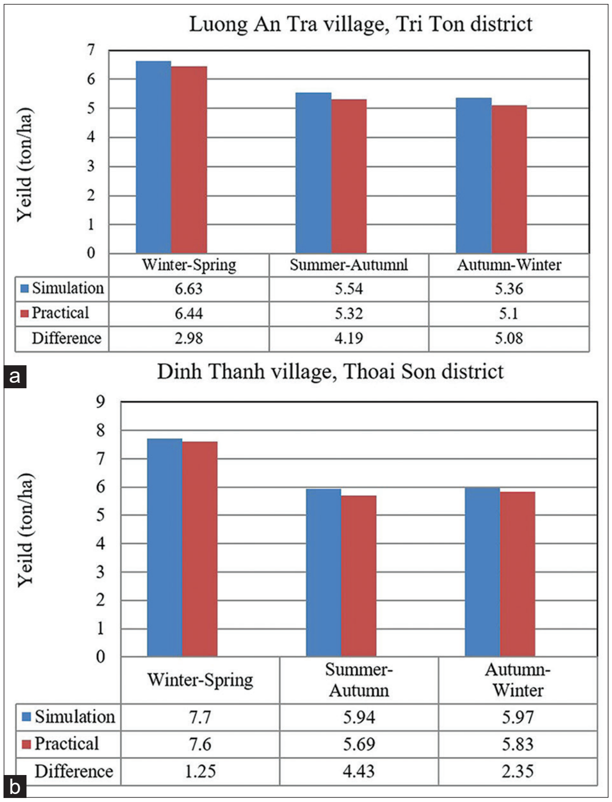

Fig 6. The practical and simulation yields in different seasons in two locations: (a) Luong An Tra and (b) Dinh Thanh villages.

rice yields is 1% to 5%. The average anticipated yield for each district was calculated and compared to the actual yield and output to determine the study's applicability. Fig. 7a shows the relationship between practical and simulated yields ($R^2 = 0538$). While Fig. 7b shows the R^2 between the interpreted and statistical areas ($R^2 = 0.89$).

Monitoring of rice sowing

The canopy absorbs red light for healthy plants, reflects more near-infrared light, and has a high NDVI value (Kham et al., 2007). The image processing results show that NDVI value gradually increases with the increase in plant cover, biomass, tree height, etc., reaching a maximum of 1. This intermediate evaluation makes it possible to distinguish the seasonal features of materials like biomass, leaf area index (LAI), and photosynthetic capacity.

These traits are essential and heavily influenced by the type of plant cover, the weather, physiological traits, biochemical processes, and pests. Using the approach suggested by Hien & Minh (2010), the Winter-Spring crop's 2012–2013 map was created, showing the progress in the province of AnGiang (Fig. 8). It shows that the rice sowing starts at the end of Oct 2012 and lasts until Jan 2013 during the Winter-Spring crop. The beginning date of sowing separates three stages:

Stage 1: Beginning around the end of October and lasting until the first week of November, particularly in the districts of An Phu, Tinh Bien, and Tri Ton, where rice is grown for two crops, as well as in a small region of PhuTan where triple rice crops are grown.

Stage 2: Most of the Winter-Spring rice season lasts from the second week of November to the fourth of December. Most of the province's rice-growing regions are concentrated there.

Stage 3: is divided into three-crop rice production regions that underwent their final sowing in the first half of January 2013, located in PhuTan, ChoMoi, and ChauPhu districts.

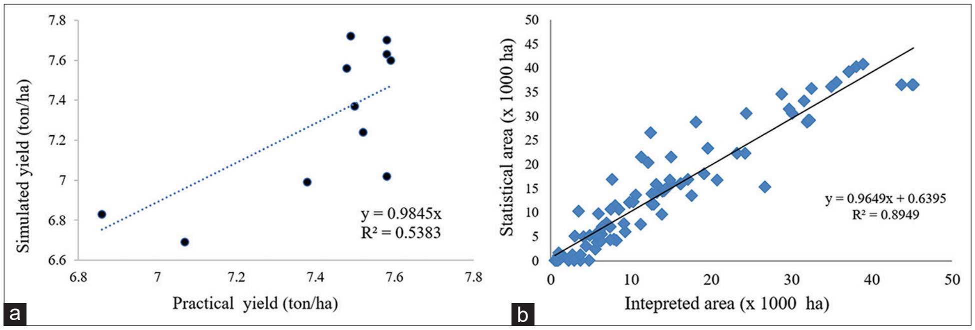

Fig 7. (a) The relationship between statistical and predicted rice yield in the Winter-Spring cropping season 2012-2013 study area. (b) The relationship between statistical and predicted rice sowing date area in the Winter-Spring cropping season 2012-2013 study area.

Table 2: The predicted and statistical rice yield and production of Winter-Spring in the 2012-2013 cropping season

No.	District	Rice yield			Rice production		
		Statistical (tons/ha)	Predicted (ton/ha)	Difference (%)	Statistical (ton)	Predicted (ton)	Difference (%)
1	TriTon	6.83	6.86	0	278,548	276,568	-1
2	TinhBien	6,69	7.07	6	108,350	114,902	6
3	ChauDoc	6,99	7.38	6	48,924	53,166	9
4	AnPhu	7.02	7.58	8	106,447	108,698	2
5	TanChau	7.72	7.49	-3	90,339	96,099	6
6	PhuTan	7.56	7.48	-1	169,185	163,704	-3
7	ChauPhu	7.63	7.58	-1	281,808	259,059	-8
8	ChoMoi	7.37	7.50	2	123,179	141,526	15
9	ChauThanh	7.60	7.59	0	221,743	221,379	0
10	LongXuyen	7.24	7.52	4	38,883	44,263	14
11	ThoaiSon	7.70	7.58	-2	281,627	285,330	1
Whole province			7.35	1		1,766,289	1

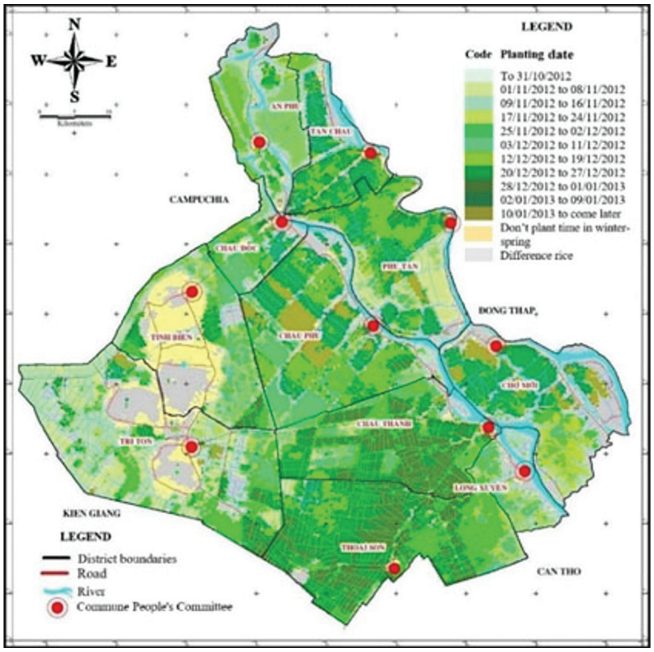

Fig 8. The rice sowing progress in the study area from October 2012 to January 2013.

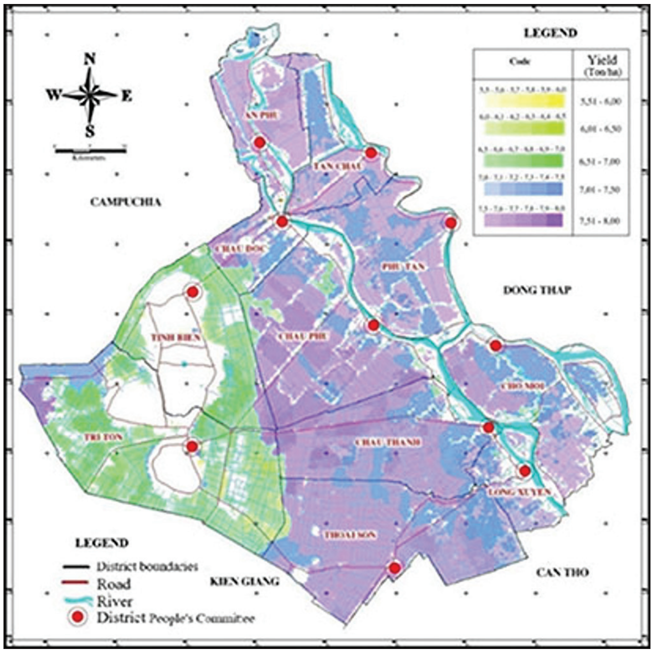

Fig 9. Rice yield distribution in the study area of Winter-Spring in the 2012–2013 cropping season.

Mapping the rice yield

Maps of the soil and the rice growth stages are combined to create mapping units. The results of remote sensing interpretation were linked to the Aquacrop model result to delineate the rice yield distribution. Fig. 9 shows the Winter-Spring rice yield map for 2012–2013, and each map unit contains information about the weather, crops, and soil qualities.

According to the findings, rice yields in the LongXuyen quadrangle's alkaline TinhBien and TriTon districts vary from 5.8 to 6.8 tons/ha. The maximum production of 7.8 tons/ha is primarily spread in the ChauThanh and ChauPhu districts, a portion of the ThoaiSon district, and the area bordering ChauThanh and ChauPhu. The rice yield is lower than on alluvial soil, about 6.5 to 6.8 tons/ha. However, the rice yield is 7.2 to 7.8 tons/ha in the Tinh Bien, TriTon, and Thoai Son districts.

According to Table 2's findings, the deviation rate between statistical yield and interpretation varies from -6% to 8% at the district level but only 1% at the provincial level. Therefore, the research's conclusions can forecast rice yield and production and provide suitable measures for food security.

CONCLUSION

The study concludes that it is possible to simulate the distribution of rice yield over the lands using the Aquacrop rice crop model in combination with remote sensing and a geographic information system based on the properties of soils. The progress of the rice sowing map is delineated from the remote sensing interpretation and the simulation findings of rice production from the Aquacerop model.

The simulation results delineate the rice crop map for the demonstrated area. Each district's average yield is calculated and compared to statistical productivity, showing a range of -3 to 8% between two periods. The province as a whole has a low difference rate. The simulation and delineation of rice production using remote sensing and crop models is a solid strategy for yield prediction and improving the country's or region's agricultural management plan. The quality of the input data, including soil weather and remote sensing, affects the accuracy of the results.

ACKNOWLEDGMENT

The annual study, code B2019 TCT 06, is supported by the Ministry of Education and Training, CanTho University, and the VLIR (CTU-Belgium) project, respectively.

Authors' contributions

Vo Quang Minh: Supervision, write an overview, read and edit the manuscript, final correction and approval Tran Thi Hien: Data collection, processing, reading, and editing manuscript.

REFERENCES

Dente, L., G. Satalino, F. Mattia and M. Rinaldi. 2008. Assimilation of leaf area index derived from ASAR and MERIS data into CERES-Wheat model to map wheat yield. Remote Sens. Environ. 112: 1395-1407.

Hansen, J. W., A. Potgieter and M. T Tippett. 2004. Using a general circulation model to forecast regional wheat yields in northeast Australia. Agric. Forest Meteorol. 127: 77-92.

Hien, T. and V. Minh. 2010. Modi's Remote Sensing Image Tracking the Progress of Sowing Seeds on Rice Land in the Mekong Delta. In: Proceedings of the National Conference on GIS Applications. Agriculture Publishing House, Vietnam, p. 85-93.

Jongschaap, R. E. E. 2006. Run-time calibration of simulation models by integrating remote sensing estimates of leaf area index and canopy nitrogen. Eur. J. Agron. 24: 316-324.

Kham, D., B. Giang, C. Thu and N. Huyen. 2007. Using Multi-temporal Remote Sensing Data to Evaluate Changes in Vegetation Cover Index and Some Analysis on Rice Season and Growth Status in the Red River Delta and the Mekong Delta. The 10th Scientific Conference of the Institute of Hydrometeorological Sciences.

Qin, J., S. Liang, S. Li and J. Wang. 2008. Development of the contiguous model of the canopy radiation transfer model to study the sensitivity and inverse of the leaf area index. IEEE Trans. Geosci. Remote Sens. 46: 2028-2037.

Raes, D., S. Pasquale, C. Theodore and F. Elia. 2011. Reference Manual, Chapter 2-AquaCrop, Version 7.0-August 2022. FAO, Italy, p. 385.

Raes, D., P. Steduto, T. C. Hsiao and E. Fereres. 2009. AquaCrop-The FAO crop model to simulate yield response to water: II. Main algorithms and software description. Agron. J. 101: 438-447.

Rouse, J., R. Haas, J. Schell and D. Deerin. 1973. Great Plains Vegetation System Monitoring with ETRS. In: Proceedings, Earth Research Technology, Satellite-1 Symposium. Available from: https://www.indexdatabase.de/db/r-single.php?id=47

Setiyono, T. D., E. D. Quicho, L. Gatti, M. Campos-Taberner, L. Busetto, F. Collivignarelli, F. J. García-Haro, M. Boschetti, N. I. Khan and F. Holecz. 2018. Spatial rice yield estimation based on MODIS and sentinel-1 SAR data and ORYZA crop growth model. Remote Sens. 10: 293.

Son, N. T., C. F. Chen, C. R. Chen, H. N. Duc and L. Y. Chang. 2014. A phenology-based classification of time-series MODIS data for rice crop monitoring in mekong delta, Vietnam. Remote Sens. 6: 135-156.

Steduto, P., T. C. Hsiao, D. Raes and E. Fereres. 2009. AquaCrop-the FAO crop model to simulate yield response to water: I. Concepts and underlying principles. Agron. J. 101: 426-437.

Thu, T., N. Hoang and N. Qui. 2015. Using the AquaCrop model to simulate the yield of soybeans grown under the conditions of using outdoor water. J. Agric. Rural Dev. J. Agric. Rural Dev. 19: 47-53.

Tuyen, N., P. Toan, N. Chiem, N. Qui, D. Nhan and V. Tri. 2017. Simulation of yield and irrigation demand for maize (*Zea Mays* L.) in the dry season in flooded areas in Chau Phu district, An Giang province. J. Agric. Rural Dev. 6.

Vanuytrecht, E., T. Hsiao, E. Fereres, L. Heng, M. García-Vila and P. Mejías. 2014. AquaCrop: FAO'S crop water productivity and yield response model. Environ. Model. Softw. 62: 351-360.

Wheeler, T. R., P. Q. Craufurd, R. H. Ellis, J. R. Porter and P. V. Vara Prasad. 2000. Temperature variability and the yield of annual crops. Agric. Ecosyst. Environ. 82: 159-167.