MAPPING AND MONITORING THE RICE CROP IN VIETNAM: EXPERIENCED USING RIICE TECHNOLOGIES

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ABSTRACT: The Remote sensing based Information and Insurance for Crops in emerging Economies (RIICE) project (2013-2021) is a collaborative initiative between the International Rice Research Institute, SARMAP, Ministry of Agriculture and Rural Development, Vietnam. The project makes use of Earth Observation technology to regularly and timely monitor rice area and yield. These are the underlying seasonal information produced by RIICE technologies at the commune level in seven provinces since 2016. This study summarizes the methodological development carried out to produce detailed maps of rice area, start of season, and yield using RIICE technologies for the case of study of seven provinces in the main rice regions of Vietnam. For the purpose of this study results of the last three years from 2018-2020 were illustrated and discussed. The rice area was verified with a deviation that varied from 2.2 to 9.5%. On the other hand, rice yield estimates were compared with the reported statistical data and it shows an agreement of more than 90% at the province level. With RIICE's products being utilized by BaoViet, insurance products/schemes have been implemented and being practiced in rice crop insurance. This shows that RIICE technologies are a useful tool for rice monitoring and possible application to agricultural crop insurance.

1. INTRODUCTION

Rice production plays an important role in the agricultural production structure of Vietnam, rice yield and rice production are expected from the middle of the crop to have a consumption plan for farmers and managers. However, the cost for the actual investigation of the growth of rice takes a lot of time and human resources. Many researchers (Lam-Dao et al., 2009; 9; Setiyono et al., 2018; Phung et al., 2020) pointed out that remote sensing image data is suitable for agricultural monitoring in general and rice crop monitoring in particular in tropical regions such as Vietnam. Besides, with the strong development of predictive models, the estimation of rice yield has been carried out by many studies with both optical and Radar images (Peng et al., 2011; Holecz et al., 2015). Optical remote sensing image data has been widely used for the purpose of monitoring and estimating productivity in the world and in Vietnam, Kham et al. (2011) built a model to predict rice yield and output in the Red River Delta using MODIS NDVI image data but affected by cloud. On the other hand, many authors have used radar images to monitor the time of sowing (Nelson et al., 2014; Phung et al., 2020), according to which the strongest growth time of the crop is peak growth and index correlation. rice growth with photo.

Vietnam is one of the most rice exporting countries. However, agricultural production is impacted by many risks due to natural disasters (storms, floods, droughts and salinity) that cause many damages to farmers. Although agricultural insurance has been issued by the Vietnamese government since 2011 (The Prime minister, 2011), the mechanism and method of insurance implementation are still difficult, the implementation is thus still limited.

To serve in agricultural management and support for insurance of rice, the Remote sensing based Information and Insurance for Crops in emerging Economies (RIICE) project started in 2013. This is a collaborative initiative between the International Rice Research Institute (IRRI), SARMAP (a Switzerland-based remote sensing company), Ministry of Agriculture and Rural Development (MARD), Vietnam and is funded by Swiss Agency for Development and Cooperation (SDC). RIICE technologies relies on the integration of MAPcape-RICE® and Rice Yield Estimation System (RiceYES) softwares. MAPscape-RICE® uses the Synthetic Aperture Radar (SAR) to detect rice areas, the start of season (or planting) days, and the Leaf Area Index (LAI) while RiceYES uses ORYZA crop growth simulation model (Bouman et al., 2001) to provide spatially explicit yield forecast and end-of-season estimates at harvest time. Regular crop monitoring was made possible by freely available Sentinel-1 Synthetic Aperture Radar (SAR) data provided through the Copernicus initiative of the European Space Agency (ESA), every 12 days. These images are not sensitive to clouds and are well suited to map rice crops, particularly in Asian countries where cloud conditions are an issue, particularly during the wet/rainy season.

Though. rice monitoring activities in Vietnam started in 2013, the data that will be shown and discussed in the paper will be focused on the last three years of the dominant season. For An Giang, Dong Thap, Nam Dinh, Thai Binh, Nghe An and Ha Tinh, the dominant season is the Winter-Spring while Summer-Autumn is the dominant season for Binh Thuan. This paper summarizes the methodological development carried out to produce detailed maps of rice area, start of season, yield and its application in insurance in the case study in 7 provinces located in three regions of North, Center and South of Vietnam.

2. MATERIALS AND METHODOLOGIES

An overview of the RIICE service is shown in Figure1. Rice area, emergence/transplanting date, phenological monitoring, and Leaf Area Index (LAI) are determined/inferred exploiting remote sensing intensity time-series, while yield is estimated using the latest version of ORYZA, a crop growth model simulating rice growth based on rice crop growth, crop management, daily weather and soil data. The RiceYES interface integrates the remote sensing derived information including rice crop location, LAI and Start of Season (SoS) dates and non-remote sensing information to generate yield estimates spatially. Rice production (area multiplied by yield) is calculated at a given administrative level and delivered two times per season (mid-season and end-of-season). Rice area is provided in key phenological moments enabling crop monitoring through the season, while yield is forecasted at mid-season and estimated at harvest time.

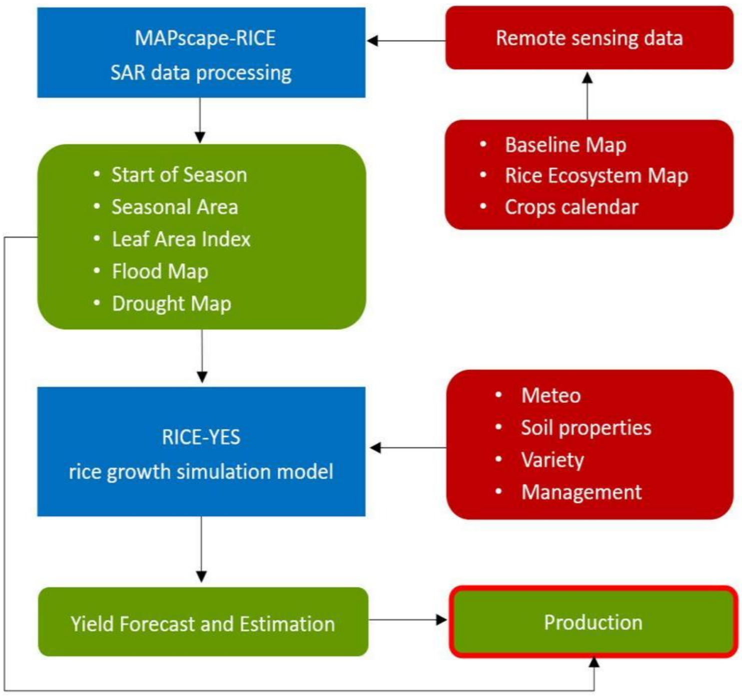


Figure 1. Methodology

2.1 The study area

Since 2013 Vietnam has been part of the rice monitoring activities under the RIICE project. Initially, it started in two provinces, Nam Dinh and Soc Trang, representing the Red River and Mekong River Delta, respectively.

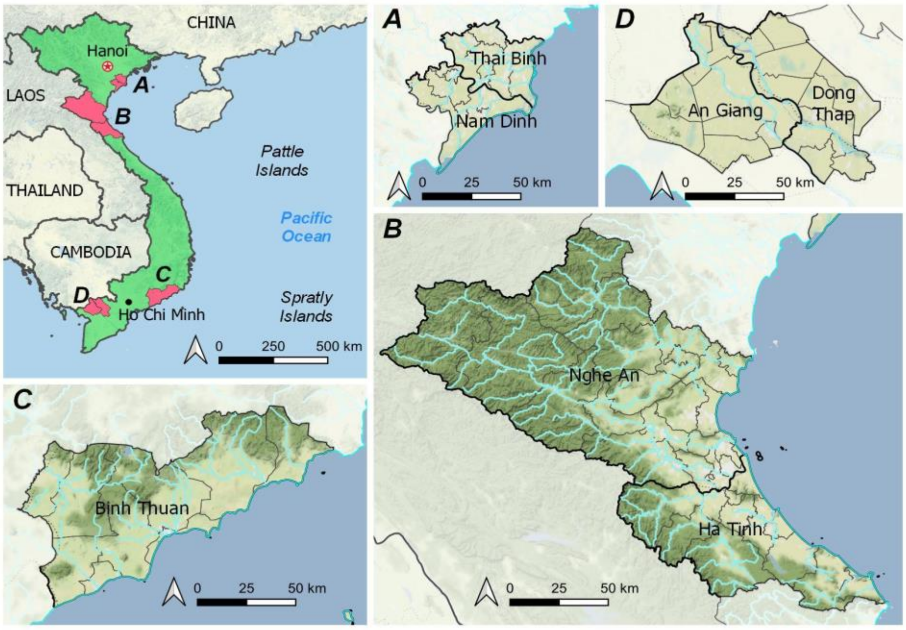


Figure 2. Location of the rice monitoring activities

Due to the good feedback about the project the rice monitoring activities expanded to other provinces, covering the whole Mekong River Delta and Red River Delta. Starting from the 2019 cropping season, 7 provinces namely Nam Dinh and Thai Binh in the Red River Delta, An Giang and Dong Thap in Mekong River Delta, Nghe An and Ha Tinh in the North Central Coast Region and Binh Thuan in the South Central Coast Region (Figure 2) were chosen to represent the different rice ecosystem in Vietnam as a pilot for a new insurance scheme based on RIICE data. Over these provinces, rice area/yield estimates at the commune level from 2016 to present have been generated.

2.2 Data

2.2.1 Satellite data

To generate the rice products, the study used multi-temporal Synthetic Aperture Radar (SAR) images from Sentinel-1 (C-band, vv and vh polarization SAR with 20 m spatial resolution and 6/12 days temporal resolution) and Sentinel-2 (multispectral optical data with 10 m spatial resolution and 5 days temporal resolution) from the Copernicus Programme of European Space Agency (ESA), and LANDSAT-8 (multispectral optical data with 30 m spatial resolution and 16 days temporal resolution) from the National Aeronautics and Space Administration (NASA) for rice area and rice seasonality and for yield estimation.

2.2.2 Field data

In general, there are two main ground data collections conducted within the season. First field data collection is conducted during the early part of the cropping season to collect information on the start of season of rice and other seasonal crops. This is done primarily to validate the start of season coming from remote sensing and what is actually happening in the ground. Another field data collection was conducted towards the end of the season for rice and non-rice validation. The second fieldwork is to evaluate the accuracy of the rice area maps. Information such as field coordinates, planting dates, crop establishment methods (for rice), crop stage, types of crops, expected time of harvest, ecosystem, and geotagged photos were collected. During the initial phase of the RIICE project, field data collection was rigorously done. However, given the limitations in terms of mobility due to the COVID-19 pandemic, ground data collection is limited during the 2020-2021 cropping seasons.

2.2.3 Other inputs in yield estimation

In yield estimation, additional data such as daily weather information, varietal characteristics and crop management were also used in generating yield estimates. The weather data which includes solar radiation, wind speed, and vapor pressure, minimum and maximum temperature and rainfall were used in the model. The weather information comes from NASA POWER (a publicly available global weather data produced by NASA Langley Research Center Power Project). Another input is the soil information which was obtained from the World Inventory of Soil Emission potential (WISE) dataset and Harmonized World Soil Database (HWSD) were used in the model. Similarly, field information, particularly crop management practices (amount of nitrogen fertilizer application per hectare, irrigation management, and crop establishment) were also used in the model. Likewise, maturity duration and phenological characteristics of the popularly grown varieties in the area were also used in the model.

2.3 Methods

2.3.1 Rice area and Start of Season detection

An automated processing chain is followed to convert the Sentinel-1 Single Look Complex or Ground Range time-series into terrain geocoded intensity values. The customized functionality is a module within MAPscape-Rice, which includes the following steps: strip mosaicking, image co-registration, multi-temporal speckle filtering, terrain geocoding, radiometric calibration and normalization, Anisotropic Non-Linear Diffusion (ANLD) filtering, and temporal smoothing.

The rice crop calendar drives the identification of the effective cultivated seasonal rice area. Nevertheless, other factors like the existence of other crops, the various crop practices and ecosystems may make it difficult – sometimes significantly – its correct assessment. For this reason, prior to the rice area generation, a Baseline Map and, where needed, a Rice Ecosystem Map are produced. The data sources for the Baseline Map generation are temporal-spectral descriptors derived from multi-annual Sentinel-1 intensity time-series and, when available – in principle limited to the Dry Season – multi-temporal Sentinel-2 and Landsat-8 data (Holecz et al., 2015). Based on ground samples of the various land covers, the most uncorrelated temporal-spectral are selected and used in a Decision Tree classifier. Typically, the Baseline Map includes cropland, permanent and temporary water, wetlands, permanent vegetation, and potential rice area per season. It is worth mentioning that temporal-spectral descriptors have an agronomic meaning (Nelson et al., 2014), hence, in turn, they are valuable parameters for the knowledge-based rice detection algorithm.

The knowledge based rice detection algorithm, originally proposed in Nelson et al. (2014) for X-band HH data and adapted to C-band VV/VH data (Campos-Taberner et al., 2017) is then applied to the intensity time-series to identify the rice area and SoS. The rice identification algorithm, which is exclusively applied on pixels belonging to potential rice as per the Baseline or Rice Ecosystem Map, is based on a set of rules defined using a priori knowledge on the rice calendar, crop practices, and agro-ecological conditions. The main rules are as follows:

1. Rice exclusion condition: If the average intensity is lower/higher than expected, or average intensity is below a minimum value for longer than expected or variation of intensity larger than expected, then it is not rice.

2. Presence of flooding conditions at the SoS: The temporal series is analysed starting from the first image acquisition to identify when intensity drops below a maximum value for SoS flooding; this time is set as SoS.

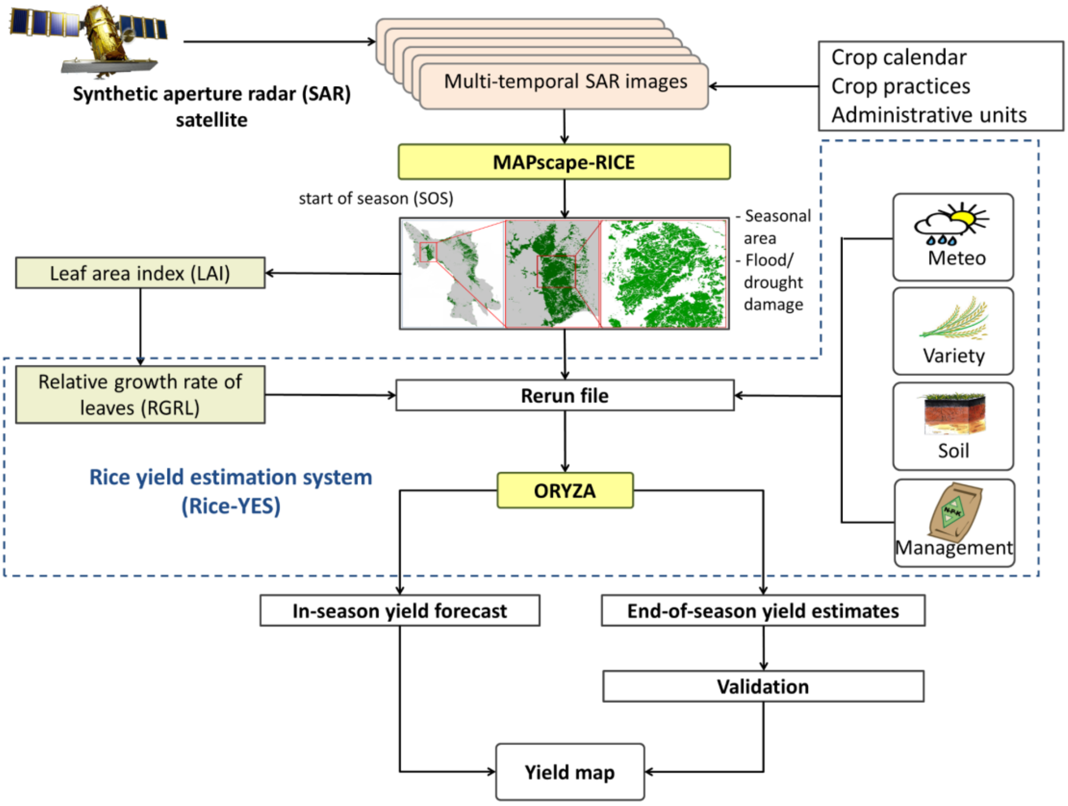
3. Confirmation of rice presence: After flooding detection, rice presence is confirmed if the intensity increases after SoS, which is consistent with the expected behaviour for rice crops (rapid growth of rice biomass after flooding).

Together with the rice cultivated area and the SoS, LAI – a measure of the photosynthetic active area – is a key parameter of the rice growth model. LAI values at the early leaf expansion stage, corresponding approximately to 33% of rice maturity progress (roughly 40 days after SoS for a 110-day duration rice variety), are inferred from intensity time-series using a modified version of the Water Cloud Vegetation Model (Attema and Ulaby, 1978) based on the empirical assumption of plant height and moisture dynamic described in Yang et al. (2009). It is worth mentioning that at the initial stage, an LAI calibration phase using ground data collected with PocketLAI or ceptometer is carried out (Francone et al., 2014). Given occasional fluctuations of inferred and in situ collected values, resulting LAI inferred time-series are smoothed using the LAI phenology approach based on partitioning of leaf expansion and senescence processes (Setiyono et al., 2011).

In times of extreme weather conditions like floods and drought, RIICE is also capable of assessing the extent of the affected area. Using the images from 5th to 23rd July 2018 flood map is generated based on the analysis of SAR data between pre and post-flooding events.

2.3.2 Yield estimation

Yield estimation involves several processes and uses different software- MAPscape-RICE®, ORYZA, Rice-Yield Estimation System (Rice-YES) and Quantum GIS (QGIS). The operational diagram as shown in Figure 3, illustrates the processes of the remote sensing-based yield estimation system starting from the satellite acquisitions to the integration of SAR data into ORYZA model until the generation of yield forecast or estimates and final yield map (in raster file) using the Rice-Yield Estimation System (Rice-YES).



(Source:Setiyono et al. 2018)

Figure 3. Processing diagram of yield estimates using SAR and ORYZA crop growth model

Rice-YES serves as an interface that integrates the remote sensing information and ORYZA model to generate yield estimates. ORYZA crop model is a process-based rice growth and yield estimation model that captures complex and dynamic interactions among weather, agronomic management, crop characteristics, and soil properties.

Leaf area index (LAI) acquired from SAR signature analysis is the main input that comes from remote sensing together with the start of season. The computation of the LAI is based on the water cloud model. LAI values at the early leaf expansion stage (at 33% of rice maturity progress, roughly 40 days after start of season for 110 days rice) are inferred from radar backscatter with parameters calibrated with in situ LAI measurements. Inferred LAI are finally used to calibrate the relative leaf growth rates parameters in ORYZA. Setiyono et al. (2018) provided a detailed explanation of how the system operates from the assimilation of SoS and LAI data from multi-temporal SAR images until the aggregation of yield estimates.

2.3.3 Validation of rice area and yield

Under the RIICE project, a standard protocol has been defined for collecting ground data. Two field campaigns were done during each monitored season: the first, within 2 months after the beginning of the season, for collecting calibration data about rice crop practices (transplanted, direct-seeded, irrigated, etc) and biophysical parameters such as Leaf Area Index; the second campaign, few weeks before the harvest, aimed to collect validation ground truth data. The validation points were classified into two land cover types - rice and non-rice. A confusion matrix was used to validate the rice area estimates against the collected validation ground truth points (Nelson et al., 2014). The overall accuracy of the rice/non-rice classification and the kappa value were recorded and an accuracy of 85% is the benchmark for RIICE products. It is worth mentioning that the amount of calibration ground data needed decreased significantly after the first two monitored seasons.

The validation of the yield estimates involved comparing the satellite-based yield results at the province or district level to that of the official yield reported coming from government agencies. For this study, the RIICE yield estimates were compared with the General Statistics Office (GSO) of Vietnam. Root mean square error (RMSE), normalized root mean square error (NRMSE), and agreement were calculated.

2.4 Implementation of insurance program using RIICE products

One of the important outcomes of the rice monitoring in Vietnam is that the data generated by RIICE project is now being used by insurance companies. NIAPP, as the lead agency, provided the final data to BaoViet. The estimates of rice area planted and yield is the main data or information being used.

The rice yield estimates at commune level during the last three years are used. The average yield (commune level) from these three years is calculated and used as reference yield for insurance pay-out schemes.

During the season, the rice area at commune level is provided to BaoViet within 30 days from the start of season (or the last day of insurance/sale cut-off) and this data is used as the rice area insured. On the other hand, yield estimate (commune level) is provided within 10 working days after the flowering stage (or peak of season).

In the case of rice damaged during the season brought about by the extreme weather conditions (floods, storm, drought), estimated yield will be provided to be compared with the approved/insured yield value. Area affected and yield loss will then be computed and process compensation, if necessary. The estimates on rice area affected and yield loss is assessed by NIAPP and submitted to BaoViet within 10 working days after the calamity.

Payment Method

The principle of insurance pay-out scheme is based on the estimated yield loss at harvest calculated using three-year historical average yield at commune level. If the estimated yield at harvest time is less than 90% of the historical average/insured yield, the reduction is compensated by insurance (Bao Viet, Bao Minh).

Payment = Affected area * yield reduction * average price of rice determined by people committees

where:

Yield reduction = 90% average yield - estimated yield at harvest

3. RESULTS AND DISCUSSIONS

3.1 Rice area and start of season maps

Figure 4 shows the rice area during the Winter-Spring seasons (2018-2020) of the 7 provinces provided by RIICE technology. The percentage difference for each cropping season is also analyzed and can be seen in the same Figure. The chart shows that the rice area of the two provinces in the Mekong Delta is superior to the remaining provinces with over 200,000 hectares per cropping season. The remaining provinces had less rice cultivation area with ranges from 63,000 ha to less than 100,000 ha. Binh Thuan province has the lowest rice area with a little more than 40,000ha per cropping season.

Figure 4 also shows the deviation between detected and statistical data, where the deviation ranges from 2.2 to 9.5%. The difference is low for the main rice-producing regions of the Mekong Delta with a common level of 2-3%. The difference of 3-9% in the remaining provinces.

Figure 5 shows the 2016-17 Winter-Spring season rice area map and the accuracy assessment results. Few weeks before the harvest around 600 locations have been visited to collect validation points, according to the RIICE validation protocol described in Section 2.3. The confusion matrix derived from the ground truth data shows the overall accuracy of 87.5% and kappa index of 0.75. It is worth mentioning that all the rice areas derived between 2013 and 2019 have been validated according to the RIICE validation protocol and the overall accuracies were above the selected benchmark of 85%. In 2020 and 2021, due to pandemic constraints, very limited fieldwork activities have been carried out and proper calibration/validation data were not collected.

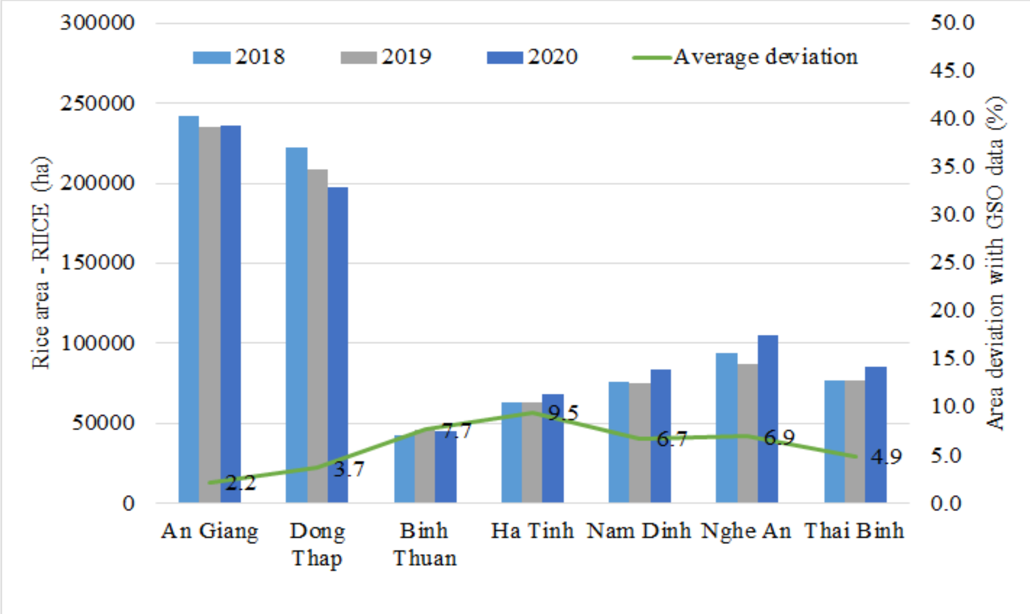
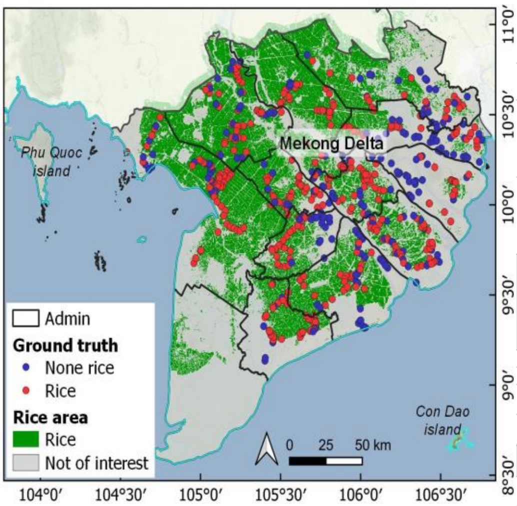


Figure 4. Rice area of the dominant seasons of the study area in 2018-2020



		Predicted class from the map		
		Rice	Non-Rice	Accuracy
Actual class from survey	Rice	321	45	87.7%
	Non-Rice	29	199	87.3%
	Reliability	91.7%	81.6%	87.5%
Average accuracy		87.5%		
Average reliability		86.6%		
Overall accuracy		87.5%	Good Accuracy	
Kappa index		0.75		

Figure 5. Rice area with confusion matrix, Winter-Spring season 2016-2017, Mekong River Delta.

Together with the rice area, the dominant/main crop season start dates are produced in MAPscape using the Cultivated Area and Seasonal Dynamic tool. The start of season days in the dominant seasons in 2020 is shown in Figure 6 for seven provinces. With both satellite Sentinel 1A and 1B, the SoS in these regions were detected weekly. During the Winter-Spring crop, An Giang and Dong Thap are mainly sowed from November to the end of January. However, in the Red River Delta and the Northcentral region the planting time is one (1) month later than in the south (from the end of January to the beginning of March). Nghe An and Ha Tinh started planting from mid-January to mid-February. However, for Binh Thuan, the Summer-Autumn crop is the main crop in the province and the sowing time is from mid-April to August.

As shown in the SoS maps, the beginning of the season varies significantly even within a single province, especially in the Mekong River delta and South Central region. This information, derived at a resolution of 20x20 meters, is important both for an accurate yield forecast and estimation and for a damage assessment in case of flood and drought.

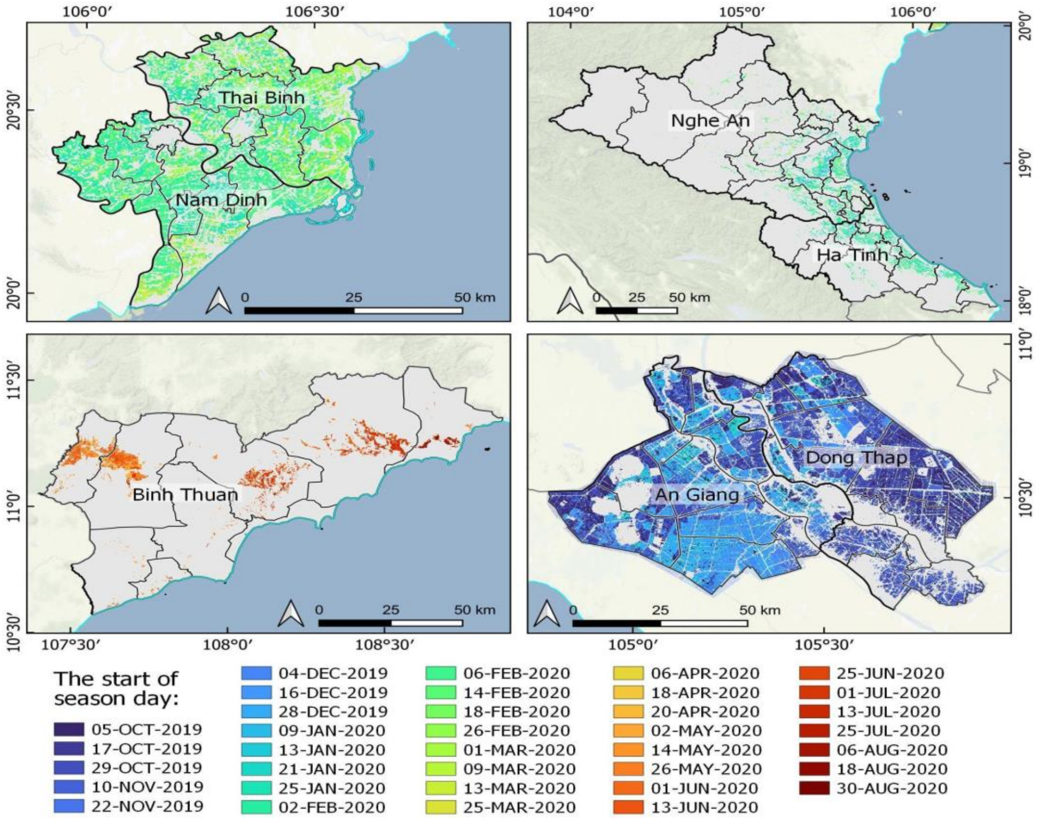


Figure 6. Start of season maps of dominant season of the study area in 2020

3.2 Yield estimation for rice production

The estimated yield map of the dominant crops during the 2018-2020 in the study area is shown in Figure 7. Winter-Spring is the main crop in most provinces, thus the average yield is quite high. Especially in the Mekong Delta and the Red River Delta, the average yield at the commune level was more than 7.0 tons/ha for An Giang, Dong Thap, Thai Binh, Nam Dinh and Nghe An. However, due to unfavorable climatic conditions, the rice yield in Ha Tinh was around 5.5 tons/ha. For Binh Thuan province, the main planting season is the Summer-Autumn crop, with an average yield of over 6.0 tons/ha.

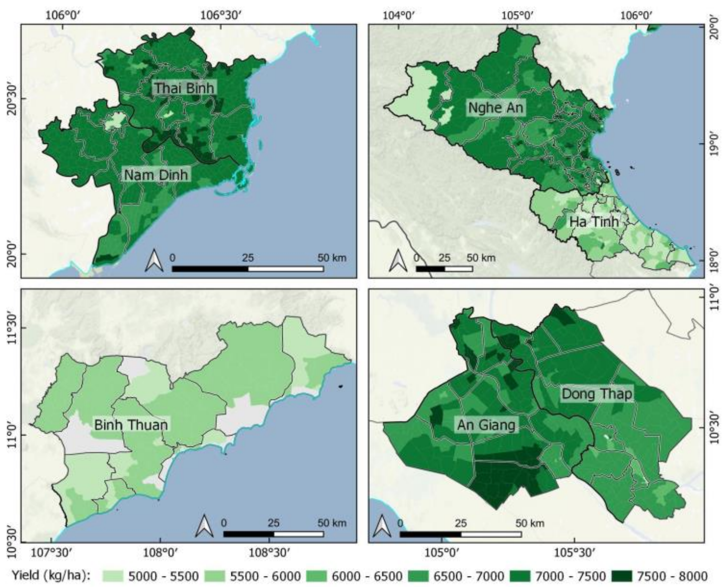


Figure 7. The yield maps of the dominant season of the study area in 2020

The variations in yield can be attributed to the different sowing dates within the province. A good example is the case of Dong Thap, wherein during the Winter-Spring cropping season the southeast part of the province had an earlier sowing date (early October). However, because of this early planting (that may have adverse impacts of change in weather) this part of the province has lower yield as compared to other areas.

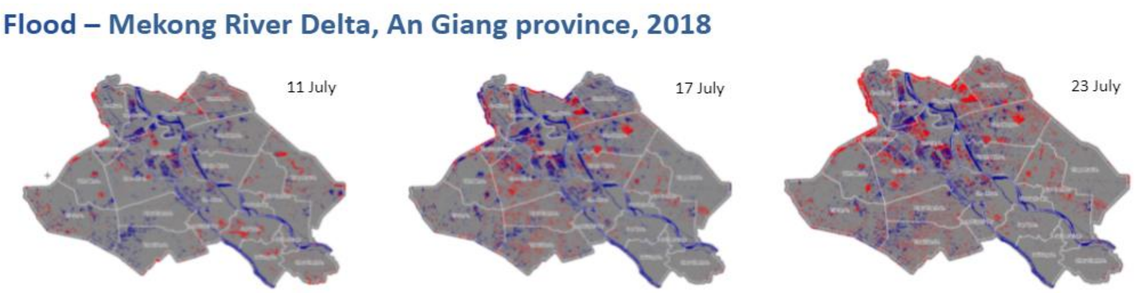
Table 1 shows the validation of 2018 to 2020 dominant cropping season estimated yield compared to the government's reported yield. Province level aggregation shows that yield estimates range from 5.42 t/ha (Binh Thuan) to 7.61 t/ha (An Giang). Among the seven provinces, Ha Tinh and Binh Thuan consistently have the lowest yield average at the province level from the 2018 to 2020 dominant season. This can be attributed to the different climate conditions, frequent water shortages, and poor soil quality in these areas as compared to other provinces. For Binh Thuan, it is also due to different season's yield estimates (Summer-Autumn) as compared to other provinces (Winter-Spring). Yield estimates RMSE range from 0.03 t/ha (Ha Tinh) to 0.66 t/ha (Binh Thuan). In terms of yield agreement between estimated and reported yield, it shows that six provinces have consistently above 90% agreement. The resulting agreement shows that SAR-based generated yield complemented well with the reported yield at the province level.

Table 1. Comparison of end-of-season yield and reported yield, dominant season, 2018 – 2020

Year/ Province	**2018**				**2019**				**2020**			
	A	B	C	D	A	B	C	D	A	B	C	D
An Giang	7.52	7.35	0.17	98	7.61	7.10	0.51	93	7.24	7.17	0.07	99
Dong Thap	7.14	6.99	0.15	98	7.16	6.99	0.17	98	7.01	7.24	0.23	97
Binh Thuan	5.42	5.22	0.20	96	6.04	5.44	0.60	89	5.74	5.69	0.05	99
Nam Dinh	7.16	6.95	0.21	97	7.20	6.94	0.26	96	7.12	6.94	0.18	97
Thai Binh	6.78	7.18	0.40	94	7.02	7.13	0.11	98	7.34	7.07	0.27	96
Ha Tinh	5.67	5.64	0.03	99	5.78	5.57	0.21	96	5.52	5.48	0.04	99
Nghe An	7.43	6.75	0.68	90	7.36	6.62	0.74	89	7.15	6.65	0.50	92

A = RIICE estimates (t/ha), B = Reported yield from Government Statistics Office, Vietnam (t/ha), C = RMSE (t/ha), D = Agreement (%)

Besides the regular area/yield monitoring, RIICE technology could be used for monitoring perils such as floods and drought. An example of flood assessment done in 2018 over An Giang province is shown in Figure 8. With the availability of the standard RIICE products (rice area and SoS maps), it was possible to map the extent of flood, and to easily detect the flooded rice area. Moreover, the flooded rice area has been disaggregated by the beginning of crop season dates using the information from the SoS map.



District	Area (ha)	Total rice area (ha)	Total flooded area (ha)	Total flooded rice area (ha)	Flooded rice area disaggregated by SoS date						
					06 04 18	12 04 18	18 04 18	24 04 18	30 04 18	06 05 18	12 05 18
Long Xuyen City	11401.4	3186	411.84	121.4	0	0	91	11.36	12.88	0.28	5.88
Chau Doc Town	10381.9	5075.16	711.44	416.56	0	0	124.2	186.24	45.04	42.92	18.16
An PHu D.	21693.9	10103.6	620.96	256.84	0	0	138.96	36.28	69.44	12.12	0.04
Tan Chau D.	16984.4	5408.24	669.52	46.2	0	0	16.12	5.64	3.96	13.6	6.88
Phu Tan D.	32687.7	12500.8	1940.2	371.92	0	0	19.92	64.52	33.24	77.36	176.88
Chau Phu D.	45192.6	26933.8	947.32	144.6	0	0	29.28	51.56	7.56	18.44	37.76
Tinh Bien D.	35388.9	14626.8	1027.96	600.36	0	0	173.32	256.24	133	18.16	19.64
Tri Ton D.	59967.7	25528.5	1610.08	426.04	0	0	111.76	54.16	56.4	126.72	77
Chau Thanh D.	35512.6	27632	220.2	111.24	0	0	44.84	16.96	22.52	9.92	17
Cho Moi D.	37014.9	9761.68	926.88	429.6	0	0	252.4	6.56	4.24	30.6	135.8
Thoai Son D.	46631.7	33262.4	471.2	220.88	0	0	107.96	44.8	13.04	10.92	44.16

Figure 8. Flooding detected in An Giang and Dong Thap in 2018

3.3 Application of RIICE products in agricultural insurance scheme

The cultivated area and average yield per cropping season of the 7 provinces for the years 2017-2020 have been provided to Bao Viet. Based on historical data the average yield for each village was calculated. Since then, agricultural insurance for rice has been implemented since 2020. In which, in 2020, Baoviet provides insurance products for the Summer-Autumn season in Nghe An with 102 communes in 8 districts (Yen Thanh, Dien Chau, Do Luong, Hung Nguyen, Nam Dan, Nghi Loc, Quynh Luu, Thanh Chuong) with a total area of 1,465ha for 7,219 households insured.

In the Summer-Autumn crop of 2021, Bao Viet had a contract for rice insurance at communes in 3 districts (HungHa, Kien Xuong and Tien Hai) in Thai Binh province with the total contract value around 74000 USD for 4,928 households insured.

Regarding damage payment, in the year 2020 in Nghe An province, Summer – Autumn crop, there was recorded a decrease in productivity due to the impact of natural disasters. Cases of compensation for damage to affected farmers in the amount of 146 million VND (nearly 7, 000 US$).

3.4 Experience in using RIICE technologies

In application, the main advantage of the RIICE technologies is the availability of user-friendly software, developed and customized since 2013 by software developers, modellers and agronomists: MAPscape and RiceYES. Both software is continuously updated to support new sensors (UAV and satellite).

One of the biggest challenges faced in this work was carefully detecting the rice area in regions where different crops with similar seasonal signals as rice were growing. With respect to this issue, significant improvements have been made by generating a reliable rice baseline map: the analysis of multi-annual Earth Observation time series data (SAR and optical) and the integration of ancillary data, together with the interpretation by agronomists expertises , led to obtaining accurate results.

Due to the characteristics of cultivation that depend on the irrigation system, in many provinces, there is a large difference in planting time for each season. For example, the case of early Winter-Spring crop cultivation in Dong Thap and An Giang. To handle such complex heterogeneity, the system is able to analyse long time series data and exploit the crop calendar information defined per each season and region; moreover, the analysis can be done at various extensions, based on administrative units or agro-ecological zones, making the system robust and flexible.

RiceYES is a powerful tool in RIICE technology that integrates remote sensing and non-remote sensing information. In this study, a big effort has been made to dramatically reduce the computational power and time needed for yield estimation at the pixel level. Now the yield can be estimated allowing the release of accurate information not only at the province and district levels, but also at the commune level. In fact, in the same province, there are many regions with different sowing dates, different rice varieties and different farming methods. In those cases, RiceYES was implemented for many regions with different rice varieties and implemented parameters and then aggregated to produce the final yield map.

4. CONCLUSION

In this study, we presented the RIICE methodology and its application in Vietnam. Generated rice area and yield data using RIICE technologies are proven over the years (2013-2021) and as illustrated in the rice area accuracy (2016-2017) and yield agreement with the dominant seasons of 2018-2020. The technology has been applied over the main rice production areas; the results demonstrate the system can be used in different ecosystems and can be extended at the national level. All the information is timely produced and delivered by NIAPP to MARD and is published through a dedicated web page and bulletins.

The information provided by RIICE has been also used for the implementation of a rice insurance scheme at Bao Viet Company for two provinces of the Red River Delta and promises to be expanded to other provinces in Vietnam in the coming seasons.

Upgrades are essential and on-going both in terms of methodology refinements and in terms of new data. With respect to Earth Observation data, the availability of Sentinel-1 every 6 days everywhere would contribute to more precise detection of the SoS, crucial for yield modelling; very high resolution time-series data (technically viable but costly) would improve the rice area in scattered and fragmented rice ecosystems. Concerning the yield component, key information which would improve estimates are the availability of real-time local weather data (currently weather data used are derived from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), the integration of a high resolution soil map and more detailed information on crop varieties and management practices. More systematic validation of yield assessment through crop cut experiments (CCE) will also provide a regional dataset to facilitate the objective evaluation of crop modelling improvements.

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