DEVELOPMENT OF A SATELLITE-BASED MODULAR MAPPING AND ASSESSMENT PROGRAM FOR RICE PRODUCTION FOR THE PHILIPPINES: THE MAPALAY PROJECT EXPERIENCE

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ABSTRACT: This study presents the development of a software module within the European Space Agency's (ESA) open source Sentinel Application Platform (SNAP) that classifies rice areas from pre-processed satellite remote sensing data with sufficient accuracy. The *Mapalay* methodology includes: (1) basic processing of S1A GRD (VH) images covering Bataan for 2017 Season 1: September 2016 to March 2017, and Season 2: May 2017 to September 2017, Sentinel-1 Toolbox tools (S1TBX), (2) rice area mapping using the Mapalay plug-in created, and (3) output assessment by comparing with corresponding rice maps and ground-validated monitoring field (MF) and rice-not rice (RnR) points acquired from the Philippine Rice Research Institute (PhilRice). The SNAP pre-processing workflow involves Application of Precise Orbits, Calibration, Layer Stacking, Multi-looking (20m x 20m), Speckle Filtering, and Terrain Correction. Pre-processed images were classified for Rice and Not Rice areas using a rule-based algorithm. MF points correspond to PhilRice -monitored rice areas from Start of Season to harvest. RnR points include rice areas and non-rice areas (e.g. corn fields). *Mapalay*'s rice classification outputs Leaf Area Index (LAI) band, Start-of-Season (SoS) band, filter flag band, and a Rice Classification band. Results show that, if "Rice" includes all features classified as Rice, Late Rice, and Early Rice, produced accuracies as high as 100% and as low as 90% when compared with MF points; and as high as 83.33% and as low as 40% when compared with RnR points are observed. Area-wise, results show an approximately - 37,000 hectare difference with PhilRice's classified rice map. If "Rice" only includes all those classified as Rice and Late Rice, accuracies as high as 70.59% and as low as 53.33% when compared with MF points; and as high as 66.67% and as low as 30% when compared with RnR points are observed. Area-wise, – 4,700 to – 8,700 hectare difference with PhilRice's classification is produced. Incorporating additional physical parameters (e.g. elevation) and use of other possible datasets (e.g. Sentinel-2) can be implemented in the future for improved rice classification performance.

1. INTRODUCTION

Rice is the basic staple food for the majority of the population in Asia. In the Philippines, rice production is important to food supply and economy. It had the biggest share among the country's agriculture commodities in terms of value, accounting for 26.2% in 2017. (BusinessWorld, 2018) Thus, the availability of accurate and timely accounting of rice production is an essential element in the planning, assessment, and management of rice in the country.

Satellite Remote Sensing technology has increased in popularity as a tool that can measure and monitor the Earth's surface. Remote sensing datasets have become a prime data source to be used as a tool for monitoring food resources focused on crop production for the last thirty years (Ducheyne, Tack, & Hendrickx, 2013). Of particular interest are radar active sensors which operate using microwave radiation, producing high-resolution imagery of the Earth's surface day or night, in all weather, penetrating through the clouds. With these capabilities, there would be a higher level of assurance that SAR data can be generated periodically, enabling measurements and change detection of large areas at regular intervals which can help the agriculture sector, in planning and support of rice production in the country. In fact, SAR has been used for rice mapping and monitoring in the Philippines since 2013 through the Remote Sensing-based Information and Insurance for Crops in Emerging Economies (RIICE) and the Philippine Rice Information System (PRISM) projects. Complementary, there are a lot of freely-available SAR data suitable for rice mapping and assessment. Of particular interest are Sentinel 1A (S1A) datasets from the European Space Agency (ESA). Sentinel 1A satellite was launched by ESA and operates at C-band (2.4 GHz), acquiring global coverage every 12 days since 2014.

The radar signal measured is called backscatter or sigma-naught (σ^0). The understanding of radar backscattering of paddy fields in relation to rice growth is a key concept because plant parameters such as height, leaf area index

(LAI), biomass, water content, and plant structure, are significantly correlated with radar backscatter. (Inoue, et al., 2002) The temporal variation of backscatter can be regarded as a function of rice crop growth. Yearly, the variation in the backscatter of rice is higher than any other agricultural crops. Before rice are planted, the paddies are flooded with water for land preparation, hence, the radar backscatter is low. The signal experiences specular reflection with undisturbed flat water and returns little to no signal back to the satellite. During the vegetative and reproductive phases of rice, the backscatter continuously increases until the crop reaches its maximum at the heading stage. As there are increase in the density, height, and biomass of the crop, the radar backscatter returning to the sensor also increases because more area is available for reflection of the radar signal via double-bounce and direct volume scattering. (Nguyen, et al., 2015)

The relationships that exist between rice crop characteristics and backscatter coefficients from different wavelengths have been used to derive different types of algorithms for classifying rice from SAR data. There are a lot of methods for extracting temporal features from the data by the means of using theoretical models, supervised classification algorithms, image ratio models, and rule-based classification approach. However, rule-based classification offers usage of smaller number of inputs and rules that can be quickly fine-tuned from site to site and season to season in the case of rice area mapping. It also considers varietal choice, crop establishment methods, and crop management practices in the development of a robust rice detection algorithm because they have a significant effect on the structure of both the plant and the canopy, water content, and the growth rate of the crop, as compared to the other available methods. (Nelson, et al., 2014)

Consequently, a computer software system that will process huge volumes of SAR data and enable rice area mapping will then be needed. For this matter, "Development of Satellite-based Modular Mapping and Assessment Program for Rice Production for the Philippines", also known as MAPALAY Project, aims to develop an open source software toolset for processing satellite remote sensing data that can produce accurate and timely information on rice production in the country. The chosen implementation platform for this project's rice classification algorithm is the Sentinel Application Platform - or SNAP. This is an open source software platform that has a collection of executable tools and Application Programming Interface (API) which is mainly developed by ESA to facilitate the utilization and processing of Sentinel 1, Sentinel 2, and Sentinel 3 datasets. The highlighted technological innovations of the SNAP environment are: Extensibility, Portability, Modular Rich Client Platform, Generic EO Data Abstraction, Tiled Memory Management, and a Graph Processing Framework. (European Space Agency, 2018)

The researchers aim to design the software application tool for rice classification as a plug-in within the SNAP software. Sentinel-1 Toolbox (S1TBX) in SNAP, which consists of basic processing tools, was explored and utilized for pre-processing S-1A Ground Range Detected (GRD) and VH-polarized imageries, prior to rice classification using the developed plugin. Since the software that will be used is open source, end-users can collectively save money paid for proprietary software system and the difficult task of constructing a new software can be avoided. Apart from the cost saving feature using this open-source software entails, it also opens the opportunity to collaborate and adapt other people's work into our own. Developers can see how the open source software works, modify and add to it in line with the needs of the end user. This is especially beneficial when working in a highly specialized field since general software solutions are often insufficient for our needs.

2. METHODOLOGY

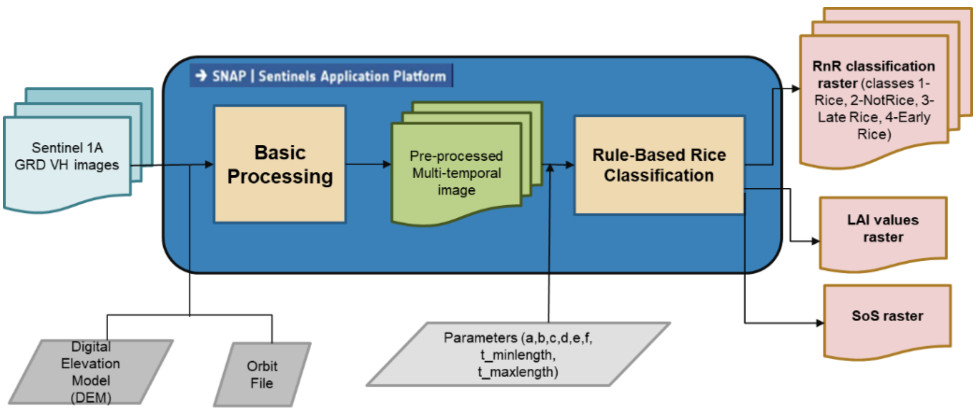


Figure 1. Overview of the methodology

2.1 Data Input

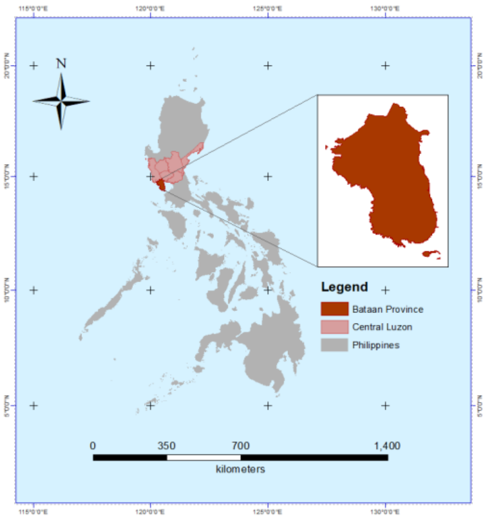


Figure 2. Location map of the study area

Multi-temporal Sentinel-1A Synthetic Aperture Radar (SAR) images were obtained from the European Space Agency (ESA) Copernicus Open Access Hub, previously known as Sentinels Science Data Hub, which provides systematic free access to Sentinel-1, Sentinel-2, and Sentinel-3 user products. Sentinel-1 mission operates in C-band frequency (8-4 GHz or 3.8 – 7.5 cm) and has a 12-day revisit period. All data obtained were Level-1 Ground Range Detected (GRD) in dual polarization (VV+VH) and Interferometric Wide (IW) swath mode with swath width of 250 km and with a geometric resolution of 5 m x 20 m. Level 1 GRD products has been detected, multi-looked, and projected to ground range using WGS84 ellipsoid model. (European Space Agency, 2018) The scenes covering Central Luzon were selected, covering the dates September 2016 to March 2017 of 2017 Season 1 (Wet Season) and May 2017 to September 2017 of 2017 Season 2 (Dry Season).

The Central Luzon region is an ideal project site for rice mapping purposes as it is the largest plain and the “rice granary” of the Philippines. This region covers the provinces of Bataan, Bulacan, Nueva Ecija, Pampanga, Tarlac, and Zambales. In this study Bataan province was used as the main test site in developing the algorithm and the software module in SNAP because of its size and it fits in just one scene for the dates covered, with no more need for mosaicking two images for it.

Corresponding rice maps and ground validated points for the study period were acquired from Philippine Rice Research Institute (PhilRice). These data were processed and collected by the Philippine Rice Information System (PRISM).

2.2 Processing

S1TBX tools were utilized to convert the multi-temporal S1A GRD pixel values into terrain-geocoded sigma-naught (σ^0) values. The basic processing chain include Apply Orbit, Calibration, Layer Stack, Multi-looking, Speckle Filtering, Terrain Correction, and Conversion to dB.

2.3 Rule-based Rice Detection Algorithm

For this phase of the MAPALAY project, a rule-based rice classification algorithm was developed based from the studies of (Holeczs, et al., 2013) and (Nelson, et al., 2014). This approach was preferred because it is simple, repeatable, and suitable for rapid rice mapping over a large area. It also only requires a few number of inputs which can be adjusted from site-to-site or season-to-season. The rules and parameters are derived from the relationship between the agronomic knowledge of rice crop and its corresponding backscatter from multi-temporal SAR data.

Parameters	***Description***
a	lowest mean
b	highest mean
c	maximum variation
d	maximum value at Start of Season
e	minimum value at tillering stage
f	minimum variation
$t_{minlength}$	minimum number of days of season
$t_{maxlength}$	maximum number of days of season
t_{last}	last date of temporal image
$t_{maxunderwater}$	maximum time underwater

Figure 3. List of parameters used and their descriptions

Figure 3 lists all the parameters used in the algorithm which were derived from acquiring the statistics of the σ^0 temporal signature of monitored rice fields. The mean, maxima, minima, and range of σ^0 were determined across all monitored rice fields per site. Other parameters such as t_*minlength*, *t_maxlength*, *t_last*, and t_*maxunderwater* correspond to a certain value. In agronomic perspective, t_*minlength* correspond to the period from start of season to rice flowering stage which can be set to 40 to 70 days; *t_maxlength* correspond to the average 120-day rice crop cycle; *t_last* correspond to the number of SAR images as input, usually 10-12 images to capture one rice cropping period of 120 days; and *t_maxunderwater* correspond to the maximum days of agronomic flooding which can be set to 40 to 50 days.

The algorithm developed checks every pixel of a multi-temporal σ^0 stack and applies the rules for rice classification. A rule first excludes all evident non-rice pixels which fall outside the thresholds defined by the parameters *a, b, c, f,* and *t_maxunderwater*. These pixels will be excluded as "Not Rice". Retained pixels are iteratively scanned to identify their Start of Season (SoS) and check if the σ^0 value at SoS is within the range as defined by parameter *d*. At this point, a pixel can be tagged for further analysis to qualify as "Rice" or to check if it is "Early Rice" or "Not Rice". The next rules check whether a pixel is "Rice" or Late Rice. If the temporal signature of a pixel is consistent with the trend expected from a growing rice crop from SoS to tillering whose minimum value is defined by parameter *e,* and if the projected End of Season date as given by *t = t_sos + t_minlength*, is beyond *t_last,* the pixel will be classified as "Late Rice". Pixels who pass this rule continue to the last condition which check if there are sudden drops in σ^0 in the whole temporal signature of the pixel. Analysis on this part depends on the time of its occurrence and depends on how it compares with parameter *a*. If there are no unexpected drops in σ^0 or drops in σ^0 greater than parameter *a*, the pixel will finally be classified as "Rice". Pixels who don't pass this condition is tagged as "Not Rice".

2.4 Plug-in development in Sentinel Application Platform (SNAP)

A plug-in within SNAP was developed to apply the rule-based rice classification to the multi-temporal σ^0 stack. Figure 4 shows the MAPALAY plug-in graphical user interface (GUI) in SNAP. The inputs on the I/O Parameters tab are the source product or the multi-temporal σ^0 stack and the desired file name and directory of the output. The output file format is BEAM-DIMAP. On the Processing Parameters tab, users just have to input the corresponding parameter values. "Start of Date in Band Name" is asked to determine where the date in the band name of an image begins. This is a simple method to extract image dates from their band name in the multi-temporal σ^0 stack. Once the values are filled, users can already run the process. Additional options include "RnR Mode" which just reclassifies the bands to Rice and Not Rice, and "Export Parameters to .xml" which generates an xml of the parameters to keep a record of them. The generated xml can be loaded as an input to the plug-in if the users want to use the same settings.

The outputs of this process are 4 rasters: Classification band, Start of Season (SoS) band, Leaf Area Index (LAI) band, and Filter flag band. Classification band is a raster with the four (4) classification: "Rice", "Not Rice", "Late Rice", and "Early Rice". SoS band reflects the identified date of SoS date of all pixels classified as "Rice", "Late Rice", and "Early Rice". LAI band contains the approximate LAI values for each rice pixels. Lastly, Filter flag band contains the rules where pixels passed or failed, used for debugging.

SNAP plugins are inherently written in Java, but by utilizing the *snappy* library, the core script can be written in Python. The current version of MAPALAY Rice Classification plugin was written using Python 3.4 and 2.7 in PyCharm (ver. 2018.1.4 Community Ed.). The Java structure was coded using IntelliJ IDEA (ver. 2018.1.6 Community Ed.) and built with Maven 3.5.4 incorporated into it.

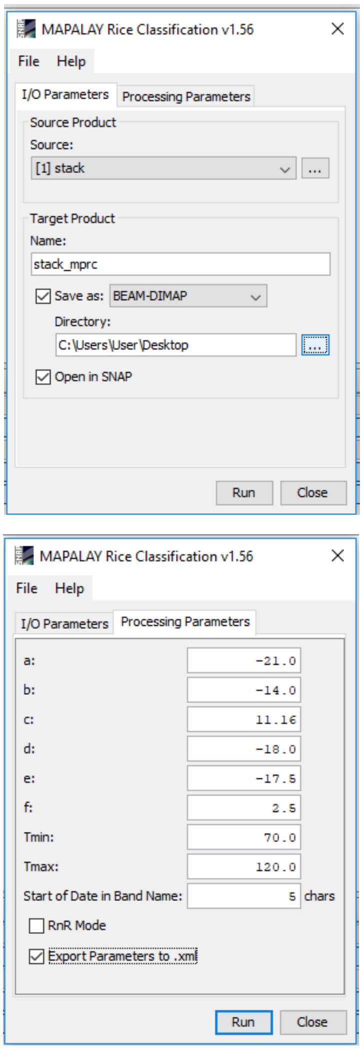


Figure 4. The MAPALAY plug-in interface in SNAP. (Top) I/O Parameters tab; (Bottom) Processing Parameters tab

3. RESULTS & DISCUSSION

Two comparison of the Rice – Not Rice (RnR) classification results were made. The first one (Part A) was done to test the MAPALAY plug-in's RnR classification performance using PRISM's multi-temporal stacked image for 2017 Season 1 of Bataan as input. The idea behind is to have the same input as PRISM prior to their rice classification using the MAPscape-RICE™ and see if the MAPALAY results were comparable. The second comparison (Part B) was done using the multi-temporal σ^0 stacked image for 2017 Season 1&2 of Bataan as processed in SNAP. This will present outputs based from the developed processing workflow in MAPALAY from processing of images to rice classification. Both comparisons to be presented will have the following computations:

1. Comparison of classification results in terms of area differences (has)
2. Confusion matrix using Monitoring Field (MF) points
3. Confusion matrix using RICE – Not Rice (RnR) points

Also, computations where Early Rice is not considered as "Rice" were included. This was based from experts saying, that there is no current way to strongly support if the Early Rice trend really signify an Early Rice. Although it may pass the rules satisfying Early Rice trend, there are no current ways to backtrack if it was previously a rice field in the previous dates prior to the study period.

A. Using PRISM's input for Bataan 2017 Season 1

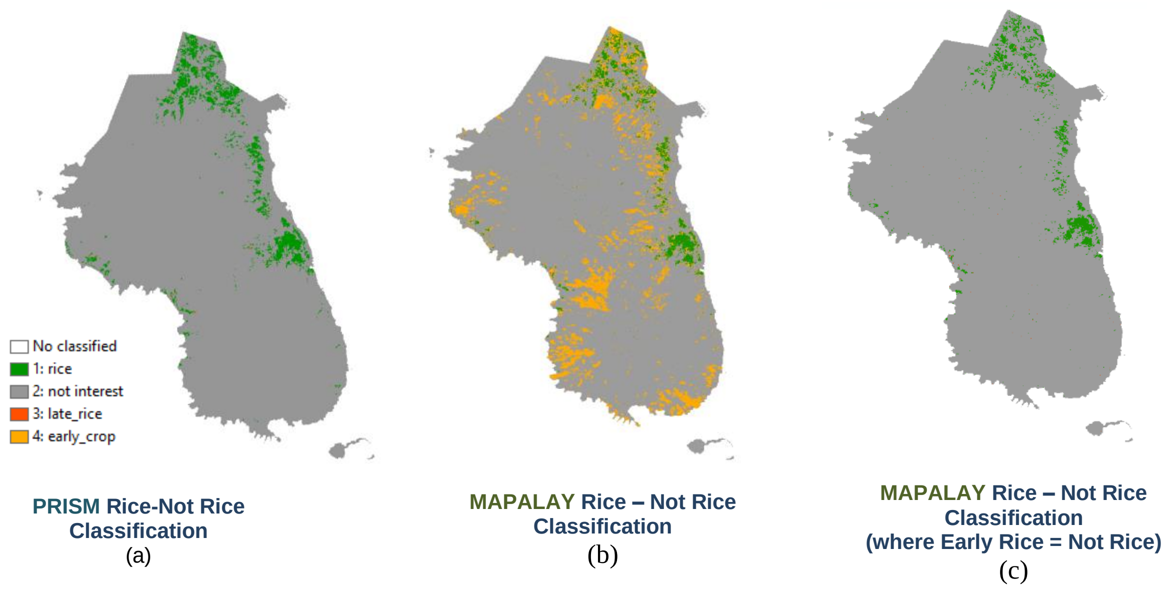


Figure 5. PRISM and MAPALAY rice classification outputs for Bataan 2017 Season 1, using the same input for classification. (a) PRISM RnR, (b) MAPALAY RnR where Rice = Rice + Late Rice + Early Rice, and (c) MAPALAY RnR where Rice = Rice + Late Rice

GridCode	Class	PRISM No. of Pixels	MAPALAY No. of Pixels	Difference
0		52,588	-	52,588
1	Rice	230,225	127,488	102,737
2	Not Rice	3,745,900	3,480,569	265,331
3	Late Rice	988	2,155	(1,167)
4	Early Rice	-	419,606	(419,606)
		4,029,701	4,029,818	(117)

Figure 6. In pixels, comparison of PRISM and MAPALAY rice classification for Bataan 2017 Season 1

By visual inspection, major variation in PRISM and MAPALAY outputs are from the detection of a lot of "Early Rice" pixels. If these "Early Rice" pixels were treated as "Not Rice", it can be observed that the MAPALAY classified "Rice" pixels follow the same trend where major rice field are, but were lesser than those of PRISM's.

The rasters were expressed in 20 m x 20 m resolution. Quantitatively, if "Rice" includes those that were classified as *Rice*, *Late Rice* and *Early Rice*, there was a difference of -12,721.44 has, as there were more pixels that were classified as "Rice" via the MAPALAY rice classification compared to PRISM's classification. Consequently, difference in "Not Rice" is 12,716.76 has more than PRISM's classification. If "Rice" does not include those classified as *Early Rice*, the difference is 4,062.8 has, indicating that the results from MAPALAY is more than PRISM's classified "Rice". The difference in "Not Rice" is -4,067.48 has which is lesser than PRISM's classification.

A.2. Confusion matrix using Monitoring Field (MF) points

Class	*Rice*	*Not Rice*	Total	UA (%)
Rice	18	2	20	90.00%
Not Rice	0	0	0	100.00%
Total	18	2	20	
PA (%)	100.00%	0.00%		

Overall Accuracy (%):
90.00%

(a)

Class	*Rice*	*Not Rice*	Total	UA (%)
Rice	11	9	20	55.00%
Not Rice	0	0	0	100.00%
Total	11	9	20	
PA (%)	100.00%	0.00%		

Overall Accuracy (%):
55.00%

(b)

Figure 7. Confusion Matrices using the 20 MF points for Bataan 2017 Season 1, (a) where Rice = Rice + Late Rice + Early Rice; (b) where Rice = Rice + Late Rice

A. 3 Confusion matrix using Rice – Not Rice (RnR) points

Class	*Rice*	*Not Rice*	Total	UA (%)
Rice	5	4	9	55.56%
Not Rice	1	2	3	66.67%
Total	6	6	12	
PA (%)	83.33%	66.67%		

Overall Accuracy (%):
58.33%

(a)

Class	*Rice*	*Not Rice*	Total	UA (%)
Rice	5	4	9	55.56%
Not Rice	1	2	3	66.67%
Total	6	6	12	
PA (%)	83.33%	66.67%		

Overall Accuracy (%):
58.33%

(b)

Figure 8. Confusion Matrices using the 12 RnR points for Bataan 2017 Season 1, (a) where Rice = Rice + Late Rice + Early Rice; (b) where Rice = Rice + Late Rice

To further test the results, confusion matrices were made versus ground validated points from PhilRice. Monitoring Field (MF) points correspond to PhilRice-monitored rice areas from Start of Season to harvest. Rice – Not Rice (RnR) points on the other hand, include rice areas and non-rice areas (e.g. corn fields and grassland) validated from the field. For Bataan 2017 Season 1, there were 20 MF points and 12 RnR points which were used in the analysis. Take note that two (2) confusion matrices were provided, one where "Rice" is made up of classified Rice, Late Rice, and Early Rice; and another one where "Rice" is only made up of Rice and Late Rice. It is important to make separate matrices to show the differences in accuracies when Early Rice is treated as "Rice" or "Not Rice". Results show that the developed MAPALAY rice classification can classify significant number of Rice areas.

B. Using processed image from SNAP as input

Previously, the analysis shown used the same input PRISM used in their rice classification. This multi-temporal σ^0 stacked image was processed in MAPscape-RICE™, which involves complex and advanced filters. For this second analysis, the multi-temporal σ^0 stacked image used as input has been pre-processed in SNAP before finally proceeding to rice classification using the developed MAPALAY plug-in.

The analysis for this part will be presented in two (2) cases: Bataan 2017 Season 1 and Season 2.

Case 1: Bataan 2017 Season 1

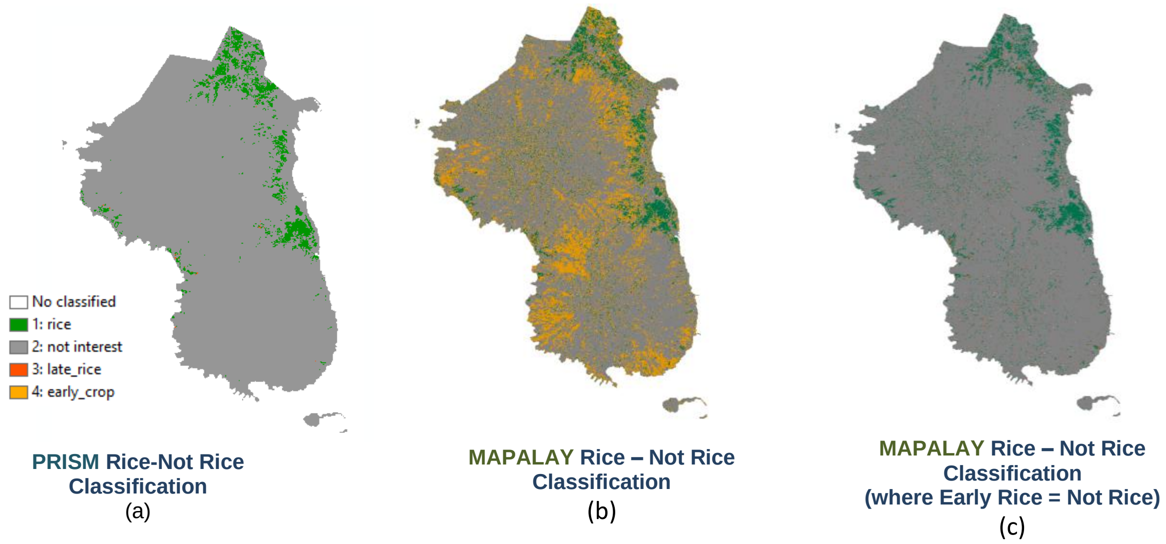


Figure 9. PRISM and MAPALAY rice classification outputs for Bataan 2017 Season 1, where MAPALAY outputs were processed in SNAP.. (a) PRISM RnR, (b) MAPALAY RnR where Rice = Rice + Late Rice + Early Rice, and (c) MAPALAY RnR where Rice = Rice + Late Rice

By visual inspection, MAPALAY results appear to be "grainy". In this version of the MAPALAY plug-in, no further masks or advanced filters were added yet. This could be addressed mainly by adopting a DEM/slope filter and masking out of known non-agricultural areas such as forests, urban, and water areas. The result in Figure 9b and 9c, show that there are a lot of classified "Early Rice" and "Rice" on the mountain slopes of Bataan which should be checked for improvement.

B.1.1. Comparison of classification results in terms of area differences (has)

GridCode	Class	PRISM No. of Pixels	MAPALAY No. of Pixels	Difference
0		52,588	-	52,588
1	Rice	230,225	301,966	(71,741)
2	Not Rice	3,745,900	2,275,821	1,470,079
3	Late Rice	988	47,122	(46,134)
4	Early Rice	-	793,463	(793,463)
		4,029,701	3,418,372	611,329

Figure 10. In pixels, comparison of PRISM and MAPALAY rice classification for Bataan 2017 Season 1

Based from results if "Rice" includes those that were classified as Rice, Late Rice and Early Rice, there was a difference of -36,453.52 has, as there were more pixels that were classified as "Rice" via the MAPALAY rice classification plug-in compared to PRISM's classification. Consequently, difference in "Not Rice" is 60,906.68 has which is more than PRISM's. This trend is the same with the first analysis. However, if "Rice" does not include those classified as Early Rice, the difference is -4,715 has, indicating that the results from MAPALAY is more than PRISM's classified "Rice". The difference in "NotRice" is 29,168.16 has which again, is more than PRISM's.

B.1.2. Confusion matrix using Monitoring Field (MF) points

Class	*Rice*	*Not Rice*	Total	UA (%)
Rice	17	0	17	100.00%
Not Rice	0	0	0	100.00%
Total	17	0	17	
PA (%)	100.00%	100.00%		

Overall Accuracy (%):
100.00%

(a)

Class	*Rice*	*Not Rice*	Total	UA (%)
Rice	12	5	17	70.59%
Not Rice	0	0	0	100.00%
Total	12	5	17	
PA (%)	100.00%	0.00%		

Overall Accuracy (%):
70.59%

(b)

Figure 11. Confusion Matrices using the 17 MF points for Bataan 2017 Season 1, (a) where Rice = Rice + Late Rice + Early Rice; (b) where Rice = Rice + Late Rice

B.1.3. Confusion matrix using Rice – Not Rice (RnR) points

Class	*Rice*	*Not Rice*	Total	UA (%)
Rice	9	0	9	100.00%
Not Rice	2	1	3	33.33%
Total	11	1	12	
PA (%)	81.82%	100.00%		

Overall Accuracy (%):
83.33%

(a)

Class	*Rice*	*Not Rice*	Total	UA (%)
Rice	6	3	9	66.67%
Not Rice	1	2	3	66.67%
Total	7	5	12	
PA (%)	85.71%	40.00%		

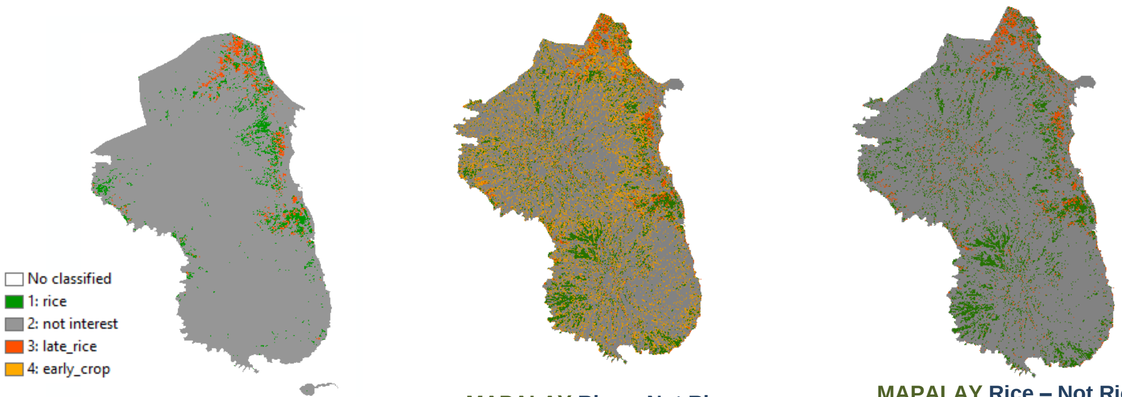
Overall Accuracy (%):
66.67%

(b)

Figure 12. Confusion Matrices using the 12 RnR points for Bataan 2017 Season 1, (a) where Rice = Rice + Late Rice + Early Rice; (b) where Rice = Rice + Late Rice

Comparing with 17 MF points and 12 RnR points, results show good accuracy, up to 100%, if Early Rice pixels were accounted as "Rice". If Early Rice is accounted as "Not Rice", there were significant changes with the accuracies.

Case 2: Bataan 2017 Season 2



PRISM Rice-Not Rice Classification
(a)

MAPALAY Rice – Not Rice Classification
(b)

MAPALAY Rice – Not Rice Classification (where Early Rice = Not Rice)
(c)

Figure 13. PRISM and MAPALAY rice classification outputs for Bataan 2017 Season 2, where MAPALAY outputs were processed in SNAP. (a) PRISM RnR, (b) MAPALAY RnR where Rice = Rice + Late Rice + Early Rice, and (c) MAPALAY RnR where Rice = Rice + Late Rice

By visual inspection, MAPALAY results appear to be "grainier" for this season. This season corresponds to the dry season in the Philippines. As observed from the PRISM result, there are now a lot of pixels classified as "Late Rice", some of which are also classified in the MAPALAY results.

B.2.1. Comparison of classification results in terms of area differences (has)

GridCode	Class	PRISM No. of Pixels	MAPALAY No. of Pixels	Difference
0		65,884	-	65,884
1	Rice	257,062	403,900	(146,838)
2	Not Rice	3,707,820	2,177,657	1,530,163
3	Late Rice	46,705	118,688	(71,983)
4	Early Rice	-	714,109	(714,109)
		4,077,471	3,414,354	663,117

Figure 14.In pixels, comparison of PRISM and MAPALAY rice classification for Bataan 2017 Season 2

Based from the results if "Rice" includes those that were classified as Rice, Late Rice and Early Rice, there was a difference of -37,317.2 has, as there were more pixels that were classified as "Rice" via the MAPALAY rice classification compared to PRISM's classification. Consequently, difference in "Not Rice" is -69,639.64 has which is also more than that of PRISM's. If "Rice" does not include those classified as Early Rice, the difference is -8,752.84 has, indicating that the results from MAPALAY is more than PRISM's classified "Rice". The difference in "NotRice" is -98,204 has which is also more than PRISM's classification.

B.2.2. Confusion matrix using Monitoring Field (MF) points

Class	*Rice*	*Not Rice*	Total	UA (%)
Rice	15	0	15	100.00%
Not Rice	0	0	0	100.00%
Total	15	0	15	
PA (%)	100.00%	100.00%		

Overall Accuracy (%) : 100.00%

(a)

Class	*Rice*	*Not Rice*	Total	UA (%)
Rice	8	7	15	53.33%
Not Rice	0	0	0	100.00%
Total	8	7	15	
PA (%)	100.00%	0.00%		

Overall Accuracy (%) : 53.33%

(b)

Figure 15. Confusion Matrices using the 15 MF points for Bataan 2017 Season 2, (a) where Rice = Rice + Late Rice + Early Rice; (b) where Rice = Rice + Late Rice

B.2.3. Confusion matrix using Rice – Not Rice (RnR) points

Class	*Rice*	*Not Rice*	Total	UA (%)
Rice	4	3	7	57.14%
Not Rice	3	0	3	0.00%
Total	7	3	10	
PA (%)	57.14%	0.00%		

Overall Accuracy (%) : 40.00%

(a)

Class	*Rice*	*Not Rice*	Total	UA (%)
Rice	2	5	7	28.57%
Not Rice	2	1	3	33.33%
Total	4	6	10	
PA (%)	50.00%	16.67%		

Overall Accuracy (%) : 30.00%

(b)

Figure 16. Confusion Matrices using the 10 RnR points for Bataan 2017 Season 2, (a) where Rice = Rice + Late Rice + Early Rice; (b) where Rice = Rice + Late Rice

Comparing with 15 MF points and 10 RnR points, results show that the developed MAPALAY rice classification can detect a significant number of Rice areas using the processed image from SNAP, for Bataan 2017 Season 2.

Evidently, there are a lot of confusion in the algorithm in correctly determining Rice, Late Rice, and Not Rice. These differences will be accounted to address the seasonality of rice to improve the rice classification algorithm.

4. CONCLUSIONS

Overall, the team has successfully built an installable rice classification algorithm plugin within SNAP. The necessary parameters and options can be changed in the GUI, including the toggles for automatic parameter file exporting and RnR modes. It takes a stacked, multi-temporal product and outputs another stacked, multiband product containing the Rice Classification, LAI, SoS, and filter flag bands. Implementing various optimizations has led to 30%+ speed improvements. Testing the algorithm for real-world data using the whole province of Bataan yielded a competitive execution time of around 10 minutes per run.

In terms of the outputs of the developed rice classification plug-in within SNAP, a significant number of "Rice" areas can be detected for Bataan 2017 Seasons 1 & 2. If "Rice" includes all those classified as Rice, Late Rice, and Early Rice, results show accuracies as high as 100% and as low as 90% when compared with MF points; and as high as 83.33% and as low as 40% when compared with RnR points. In terms of area, results show around -37000 has difference which is around 900,000 more pixels than PRISM's classification. If "Rice" does not include those classified as Early Rice, results show accuracies as high as 70.59% and as low as 53.33% when compared with MF points; and as high as 66.67% and as low as 30% when compared with RnR points. In terms of area, results show around -4700 to -8700 has difference, or around 200,000 pixels more than PRISM's classification. The differences account mostly to the confusion between Rice, Late Rice, Early Rice, and even Not Rice. More improvements can still be done, especially by incorporating Digital Elevation Model (DEM), slope, masking out of known non-rice areas, and by implementing supplemental machine learning algorithms, to improve results.

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