Historical Paddy Rice Growth and Phenology Pattern Estimation Using Dual Polarization of Sentinel 1

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***Abstract*—Availability of a good record of paddy rice growth condition is important for obtaining sustainable paddy rice production in agricultural countries like Indonesia. A multi-temporal of synthetic aperture radar (SAR) images of dual-polarization Sentinel-1 data collected from January 2020 to January 2021 are good enough to show the variation occurs in two or more regions in Lampung Province based on starting their cultivation time in the paddy field. This study provides the recommendation for detecting paddy rice phenology from two different approaches. Backscatter values (σ0) generated from VV, VH, VV/VH, and VV-VH and dual-polarization radar vegetation index (DpRVI) that has arranged to show the paddy rice growth and phenology pattern are compared with the observation directly from the field at a different time of cultivation period. Both patterns matching with the acquisition time of the direct observation has represented the similar pattern created by radar backscatter and dpRVI with an accuracy of about 85%. The characteristic of phenology and paddy rice growth pattern in the many regions in Lampung province is possible to detect using backscatter values and DpRVI.**

Keywords*—*paddy rice, phenology, DpRVI, Sentinel-1, Lampung

I. INTRODUCTION

One of the most important cultivated plants in human civilization is rice (Oryza sativa), because it is one of the main sources of carbohydrates for the majority of the world's population, especially for the majority of Asian countries [1]. Indonesian people are dependent on rice as the main source of carbohydrates and as a raw material for traditional foods. According to BPS data in 2020, Indonesia can produce 54,65 million tons of rice per year to comply with the population's rice needs [2]. One of the most rice-producing provinces in Indonesia is Lampung. In 2020, Lampung is one of the provinces that has a major contribution to rice production in Indonesia [3]. Lampung province in 2020 produces 1.52 million tons of rice [4]. The highest rice production in Lampung province is in Central Lampung, East Lampung, Mesuji and South Lampung Regencies [4]. The high demand for rice, followed by population growth which is increasing every year affects increasing the demand for rice. Meanwhile, the area of productive rice land continues to decrease [5]. It is necessary to make sustainable development in the agricultural sector so the demands of rice can be fulfilled.

One of these efforts is carried out by utilizing remote sensing technology based on synthetic aperture radar image data processing. Remote sensing data has been widely used in agriculture, including monitoring the classification of paddy fields, identifying rice growth and estimating rice production over a large area [6]. The length of the rice-growing process must be able to be observed properly. The production of rice fields depends on the quality of the rice plant during its growth period. There are three phases of rice growth, the vegetative, reproductive, and ripening phases [7]. In the vegetative phase, there are 3 stages of growth (seeding, tillering, stem elongation), during the reproductive phase there are 2 stages of growth (booting, heading) and during the ripening phase, there are 3 stages of growth (milk, dough, maturity) [8]. From each growth stage, some characteristics can be used as guides in the monitoring process.

Observing paddy fields in Indonesia is not optimal when using optical data, such as Landsat TM, ETM, and Landsat 8 [9]. That is because Indonesia is located in an equatorial area with a tropical climate with two seasons and of course cloud cover is the main obstacle in monitoring rice fields [10]. Therefore, the use of SAR data is a very appropriate choice. Not only better with a large spatial resolution [11], but also free from weather disturbances, and have longer wavelengths compared to optical images [6]. In the end, monitoring of paddy fields using SAR data can be done better, so that it can help to know the entire rice growth phase, based on VV, VH, VV/VH polarization and multitemporal data [6]. The existence of high-resolution images that observe paddy growth phase is very important to improve the quality of rice production [12].

Data interpretation is carried out based on variations of the combination of polarization and certain backscatter values [6]. In research conducted by Yonezawa [13] used RADARSAT-2 data with VH, HH, VV, and HV polarization for monitoring rice, soybeans and grass. The three growths of crops can be distinguished, according to the distribution of the backscatter value.

Related to the use of sentinel 1, research conducted by Nuevo, Dorado et al. [11] found that the backscatter value on VV and VH has a unique trend pattern. VV and VH values are not the same because VV always has higher values than VH, but both have the same pattern, VV and VH backscatter values in the waterlogging and early planting phases will decrease but will tend to increase as harvest time approaches [11]. This is also following the research conducted by Supriatna et al. [14] showed that the backscatter value in the early planting phase decreased or was smaller and would increase as harvest time approached. Based on these two studies, there are indications that the backscatter value of Sentinel 1 SAR data at 1 time of rice planting has a graphic shape that tends to resemble the shape of a hill.

Many studies also report that the use of RVI (Radar Vegetation Index) can be utilized as a mechanism for scattering values caused by the complexity of the vegetation structure. This formula was first introduced by Kim andvan Zyl [15]. RVI is usually used as a method for monitoring vegetation growth rates using time series data [16]. Scattering in RVI is very sensitive to biomass and aquatic vegetation but has low sensitivity to the effects of environmental conditions [16]. In Sentinel-1 data, the use of RVI needs to be adjusted. Mandal et al. [17] used a modification of the RVI named DpRVI to observe the phenological phase of plant growth.

Sentinel-1 data availability is more abundant and easily accessible than Radarsat. Although the processing results will not be as good as RADARSAT or other images with full-polarization, the information obtained from the use of Sentinel-1 can still contribute well to the observation of the phenological pattern of rice plants. This study intends to estimate the phenological pattern of paddy rice according to variations of backscatter value Sentinel-1 data then compared with the same pattern from the DpRVI results, the backscatter and DpRVI value was validated by matching it with the physical condition of paddy in the study area to see the historical pattern of paddy rice growth in the same place at 2 different times. Hoped that the backscatter values and phenological patterns can be used to estimate rice production and observe rice growth stages at different times and locations.

II. Methodology

A. Study Area

A study of rice phenology was conducted in Sidosari village, Natar, South Lampung on a rice field area of 280 *Ha* (Fig.1.). Natar is one of the largest rice-producing districts in South Lampung with a total production of 24,981 tons in 2020 [18]. This study area is an irrigated rice field whose sources of water for the field are come from irrigation canals and rainwater so that rice fields can be planted with rice throughout the year.

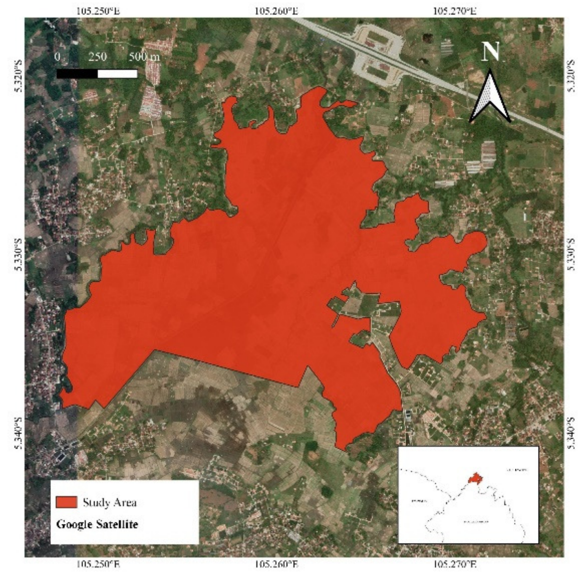


Fig. 1. Study Area For Monitoring Phenological Stages Of Paddy Rice In Sidosari Sub District South Lampung Residence.

B. Data

GRD-HD (Detected High-Res Dual-Pol) Level-1 is a product of Sentinels-1A and -1B which can be downloaded at search.asf.alaska.edu. Twenty of Sentinel-1 SAR data with different acquisition times was used in this study. The image data acquisition was taken from August 10, 2020, to April 19, 2021, using the L1 Detected High-Res Dual-Pol (GRD-HD) file type, IW beam mode, Polarization VV+VH with Ascending direction (TABLE 1).

TABLE I. List Of Sentinel 1 Data and Used For Phenologhycal Stages Monitoring

Number	Acquisition Time	File Type	Beam Mode	Polarization	Direction	Function	Amount
1.	10/08/2020 - 13/01/2021	L1 Detected High-Res Dual-Pol (GRD-HD)	IW	VV+VH	Ascending	Estimation	13 Data
2.	1/01/2021 – 19/04/2021	L1 Detected High-Res Dual-Pol (GRD-HD)	IW	VV+VH	Ascending	Validation	9 Data

C. Data Processing

The standard procedure for handling Sentinel-1 data is to apply orbit, calibration, speckle filtering and terrain correction. All these steps are doing in SNAP 8.0. The applied orbit required to correct the position of the satellite and its position. The pixel values are also required for calibration to get true values and also to minimize the noise, a Lee filter applied in the speckle filtering stage. To improve the SAR data, the topography of the data must be corrected so that it can show a more precise land surface using the terrain correction menu. The final result of the image processing is projected into the WGS 48s projection system and then exported to GeoTIFF.

The backscatter value is converted into decibel units (dB) calculated manually using the raster calculator in QGIS using the formula (Eq. 1), and the result is used to calculate the dpRVI (Eq.2).

*10*Log(ABS(band 1))* (1)

(4"dB VV")/("dB VV" + "dB VH")* (2)

To find out the pattern of rice growth in the study area, the backscatter dB and dpRVI value was calculated. The estimated rice growth pattern that has been formed through SAR data is then compared with the backscatter dB and dpRVI value with SAR data used as validation and visually matched with physical paddy condition from direct observation in the study area periodically starting from January 13 2021 to April 5 2021, with 7 times observation as validation of growth time rice.

D. Estimation and Validation of Phenological Pattern

Phenological patterns are formed from trend values backscatter on each VV and VH channel, as well as the DpRVI values. The maximum, minimum and average values are estimates of the pattern of rice growth in the study area. To find out the pattern, data collection and the creation of various backscatter value distribution charts need to be made using a spreadsheet.

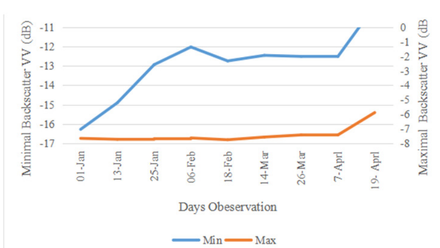
Historical Patterns of paddy phenology were obtained from the results of matching physhical paddy condition in the study area with backscatter values of VV, VH and DpRVI values at each stage of paddy growth stage. Direct observation in the study area is carried out to equalize the appearance of the rice growth phase which is then seen how the trend of VV and VH values, as well as DpRVI values.

The paddy growth phase that has been identified on direct observation was matched with the data acquisition time of Sentinel-1. The values of VV, VH, and DpRVI which have been validated with the physical condition of paddy on direct observation can be used as a reference as the values contained in each phase of rice growth. These data are related to the backscattering values of VV, VH, and DpRVI values from all Sentinel-1 data by classifying the VV values. VH and DpRVI approximate the reference data. Then the data can provide an estimate of the pattern of phenology and rice cultivation on backscattering data and past DpRVI values.

III. RESULT AND DISCUSSION

Validation using direct observation, there are 7 phases of paddy growth observed. This growth phase forms one paddy planting period. On January 13 2021, paddy began to start the tillering stage, later on, 1 February 2021 is the stem elongation stage, both stages are part of the vegetative phase. The reproductive phase began to be observed on February 23 2021, where paddy experienced the boot stage and on March 2, 2021, entered the heading stage. On March 16, 2021, it was observed that paddy began to enter the maturation phase marked by the start of the dough grain stage which also occurred on March 25, 2021. Paddy began to occur in the mature grain stage on April 5, 2021, and on April 19, 2021, the paddy had been harvested.

The results of processing nine Sentinel-1 data which are used as validation form a growth stages pattern. The backscatter values for VV (Fig.2.a) and VH (Fig.2.b) were at their lowest during the early planting period and began to increase as the harvesting stage approached. Although the values of VV and VH are not identical, where the value of VV is higher than the value of VH, these two polarizations have the same value development trend. The increase of backscatter values in the VV polarization will be followed by an increase in VH polarization too, the decrease in the backscatter values of VV polarization will also be followed by a decrease of the VH polarization values. Different things are found in the results of the DpRVI value. The trend of value development in DpRVI (Fig.2.c) is not the same as the trend in VV and VH backscatter values. The DpRVI values tend to be less characteristically patterned.



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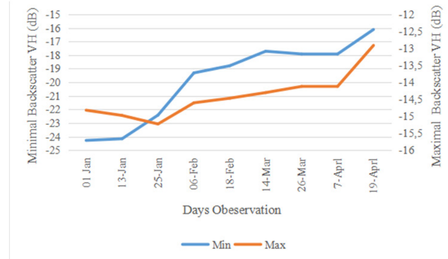

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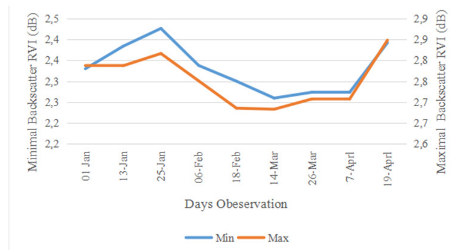

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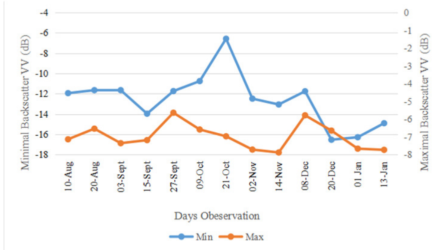
Fig. 2. Trend of backscatter values in VV (a) VH (b) polarization with dpRVI (c) values in the validation data.

Based on direct observation and Sentinel-1 processing data, it was found that there was a relation between backscatter and DpRVI values with paddy phenological conditions through visual matching of rice appearance and backscatter and DpRVI values (TABLE II). This value is obtained based on the sample area in SAR data taken at a distance of 20 m from the point of taking direct observation. However, on 2 March 2021, there is no Sentinel-1 data was available. This is caused by the orbital timing of Sentinel-1.

TABLE II. Distribution Of Backscatter and dpRVI Values At Each Stages Of Paddy Growth

DATE	STAGES	VV	VH	DpRVI
13/01/2021	Tillering	-11.430	-19.367	2.805
01/02/2021	Stem Elongation	-10.441	-17.756	2.525
23/02/2021	Booting Stage	-9.991	-15.940	2.459
02/03/2021	Heading Stage	-	-	-
16/03/2021	Dough Grain Stage	-10.349	-15.940	2.430
25/03/2021	Dough Grain Stage	-10.635	-16.479	2.431
5/04/2021	Mature Grain Stage	-7.447	-15.149	2.682
19/04/2021	Harvest	-6.827	-15.823	2.794

In Sentinel-1 data processing which is used as estimation data, it can be seen that the backscatter VV value (Fig.3.a) has a range of values between -16 to -5, the backscatter value VH (Fig.3.b) has a range of values between -24 to -13, and the value of dpRVI (Fig.3.c) has a range of values between 2.3 to 2.8. The trend of development values in VV, VH, and DpRVI has not yet been identified. Therefore, it is necessary to match the backscatter VV, VH, and DpRVI values to the reference value (TABLE II) to classify the rice growth stage in the estimated data.



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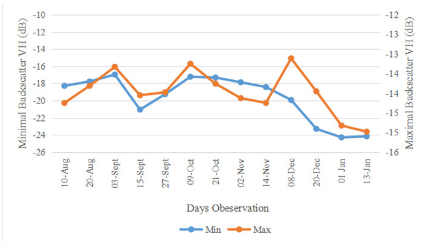

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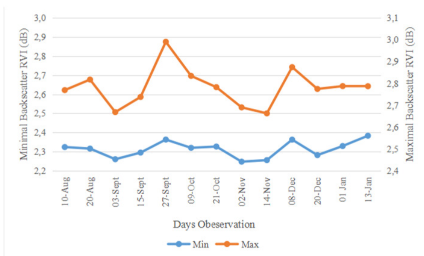

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Fig. 3. Trend of backscatter values in VV (a) VH (b) polarization with dpRVI (c) values in the estimation data.

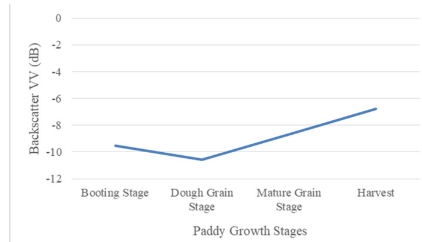
To estimate the paddy growth stages in the estimation model, the RMSE (Root Mean Square Error) value is calculated on the VV, VH, and DpRVI data against the validation data referring to the classification results (TABLE II). This step is taken to determine the level of accuracy of the estimation models. From the results of the RMSE calculation (TABLE III.) it can be seen that the smallest RMSE value is in the DpRVI data which is had a 0.144 value, then VH data with a 0.287 RMSE value, and VV data with a 0.662 RMSE value. The results of the RMSE calculation show that the overall results of VV, VH, and DpRVI data, none of these data have a RMSE value more than 1, which means that the entire data can be used as an estimation model. The lower RMSE value the variation in the estimated value is getting closer to the variation in the validation value. So, the best way to estimate paddy phenology is using DpRVI data.

TABLE III. The Result Of Mean Error And RMSE

Data	Mean Error	RMSE
VV	0.438	0.662
VH	0.082	0.287
dpRVI	0.020	0.144

Based on the estimation model that has been made, it can be seen that on August 10, 2020, paddy has entered the boot stage, then on September 15, 2020, paddy enters the dough grain stage. On October 9, 2020, paddy has entered the mature grain stage, then on October 21, 2020, rice has been harvested. Referring to the results of direct observations where paddy planting takes about 3.5 months, it can be estimated that the initial phase of paddy planting in the estimation model starts around June 2020. This shows that in one year the rice fields in the Sidosari village, Natar, South Lampung have 2 planting periods. The first planting period is in January-April and the second planting period is in June-October. There is a gap of two months in each planting period.

Meanwhile, the trend pattern of the backscatter values of VV, VH, and DpRVI values in the estimation data has the same pattern as in the validation data (Fig. 2). The backscatter values for VV (Fig.4.a) and VH (Fig.4.b) were at their lowest during the early planting period and began to increase as the harvesting stage approached.



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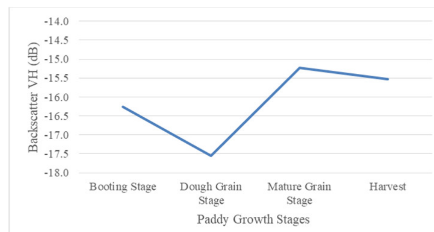

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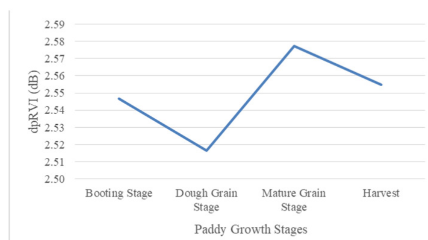

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Fig. 4. Trend of backscatter values in VV (a) VH (b) polarization with dpRVI (c) values in the estimation models.

The result of this study is suitable with previous research about rice growth monitoring using SAR data. In research conducted by Ritchie et al.[11] found that each backscatter value in each polarization has its pattern. The backscatter VV and VH values at the early planting period will decrease and will increase as the harvest stage approaches. Dirgahayu et al. [19] also found that the VV and VH values tend to increase along with entering the paddy planting period. Lestari et al. [6] stated that VH polarization can represent phonological paddy better than VV polarization. But in a study conducted by Mandal et al. [17] found that DpRVI can also be used well to observe the growth phase of plants.

CONLUSION

The combination between dual-polarization of Sentinel-1 data can be used to observe paddy phenology and estimate paddy growth phases in the past and another area in Lampung

Province. The best way to make an estimation model is using DpRVI data compared to VH and VV polarization data.

Based on the results of the estimation model, it can be seen that the rice fields in Sidosari village, Natar, South Lampung planted paddy twice. The first planting time is in January-April and the second planting time is in June-October. There is a gap of two months in each planting period.

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