Monitoring of Rice Growth Phases Using Multi-Temporal Sentinel-2 Satellite Image

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Abstract. Rice is the primary source of nutrition food of more than half of the world's population, and it is hugely important in the global economic growth, food security, water use, and climate change. The need for satellite systems to monitor rice crops and assist in rice crop management is gaining in popularity. The European Space Agency's (ESA) launched Sentinel-2 A + B twin platform's which enhanced the temporal, spatial, and spectral resolution, opening the way for their widely use in crop monitoring. Aside from the technical features of the Sentinel-2 A and B constellation, the easily accessible type of information they generate as well as the appropriate support software have been significant improvements for rice crop monitoring. In this study, the spectral reflectance has been analysed to find how far their potential in determining rice growth phases. The highest spectrum in reflectance was observed in the near infrared (NIR) region (842 nm). Because of the structure of mesophyll cells tissues and the inner backscatter of air spaces, moisture content, and air–water abstraction layers within the leaves, the reflectance in the NIR region seems to be much larger than in the visible band. The multi-temporal vegetation index namely Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), and Normalized Difference Moisture Index (NDMI) have derived from ten Sentinel-2 images cover the entire rice season. These indices have been tested to determine the rice growth phases over the rice season. The spatial distribution of each tested indices is displayed in the map output. The maps are then analysed and compared to determine the potential of each index in determining rice growth phases. It was discovered in this study that there was a quadratic correlation between all of the tested indices and rice age. The Normalized Difference Vegetation Index (NDVI) is the most accurate vegetation index for estimating rice growth phases, followed by SAVI and NDMI.

1. Introduction

In Asia, rice production supports food security, with more than 1.21 billion tons harvested in 2018 to feed 4.56 billion people. Rice production is often disrupted by the effects of climate change, water shortages, and soil degradation, necessitating increased monitoring to ensure long-term food production [1]. In Malaysia, it's common apply for regime officers at the sub-district level to gather knowledge on
rice crops that support farmers' field visits and knowledge. Aggregation this data is pricy, non-real-time, and ineffective for managing spatial-temporal changes in rice-producing regions.

It is really important to know the different stages of the rice growth cycle. In Malaysia, the rice growing season is divided into three distinct phases [2]. The first phase is from planting to early vegetative stages, during which the rice plot is exposed to soil that is then saturated with water, causing paddy seedlings to develop through the water. Then, the second phase is from vegetative to reproductive stages. Rice's reproductive to maturity stages are the final stages of growth. Plants grow grains as they mature, turning rice plots yellow, and the field is harvested soon after, reverting to a plot of exposed soil. [3].

VIs (vegetative indices) was generated by combining numerous wavebands and relating them to varied vegetation parameters. The goal of VIs is to improve the vegetation signal, while reducing solar radiation and soil background outcomes [4][5]. Increasing focus is given to the use of satellites to monitor and support crops. The European Space Agency (ESA) has established Sentinel-2 A + B twin platform with a better temporal, spatial and spectral resolution, making its popularization in high-tech agriculture practical. In addition to the technical capabilities of the Sentinel-2 A+B constellation, the open-access nature of the information they create and the software for agricultural supervision available are significantly improved [6]. The twin Sentinel-2 A + B platform has substantially expanded its agricultural monitoring and crop management capabilities globally compared with previous satellite imaging systems [7][8].

The normalized vegetative difference index (NDVI), that links the near infrared (NIR)/Red quantitative relation to the Leaf Area Index (LAI), is one amongst the foremost wide used VIs [9]. More contemporary research has demonstrated that NDVI is a significant contributor in canopy light interception since NDVI measurements are saturated over the whole season. Once the land surface is not utterly coated by vegetation, the Soil Adjusted Vegetation Index (SAVI) adds reflectivity within the blue region of the spectrum to account for the consequences of soil on analysed images, to regulate for soil background within the application of VIs. SAVI was developed by, that is outlined as $\text{SAVI} = \frac{\text{RNIR} - \text{Rred}}{\text{RNIR} + \text{Rred} + \text{L}}$, wherever L is associate adjustment parameter that is typically 0.428 if using Sentinel 2 and 0.5 if using another satellite imagery like Landsat. The NDMI (Normalized Difference Moisture Index) indicates crop water stress and is computed as the ratio of the difference and sum of the refracted radiations in the near infrared and SWIR, i.e. $(\text{NIR-SWIR})/(\text{NIR+SWIR})$. The interpretation of the exact value of the NDMI allows for the instantaneous identification of agricultural or field regions with water stress concerns. These indices are used to measure precisely the stages of rice growth, allowing the reconstruction of rice production's temporal evolution. This study was carried out with the aim of Monitoring of Rice Growth Phases Using Multi-Temporal Sentinel-2 Data in Kota Sarang Semut. Several objectives are highlighted to achieve the goals, including to identify which spectral reflectance is the most suitable in determining rice growth phases in Kota Sarang Semut and to determine the rice growth phases using different type of indices including Soil Adjusted Vegetation Index (SAVI), Normalized Vegetative Difference Index (NDVI), and the Normalized Difference Moisture Index (NDMI).

2. Study Area
For this study, the area selected is at Kota Sarang Semut which located at 5° 58’ 59.99” N, 100° 23’ 59.99” E in Kedah, Malaysia. It is located at near km 16 on the Alor Star–Gurun main trunk route, near the Pendang town junction. Kota Sarang Semut (Region IV) is one of the regions that has large area well-irrigated and organised rice paddy in Kedah and also in Malaysia. Figure 2 shows the study area that will be selected in this study. The total area of Region IV is 25,336 ha with involving 6,334 samples.
3. Methodology
The methodology flowchart illustrated in Figure 2. In general, the flowchart represented the project planning, the data acquisition phase and how the data were processed before the final result was produced. The methodology has separated into five phases which are phase 1 is background study and phase 2 is data preparation. A few types of data and software were needed before proceeding to phase 3 which is data pre-processing. After that, phase 4 is focusing on data processing, and the final phase is data analysis and visualised the result in the map output.

3.1. Data Preparation
Sentinel-2 Imagery was used in this study. Rice crop region in Kota Sarang Semut is quite dense, hence high spatial resolution with multi temporal satellite imagery is required to cover the entire growing season of rice crop. Sentinel-2 satellites offer multispectral images with three different spatial resolutions (10m, 20m, 60m) and a high temporal resolution. In this study, Sentinel-2 images with Level-2A had been downloaded from Copernicus Open Hub. Level-2A processing involves scene classification and atmospheric correction applied to TOA Level-1C orthoimage outputs. The primary product of Level-2A is an orthoimage Bottom-Of-Atmosphere (BOA) corrected reflectance product. The images products of Level-2A will be resampled and produced with similar spatial resolution for all bands (10 m, 20 m or 60 m). Ten selected images were downloaded to cover the entire rice growing stages of the rice crop all across the season with the least amount of cloud cover over the study area. The total of images that had been downloaded starts from March 2020 until September 2020 which covers the one whole growing season of rice crop. Figure 1 shows the example of Sentinel-2 imagery that has been used in this study.
Figure 2. Flowchart of Methodology
Figure 3. Sentinel-2 Imagery

Other than Sentinel-2 image, rice crop calendar is essential in this study to provide and show the date of rice planting and harvesting during the rice seasons. This data can be obtained online from the trusted website or any agencies that are related to rice industry. One of the agencies that handle Malaysia’s rice industry is MADA. From rice crop calendar, it is easier to know the date and duration for every phase during the rice season.

3.2. Data Pre-processing
The images from Sentinel-2 need to undergo a few pre-processing before proceeding to the next stage. Pre-processing may improve image quality by eliminating data acquisition errors. The pre-processing steps including resampling, subset and clipping to area of study.

3.3. Data Processing
3.3.1. Determine the temporal rice growth by using different type of indices. In this study, a few types of VIs were selected in order to determine their potential in detecting and monitoring rice growth phases. The three indices that has been tested namely as NDVI, SAVI and NDMI. This computation process has been done by using QGIS software. The raster calculator in the QGIS software was used to perform the indices calculation.

The NDVI has been used to estimate the vegetation cover and growth activities in qualitatively and quantitatively. A greenness and biomass of vegetation can be measure by NDVI. High NDVI values shows green and low NDVI values indicate less green. Red and Near-Infrared Reflectance wavelengths are generally used. NDVI has also been calculated and included in this study for these reasons. NDVI was calculated as follows:

\[
\text{NDVI} = \frac{(B08 - B04)}{(B08 + B04)}
\]

Equation (1)
Where Band 8 is NIR and Band 4 is Red.
### Table 1. The range of NDVI values based on the ages of rice plant and rice phases

| NDVI values | Vegetation density | Ages of rice plant (days) | Rice phases         |
|-------------|--------------------|---------------------------|---------------------|
| < 0.170     | Non-vegetation / water | < 20                      | Transplanting      |
| 0.170 - 0.310 | Very low           | 20 - 30                   | Vegetative         |
| 0.310 - 0.450 | Low                | 30 - 40                   | Vegetative         |
| 0.450 - 0.520 | Medium             | 40 - 60                   | Reproductive       |
| 0.520 - 0.884 | High               | 60 - 90                   | Reproductive/heading |
| 0.450 - 0.520 | Medium             | 90 - 110                  | Ripening           |
| 0.310 - 0.450 | Low                | > 110                     | Ripening           |

SAVI was also a selected index in this study. This index was designed to reduce background influences or impacts of vegetation without photosynthesis. SAVI was expressed using Equation (2) as below:

\[
\text{SAVI} = \frac{(B08 - B04)}{(B08 + B04 + L)(1 + L)} \quad \text{Equation (2)}
\]

Where L is the vegetation density function. The value of L differs according to the amount or cover of green vegetation: in places with a lot of green vegetation, L=0; and in regions with no green vegetation, L=1. In most cases, a L=0.5 fits well and is usually standard value applied. In this study, L was ideal for modifying soil-optical characteristics with a value of 0.5.

### Table 2. The range of SAVI values based on the ages of rice plant and rice phases

| SAVI values | Vegetation density | Ages of rice plant (days) | Rice phases              |
|-------------|--------------------|---------------------------|--------------------------|
| < 0.255     | Non-vegetation / water | < 20                      | Transplanting            |
| 0.255 - 0.450 | Very low           | 20 - 30                   | Vegetative               |
| 0.450 - 0.675 | Low                | 30 - 40                   | Vegetative               |
| 0.675 - 0.900 | Medium             | 40 - 60                   | Reproductive             |
| >0.900      | High               | 60 - 90                   | Reproductive/heading     |
| 0.675 - 0.900 | Medium             | 90 - 110                  | Ripening                 |
| 0.450 - 0.675 | Low                | > 110                     | Ripening                 |

The NDMI is a normalized difference moisture index that indicates moisture with the NIR and SWIR bands. The SWIR band reflects changes both in water content and spongy mesophyll on vegetation canopies, whereas the internal structure of the leaves and the dry matter substance of the leaves are altered by the reflectance of the NIR, but not in the amount of water. The combination of the NIR and the SWIR eliminates differences produced by the internal structure of the leaves and the dry matter substances of the leaf. In the internal structure of the leaf the amount of water available primarily determines spectral reflection in the SWIR interval. Therefore, the SWIR reflection is negatively linked to the water content of the leaf. NDMI was used, in short, to track and propose changes to the water content of the leaves. NDMI was calculated using the reflectance of near infrared (NIR) and the short-wave infrared (SWIR):

\[
\text{NDMI} = \frac{(B08 - B11)}{(B08 + B11)} \quad \text{Equation (3)}
\]

Where Band 11 is SWIR.
Table 3. The range of NDMI values based on the depth of water during different crop growth stages

| NDMI values | Depth of water (cm) | Stage of crop                                      |
|-------------|---------------------|---------------------------------------------------|
| < -0.200    | No water            | Bare soil                                         |
| -0.200 - 0.000 | (2 - 3cm)        | At transplanting                                  |
| > 0.400     | (4- 5cm)           | After transplanting (5 to 20 days)               |
| 0.200 - 0.400 | (2 -3cm)       | During tillering (22 to 42 days)                 |
| 0.000 - 0.200 | Drain the water for 3 days | At maximum tillering                             |
| > 0.400     | (4 -5cm)           | Reproductive stage, Panicle emergence, Heading & Flowering |
| -0.200 - 0.000 | Gradually drain the field into Saturation Withdraw water 12 days before harvest. | Ripening stage (21 days after full flowering), Maturity |

3.3.2. Estimate the yield of rice production using Leaf Area Index (LAI).
The LAI is the ratio of the total surface area of all leaves to the plant’s soil area. The percentage of vegetation per unit area is defined by LAI, which is a static term. It is a biomass and canopy resistance indicator. The measure of crop growth and production is also examined. The ability to rapidly evaluate the LAI with remote sensing VI’s provides a way to estimate the rice yield production and evaluate the productivity of the vast geographical area fast. As seen by Equation (4), LAI was calculated using a surface energy balance algorithm.

\[
\text{LAI} = -\ln \left( \frac{(0.069 - \text{SAVI})/0.59}{0.9} \right)
\]
Equation (4)

The rice yield was determined using LAI and NDVI. The July 25th NDVI layer was calculated using the temporal profile of NDVI of the rice crop taken from sentinel-2 images (the peak greenness of rice corresponding to the heading stage). The LAI was also calculated using data from the same day. The rice yield map was calculated using the empirical statistical model presented and tested by [10] as given in Equation (5).

\[
Y = -3.110 + 1.684 \times (\text{LAI}) + 12.458 \times (\text{NDVI})
\]
Equation (5)

Where Y is the estimated yield, (LAI) is the leaf area index computed from Equation (4), and NDVI is the Normalized Difference Vegetation Index determined from the peak greenness of rice crop growth stages.

4. Result and Analysis
All results including graphical data of spectral reflectance, map of rice growth phases and map of rice yield will be analysed. The analyse process is based on the results observation after processing. The result start with analysing rice growth phases map for each indices tested (NDVI, SAVI and NDMI) and its validation, followed by comparison the potential of indices in determine the temporal rice growth phases.
4.1. Determination of Temporal Rice Growth Phases Using Different Type of Indices

All single images with different date were processed individually. The final outputs were then presented into a map. This resulted in a continuous series of indices temporal values for each image throughout the growth season. The computed indices were used to analyze the spectral response of rice at various phonological stages. The rice growth phases are classed by using the range value as in section 3.3.1.

4.2.1. NDVI Spatial Distribution over the growing season of rice crop. The NDVI is one of the most often used vegetation indices in agriculture, particularly for detecting living green plant canopies and hence presenting greeness. This index takes advantage of two spectral band characteristics: chlorophyll pigment absorptions in the Red band (665 nm) and strong reflectance of plant components in the NIR band (842nm). It is determined as the normalised ratio of the red and near-infrared bands. As strong photosynthetic activity results in lower reflectance coefficient values in the red portion of the spectrum and higher values in the NIR region of the spectrum, the ratio between these indicators clearly distinguishes vegetation from other natural objects. Values ranging from -1 to 0 represent dead plants or inorganic things such as stones, roads, homes include clouds. NDVI values for living plants range between 0 and 1. Figure 4 below shows the spatial distribution of NDVI over the study area.

4.2.2. SAVI Spatial Distribution over the growing season of rice crop. The SAVI minimizes the impact of bare soil on the image of the study area. SAVI is used to reduce the influence of soil in vegetation observation in regions with low vegetative cover and exposed soil surfaces. SAVI values vary from -1.0 to 1.5 when the L value 0.5 is used, with low values indicating a low coverage of vegetation. Figure 5 below shows the spatial distribution of SAVI over the study area.

4.2.3. NDMI Spatial Distribution over the growing season of rice crop. The NDMI is usually used to measure the water content of plants. It is derived as a ratio of the NIR and SWIR bands, allowing it sensitive to changes in liquid moisture contents and rice crop spongy mesophyll. The interpretation of the absolute value of the NDMI allows for the instant identification of farm or crop areas with water stress concerns. NDMI is easily understandable because the numbers range from -1 to 1, and each value corresponds to a different agricultural condition, regardless of crop. The average NDMI values of a crop also varies according to the rice growth stage. The NDMI values over areas with soil backgrounds are negative, while those over areas with green vegetation are positive. High values of NDMI (in blue) correspond to high vegetation water content and to high vegetation fraction cover. Low NDMI values (in red) correspond to low vegetation water content and low vegetation fraction cover. Also, in period of water stress, the NDMI values will decrease. Figure 6 shows the spatial distribution of NDMI over the study area.

4.2.4. Comparing the potential of tested indices namely NDVI, SAVI, NDMI in determine the rice growth phases. Figure 7 shows the rice growth stages corresponding to different indices values. Prior preparing to transplant (March 2020), the rice crop area had no plant with active photosynthetic activity except for bare soil only. As a result, the tested indices show lowest value due to a lack of cultivation. Except during the germination phases, NDVI and SAVI always have a higher value than NDMI. According to Figure 7, farmers often perform some field preparation during the early stages of rice growth (from middle of April until early of May 2020). The rice field is flooded at this stage for allowing the roots to develop nicely. This resulting to the value of NDMI is higher than NDVI and SAVI because water is covering the crop in the satellite image. During the transplanting to germination stage the value of NDVI and SAVI will be low due to light reflection will be more from water than rice chlorophyll. The NDVI values increased after planting and seed germination, with the average value ranging from 0.17 to 1. This is due to the active photosynthesis of young and healthy rice crops during the growing season, which provides strong reflectance in NIR band and absorbs red reflection. Not only is the value changing, but so is the spatial extent as the crop develops until July 25th (maximum point), when it reaches its peak greenness stage (heading stage).
This is same goes to SAVI where the value also increases until the heading stages. Meanwhile in NDMI, during maximum tillering stage (21st May 2020) the value of NDMI drop to around 0.3 because the effect of water has been drained for a few days to kill pests and rise again to the maximum value during heading stage where the panicle is fully visible, and the rice crop cover is highest. After this period, the plants matured, and the value of tested indices begins to drop again from the heading phase till harvesting (early of September 2020) due to crop canopy yellowing and water drainage in rice crops. During the maturation stage (grain filling, milking, and maturity), there is a decrease in leaves and stems moisture levels as well as a decline in the number of leaves. Until the latter part of this period, irrigation is turned off until harvest. The high temporal access to indices data gives more information about the crop season. The unique spectral characteristics in the heading, planting, and harvesting stages could be analysed to determine the planting and harvesting timing limits. However, continuous crop monitoring and yield prediction using optical remote sensing are limited by poor atmospheric conditions, which can result in data gaps, particularly during crucial growth stages. Also, Crop calendars are really not the same across the area, making it difficult to gather information on rice growth stages, particularly sowing and harvest time.

Figure 4. The spatial distribution of NDVI over the rice growth season at Kota Sarang Semut
**Figure 5.** The spatial distribution of SAVI over the rice growth season at Kota Sarang Semut

**Figure 6.** The spatial distribution of NDMI over the rice growth season at Kota Sarang Semut
4.2.5. *Regression Analysis Between Rice Age and Indices*. The regression analysis is then applied to several rice age in this study using tested indices to determine the correlation between the rice age and the vegetation index. The ideal approximated curve model has been chosen to create a formula for the correlation between the vegetation index and the rice age. A quadratic correlation is found between the relationship of rice age and vegetation index. The Normalized Difference Vegetation Index (NDVI) is the most accurate vegetation index for estimating rice age, followed by SAVI and NDMI (Figure 10). The relationship pattern between rice age and NDVI is shown by formula of \( y = -0.0001x^2 + 0.0181x + 0.1227 \) with \( R^2 = 0.9164 \) where \( x \) and \( y \) are rice age in days and NDVI value, respectively (Figure 10a). This quadratic formula is come out from the regression analysis that has been done as shown in figure 10a. According to figure 8, the peak of the vegetation index occurs nearly three months after plantation. This is the transition phase between the vegetative and reproductive stages. As a result, the rice vegetation index has a quadratic correlation with rice age. Table 4 shows the correlation coefficients between rice age and vegetation index.

![Figure 7. The rice growth stages corresponding to different indices values](image)

![Figure 8. Relationship Between Rice Age and NDVI](image)

![Figure 9. Relationship Between Rice Age and SAVI](image)
Figure 8. Relationship Between Rice Age and Vegetation Indices for Tested Indices.

Table 4 The Regression Statistics for Relationship Between Rice Age and Tested Indices

|                  | NDVI      | SAVI      | NDMI      |
|------------------|-----------|-----------|-----------|
| Multiple R       | 0.95517   | 0.95096   | 0.89645   |
| R Square         | 0.91235   | 0.90433   | 0.80362   |
| Adjusted R Square| 0.90204   | 0.89308   | 0.78051   |
| Standard Error   | 0.07564   | 0.10042   | 0.11553   |
| Observations     | 20        | 20        | 20        |

5. Conclusion
The study highlights the potential of the different indices namely NDVI, SAVI and NDMI which combines with multi-temporal Sentinel-2 data to detect and monitor rice growth phases. The methods for rice mapping and monitoring employed in this study are based on knowledge of rice plant temporal development and related temporal data. Crop discrimination relied heavily on multi-temporal data derived from Sentinel-2 satellite imagery. The maps can be used for the local scale to plan farm activities and to help organise labour at the appropriate time. It also provides knowledge for local governments, planners, and decision-makers to assess the rice-growing region for every rice season.

As a consequence, using vegetation indices determined from wavelength range sensitive to the factors mentioned can aid in identifying the contributing factors of differences in rice growth stages. The spatial distribution of each tested indices is displayed in the map output. The maps are then analysed and compared to determine the potential of each index in determining rice growth phases. It was discovered in this study that there was a quadratic correlation between all of the tested indices and rice age. The Normalized Difference Vegetation Index (NDVI) is the most accurate vegetation index for estimating rice age, followed by SAVI and NDMI.

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