Monitoring Rice Growth Stages Using Sentinel-2 Satellite Imagery in Northeastern Thailand

Aroonroth Sricharounchot[1*], Sarawut Arthayakun[1,2], Kittiphop Simachokchai[1],
Rungthip Nuangtawee[1], Nattapon Mahavik[2,3]
[1]Department of Royal Rainmaking and Agricultural Aviation, Bangkok 10900, Thailand
[2]Department of Natural Resources and Environment, Faculty of Agriculture Natural Resources and Environment, Naresuan University, Phitsanulok 65000, Thailand
[3]Water Resources Research Center, Faculty of Engineering, Naresuan University, Phitsanulok 65000, Thailand
*Email : aroonroth.sri@royalrain.go.th

Abstract: *Rice is an important economic crop in Thailand, accounting for 50 percent of the agricultural area, with the majority cultivated in the northeastern region. It serves as a staple food for domestic consumption and a crucial export commodity, making Thailand one of the world's leading rice exporters. Consequently, data on rice growth is essential for forecasting and planning the management of limited water resources to optimize agricultural productivity. Current remote sensing techniques play a vital role in surveying extensive and inaccessible agricultural areas. Data derived from satellite image analysis is a crucial tool for monitoring current conditions and forecasting future scenarios. This study used high spatial and temporal resolution imagery from the Sentinel-2 satellite to monitor rice growth. The satellite data is analyzed to extract spatial parameters of vegetation indices, specifically the Enhanced Vegetation Index (EVI) and the Normalized Difference Moisture Index (NDMI), to differentiate rice growth stages over time. The analysis results are validated through field surveys to determine the correlation between the index and rice growth, and they are presented in map format. Rice growth is monitored using remote sensing techniques in five stages: seedling, tillering, reproductive, ripening and harvest. Utilizing remote sensing techniques in this manner enhances the efficiency and precision of crop planning and water usage.*

Keywords: Rice growth stages, Sentinel-2, Vegetation Index, EVI, NDMI

1. Introduction

Rice is a staple food for people around the world, particularly in Southeast Asia, where Thailand is one of the leading rice producers globally. The majority of the country's rice cultivation occurs in the northeastern region. However, this area often faces challenges such as irregular rainfall, drought, and limited access to water resources. Since most rice farming in the region relies on rainwater, it is difficult to consistently regulate the water supply to meet demand. In some years, there is an excess of water, in others, there is a shortage, directly impacting rice yields. Monitoring the growth stages of rice is essential for effective water management, optimal fertilizer use, and yield prediction.

Satellite technology to monitor agricultural crop growth has gained significant attention due to its ability to continuously observe large agricultural areas and provide real-time information on crop health, growth stages, and environmental conditions. With increasingly available free data, this technology is highly effective for tracking agricultural activities, as it offers improved temporal, spatial, and radiometric resolution (Soriano-González et al., 2022). The Sentinel-2 satellite is one of the systems that provide multispectral imagery with relatively high spatial resolution, making it particularly suitable for agricultural monitoring. Its frequent orbiting allows for continuous observation of crop development. Additionally, it enables the analysis of key plant physical parameters, such as water requirements, soil moisture, and stress factors. This technology can also be applied to study drought conditions or nutrient deficiencies in crops, offering significant benefits for agricultural areas by improving water resource management and enhancing crop yields.

This research aims to test the use of Sentinel-2 satellite imagery for monitoring the growth stages of rice in the northeastern region of Thailand. By analyzing satellite imagery data through vegetation indices such as the Enhanced Vegetation Index (EVI) and the Normalized Difference Moisture Index (NDMI), the study seeks to establish correlations between rice growth stages throughout the entire cultivation season—from soil preparation to harvest. This enables continuous monitoring of rice development, which is highly beneficial for resource management in rice production, enhancing decision-making accuracy and yield estimation. The study also facilitates optimal management of limited water resources, including weather modification through artificial rainmaking to alleviate water stress during the frequent dry spells in Thailand's rainy season. Additionally, the findings contribute to developing integrated groundwater and surface water management systems to mitigate water scarcity and reduce drought risks. This research provides a valuable spatial dataset for addressing the impacts of climate change in Thailand, which is expected to intensify shortly.

2. Materials

2.1 Study area

The study area is focused on the northeastern region of Thailand, encompassing 20 provinces with a total area of 175,872.35 square kilometers. This region has the largest proportion of agricultural land, accounting for 70.35%, followed by forest areas, community areas, water bodies, and miscellaneous land, which represent 15.76%, 6.31%, 4.00%, and 3.59%, respectively (Land Use Policy and Planning Division Department, 2023). Of the agricultural land, 66.84% is located outside irrigation zones, and rice cultivation accounts for 39.81%, or 70,023.29 square kilometers, as shown in Figure 1.

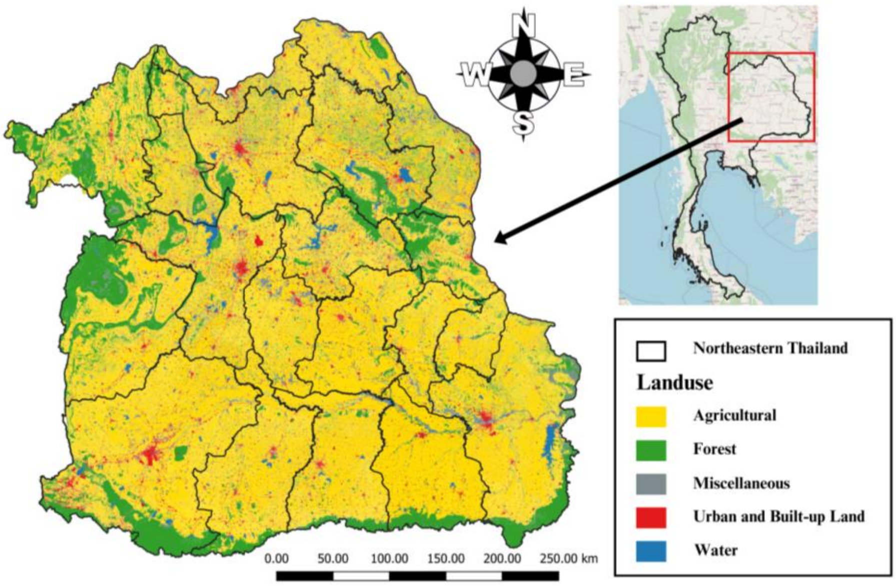

Figure 1 The land use distribution of the study area.

2.2 Sentinel-2 Satellite

Sentinel-2 is part of the European Space Agency's (ESA) Copernicus program, designed to monitor the environment and manage natural resources. The Sentinel-2 system consists of two satellites, Sentinel-2A and Sentinel-2B, which work together to provide rapid, high-resolution coverage of the Earth's surface. The satellites are equipped with the Multispectral Instrument (MSI), which captures imagery across a wide range of multispectral bands, including visible light, near-infrared (NIR), and shortwave infrared (SWIR). The instrument can capture images across 13 spectral bands with spatial resolutions of 10 meters for the red, green, blue, and NIR bands, 20 meters for the SWIR-related bands, and 60 meters for atmospheric monitoring bands. With a revisit time of 5 days, Sentinel-2 is highly valuable for agricultural crop monitoring (Ramadhani et al., 2020).

2.3 Rice Growth Stages

The rice growth can be divided into five stages: 1) Seedling stage (germination and early growth), which lasts approximately 1-30 days after planting, during which the rice plant develops its root system and the first leaf. 2) Tillering stage is a period of rapid growth during which the plant develops more leaves and stems. 3) Reproductive stage, when the rice plant begins the process of flowering and pollination, is a critical stage for yield as rice grains begin to form. 4) Ripening stage, the final stage before harvesting, during which the rice grains fully develop and transition from green to yellow, a stage crucial for grain quality, and 5) Harvest stage, where the rice is harvested at approximately 120-150 days of age (Sheng et al., 2022), as shown in Figure 2.

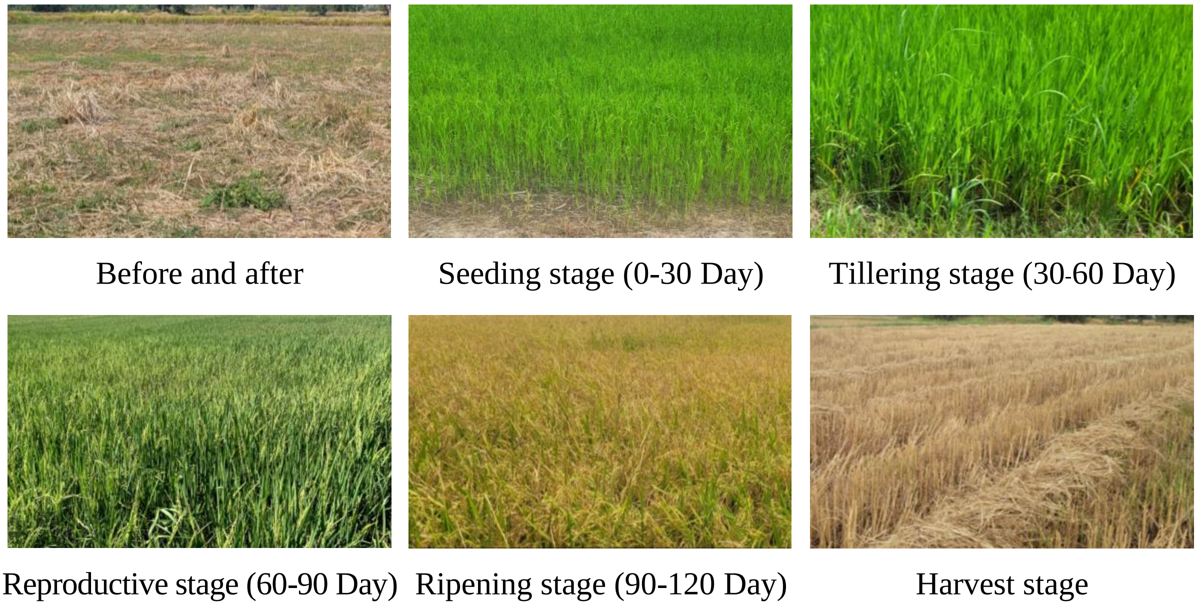

Figure 2 Rice Growth Stages

3. Methodology

3.1 Satellite Image Preparation

This study utilized Sentinel-2 Multispectral Instrument (MSI) imagery, specifically the L2A product, which has undergone radiometric correction, providing Bottom-Of-Atmosphere (BOA) reflectance data and geometric correction with a spatial resolution of 10 meters. A total of 35 images from the study area were downloaded and mosaicked into a single image to cover the entire rice cultivation area in the northeastern region of Thailand. Cloud-covered areas were excluded based on BOA reflectance thresholds, where Band 2 (BLUE), Band 3 (GREEN), Band 4 (RED), and Band 11 (SWIR) values greater than 4500, and Band 8 (NIR) values greater than 5900, were classified as cloud-covered regions and removed from the analysis. The research period spanned from May to December 2023, during which satellite images were downloaded every ten days, with 24 acquisition days and 840 images. These satellite images were prepared for subsequent analysis to monitor rice growth across the entire cultivation area in northeastern Thailand throughout the growing season, from soil preparation to harvest.

3.2 Calculation of Enhanced Vegetation Index (EVI)

The Enhanced Vegetation Index (EVI) is a metric used to measure the greenness and health of vegetation, building upon the Normalized Difference Vegetation Index (NDVI). EVI is specifically designed to reduce the influence of factors such as soil reflectance and atmospheric effects, which NDVI may not effectively account for in certain situations (Miura et al., 2008). The equation for EVI is presented in Equation 1:

$$EVI2 = 2.4\frac{(NIR-Red)}{(NIR+Red+1)} \quad (1)$$

where NIR is the near-infrared reflectance, and Red is the red band reflectance.

3.3 Calculation of Normalized Difference Moisture Index (NDMI)

The Normalized Difference Moisture Index (NDMI) is a metric used to analyze moisture levels in vegetation or soil by utilizing data from remote sensing, such as satellite imagery or specialized sensors. NDMI helps monitor moisture levels in agricultural areas and assists in water resource management (Khamnoi & Charoenpanyanet, 2022). The equation for NDMI is presented in Equation 2:

$$NDMI = \frac{(NIR-SWIR)}{(NIR+SWIR)} \quad (2)$$

where NIR is the near-infrared reflectance, and SWIR is the shortwave infrared reflectance.

3.4 Sample Rice Fields

This study selected 20 sample rice fields, each with an area of more than 1,600 square meters (or one rai). A simple random sampling method was employed to ensure that the samples were evenly distributed across rice cultivation areas outside the irrigation zones in northeastern Thailand. Field data collection occurred between May and December 2023 to monitor rice growth throughout the entire cultivation season, from soil preparation to harvest, as shown in Figure 3.

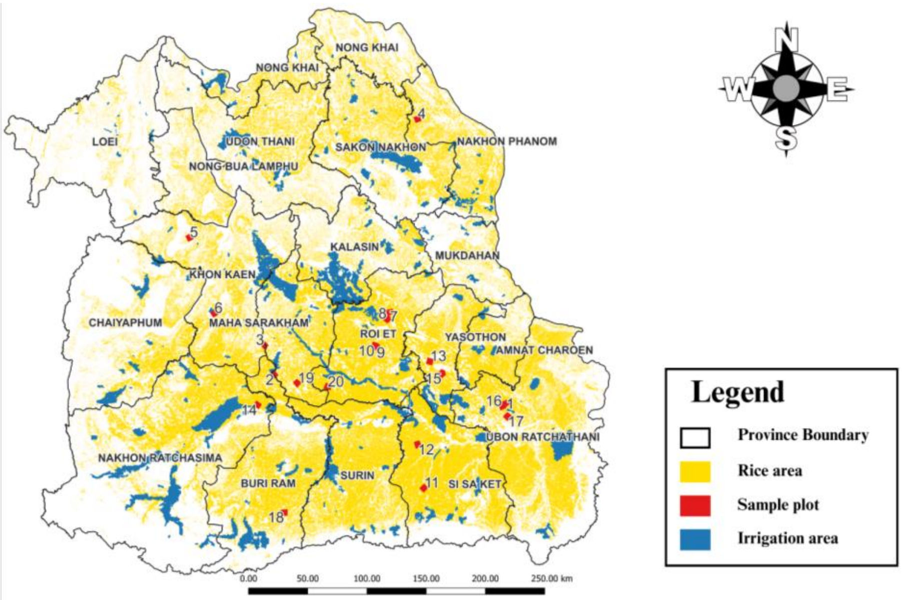

Figure 3 Locations of the 20 Sample Rice Fields Used in the Study

3.5 Correlation Analysis Between Rice Growth Stages and Index Values

The correlation between rice growth stages and the EVI and NDMI values was determined using regression analysis (Hasniati et al., 2022). The EVI and NDMI values represent the average of all pixel points within the sample rice fields derived from Sentinel-2 satellite imagery for the 20 samples. This analysis was conducted across the rice growing season to assess the relationship between the growth stages and the index values.

4. Results

4.1 Correlation Between Average EVI and Rice Growth Stages

In the seedling stage (0-30 days), rice begins to sprout and develop its first leaves. The EVI value starts increasing from a low level as the plants accumulate chlorophyll and undergo slight growth. However, EVI may remain low during this period due to higher reflectance from soil and water than vegetation, with reflectance values ranging from 0.1 to 0.24. During the tillering stage (30-60 days), the rice plants grow rapidly, with substantial development of leaves and stems, leading to a significant increase in chlorophyll accumulation. As a result, EVI rises due to the more excellent green vegetation coverage, with reflectance values between 0.24 and 0.26. In the reproductive stage (60-90 days), rice begins to flower and initiate the pollination process. Energy shifts towards seed formation, though the plant still exhibits good growth as the leaf structure remains intact. The EVI increases but remains similar to the vegetative stage, with reflectance values ranging from 0.26 to 0.6. During the ripening stage (90-120 days), the rice stops growing in terms of leaves and stems, focusing on grain development. The seeds start turning from green to yellow. EVI decreases during this stage, reflecting the decline in chlorophyll levels as the leaves begin to degrade and the plant prepares for harvest, with reflectance values between 0.26 and 0.6. In the harvest stage (120-150 days), the EVI value drops sharply as the harvested fields are dominated by yellow stubble. This results in minimal chlorophyll reflectance, with values ranging from 0.26 to 0.10. Table 1 and Figure 4 show the detailed average EVI reflectance for each growth stage of rice. These values are consistent with the EVI reflectance of the sample rice fields at different growth stages, as depicted in Figure 5.

Table 1 The range of EVI averages based on the ages of rice plants and growth stages

EVI values	Ages of rice plant (days)	Rice stage
< 0.10	< 0	Before and After
0.10-0.24	0-30	Seeding
0.24-0.26	30-60	Tillering
0.26-0.60	60-90	Reproductive
0.26-0.60	90-120	Ripening
0.26-0.10	> 120	Harvest

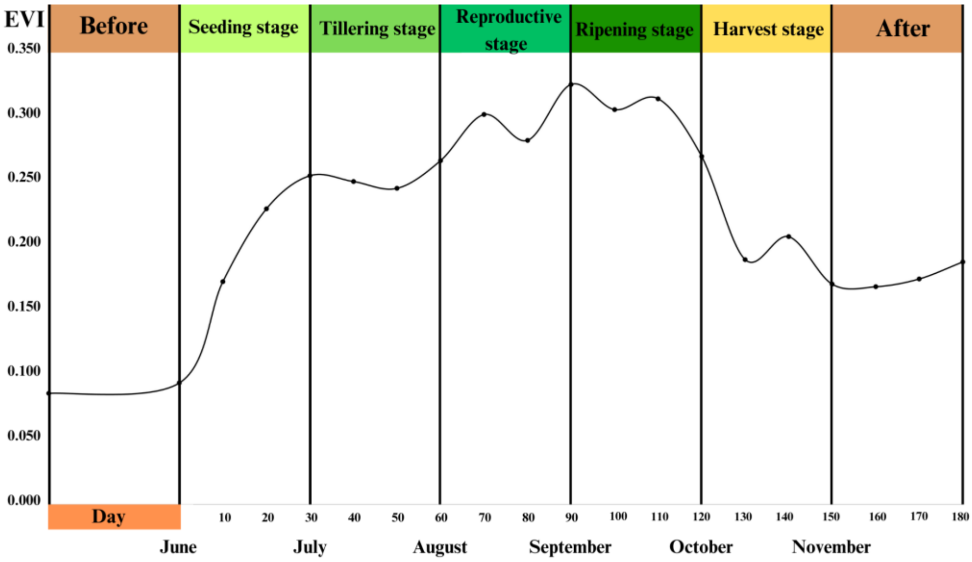

Figure 4 Correlation Between Average EVI and Rice Growth Stages

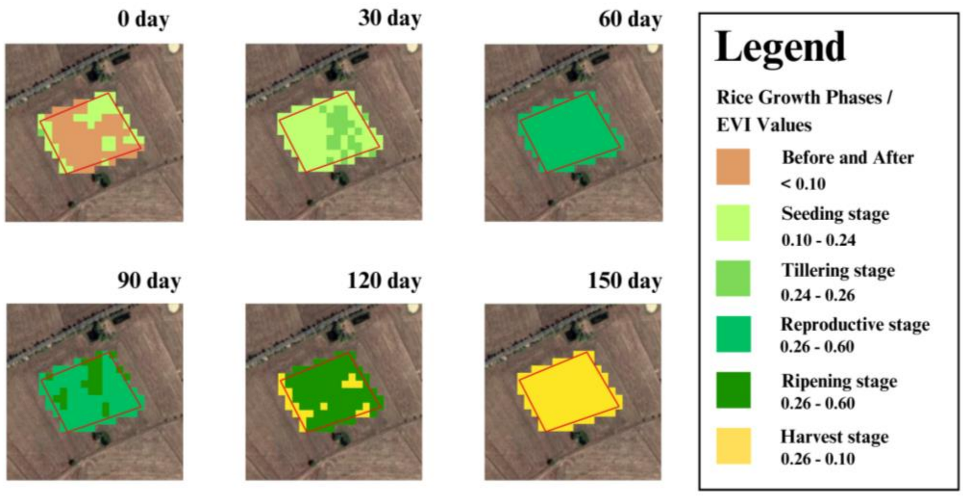

Figure 5 EVI Reflectance of Sample Rice Fields by Growth Stages

4.2 Correlation Between Average NDMI and Rice Growth Stages

In the seedling stage, during rice growth ages of 0–30 days, the rice plants are just beginning to germinate, developing roots and the first leaf. NDMI values during this stage are generally low because rice is often cultivated at the beginning of the rainy season using dry-seeding methods while awaiting seasonal rainfall, resulting in low soil moisture. The NDMI reflectance ranges from 0.10 to 0.20. In the tillering stage, ages 30–60 days, rice plants grow rapidly, with significant leaf and stem development. Water demand is very high during this period as plants require moisture to support photosynthesis and leaf growth. NDMI values increase, reflecting the accumulation of moisture in both leaves and soil, which is vital for plant growth. The NDMI reflectance ranges from 0.20 to 0.30. In the reproductive stage, ages 60–90 days, the rice plants enter the flowering and seed development phase. Water demand remains high, but NDMI values may stabilize or slightly decrease as moisture is redirected from supporting leaf and stem growth to reproductive processes. Adequate moisture in this stage is critical as it directly impacts future rice yields. The NDMI reflectance ranges from 0.15 to 0.25. In the ripening stage, ages 90–120 days, the rice grains reach full maturity, turning from green to yellow. Water demand decreases, and NDMI values decline as plants require less moisture. The leaf area reduces, and the soil may begin to dry. The reduction in NDMI indicates that rice is approaching the final stage of development and is ready for harvest. The NDMI reflectance ranges from 0.10 to 0.20. In the harvest stage, ages 120–150 days, NDMI values drop sharply as the harvested fields, now consisting of yellow stubble, have minimal vegetation cover. The NDMI reflectance is less than 0.1. Table 2 and Figure 6 show the detailed average NDMI reflectance for each rice growth stage, which is consistent with the NDMI reflectance of sample rice fields according to growth stages, as shown in Figure 7.

Table 2 The range of NDMI averages based on the ages of rice plants and rice stages

NDMI values	Ages of rice plant (days)	Rice stage
< 0.1	< 0	Before and After
0.10-0.20	0-30	Seeding
0.20-0.30	30-60	Tillering
0.15-0.25	60-90	Reproductive
0.10-0.20	90-120	Ripening
< 0.1	> 120	Harvest

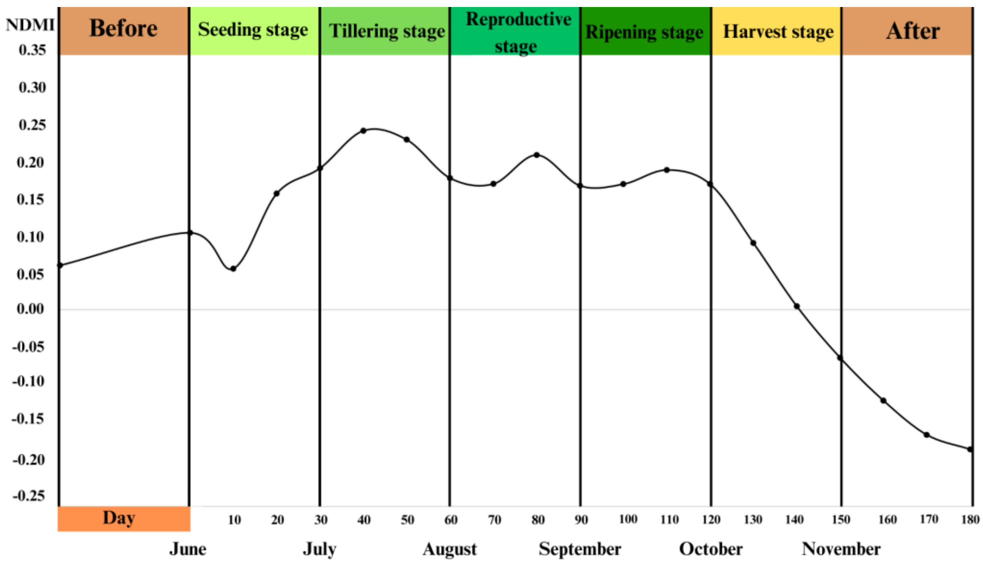

Figure 6 The correlation between average NDMI values and the growth stages of rice.

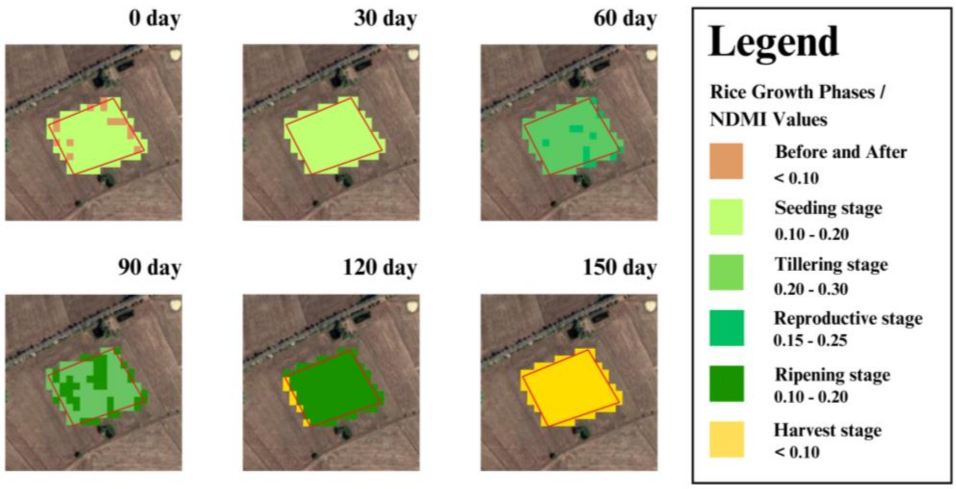

Figure 7 NDMI reflectance of sample rice fields at various growth stages.

4.3 Regression Analysis Between Rice Growth Stages and Index Values

The study applied regression analysis to explore the relationship between the rice growth stages and the EVI and NDMI indices. A curve-fitting model was used to determine the best-fit equation that describes the relationship. The analysis revealed that the relationship between the rice growth stages and the EVI index had a correlation coefficient of 0.8561, with the regression equation: $y = -0.0028X^2 + 0.0514X + 0.068$, as shown in Figure 8. Similarly, the relationship between the rice growth stages and the NDMI index had a correlation coefficient of 0.8242, with the regression equation: $y = -0.0035X^2 + 0.053X + 0.0241$, as illustrated in Figure 9.

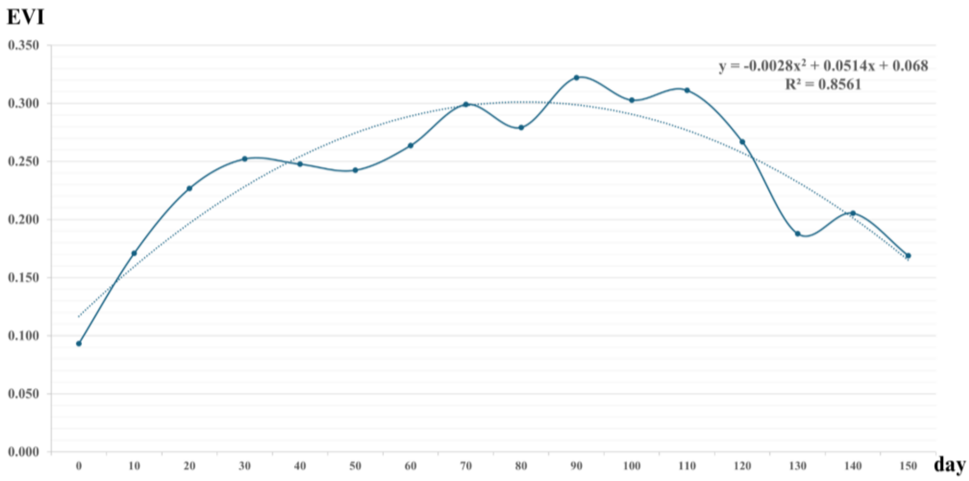

Figure 8 Relationship Between Rice Growth Stages and EVI Index Values

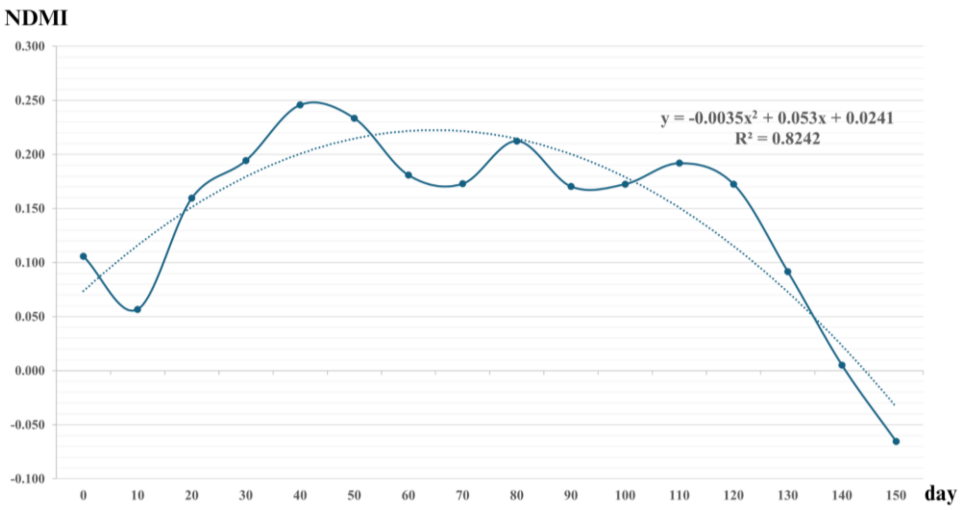

Figure 9 Relationship Between Rice Growth Stages and NDMI Index Values

5. Conclusion

Using Sentinel-2 satellite imagery to monitor rice growth in northeastern Thailand revealed a strong correlation between the Enhanced Vegetation Index (EVI) and Normalized Difference Moisture Index (NDMI) with rice growth stages. The EVI values aligned well with the development of chlorophyll and plant density during different growth stages, mainly showing an apparent increase during the tillering and reproductive stages. Conversely, EVI values decreased as the rice entered the ripening and harvest stages. NDMI effectively indicated moisture levels in leaves and soil, which are critical for plant growth and development. The results showed that NDMI values increased during the tillering stage while showing stability or a slight decrease during the reproductive and ripening stages as the water demand of the rice was reduced. Regression analysis between rice growth stages and both indices (EVI and NDMI) provided a clearer understanding of changes in each stage. These findings highlight the potential of remote sensing technology in monitoring rice growth, enabling improved accuracy in yield estimation and water management for rice cultivation. Future studies should expand the sample size, consider geographical diversity, and incorporate other vegetation indices to achieve more comprehensive and accurate analyses.

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