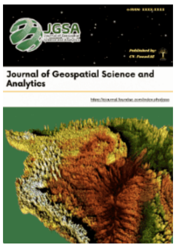

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Rice growth dynamics: NDVI modeling with sentinel-2 and environmental influences

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Abstract

Accurate monitoring of rice growth phase and phenology is crucial for food security in Indonesia, where rice is a staple crop. This study utilizes Sentinel-2 imagery and remote sensing techniques to efficiently assess rice growth dynamics over a large agricultural area at PT. Sang Hyang Seri, Subang, West Java. The Normalized Difference Vegetation Index (NDVI) was derived from Sentinel-2 data and correlated with plant age to determine rice growth stages. Furthermore, the influence of rainfall, soil type, and slope on NDVI values was analyzed to quantify the impact of these physical factors on rice development. Results indicate that the temporal trend of NDVI during the rice growth cycle can be effectively modeled using a second-order parabolic curve. While the overall rice growth duration was approximately 110 days, land units delineated based on physical factors (OATRAL, DFTRL, DFTTL) exhibited variations in NDVI values, suggesting differential plant fertility. Correlation analysis revealed that rainfall, soil type, and slope significantly affect plant fertility, though not the overall growth duration. Nursery duration, however, was found to influence the age of rice planting. These findings demonstrate the utility of Sentinel-2 NDVI for high-resolution monitoring of rice phenology and highlight the importance of considering environmental factors for optimizing rice production in the region.

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INTRODUCTION

Rice is one of the main cereal crops in the world that plays an important role in food security (Phung, H. P. et al., 2020), including Indonesia. It is because 90% of the Indonesian population

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relies on it as a staple food and rice is widely cultivated by Indonesian farmers (Syafriyyin, M. A. & Sukojo, B. M, 2014). The total population of Indonesia in 2024 reached 282 million people (bps.go.id) with an average rice consumption of 79,08 kg/capita/year. As increasing population, it has an impact on the rice need (Wicaksono, M. G. S., et al. 2022). Also, Wicaksono, M. G. S., et al. (2022) told that by population growth, it is important to increase rice supply and also rice productivity, to avoid importing rice from other countries, to reach food security and answer the second goal of the SDGs (Sustainable Development Goals), that is zero hunger (Triscowati, D. W. et. al., 2019). Besides, during climate change, and various environmental factors paddy ecosystems faced unprecedented challenges that affect rice productivity, and it is important to ensure sustainable paddy production (Qin, Z., et. al., 2025). Therefore, assesing rice growth phases becomes important for proper management of the rice crop, as understanding of a healty crop to produce high quality and quantity rice productivity. And the ability to identify rice growth stages is important for proper management of the rice crop.

Rice growth phase can identify by knowing its phenology that calculated from time series images based from Vegetative Indices (VIs) such as NDVI (Normalized Difference Vegetative Index) to represent dynamics in every stage of rice growth (Liu, J. et. al. 2023). In past, Van Niel and Mc. Vicar (2001) also stated that monitoring of rice growth phase should be accompanied by an understanding of the phenology of this plant. Rice growth phase was tended to occur in a short period and covers a large area, therefore an approach is needed to monitor from the planting phase, vegetative, generative and fallow which is close to near real-time (Endiviana, O. A., et. al. 2022). Recently, remote sensing has shown impressive potential in mapping crop types and monitoring crop dynamics, thus becoming an effective means for agricultural mapping (Li, G. et. al., 2022). Remote sensing can provide information on the condition and distribution of agricultural land quantitatively and qualitatively (Suspidayanti, L. & Rokhmana, C. A., 2021). This is because multitemporal satellite remote sensing images can capture the entire crop growth process (W. Chen and G. Liu, 2024). Moreover, Endiviana, O. A., et. al. (2022) added that by optimizing the use of remote sensing methods, we also can analyze rice growth phase spatially.

Rice growth has dynamics and it's strongly influenced by environmental conditions and factors (Endiviana, O. A., et. al. 2022). Previous studies, explained many factors that causes a rice growth dynamic. Interaction of climate, topography and soil properties were defined as the significant factors affecting rice growth dynamics in Punjab, Pakistan (Liu, J. et. al. 2023). Before, Abbas, S. and Mayo, Z. A. (2021) clearly explained how the temperature and rainfall impacted on rice production in same place. On the other hand, in tropic climate, like Indonesia, having different environmental factors that affect rice growth phase. This different condition giving different variety of environmental factors that causes rice growth dynamics. Therefore, it is important to asses rice growth phase through remote sensing and its environmental factors influence. Remote sensing can investigate the influence of environmental conditions on the precision of multispectral imaging, particularly in the calculation of vegetation indices (VIs) (Haque, M. A., et. al., 2024).

Previously, Endiviana, O. A., et. al. (2022) explained rice growth dynamics through affected of LAI to various Vegetation Index (NDVI, ARVI, SAVI). Hisham, N. H. B., et al (2022) conducted monitoring of rice growth phases with sentinel-2 data using NDVI, SAVI and NDMI vegetation indices in Malaysia. Lai, J. K. & Lin, W. S. (2021) conducted a study on rice panicle initiation using the NDVI vegetation index in Taiwan. NDVI chosen caused this index was common and widely used to assess vegetation coverage, including monitor crop growth, and predict yields (Wang, J., et. al., 2025). Then, Liyantono, et al (2020) studied the analysis of rice productivity using vegetation indices from sentinel-2 and UAV imagery. And, as I maintained before, Liu, J. et. al. (2023) and Abbas, S. and Mayo, Z. A. (2021) explained factors that cause rice growth dynamics. However, the research discussed that factors is limited and few. So, this research aims to renew, enrich, and giving a complete review of rice growth dynamics and its environmental factors influence.

Therefore, this research was conducted to monitor rice growth phase with NDVI index through multi-temporal based remote sensing to create relationship between NDVI as greenness index with age of plant, also spatial distribution of rice growth. Then, explain environmental factors influencing dynamics of rice growth, i.e. rainfall, slope, and soil type. This research placed in PT. Sang Hyang Seri, Subang, West Java as a agricultural company that produce rice with total area of 3,140 hectares. This place selected caused Subang is the third highest rice producing regency in Indonesia (942,932 tons of GKG (Dry Milled Paddy)) (subang.go.id). This research needed high spatial resolution sensor to produce high quality information from narrow area. So, Sentinel-2 is suitable for this research. Sentinel-2 is open sources satellite with 10 m resolution in RGB bands. With its improved spatial, spectral and temporal resolution, is specifically designed to meet the needs of agriculture (Segarra, et al. 2020).

METHOD

Location and Research Time

This research was a spatiotemporal analysis with quantitative approach including several geo-calculated data to show the rice growth phase with GIS (Geography Information System). This research was conducted directly with field observations to determine the growth phase of rice. During processing datasets, this research was used various Tools, like Google Earth Engine, Visual Studio Code, QGIS, ArcGIS, and Excel. In addition, secondary data collection was carried out as in the Table 1. This research was conducted in the rice field area of PT. Sang Hyang Seri, Subang, West Java. The area of PT. Sang Hyang Seri itself is located in three sub-districts, namely Ciasem District, Patokbeusi District, and Blanakan District. This research was conducted from June 2022 to July 2023. The detail of research location appearance in Figure 1.

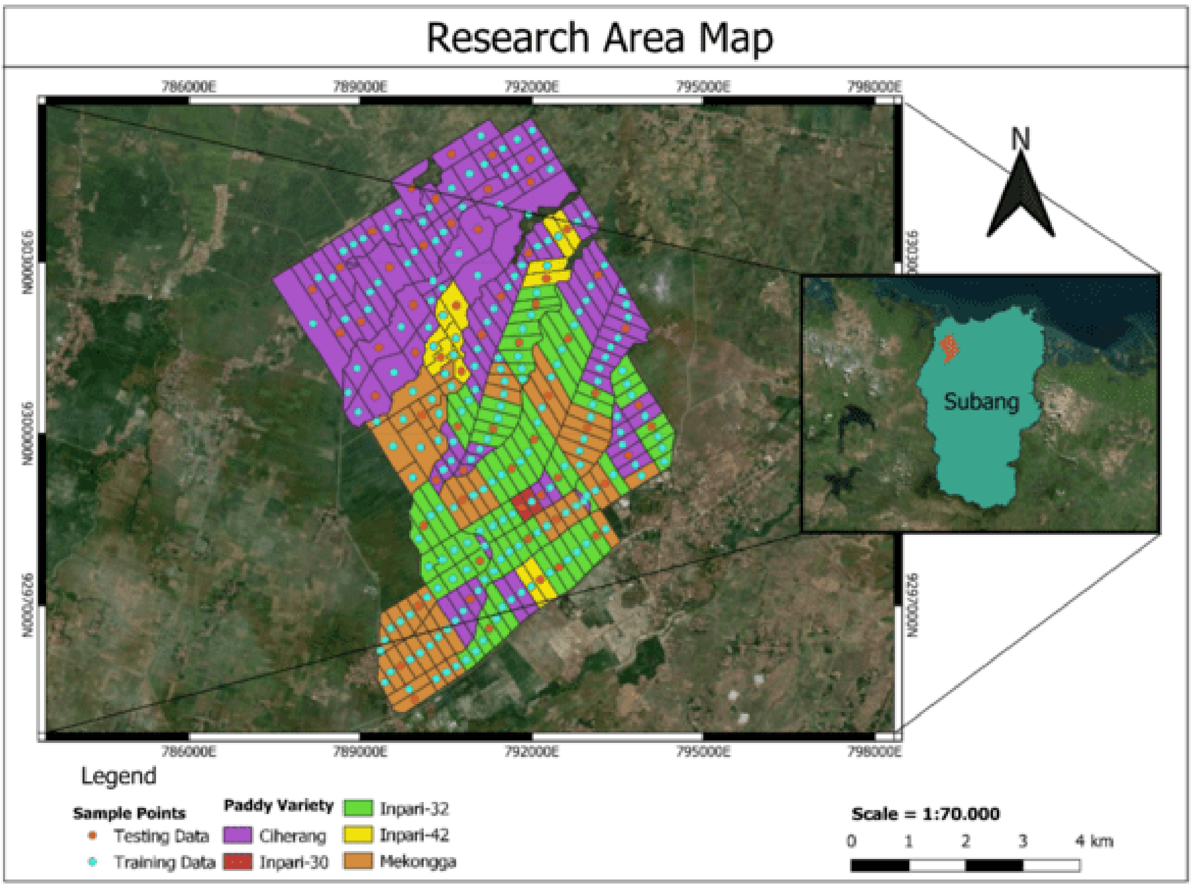


Figure 1. Research Area Map located in PT. Sang Hyang Seri, Subang, West Java

Research Data

The research data used in this study consists of primary data and secondary data. Primary data is obtained through direct observation and secondary data is obtained through various agencies without an observation process. can be seen in the Table 1.

Table 1. Types and Sources of Data in Research

No	Data	Source	Explanation
1	Sentinel Level 2A	Google Earth Engine	Rice Growth Phase Maps
2	Ground check of rice growth phase field	Direct Observation	Rice Growth Phase Maps and Graphs
3	Rice Planting Time Data, Sowing Date, Harvest Date, Fertilization and Irrigation	PT. Sang Hyang Seri	Rice Growth Phase Maps and Graphs
4	Shapefile of paddy fields in PT. Sang Hyang Seri area	PT. Sang Hyang Seri	Rice Growth Phase Maps
5	Soil Type	Center for Agricultural Land Resources Research and Development (BBSDLP)	Environmental Factors
6	Rainfall	CHIRPS	Environmental Factors
7	Slope and Elevation	DEMNAS	Environmental Factors

Estimation of Rice Growth Phase based on NDVI values

This research used Sentinel-2 Image Collection with high 10 m spatial resolution with cloud cover less than 20% to create NDVI Maps to extracts Rice Growth Phase numericly and spatially. Sentinel-2 also preprocessed by performing cloud removal functions, filtering the number of clouds in Google Earth Engine. NDVI data calculated to obtain the vegetation index. This process is carried out in Google Earth Engine with the Normalized Difference function to produce NDVI values for the period 1 June 2022-31 October 2022 every block of rice fields. Normalized difference vegetation index (NDVI) is an index introduced by (Kriegler et al., 1969) and refined by (Rouse et al., 1973). NDVI uses Red and Near Infrared bands in remote sensing to determine vegetation index from satellites. The following is the NDVI algorithm (Lillesand and Kiefer, 1994) in equation (1) as follows:

$$NDVI = (\rho\_NIR - \rho\_RED)/(\rho\_NIR + \rho\_RED) \quad (1)$$

where:
ρ_NIR=near infrared band value,
ρ_RED=red band value.

According to Gujarati, D. N. (2003) and Hair Jr, JF, Black, WC, Babin, BJ, & Anderson, RE (2018) the development of a regression model for the analysis of the relationship between vegetation index (NDVI) and days after planting for the analysis of rice growth phases includes regression analysis and model validation. Before the regression analysis was carried out, normality and linearity tests were carried out on the data to be used. After that, the data was divided into training data and testing data. Then from the training data, a regression analysis was carried out to determine the best model parameters and estimate the relationship between the independent variables (rice age) and the dependent variable (vegetation index).

This steps also threated in the testing data. Model validation is carried out to check the extent to which the polynomial regression model that has been developed is reliable and can be used in the analysis of rice growth phase monitoring. Model validation is carried out by determining the MSE (Mean Square Error), RMSE (Root Mean Square Error), and R-squared (R2) values. This model validation can help to determine the accuracy of the model that has been developed and determine the best model from the smallest error value.

Then, the creation of a rice growth phase map was carried out to see the distribution of rice age in a certain period based on the vegetation index value (NDVI). Map making is very important to know the distribution of rice growth phases spatially in each block at PT Sang Hyang Seri. This analysis uses imagery from June 1, 2022-October 31, 2022. Previously, NDVI imagery was downloaded from Google Earth Engine. Then the classification of rice growth phases was carried out. The classification of rice growth phases is listed in Table 2.

Table 2. Rice Growth Phases

Phase	Age	Characteristic features	NDVI
Water	1- 5 days	When the rice plants are submerged in water.	< 0.1
Vegetative 1	6-40 days after planting	When the rice plant begins to grow, both the roots and the leaves.	0.1-0.4
Vegetative 2	41-64 days after planting	When the rice plant has produced more shoots.	0.4-1
Generative 1	65-96 days after planting	The first stage of the reproductive growth period, when the rice plant forms panicles.	0.4-1
Generative 2	97 days after planting-harvest	When the rice plants flower and produce seeds.	0.1-0.4
Bera	After harvest	The period of time after harvest, when the fields are left fallow to rest and prepare for the next harvest.	<0.1

The process of distinguishing vegetative and generative phases requires at least two images with different acquisition dates (t and t-1) (Rudiana, Eka, et al., 2016). The condition of the rice growth phase can be known through changes in the NDVI value (dNDVI). The vegetative phase is marked by a positive change in the NDVI value and the generative phase is marked by a negative change in the NDVI value. Therefore, a raster calculator analysis was carried out to create a map of the rice growth phase. The formula for determining the rice growth phase is found in equations (2) and (3) as follows:

Con((“NDVI Map"-“NDVI Map-1")>=0, 0.1) >>dNDVI result (2)

Con("dNDVI"==0, Con("NDVI Map"<= 0.2, 1, Con("NDVI Map"<= 0.4, 2, 3)), Con("NDVI Map">= 0.4, 4, Con("NDVI Map">= 0.2, 5, 6))) (3)

where:
NDVI map = NDVI value on that day,
NDVI-1 = NDVI value in the previous image,
dNDVI = NDVI difference value,
1 = water phase,
2 = vegetative phase 1,
3 = vegetative phase 2,
4 = generative phase 1,
5 = generative phase 2 and
6 = fallow phase.

After that, it is visualized and laid out. To determine the accuracy of the data, a confusion matrix validation is carried out, to determine the comparison of accuracy between Sentinel-2 image data and field data in the form of ground check point data.

Environmental Factors Influence to Rice Growth Dynamics

This step mainly aims to create rice growth curve in different land units to see the variability effects to rice growth phase or age of rice. Spatially, environmental factors affected rice growth dynamics, like rainfall, soil type and slope. It's means that variability of land characteristics very affected to rice growth phase. So, Land Units Map was created to divided Sang Hyang Seri area based of those factors. Then, Rice Grwoth Phase of every land units define with polynomial regression to show different growth time of every conditions. The following in next each table below of rice field unit classification criteria at PT. Sang Hyang Seri. First, the rainfall criteria in Table 3.

Table 3. Rainfall Criteria

Code	Class	Criteria
Td	Heavy Rain	Daily rainfall above 100 mm
Tr	Moderate Rain	Daily rainfall 60-100 mm
Tt	Low Rain	Daily rainfall < 60 mm

Source: (Mohr, 1933 and IRRI, 2017)

This table describes the criteria used to assess land units for rice cultivation based on rainfall. The scoring is based on the International Rice Research Institute (2017) article on Soil and water management for rice production. Next, The Table 4. that explain the criteria used to assess land units for rice cultivation based on soil type.

Table 4. Soil Type Criteria

Code	Class	Criteria
Df	Suitable Land	Soil type Dystric Fluvisols
Oh	Less Suitable Land	Soil type Orthic Acrisols

Source: (FAO, 2007)

Topography, that specifically selected slope criteria was selected to spatial land characteristics that affected in rice growth dynamics. The slope criteria explained in Table 5. This Table 5. explains the criteria used to assess land units for rice cultivation based on slope. The flatter and gentler the land, the more suitable it is for rice growth, because rice has short roots and is vulnerable when planted on high slopes. According to Arsyad (1989), land with a slope of less than 3% is considered as land with a flat slope. Land with a slope of 4-15% is sloping-slightly steep, and land with a slope greater than 15% is sloping-steep.

Table 5. Slope Gradient Criteria

Code	Class	Criteria
L	Flat	Slope gradient below 3%
Al	Sloping-Slightly sloping	Slope gradient 4-15%
C	Steep-Sloping	Slope gradient >15%

Source: (Arsyad, 1989)

Each of these factors is then analyzed using the matching method to determine the class of land units at PT. Sang Hyang Seri. Then, a correlation is made between each factor and the NDVI value to determine its influence. After that, various environmental factors are analyzed against the rice growth phase curve in each land unit. These steps explained in Table 6.

Table 6. Relationships Between NDVI and Environmental Factors

	Environmental Factor	Correlation Type
NDVI	Rainfall	Polynomial Regression
	Soil Type	Kendall's Tau Correlation
	Slope	Linear Regression

RESULTS AND DISCUSSIONS

Estimation of Rice Growth Phase based on NDVI values

The results of the study showed that the rice growth phases were classified into water phase, vegetative 1, vegetative 2, generative 1, generative 2, and fallow. The suitability of the rice growth phase to field conditions was calculated using a confusion matrix. The results of the accuracy test with the confusion matrix can be seen in Table 7.

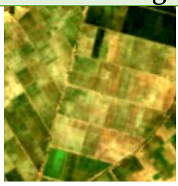
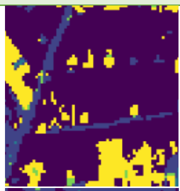
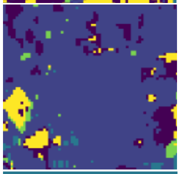
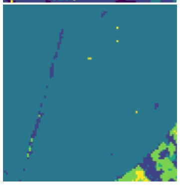
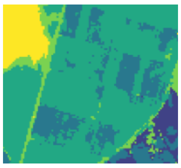
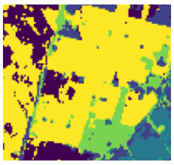
Table 7. Accuracy Test of Confusion Matrix of Rice Growth Phases with Field Data

Phase	Water	Vegetative 1	Vegetative 2	Generative 1	Generative 2	Bera	Total	U_Accuracy	Kappa
Water	7	1	0	0	0	2	10	0.7	0
Vegetative 1	0	12	0	0	0	1	13	0.923	0
Vegetative 2	0	0	10	0	2	0	12	0.833	0
Generative 1	0	0	1	6	2	1	10	0.6	0
Generative 2	0	0	0	0	10	1	11	0.909	0
Bera	1	0	0	0	1	8	10	0.8	0
Total	8	13	11	6	15	13	66	0	0
P_Accuracy	0.875	0.923	0.909	1	0.667	0.615	0	0.803	0
Kappa	0	0	0	0	0	0	0	0	0.763

Accuracy shows a value of 0.803 for producer accuracy and 0.763 for kappa accuracy . The producer accuracy value which means "recall" or "sensitivity" is calculated by dividing the number of positive samples correctly classified by the model by the total number of positive samples in the dataset. This means that 0.803 percentage of the positive class was correctly identified by the classifier model. Meanwhile, the kappa value of 0.763 indicates a class imbalance of 0.237. In the land processing stage, the land requires a wet condition that is flooded with water. When new rice plants grow (replanting), the rice field area is always flooded and what appears dominant is the water that fills the land (water phase). Along with the development of the plants, the condition of the rice fields will change to be dominated by rice leaves. According to Wahyunto, et al. (2006) at the peak of vegetative growth, a high level of greenness occurs due to the high chlorophyll content. After that period, the level of greenness will decrease, rice flowers appear, and finally turn yellow. The growth stage will end with the harvest period, and the land will be left empty for a certain period of time, depending on the planting pattern. Therefore, the growth stages of rice plants can be grouped into four categories, namely the water phase, vegetative growth phase, generative growth phase, and fallow phase.

Visualization of the rice growth phase at PT. Sang Hyang Seri can be seen in Figure 2. And Table 8. The water phase is marked by bright colors on the Sentinel-2 RGB image, and dark blue on the NDVI value. While the conditions in the rice field are still in the early planting period with small sizes. The vegetative phase is marked by dark colors on the Sentinel-2 image, with a slightly brighter blue on the NDVI value. In this phase, the NDVI value reaches its maximum. The generative phase is marked by the color of the Sentinel-2 image and field photos that are starting to turn yellow. Finally, the fallow phase is marked by the yellow color of the Sentinel-2 image and the appearance of post-harvest rice on field photos.

Table 8. Visualization of Rice Growth Phases

Sentinel-2 imagery	NDVI	Photos	Phase	Age (HST)
			Water	0-10
			Vegetative 1	10-30
			Vegetative 2	30-60
			Generative 1	60-90
			Generative 2	90-110
			Bera	110-120

The fluctuation of the vegetation index value of the rice growth phase can be seen in the legend in Figure 2. The fallow phase dominated by water is classified with an NDVI value of <0.1. Small rice and little vegetation make the NDVI value low. Vegetative phase 1 has a vegetation index value of 0.1-0.4. In this phase, rice begins to grow roots and leaves. Vegetative phase 2 has a vegetation index value of 0.4-1. In this phase, rice begins to bear offspring and is in peak growth. In the generative phase, the vegetation index value decreases from 1 to 0.4. This is because the rice begins to grow panicles and begins to turn yellow. In the generative phase 2, the decline in the vegetation index continues. In this phase, a vegetation index of 0.4 was detected, decreasing to 0.1. The fallow phase, which is the period after harvest, has a vegetation index of less than 0.1.

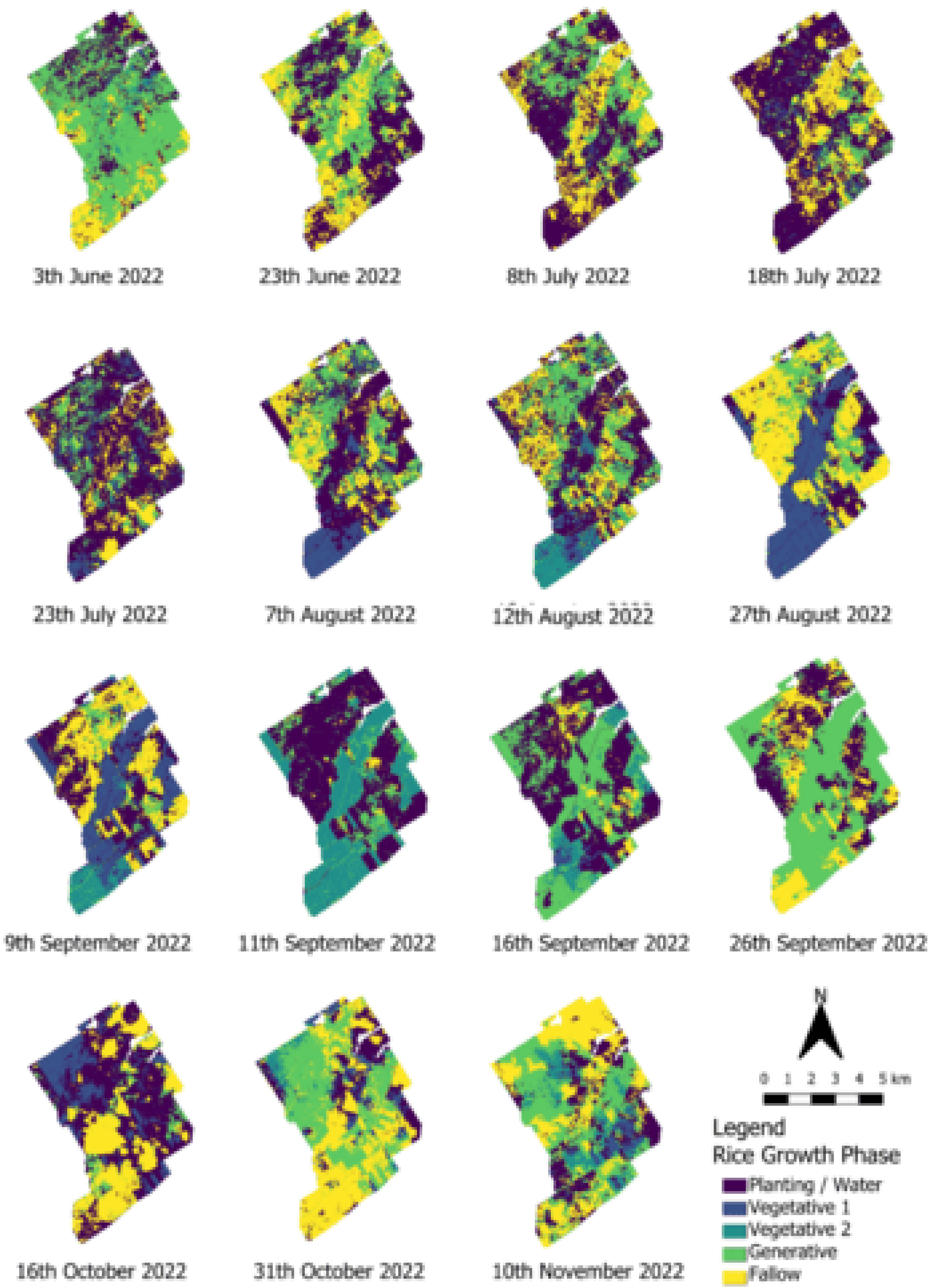


Figure 2. Rice Growth Phase Map

NDVI can be used as an indicator of biomass, relative greenness, and to determine the health status/density of vegetation in an area without being directly related to the availability of groundwater in the area (Hung, 2000), including explain rice growth age with a curve. The graph of the relationship between NDVI values and rice age forms a parabolic curve in Figure 3. This is related with the opinion of Wahyunto, et al. (2006) that the growth of rice plants from the planting phase to the harvest phase has an NDVI value that shows a parabolic curve. Rice plants usually take 3-4 months to grow from seeding to harvest, depending on the type of rice variety and the conditions of the place where the rice plants grow (Ramadhani et al., 2016). Crop growth phases inform how farm managers make decisions about application schedules (Sakamoto et al., 2005). This is in accordance with the data on changes in the area of the rice growth phase in Figure 3.2 that it takes 3 months to reach harvest time.

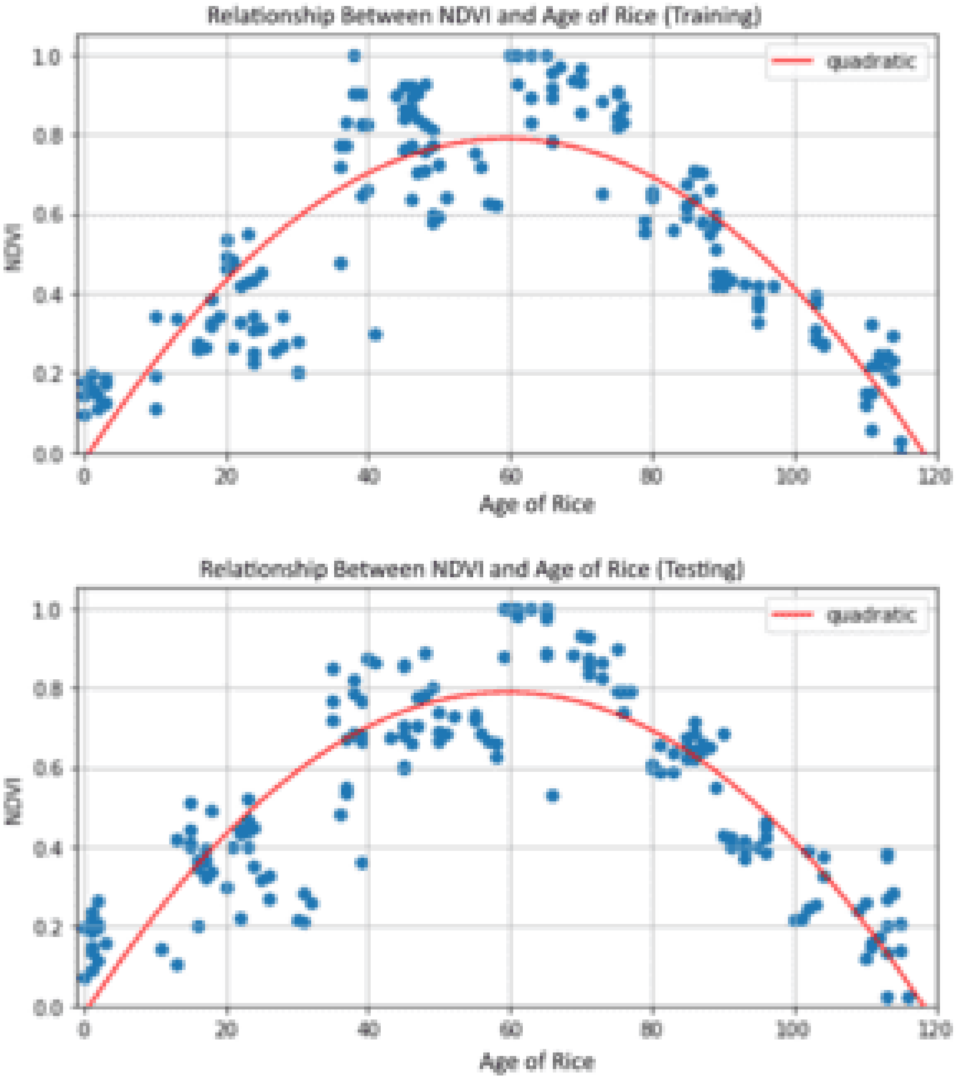


Figure 3. Polynomial Regression Model in Rice Growth Phase Training Data (top) and Polynomial Regression Model Testing Data (bottom)

NDVI in new rice plants can only be measured after the rice plants reach the age of 3-4 MST (weeks after planting), because before that age the appearance of rice plants in rice fields is still dominated by the appearance of waterlogging (Malingreau, 1981). This causes the NDVI value below 20 days to have a value below 0.2 (Figure 3). Likewise, in the fallow phase on day 100 and above, the NDVI value is below 0.2 (Figure 3). Meanwhile, the NDVI value starts to be high and reaches its peak on the 60th day indicating that the rice is growing denser (Figure 3). This is in accordance with the opinion of Wahyunto, et al. (2006) that a low NDVI value means a low chlorophyll level, while a higher value indicates that the plant is getting denser/greener.

The accuracy value of the polynomial regression model of the rice growth phase is shown in Table 9. The value of the proximity of the prediction line (red line) to the data is described in the coefficient of determination R-squared (Ramadhani, et al., 2016). If the R-squared value approaches 1, the prediction model is getting better, if on the contrary it approaches 0, it means that there is no match between the prediction line and the data. The R-squared value on the training data that is larger than the testing data explains that the model is underfitting, or the model is less able to be applied to other data. This is because there are outliers in the data that are far outside the prediction line. This is due to cloud or atmospheric interference which causes the resulting NDVI value to not be the actual value. This especially often occurs when it is difficult to distinguish between the water phase and the fallow phase. This is because it is difficult to distinguish between the fallow phase that is inundated and not inundated.

Table 9. Accuracy of Polynomial Regression Model on Training Data and Testing Data

Data Types	R-squared	RMSE	MSE
Training Data	0.81	0.136	0.1269
Testing Data	0.74	0.356	0.0185

Environmental Factors Influence to Rice Growth Dynamics

Effective monitoring of the growth dynamics of rice crops at different phenological phases is required to help yield prediction by informing farmers as to when management interventions are necessary (Fageria, 2007). The results of the study indicate that the land units in PT. Sang Hyang Seri are divided into three. Land unit 1 with the code OATRAL (Orthic Acrisols Moderate Rainfall Slightly Sloping Condition) is in the southern part with a red color on the map (Figure 4). Land unit 2 with the code DFTRL (Dystric Fluvisols Moderate Rainfall Flat Condition) is in the middle with a light blue color (figure 4). Finally, land unit 3 with the code DFTTL (Dystric Fluvisols Less Rainfall Flat Condition) is in the northern part with a purple color (figure 4). The division of the land units is based on variations in rainfall values, soil types and slope gradients spatially.

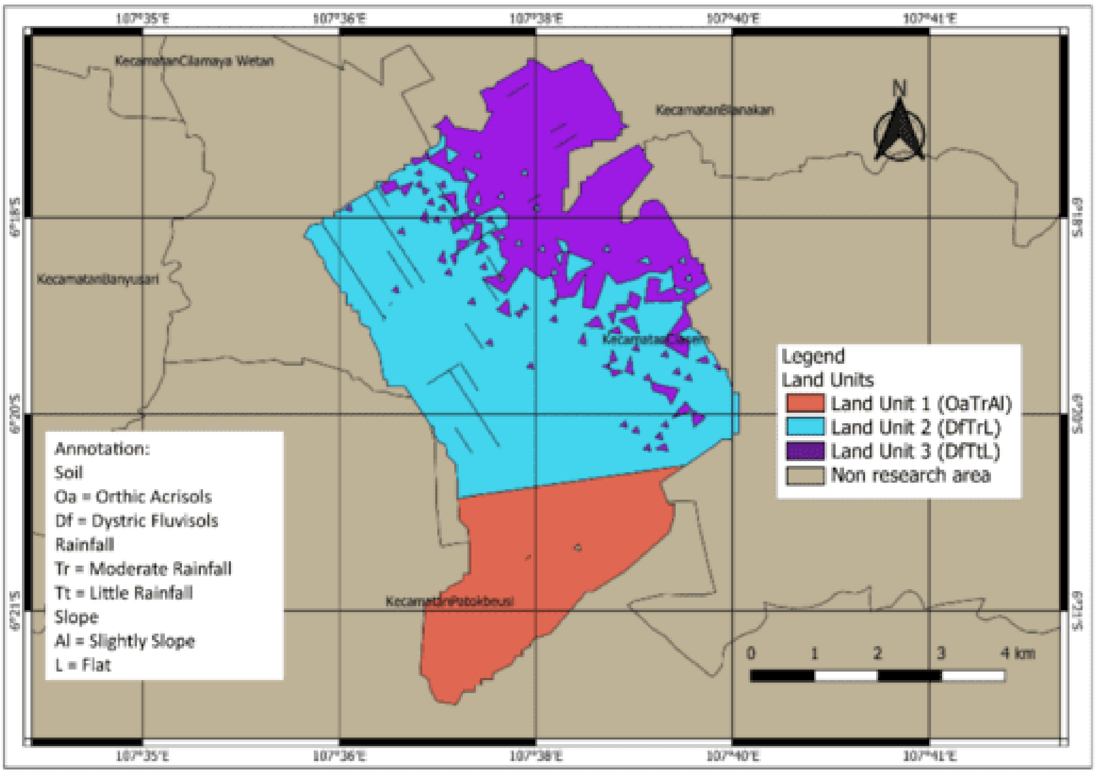


Figure 4. Map of Land Units at PT. Sang Hyang Seri

Jabal, Z. K. et. al. (2022) explained that climate factors affected to rice productivity. Rainfall, as the one of the climate factors, calculated and correlated with the NDVI value. The relationship between NDVI and days after planting in each land unit is depicted in Figure 5. The relationship forms a parabolic curve like the previous analysis. The part that increases is the water-vegetative phase while the part that decreases is the generative-fallow phase. The NDVI value is initially low. When the rice begins to grow, the NDVI value increases as the rice plants begin to turn green. Then, during the peak growth period, the NDVI value reaches a maximum. Then, during the generative period, the NDVI value decreases again until it reaches a minimum in the fallow phase. This is what makes the NDVI curve form an inverted parabolic curve. The curve in the OATRAL land unit has an R2 value of 0.7248. The curve in the DFTTL land unit has an R2 value of 0.8281 and the curve in the DFTRL land unit has an R2 value of 0.8661. All three R2 values are said to be good because all three are close to the value of 1.

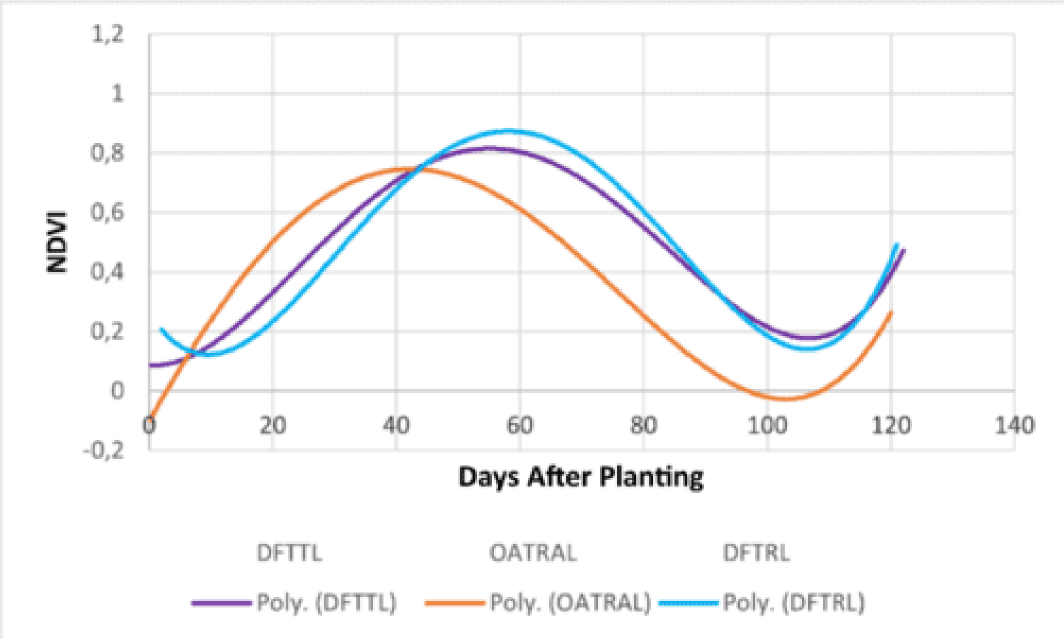


Figure 5. Rice Growth Curve on Each Land Unit

Physical geographical factors in each land unit affect rice growth. This is indicated by the differences in the three curves of the relationship between NDVI and HST values. This can be seen in Figure 3.5 where the NDVI value in land 1 peaked at 40 HST. The graph is interpreted that rice has a growth period of 100 days. This is different from land units 2 and 3 where the NDVI value peaked at 60 HST. Where both graphs interpret that rice has a longer growth period, which is 110 days. This is certainly related to the suitability of the land explained earlier.

Land unit 1 (OATRAL) has moderate rainfall with a rather gentle slope and Orthic Acrisols soil type. Land unit 2 (DFTRL) has moderate rainfall with a gentle slope and Dystric Fluvisols soil type. Land unit 3 (DFTTL) has slightly less rainfall with a gentle slope and Dystric Fluvisols soil type. Dystric Fluvisols soil type has a better influence than Orthic Acrisols for rice plant growth because it contains fluvial deposits. More or moderate rainfall and gentle slopes are more suitable for planting short-rooted rice that is resistant to erosion. This likely causes rice in land unit 2 (DFTRL) to be more fertile than in other areas. This is in accordance with the curve of land unit 2 (DFTRL) in Figure 5 which has an NDVI value close to 1 at its peak.

Physical Factors Influence to NDVI Value and Rice Growth Stage

Previous studies showed that rice requires sufficient rainfall to grow and develop. Too little rainfall can cause rice to dry out, while too much rainfall can cause rice to become submerged in water and rot (Abbas, S. and Mayo, Z. A., 2021). According to Mohr (1933), monthly rainfall above 100 mm is considered a wet month and is considered high. Land with daily rainfall of 60-100 mm according to Mohr (1933) is considered a humid month, and land with daily rainfall less than 60 mm is considered a dry month. The rainfall at PT Sang Hyang Seri shows variability, with a monthly average ranging between 100 - 150 mm. Relationship between rainfall and NDVI presented in Figure 6.

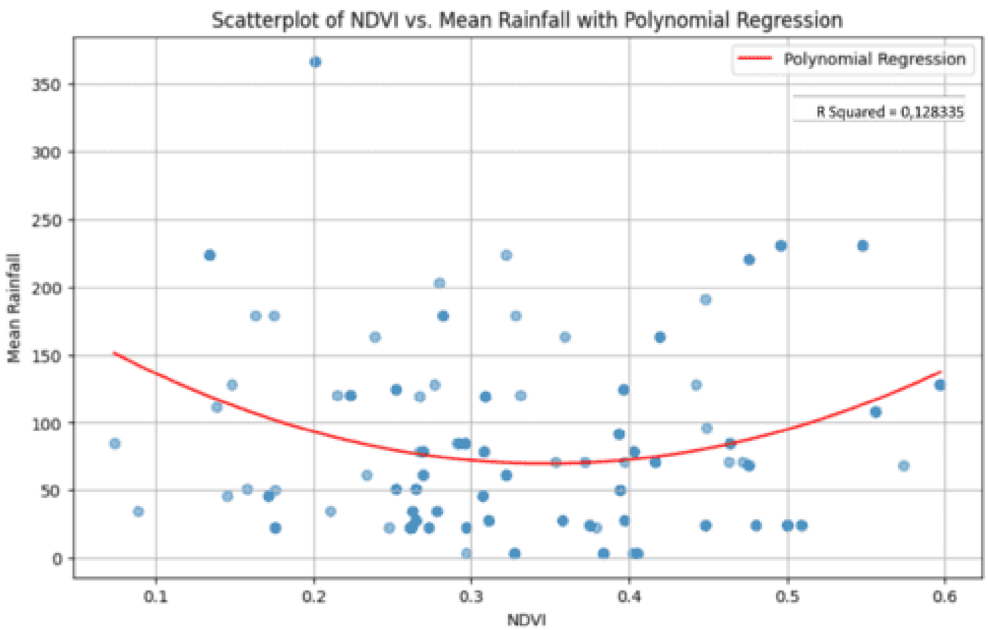


Figure 6. Rainfall and NDVI Polynomial Regression

The relationship between rainfall and NDVI value is described in a polynomial regression with an R2 value of 0,128335 (Figure 6). This indicates that the rainfall value has little effect on the variation of NDVI value. This means that only about 12% of the variation in NDVI value can be explained by rainfall. The remaining 88% of the variation is caused by other climatic factors, such as temperature that having more significant correlation than rainfall according to (Abbas, S. and Mayo, Z. A., 2021). Also, Girish and Hittalmani (2004) explained that the rice crop requires more water as compared to any other crop. Therefore, rice paddy cultivation is profitable only in those areas where minimum rainfall is 115 mm (Abbas, S. and Mayo, Z. A., 2021). At PT Sang Hyang Seri, the rainfall is suitable and meets the minimum requirements for each stage of rice growth. Then, the relationship between slope and NDVI presented in Figure 7.

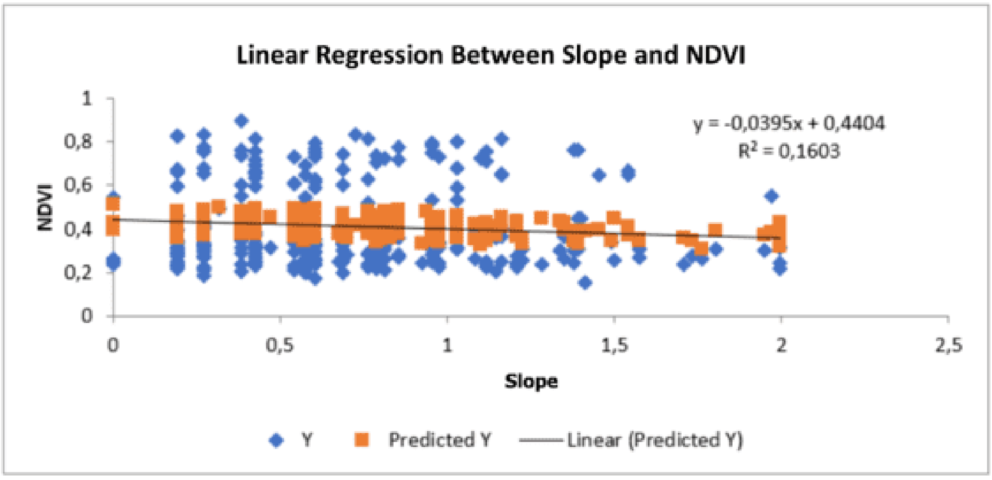


Figure 7. Slope and NDVI Linear Regression

Slope is important to rice cultivation as maintain irrigation system and water management. The slope at PT Sang Hyang Seri shows gradient variability, with a average gradient start 0 to 10°. The lower the slope, the better it is for rice cultivation. Conversely, the steeper the slope, the more negative its impact on the crop, as irrigation water tends to accumulate in certain areas, which can affect the root system and the topsoil of the land. The slope is suitable in rice cultivation. Small gradient (e.g. 0.08–0.2%) applied in developed countries like Australia in lowland system, on the other hand, for rice-upland systems in Australia had a small gradient (0.4–0.5%) with lasered-contour (Devkota, K. P., et. al, 2021). Mathematically, slope gradient has little effect on NDVI value variation with the R2 of 0.1603 (Figure 7). This means that only about 16% of NDVI value variation can be affected by slope. The remaining 84% of the variation is caused by other factors. Other topographic factor is elevation. Based on figure above, the slope gradient varies between 0-2%. If observed, when the slope value is higher, the prediction graph decreases. This shows a negative correlation where the higher the slope, the lower the NDVI value.

According to FAO (2007) the Dystric Fluvisols soil type has good drainage capacity and is usually found in river areas so it is included in the suitable soil class, because Dystric Fluvisols soil is a type of soil that is well drained and able to retain water well. Meanwhile, according to The Orthic Acrisols soil type is soil that has poor drainage and low organic matter content so it is included in the less suitable soil class. The relationship between soil type and NDVI explained in Table 10.

Table 10. Correlation between Kendall's tau Soil Type and NDVI

Information		NDVI	Soil Type
NDVI	Correlation Coefficient	1,000	0.427
	Sig. (2 tailed)		0.01
		261	261

The relationship between soil type and NDVI is represented in the Kendall's Tau correlation (Table 10) with a correlation coefficient value of 0.427. This indicates that there is a positive relationship with moderate frequency between soil type and NDVI. This means that there is a tendency for NDVI values to be higher in land units with Dystric Fluvisols compared to land units with Orthic Acrisols. This relationship has a significance value of 0.001. In statistical analysis, a p value <0.05 (or 5%) is usually considered evidence of a statistically significant relationship. A significance value of 0.01 in the Kendall correlation between NDVI and soil type means that there is a 1% chance that the relationship between the two variables is purely coincidental. The smaller the significance value, the greater the likelihood that the relationship is real (not coincidental). All of these factors have a small effect because there are other factors that affect the NDVI value, such as variety irrigation system and many more.

CONCLUSION

This study groups the rice growth phases into six categories: water phase, vegetative 1, vegetative 2, generative 1, generative 2, and fallow. The results of the accuracy test with the confusion matrix showed a producer accuracy of 0.803 and a kappa accuracy of 0.763. Visualization of the rice growth phase shows a color change from black (water phase) to yellow (fallow phase). The duration of each rice growth phase ranges from 15-20 days, with a total rice growth phase length of 110 days. The NDVI value shows a parabolic curve with a polynomial regression model that has better accuracy on training data than on testing data, this is due to data outliers caused by atmospheric disturbances. Physical geographical factors such as rainfall, soil type, and slope influence rice growth dynamics. Soil type has the highest correlation with NDVI, then rainfall, and slope. Land units with moderate rainfall, suitable soil type, and gentle slope tend to produce more fertile rice growth, seen in land unit 2 (DFTRL), and land unit 3 (DFTTL) Meanwhile, in general, the age of rice growth is significantly influenced by the length of rice seedling, seen in the shortest curve in land unit 1 (OATRAL). The other factors also affected rice growth dynamics and needed to explore in next research. There are rice variety, irrigation systems, temperature, elevation, and fertility amounts.

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