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RICE YIELD ESTIMATION USING MODIS DATA

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ABSTRACT: Information about an area and its distribution of paddy rice field is essential for food security management and water resource management. Remote sensing is one of the techniques that can be utilized to obtain the rice production information from the space. This study used MODIS image to find out a relationship between rice spectral (NDVI) and rice yield. The result shows that a quadratic equation is the best relationship form between NDVI and rice age with the R^2 ranging from 0.916 to 0.973. From three growth variables evaluated in this study, total of the rice NDVI during its lifetime (∑NDVI) showed the highest exponential relationship with the rice yield (R^2 = 0.9203) and it has the lowest the standard error of estimation (SE = 0.076). Two other variables $NDVI_{max}$ and $Age_{NDVImax}$ presented lower R^2 and higher SE of estimation, which is 0.8919, 0.5776 and 0.089, 0.175 respectively. Therefore, estimation of rice yield can be done by using equation $y = 0.4745e^{0.0504x}$, where y is the rice yield and x is the ∑NDVI.
KEYWORDS: rice field, rice yield, MODIS, NDVI

1. Introduction

Rice plant is one of the important agriculture crops in Indonesia as well as in Asia. Rice is the primary food source for more than three billions people and is one of the world's major staple foods. Paddy rice field account for approximately 15% of the world's arable land (IRRI, 1993; Khush, 2005).Information about an area and its distribution of paddy rice field is essential for food security management and water resource management (Xiao *et al.*, 2005).

Satellite remote sensing has been widely applied and has been recognized as a powerful and effective tool in detecting land use and land cover change (Treitz *et al.*, 1992; Westmoreland and Stow, 1992; Harris and Ventura, 1995). The studies of using of satellite imagery to monitor the rice growth and the rice production have been done (Shao *et al.*, 1997; Panigrahy and Sharma, 1997; Oette *et al.*, 2000; Shao *et al.*, 2001; David *et al.*, 2003). For the rice yield estimation using remote sensing data, most previous study used the Landsat data and NOAA AVHRR (Rasmussen, 1992; Rasmussen, 1997; Honghui *et al.*, 1999). Using of the Landsat data is restricted by availability of the data for temporal analysis due to the Landsat has 16 days of temporal resolution (Quarmby *et al.*, 1993). On the other hand, utilization of the NOAA image is confined by the spatial resolution. In 1000 m of the NOAA spatial resolution, high possibility in one pixel will be found several kind of land cover especially in small rice area such as in our study area. This will decrease an accuracy of assessment (Strahler *et al*., 2006).

This study used MODIS (Moderate Resolution Imaging Spectroradiometer) images. Using the MODIS images in 250 m spatial resolution for rice yield estimation give better temporal resolution compared with the Landsat imagery and better spatial resolution compared with the NOAA image. The objective of this study is to assess the potential of MODIS images for rice yield estimation and to find out the relationship between MODIS rice spectral and rice yield. The MODIS spectral evaluated in this study is a Normalized Difference Vegetation Index (NDVI).

2. Study Area, Data and Method

2.1 Background and Study Area

The study area is located in Tabanan Regency, Bali Province, Indonesia centered at latitude 8°31'50" S and longitude 115°02'30" E (Figure 1). The Tabanan Regency was selected for the study area due to Tabanan being the central production area of rice in Bali. In the study area, the rice planting is organized by a *subak*. Subak is the farmer's social organization that manages the irrigation water. Each subak consist of around 150 – 300 ha of rice field (Food Crops Agriculture Department, 2006). They usually plant the rice at the same time. An advantage for the remote sensing study with this farming system is the monitoring is made easier due to availability of a wide rice area.

2.2 Collecting rice gain sample

Some considerations used in collecting of rice grain are: (1) the rice area that was being planted should have a wide area, so that they can identify easily in the MODIS images; (2) all of observed rice should have the same variety with the purpose of difference of the rice spectral is not affected by the rice variety, but solely is influenced by the rice condition. Therefore, total of the samples that was taken in this study with that consideration are 12 samples (Table 1). In each sample location, the rice grain was collected in area of 2.5 m x 25 m. The weight of rice grain then measured in unit of kg. The rice grain of harvest result further converted to unit of ton/ha.

Figure 1.Location map of the study area. Dark color in the right image is the rice field area and white color is another land uses area. The point in that image is the observation site where rice harvest sample was p.

Table 1.Sample location of taking of grain rice harvest

Sample	Village Name	Geographic Coordinate		Rice age observation (day)	
		X	Y	Start	Finish
1	Beraban	290750.33	9048134.60	6	94
2	Pupuansawah	284957.98	9064585.63	5	93
3	Kukuh	289591.81	9055780.85	7	95
4	Gubug	290750.33	9053695.51	6	94
5	Kuwum	297701.47	9061805.17	7	95
6	RiangGede	292835.67	9060414.95	5	93
7	AbianTuwung	296311.24	9053927.22	5	93
8	Tua	300018.52	9070841.65	6	94
9	Belimbing	284030.90	9072000.18	3	91
10	Sudimara	289591.81	9052073.85	5	93
11	Pangkungkarung	290055.22	9054390.63	4	92
12	Sembunggede	290055.22	9059488.13	4	92

Explanation: Rice age observation indicated that collecting of rice spectral from the MODIS images in range of that age.

2.3 MODIS Images

Among a suite of standard MODIS data products available to the users, we used the 8-day composite MODIS Surface Reflectance Band 1-2 Product (MOD09Q1). The spatial resolution of this MODIS product is 250 m and consists of 2 bands, that is red band (620–670 nm) and infrared band (841–876 nm). In the production of MOD09Q1, atmospheric corrections for gases, thin cirrus clouds and aerosols are implemented (Vermote and Vermeulen, 1999). We collected 12 images in different MODIS composite date for each sample point. Total of the images used in this study is 23 scene images. The MODIS images were obtained from the MODIS website (http://mrtweb.cr.usgs.gov/) with the free download using USGS MODIS Reprojection Tool Web Interface (MRTWeb). MOD09Q1MYD09A1MOD09Q1

2.4 Data Analysis

Data analysis consists of preprocessing images, gathering rice spectral information from the MODIS images, and statistical analysis. Collecting the MODIS images from the websites, selecting the free cloud images, image cropping, and geographic coordinate transform are several preprocessing images that have been done. The rice spectral information obtained from the MODIS images is a Normalize Difference Vegetation Index (NDVI) with the following formula.

$$NDVI = \frac{Infrared\ band - Red\ band}{Infrared\ band + Red\ band} \quad (1)$$

Where, the red and infrared band of the NDVI equation is taken from the MODIS image. The NDVI values from the MODIS images were collected in 12 different locations. Then, a relationship between rice age and rice NDVI was performed. According to our previous research (Nuarsa and Nishio, 2007), the quadratic equation is the best relationship between rice age and rice NDVI. From the quadratic equation, we calculated 3 variables, which is peak of the NDVI value ($NDVI_{max}$), the age of the rice plant when the NDVI peak is happened ($Age_{NDVImax}$), and total of the rice NDVI during observation ($\sum$ NDVI) as described in Figure 2.

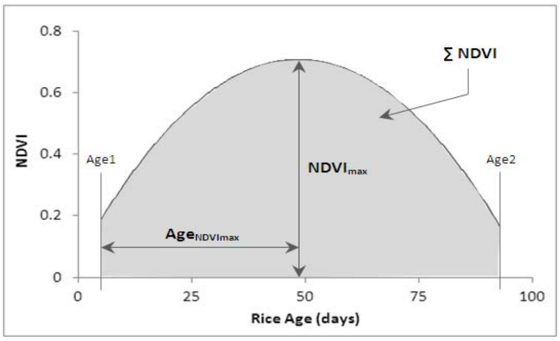

Figure 2. An illustration of method used to calculate $Age_{NDVImax}$, $NDVI_{max}$, and ∑NDVI

If $y = ax^2 + bx + c$ are the relationship equation of rice age and NDVI where y is the NDVI and x is the rice age, $Age_{NDVImax}$ can be found when $\Delta y/\Delta x$ is equal to 0. The x value can be calculated with the following equation:

$$y = ax^2 + bx + c \;; \qquad (2)$$

$$\frac{\Delta y}{\Delta x} = 2ax + b \;;$$

$$0 = 2ax + b \;;$$

$$x = \frac{-b}{2a} \;;$$

Where, y is the NDVI, x is the rice age, and a, b, c are a coefficient of x^2, x, and constant value, respectively. The x value obtained from the equation above is the $Age_{NDVImax}$. By mean of substitution of the x value in equation $y = ax^2 + bx + c$, the y value when the peak occurred ($NDVI_{max}$) can be calculated. On the other hand, ∑NDVI can be computed using the equation bellow.

$$\sum NDVI = \int_{Age1}^{Age2} (ax^2 + bx + c)\,dx \qquad (3)$$

Where, *Age1* and *Age2* are a beginning and endings of the rice plant observation, respectively. The next step of the data analysis is to find out the relationship between $Age_{NDVImax}$, $NDVI_{max}$, and ∑NDVI with rice yield. The best relationship equation then selected to estimate the rice yield. The statistical parameters used to evaluate the best relationship area is determination coefficient (R^2) and a standard error of the estimation (SE) as the following equations (Lane *et al.*, 2008).Higher value of R^2 and lower value of SE shows the better relationship.

$$R^2 = 1 - \frac{\sum y - \bar{y}')^2}{\sum y - y')^2} \qquad (4)$$

$$SE = \sqrt{\frac{\sum (y - y')^2}{n}} \qquad (5)$$

where R^2 = determination coefficient
SE = standard error of estimation
y = actual value
y' = predicted value
$\bar{y}'$ = average predicted value
n = number of sample

3. Result and Discussion

The quadratic relationship between rice age and rice NDVI for 12 samples in study area is shown in Table 2. The R^2 of these equations is high enough varying from 0.916 to 0.973. The highest $R^2$and the smallest Standard error (SE) of estimation are showed by sample 6 at the Riang Gede Village (Figure 3), and the smallest R^2 and highest SE is presented by sample 2 at Pupuan Sawah village with the R2 and SE are 0.916 and 0.067, respectively.

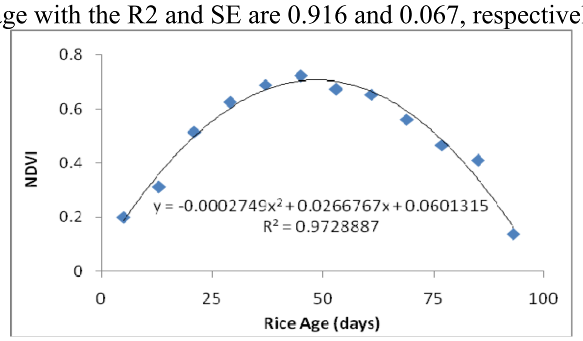

Figure 3.Relationship between rice age and rice NDVI. This sample showed a quadratic equation with the highest R^2 compared with other samples in study area.

Table 2. Quadratic equation coefficients of relationship between rice age and rice NDVI included its R^2 and Standard Error of estimation (SE).

Sample	Equation Coefficient			R^2	SE of
	a	b	c		Estimation
1	-0.000317	0.032054	-0.002647	0.966	0.046
2	-0.000272	0.028490	-0.032086	0.916	0.067
3	-0.000279	0.030654	-0.034772	0.935	0.060
4	-0.000287	0.029929	0.038867	0.946	0.054
5	-0.000236	0.022010	0.099268	0.946	0.047
6	-0.000275	0.026677	0.060132	0.973	0.036
7	-0.000285	0.029746	-0.015355	0.943	0.056
8	-0.000279	0.028580	0.033137	0.921	0.064
9	-0.000323	0.029540	0.074942	0.942	0.063
10	-0.000284	0.029380	0.023629	0.941	0.057
11	-0.000266	0.029845	-0.009157	0.956	0.054
12	-0.000273	0.026384	0.053179	0.924	0.061

The high value of R^2 indicates that there are a consistent relationship between rice age and its NDVI value and the lower SE describes that there are a small value difference of estimation result and the actual value. One of the importance factors that affected to the difference of R^2 and SE is appearance of the cloud in MODIS images. Thin Cloud coverage will give an inconsistency of the reflectance value. This will affect to the NDVI value of the rice field. Therefore, selecting of the free image from cloud coverage is one of the important steps in the prepossessing images. Decreasing information of rice spectral that be influenced to the R^2 and SE of the rice NDVI is the presence of mixed pixel. Mixed pixel means that in one pixel are not only contain the rice plant object, but they also consist of other object. This will decrease the analysis accuracy (Strahler *et al*., 2006).

By applying of Equation 1 and Equation 2, the $Age_{NDVImax}$, $NDVI_{max}$, and ∑NDVI can be calculated. The $Age_{NDVImax}$ values vary from 45.671 to 56.079. It means that from the beginning of the transplanting period, NDVI of rice increased until its age of 1.5 months to approximately 2 months, then decreased until the end of its life. The $NDVI_{max}$ values range from 0.631 to 0.828, and ∑NDVI values fluctuate from 40.123 to 56.195 (Tabel 3).

Table 3. $Age_{NDVImax}$, $NDVI_{max}$, ∑NDVI, and yield of the rice in 12 sample points.

Sample	NDVI Maximum		∑	Yield
	x	y	NDVI	(ton/ha)
1	50.559	0.808	53.062	7.280
2	52.294	0.713	47.000	5.141
3	55.034	0.809	54.955	7.638
4	52.232	0.820	55.806	8.114
5	46.650	0.613	40.123	3.840
6	48.521	0.707	46.627	5.136
7	52.112	0.760	50.402	5.330
8	51.310	0.766	51.581	5.474
9	45.671	0.749	47.539	5.216
10	51.707	0.783	52.605	7.130
11	56.079	0.828	56.195	8.578
12	48.268	0.670	45.191	4.422

Relationship between $Age_{NDVImax}$, $NDVI_{max}$, and ∑NDVI with rice yield shows an exponential form with the equation y = 0.2497e0.0623x,y = 0.3376e3.8012x, and y = 0.4745e0.0504x, respectively (Figure 4, Figure 5 and Figure 6). ∑NDVI provided the best relationship with the rice yield due to it has the highest value of R^2 (0.9230), and the lowest value of Standard Error (SE) of estimation (0.076) (Table 4). On the other hand, $Age_{NDVImax}$ and $NDVI_{max}$ showed the lower value, which is 0.5776 and 0.8919 for the R^2, and 0.175 and 0.089 for the SE, respectively. A positive correlation between LAI and ∫NDVI with the rice yield also found by Harrison *et al*., (1984) using Landsat MSS and by Rasmussen (1992) using NOAA AVHRR.

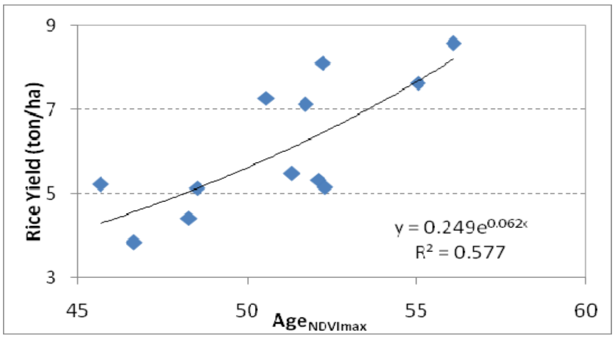

Figure 4. Relationship between the rice age at maximum NDVI and the rice yield.

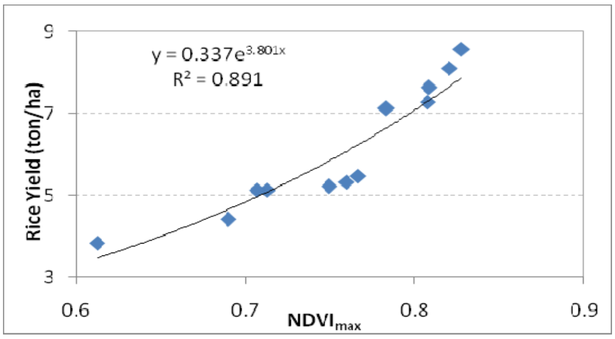

Figure 5. Relationship between the maximum NDVI and the rice yield.

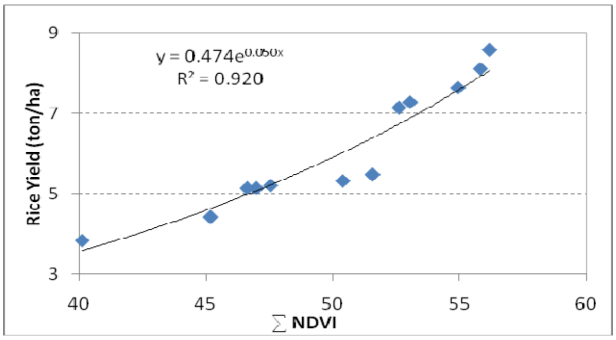

Figure 6. Relationship between the ∑NDVI and the rice yield.

A high positive correlation between ∑NDVI and rice yield means that increasing total of the rice NDVI during its lifetime will improve the rice yield. A high NDVI indicated a high value of infrared (NIR) band of the rice plant (Equation 1). NIR reflectance of rice is directly related to green biomass (Niel and McVicar, 2001). NIR light is highly scattered by water in the spongy mesophyll cells (Harrison and Jupp, 1989). It means high NDVI describe high chlorophyll content of the rice plant. Chlorophyll is the important part of the rice plant related to photosynthesis activity. The photosynthesis process will produce the carbohydrate to form rice plant tissue as well as the rice grain as a harvest yield.

Table 4. Value of R2 and SEof $Age_{NDVImax}$, $NDVI_{max}$, and ∑NDVI

Variable	R^2	SE
$Age_{NDVImax}$	0.5776	0.175
$NDVI_{max}$	0.8919	0.089
∑NDVI	0.9203	0.076

4. Conclusions

Quadratic equation is the best relationship form between NDVI and rice age with the R^2 ranging from 0.916 to 0.973. From three growth variables evaluated in this study, total of the rice NDVI during its life (∑NDVI) showed the highest exponential relationship with the rice yield (R^2 = 0.9203) and it has the lowest the standard error of estimation (SE = 0.076). Two other variables NDVImax and $Age_{NDVImax}$ presented lower R^2 and higher SE of estimation, which is 0.8919, 0.5776 and 0.089, 0.175, respectively. Therefore, estimation of rice yield can be performed by using equation $y = 0.4745e^{0.0504x}$, where y is the rice yield and x is the ∑NDVI. Based on the research result, MODIS has a potential for rice yield estimation.

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