PADDY HEALTH ANALYSIS USING IN-SITU HYPERSPECTRAL REMOTE SENSING APPROACH

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Abstract

Rice plays a critical role for providing food, income generation and socio-economic growth of people especially in Asian countries. The productions of the paddy are much depending on the health level and Nitrogen is one of key elements in fertilizer which is important for healthy paddy production. The use of remote sensing techniques in agriculture can provide repeatable assessment in monitoring capability. In this study, in-situ hyperspectral remote sensing was used for predicting the nitrogen content of paddy at different stage of plantation in Malaysia. The objectives of this study are: (1) to investigate and identify best spectral region for nitrogen content analysis in paddy leaves at different stages of plantation; (2) to identify the best vegetation index for paddy health detection with nitrogen content as health indicator and; and (3) to establish paddy health relationship with paddy nitrogen content as health indicator at different stage of plantation. By using handheld spectroradiometer (ranging from 400 nm to 1,100 nm), optimal wavebands which are sensitive to nitrogen content can be determined during field campaign. Five vegetation indices were then used for paddy health analysis based on optimal wavebands for three different stages of plantation. From the observational results, Soil Plant Analysis Development (SPAD) meter has high correlation with nitrogen content and Leaf Color Chart (LCC). The correlation between five vegetation indices and nitrogen value from SPAD meter of the paddy samples were used to analyze between plantation stages. From the result, strong correlation is detected between ratio of R830 and R550 at each phase of plantation. Regression analysis between paddy spectral reflectance and nitrogen content from SPAD meter were conducted to further determine their relationship for different plantation stages. As a result, Nitrogen content of paddy leaf is sensitive at wavelength region of 830 nm and 550 nm which claims as the sensitive portions of wavelengths that can be used for monitoring nitrogen status of paddy in precision farming in order to further recommend the amount of N fertilizer needed to get the healthy paddy production.

Keywords: *paddy[1] , in-situ hyperspectral remote sensing[2] , SPAD meter[3] , LCC[4] , nitrogen[5]*

1.0 Introduction

Paddy plays an important role for human as food sources and economic development for future generation (Bah, 2009). Production of paddy should increase 43 percent in 30 years from year 2000 due to the demanding from population always increases (Cassman, 1999). In Malaysia, Kedah is the state that has largest paddy field area (Mohd Kasri, 2000). One of important factor that contribute to paddy plantation in Kedah is cumulative rainfall which is more than 3500 mm per year.

Precision farming is conceptualized by a system approach to know the total system of agriculture towards a low input, high efficiency, and sustainable agriculture (Gholizadeh, 2009). They describe the production inputs (seed, fertilizer and chemicals) should be applied only at the time when needed and that location for most economic production in order to obtain the highest output (Peng, 1996). Paddy needs sufficient nutrient for its growth and for high productivity. The farmers must know the suitable nutrient content to prevent the usage of excess nutrients, or it will give negative impact on water quality and environment.

Nitrogen (N) fertilization is major agronomic practice that affects the growth, yield and quality of crops (Chang-Hua et al., 2010). The crops grown with sufficient amounts of available nitrogen will develop rapid growth with healthy green color while nitrogen shortage on crops will give results very poor color and unhealthy crops. (Cen et al., 2006). The importance of nitrogen's element as a key role in cell division of paddy growth were discussed. If the cell division is stopped, the leaf area decreases and potential to produce a sufficient yield will failed. Nitrogen content in paddy also will lose from denitrification process and the farmers used nitrogen fertilizer to replace back the nitrogen. (Miyama, 1988).

Soil Plant Analysis Development or SPAD meter is simple and practical tool that measure the greenness or relative chlorophyll content of leaves and determine N status in rice plant (Wahid, 2003). SPAD values gave strong relationship between nitrogen concentrations. It also can provide an indirect assessment of leaf N status (Gholizadeh et al., 2009). Other than SPAD meter, the farmers used conventional technique by using Leaf Color Chart (LCC) as an alternative determination on N fertilizer status (Wahid, 2003). SPAD readings and leaf color chart (LCC) values also showed a good correlation. LCC is a tool that structured by plastic material and contains four scales (2, 3, 4, 5). The lowest scale (2) is show that the color of leaves is yellowish and the highest scale (5) show the color of leaves is greenish. It is an eco-friendly tool in the hands of farmers. The LCC had been jointly developed by International Rice Research Institute (IRRI) and Philippines Rice Research Institute (Phil Rice) from a Japanese prototype, for the purpose of measuring the required quantity of nitrogen to be applied in paddy field and thereby to get a maximum productivity. The fertilizer will add if the color of leaves is lower than scales 3 (Boyd, 2001).

The spectral reflectance of leaves paddy weres collected using in situ measurement. The data from handheld spectroradiometer with 400nm to 1,100nm wavelenght range can show the characteristic of spectral from any objects (Jensen, 2007). The amount of electromagnetic energy that reflected from a surface which is result of energy-matter interaction can be measured and processed to derive nitrogen's concentration (Boschetti et al., 2007). Hyperspectral instruments provide reflectance measurements over a set of numerous narrow wavebands (< 10nm) that can be exploited to precisely identify regions of sensitive spectrum to plant N status (Stroppiana, 2009). This study focused on the identification the best vegetation index that gave highest correlation of nitrogen content from SPAD meter and Leaf Color Chart (LCC) for different plantation phase.

2.0 Data and Methodology

This study was conducted at paddy field around Kampung Alor Gunung with coordinate (6.1875 N, 100.3317 E) and Kampung Sungai Baru Gunung (5.9283N, 100.5053E) at Kedah. To identify indices that are suitable for nitrogen content in leaves, a number of samples of different plantation stages were selected. In this study, the samples were taken from the same species, MR 219. The three phases were determined by based on day after transplanting (DAT). For phase 1, the plot contains paddy growth around 50 to 80 DAT (panicle formation stage). Phase 2 was determined by 81 to 95 DAT (full heading stage) and phase 3 with paddy growth around 95 to 105 DAT (ripening stage). Every phase will give different reading from SPAD meter and also LCC.

Reflectance spectra of paddy leaves were collected using portable handheld spectroradiometer which records the percent reflectance at 4 nm intervals from 400nm to 1,110nm. The field of view was 3^o. Ten spectral reflectance measurements were taken for each sample in fine weather condition between 9.00 a.m and 11.00 a.m. The radiometric data is useful to estimate nitrogen concentration from the amount of electromagnetic (EM) energy that reflected from a surface (Boschetti et al., 2007). The wavelength region was subset from 550 nm to 830 nm. These regions of spectrum identify which region of reflectance recorded is most sensitive to nitrogen and chlorophyll. The quality of spectral data above 1000 nm was not good enough most probably due to the insufficient sensitivity of the silicon photo-cell used for the sensor unit at this wavelength range (Shibayama and Akiyama, 1886). This study focused on the vegetation indices of paddy using narrow bands of hyperspectral reflectance using ground-based remote sensing to determine the paddy health. Five vegetation indices which are sensitive to nitrogen content for paddy leaf were calculated. The five vegetation indices are Ratio (830/550) from Wahid et al. (2003), NDRE (Normalized Difference Red Edge Index) from Barnes et al. (2000), Simple Spectral Index (R735) from Wang et al. (2008), Ratio (810/680) from Tian et al. (2005) and Red Edge Normalized Difference Vegetation Index (NDVI R705) from Haboudane et al. (2002).

The same leaves samples were used for SPAD measurement. Triplicate readings were taken on one side of the midrib of each single leaf blade, midway between the leaf base and tip and then averaged. A SPAD threshold value of 35-36 is equal to 1.4−1.5 g N m-2 of leaf area in semi dwarf indices varieties (Peng et al., 1996). Whenever SPAD readings fell below the critical SPAD value, the crop will suffer from N deficiency and yields will decline if N fertilizer is not applied immediately. Besides that, LCC is used to determine the scale of color leaves. It measures leaf color intensity that is related to leaf N status. To measure the leaf color, the leaf must be put under the shade because direct sunlight affects leaf color readings. For geostatistical analysis, the correlation between N values from SPAD meter and five vegetation indices was calculated by using different regression type to find the highest correlation for three phases. This is to determine which vegetation index is more sensitive to nitrogen content. The correlation between vegetation index and LCC has also been done to study their relationship. For final output, the analysis of data collected at different growth stages were used to determine which spectral ratio can be used to predict leaf N amount and future crop N need for paddy health.

3.0 Results

3.1 Relationship between SPAD Reading and LCC

Leaf Color Chart is used to determine the nitrogen needed based on leaf color scale. SPAD reading and LCC reading gave highest correlation in phase 1 which is R^2= 0.7928. No correlation show in phase 3 between this two variables which gave value R^2= 0.2628. The correlation graphs are shown in Figure 1, Figure 2 and Figure 3.

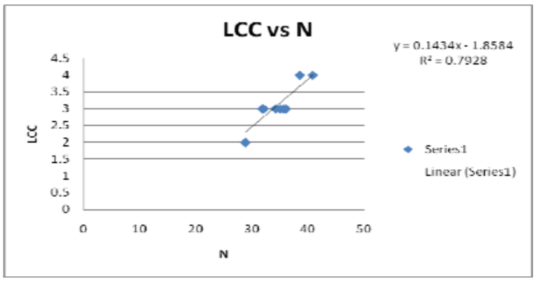


Figure 1: The regression of SPAD reading and LCC reading in phase 1.

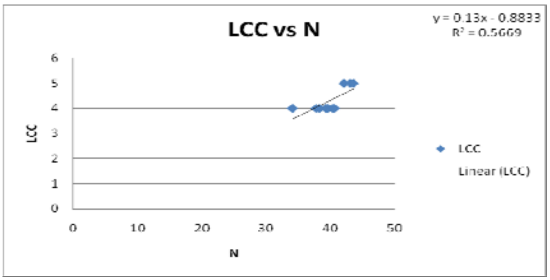
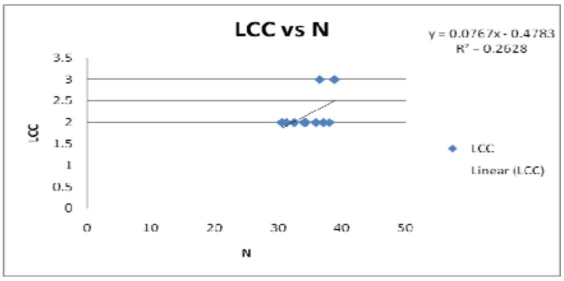


Figure 2: The regression of SPAD reading and LCC reading in phase 2.



Figire 3: The regression of SPAD reading and LCC reading in phase 3.

3.2 Relationship between Vegetation Index and N Content

To identify the best spectral region for paddy health detection, the nitrogen roles used as indicator to determine the healthiness of paddy. In the leaf level, the nitrogen sensitive band for paddy discovered which is mainly concentrates in the 550nm~690nm, 705nm~750nm and 790nm~830nm band. The wavelength range was subset from 550nm~830nm to focus only at sensitive region for every phases (Figure 4, Figure 5 and Figure 6). The ratio vegetation index of paddy leaf's nitrogen content can be calculated based on Equation 1,2,3,4 and 5.

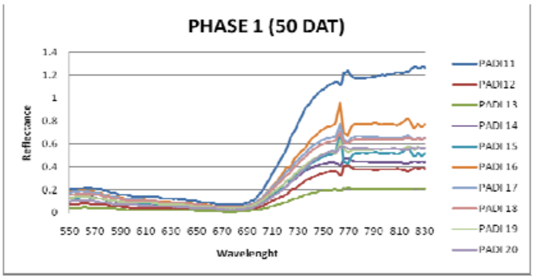


Figure 4: The paddy leaves spectrum for phase 1.

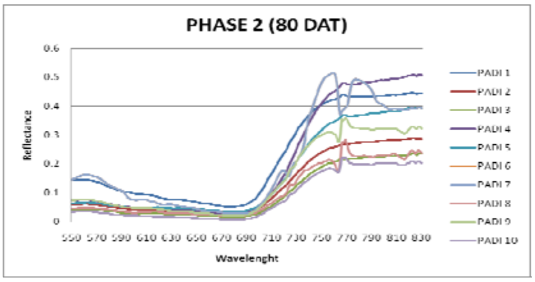


Figure 5: The paddy leaves spectrum for phase 2.

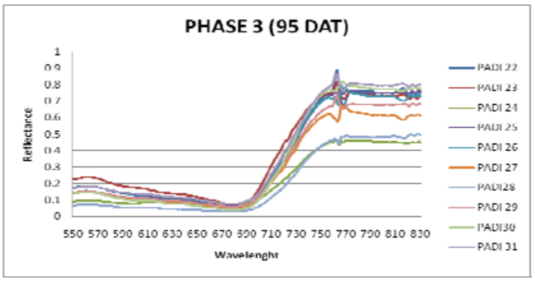


Figure 6: The paddy leaves spectrum for phase 3.

The regression value of vegetation index and nitrogen value from SPAD meter and leaf color scale for three different plantation stages are represented in Table 1. The vegetation indexes are obtained using the following equations:

1) Ratio (R830/R550) = $\frac{R830}{R550}$; **→ Eq. 1**

R830 and R550: Reflectance value at wavelength region 830 nm and 550 nm.

2) NDRE = $\frac{P790 - P720}{P790 + P720}$; **→Eq. 2**

P790 and P720: Reflectance value at wavelength region 790 nm and 720 nm.

3) SSI = $R735$; **→Eq. 3**

SSI: Simple Spectral Index

R735: Reflectance value at wavelength region 735 nm.

4) Ratio (R810/R680) $= \frac{R810}{R680}$; **→Eq. 4**

R810 and R680: Reflectance value at wavelength 810 nm and 680 nm.

5) RENDVI $= \frac{P750 - P705}{P750 + P705}$; **→Eq. 5**

RENDVI: Red Edge Normalized Difference Vegetation Index.

P750 and P705: Reflectance value at wavelength 750 nm and 705 nm.

Vegetation index of Ratio (R830/R550) shows the highest correlation, R^2= 0.907 in for phase 1 (50 DAT) as displayed in Fig. 7. Polynomial regression gives the highest correlation with nitrogen content in paddy leaves than linear and exponential. As shown in Fig. 8, phase 2 (80 DAT) give highest correlation in polynomial regression type for Ratio (R830/R550) with R^2= 0.7347. The correlation from phase 3 (80DAT) gave same type of regression with value R^2= 0.4796 in Ratio (R830/R550) as shown in Fig. 9. As the result shown as displayed in Table 1, these three phases show highest correlation from same vegetation index which is Ratio (R830/R550).

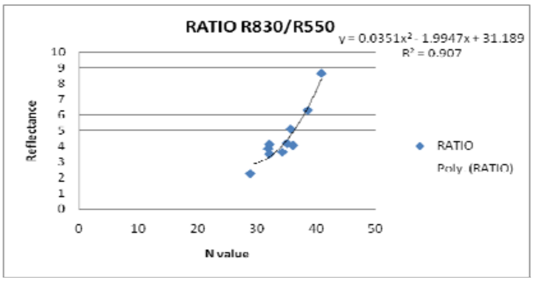


Figure 7: The regression between reflectance and N status for phase 1.

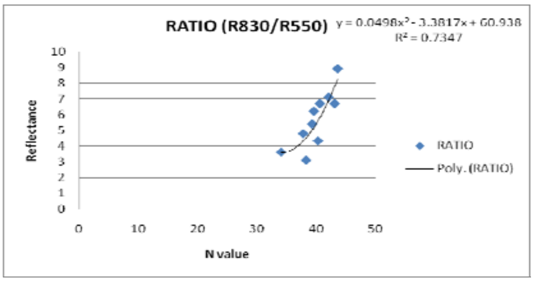


Figure 8: The regression between reflectance and N status for phase 2.

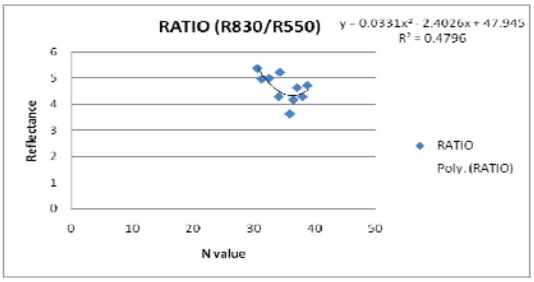


Figure 9: The regression between reflectance and N status for phase 3.

Table 1: The regression value of vegetation index and nitrogen value from SPAD meter and leaf color scale for three phases

Vegetation Index	*Phase 1* (*50-80 DAT)*		*Phase 2* (*81-95 DAT)*		*Phase 3* (*95-105 DAT)*	
	R^2	**P-Value**	**R^2**	**P-Value**	**R^2**	**P-Value**
Ratio (830/550)		0.018		0.030		0.147
Linear	0.8331		0.6646		0.3263	
Polynomial	0.907		0.7347		0.4796	
Exponential	0.8706		0.6434		0.2965	
NDRE		0.041		0.067		0.335
Linear	0.6132		0.4206		0.3147	
Polynomial	0.641		0.688		0.3314	
Exponential	0.5942		0.3921		0.2811	
R 735		0.490		0.536		0.653
Linear	0.5441		0.2107		0.1565	
Polynomial	0.5634		0.211		0.3224	
Exponential	0.5235		0.2565		0.1834	
Ratio (810/680)		0.021		0.034		0.065
Linear	0.7141		0.6314		0.3149	
Polynomial	0.763		0.6314		0.4157	
Exponential	0.6987		0.6795		0.3396	
NDVI R705		0.034		0.056		0.340
Linear	0.5868		0.5649		0.2626	
Polynomial	0.7267		0.5709		0.5356	
Exponential	0.6149		0.567		0.2907	

4.0 Discussions

The relationship between LCC and SPAD reading gave high correlation significantly to Boyd (2001). So it shows that the LCC and SPAD reading can be used to determine the nitrogen status in paddy leaf. The nitrogen status in paddy leaf is one of the factors to measure the healthy paddy leaves (Cen et. al, 2006).

In phase 3, the LCC and SPAD reading have no significant correlation. It is due to the nutrition component of rice grain mostly comes from transformation of nutrition saved in stems and leaves before heading. The most protein has already been transferred to grain from stems and leaves after maturing. Therefore, the contents of nitrogen and chlorophyll in leaf have obviously decreased in phase 3. It was clear from the results that the nitrogen values of leaves are varied at different growth stage.

In general, SPAD meter reading show high correlation with leaf nitrogen status (Gholizadeth et. al, 2009). Relationship between SPAD value and chlorophyll content is very close (R^2 = >0.8) at panicle initiation and flower initiation stages for all the varieties. Similar relationship has also been observed in the case of SPAD value and nitrogen content in leaves. The results indicated that the rice leaves showing higher SPAD readings (>35) had higher chlorophyll and nitrogen contents (Islam et. al., 2009).

In this study, the relationship between five vegetation indices and SPAD meter has been investigated. Table 1 showed that Ratio R830/R550 gave highest correlated to nitrogen status for phase 1 and phase 2 with polynomial regression. Wahid et. al (2003) and Takebe et. al, (1990) reported that Ratio R830/R550 is most effective in estimating leaf nitrogen content with given R^2= 0.89. Although phase 3 showed low correlation in Ratio R830/R550, Inoue et al. (1998) reported that correlation between Ratio R830/R550nm and leaf nitrogen content was poor during ripening period. As the result shows in highest correlation in phase 1, Ratio R830/R550 can be useful and unique variable for linking remote sensing to simple crop model.

5.0 Conclusions

Leaf Color Chart (LCC) reading and SPAD meter reading show different correlation for different growth stages. Leaves of paddy produced significant reflectance changes during the growing season. The vegetation index of Ratio R830/R550 gave high correlation to the nitrogen content in paddy leaves, which is useful for crop model using remote sensing to determine the nitrogen status directly in paddy leaves and the paddy's health can be studied for wider area. It is noted that the reflectance measurements were centered over the leaves, middle part and did not cover the entire canopy. Therefore, experimental spectral indices values for development of paddy are not relatively as representative for the whole canopy. So it will be useful to improve the accuracy and consistency of ground measured spectral information.

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