ESTIMATION OF NITROGEN OF RICE IN DIFFERENT GROWTH STAGES USING TETRACAM AGRICULTURE DIGITAL CAMERA

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ABSTRACT

Many methods are available to monitor nitrogen content of rice during various growth stages. However, this monitoring still requires a quick, simple, accurate and inexpensive technique that needs to be developed. In this study, Tetracam Agriculture Digital Camera (ADC) was used to acquire high spatial and temporal resolution in order to determine the status of nitrogen (N) and predict the grain yield of rice (Oriza sativa L.). In this study, 12 pots of rice with four different N treatments (0, 125, 175 and 250 kgha^{-1}) were used for this experimental study. Three replicates were arranged in a randomized complete block design (RCBD) for determining the status of N and predicting the yield. The images were captured in different growth stages (i.e. tillering, panicle initiation, booting and heading stage) over each pot. The Soil Plant Analysis Development (SPAD) value was used as a reference data that indirectly reflects the nitrogen status in rice. The results showed that the amounts of N were significantly correlated with NDVI and GNDVI especially in panicle initiation and booting stages, respectively. The study demonstrated the suitability of using the Tetracam images as a sensor for estimating chlorophyll content and N.

Keywords: Nitrogen, Tetracam, Remote Sensing, Rice, Vegetation Indices, NDVI, GNDVI, SAVI

INTRODUCTION

Nitrogen (N) is one of the most critical nutrients for crop production in the world. It is also the nutrient element applied in the largest quantity for most annual crops (Huber & Thompson, 2007). Fageria *et al*. (2008) reported that N was responsible for 85 per cent of variation in rice grain yield in Brazilian Inceptisol. In developing countries, intensive agricultural production systems have increased the use of N fertilizer in an effort to produce and sustain high crop yield, although only 20 to 35 per cent of nitrogen fertilizer is recovered by the crop because of the losses in several ways (Ponnamperuma & Deturck, 1993). This means that N represents the largest part in fertilizer variable input costs especially in paddy fields with a double cropping system. On the other hand, the lack of appropriate N amount can cause either N stress or N loss on the crop or environmental pollution, which is of great concern by the public.

Thus, an appropriate N management not only can improve the overall rice production to meet future food security but also preserve from the environmental pollution.

Several different methods are available for assessing the nitrogen status of the crop. One of these methods is tissue analysis such as the Kjeldahl nitrogen determination method. It is a direct and accurate way of crop nitrogen status detection, but it is time-consuming and operators are required. Another technique is using the chlorophyll SPAD metre, which can be used to estimate N status from the leaf transmittance measurement in two wavebands centred at 650 nm and 940 nm (e.g. Gholizadeh *et al*., 2009). Although this estimation can be faster and cheaper than the laboratory analysis, it still requires field references, which will be carried out from a laborious field leaf measurement (Confalonieri *et al*., 2006).

Researchers also approach the N status estimation remotely. Remote Sensing (RS) with aerial images is used to assess nitrogen over the entire fields. Shou *et al*. (2007) used the high resolution satellite to evaluate the N status of winter wheat, which proved that near infrared (NIR) reflectance has good correlation with Sap N concentration, but low correlation with shoot total N concentration and shoot biomass. Limitations of these platforms for commercial use on individual fields are the high cost of images, low temporal resolution of satellite images and short availability of usable data from satellite images because of clouds and shadows of clouds. Moreover, the accuracy of such a technique appears to be easily affected by the low resolution and obvious soil background noises (Broge & Leblanc, 2001). Airborne sensors offer much greater flexibility than satellite platforms by being able to operate under clouds and having a much finer spatial resolution (Lamb & Brown, 2001). However, this type of imagery is still costly when dedicated 'mobilization' of the aircraft is required, especially for remote locations and repeated data acquisition needs. Therefore, a rapid, accurate, simple and inexpensive method to monitor a crop's N status in the field with high temporal resolution would be of great value to make rice production more environmentally and economically sound.

Tetracam Agriculture Digital Camera (ADC) (Tetracam, Inc., Chatsworth, Cal.) is one of the ground platform remote sensors, which has been re-engineered recently to be the simplest and most flexible visible, and Near Infrared (NIR) camera. This camera can capture images in visible light wavelengths longer than 520 nm and near-infrared wavelengths up to 920 nm. Recently, Swain *et al*. (2011) used the Tetracam ADC in paddy fields for determining the total biomass and predicting the yield as a function of nutrient status in the paddy fields.

Based on Shibayam and Akiyama's (1989) study, Leaf N Concentration (LNC) can be determined by using the spectraradiometry from compiled bands of 620 and 760 or 400,620 and 880 nm. Tetracam, which has the potential for determining the amount of N in crops, covers these wavelengths. Furthermore, this lightweight camera gives this opportunity to be used for monitoring the status of nitrogen after planting or during growing stages under the cloud with high spatial and temporal resolution.

The objective of this study is to evaluate the capability of Tetracam ADC for monitoring the N status in paddy fields as a fast, inexpensive and simple technique for vast areas during different growing stages. Knowing the existing status of N before applying the fertilizer will allow farmers to practise precision farming in rice cultivation.

MATERIALS AND METHODS

Theoretical Calculation

Studies of RS applications in agriculture have used vegetation indices (VIs) to evaluate the crop reflectance. These indices are used to enhance the vegetation features and also reduce the influence of exogenous factors (Daughtry *et al*., 2000; Xue *et al*., 2004). Vegetation indices are easily used and would be an accurate and simple method in digital image analysis for determining N status in crops. In this study, three most common adopted vegetation indices were used, namely, Normalized Difference Vegetation Index (NDVI), Green - Normalized Difference Vegetation Index (GNDVI) and Soil Adjusted Vegetation Index (SAVI). Based on Hansen and Schjoerring (2003), NDVI is one of the best performing indices for estimating leaf N concentration from early stem elongation to heading in crops. NDVI is expressed as follows:

$$NDVI = \frac{NIR - R}{NIR + R} \qquad \text{Equation 1}$$

Where NIR is near infrared and R is red.
GNDVI is also used as one of the common VIs. It has been documented that GNDVI is more highly correlated to final grain yield in corn (Shanahan *et al*., 2001). It also has been shown that it can be a promising index for determining the status of N uptake in wheat during growth stages (Moges *et al*., 2005). GNDVI can be calculated utilising Equation 2 below:

$$GNDVI= \frac{NIR-G}{NIR+G} \qquad \text{Equation 2}$$

Where NIR is near infrared and G is green.
Another index, which has been chosen in this study, was SAVI. This index has been developed for minimizing the background influences since NDVI is affected by soil brightness. SAVI is formulated using Equation 3 below:

$$SAVI = \frac{NIR - R}{NIR + R + L}(1 + L) \qquad \text{Equation 3}$$

Where NIR is near infrared, R is red and L is the function of vegetation density. The value of L is critical for minimizing the influence of backgrounds in vegetation reflectance. Based on a suggestion by Huete (1988), L with the value of 0.5 is optimal for adjusting soil-optical properties.

Field Preparation

The field experiment was conducted at a farm called Field No. 2, at Universiti Putra Malaysia. The soil in the pots was obtained from the Tanjung Karang area within Block C from a major soil series, namely, Telok series (*Typci Sulfaquept*). The experiment comprised 12 pots with a dimension of 10×10 square feet. The rice (Oriza sativa *L.*) cultivar (MR-219) was sown in a completely randomized block designed with three replicates and grown under flooded conditions. In addition, four different levels of N fertilization were applied for the rice cultivar, namely, a control with no distributed fertilizer (N0), and three additional levels (N1: 22.1+31.45+22.95+8.5 kg ha^{-1}; N2: 44.2+62.9+45.9+17 kg ha^{-1}; N3: 65+92.5+67.5+25 kg ha^{-1}), which were applied at the three leaves (DAP:15-20), tillering (35-40), panicle formation (55-60) and grain formation stages (65-70).

Data Acquisition

The images were vertically obtained with the Tetracam ADC (Tetracam Inc., Chatsworth, Cal.) from the central zone of the pots during tillering, panicle initiation, booting and heading stages. All images were taken between 12:00 and 13:00 on clear days for comparable solar angle and light intensity, and stored as RAW format. The camera had been calibrated by capturing the images from the Teflon calibration tag under the same lighting conditions as the images under the study.

For a comparison of image acquisition, the SPAD-502 chlorophyll meter (Minolta, Osaka, Japan) was used to measure the chlorophyll concentration of the rice in the central of the youngest fully developed leaves. Ten measurements of leaves of each pot were taken and an average SPAD value for each pot was calculated at each sampling time as the final value of this rice sample as the referenced concentration of its nitrogen status. The grain yield data was then collected after 110 days. The yield samples were air-dried and threshed for grains with hull, and the weights were expressed on the basis of 14% moisture content

Image Processing

The images captured by the Tetracam ADC camera, which were stored in a RAW format, were uploaded to the PixelWrench2 software (Tetracam, Inc, Chatsworth, Cal.) for deriving the vegetation indices (VIs). Furthermore, NDVI, Green-NDVI and SAVI were produced for each image, in which the average VIs was estimated from each image

RESULTS AND DISCUSSION

Estimation of Nitrogen and Chlorophyll Contents Using Vegetation Indices

The Pearson's correlation between the indexed and SPAD readings is displayed in Table 1. It shows that the indices had no significant correlation with SPAD in the tillering stage, but all of them showed a significant positive correlation with the SPAD readings ($P = 0.01$) in the panicle initiation and booting stages. Moreover, Table 1 shows the positive correlation of SPAD readings and NDVI and SAVI in the heading stage, but GNDVI revealed no correlation with the SPAD readings in the heading stage.

Table 1 also shows that the highest correlation could be seen between the vegetation indices and the SPAD readings in panicle initiation. Moreover, among the indices, SAVI had the highest correlation with the SPAD readings in the same growth stage ($r^2 = 0.896$). It also appears that all the three aforementioned indices showed a downward trend in the correlation with the

SPAD readings. In other words, the correlation between SPAD and NDVI, GNDVI and SAVI decreased with the growth stage.

Table1: Correlation between Vegetation indices and SPAD reading at various growth stages

Stage	DAP	NDVI	GNDVI	SAVI
Tillering	51	$0.572^{n.s.}$	$0.567^{n.s.}$	$0.571^{n.s.}$
Panicle initiation	60	0.887**	0.886**	0.896**
Booting	79	0.785**	0.783**	0.749**
Heading	93	0.789**	$-0.356^{n.s.}$	0.654**

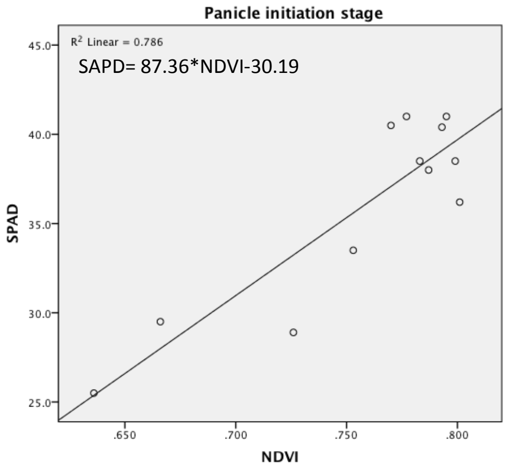
**Correlation is significant at the 0.01 level
n.s. No Significant correlation

The regression model was developed for SPAD with NDVI, GNDVI and SAVI values in SPSS (IBM® SPSS® software). The results indicated a good fit (R^2 = 0.78, RMSE = 2.59) for GNDVI in panicle initiation (Table 2). In general, the indices had the highest correlation with SPAD in panicle initiation and booting stage.

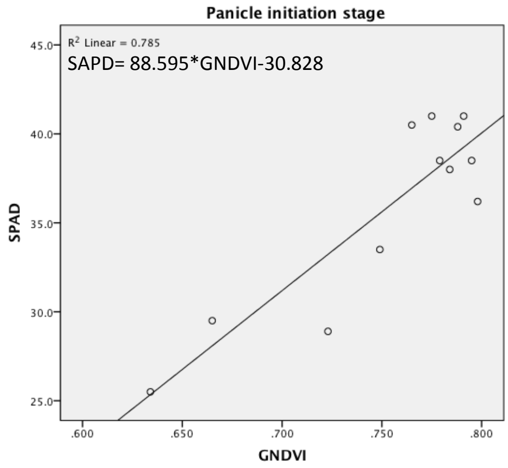
Table 2: Regression between Vegetation indices and SPAD at different growth stages

	NDVI		GNDVI		SAVI	
	R^2	RMSE	R^2	RMSE	R^2	RMSE
Panicle initiation	0.78	2.59	0.78	2.60	0.70	3.04
Booting	0.71	2.18	0.75	2.05	0.77	1.94
Heading	0.62	2.03	-	-	0.42	2.50

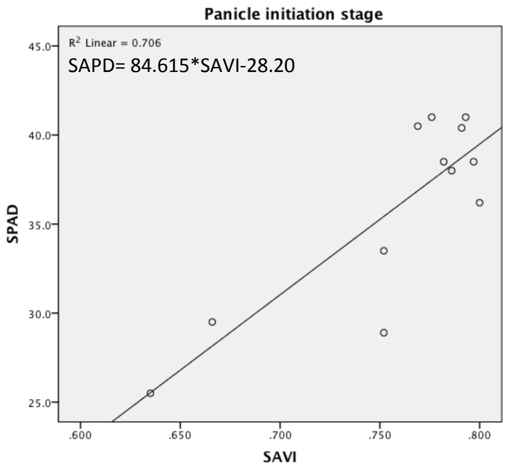
Figure 1: Regression between (a) NDVI and SPAD at panicle initiation (b) GNDVI and SPAD at panicle initiation (c) SAVI and SPAD at panicle initiation (d) NDVI and SPAD at Booting (e) SAVI and SPAD at booting (f) GNDVI and SPAD at booting (g) SAVI and SPAD at heading (h) NDVI at heading stage


Panicle initiation stage
R2 Linear = 0.786
SAPD= 87.36*NDVI-30.19
SPAD
NDVI

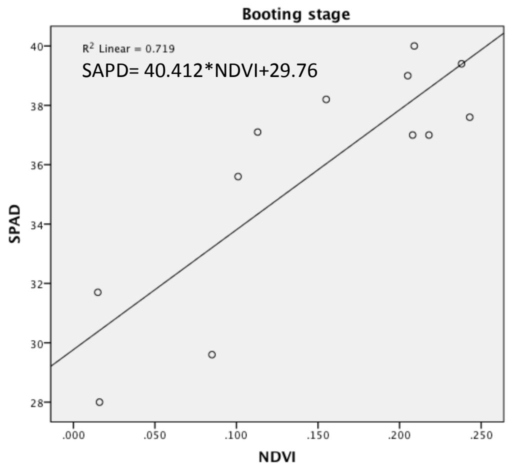
(a)


Panicle initiation stage
R2 Linear = 0.785
SAPD= 88.595*GNDVI-30.828
SPAD
GNDVI

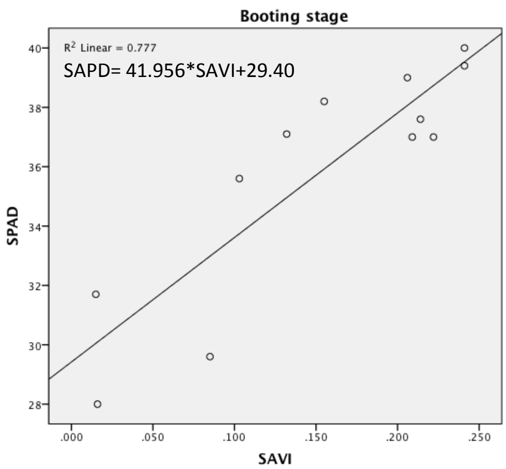
(b)


Panicle initiation stage
R2 Linear = 0.706
SAPD= 84.615*SAVI-28.20
SPAD
SAVI

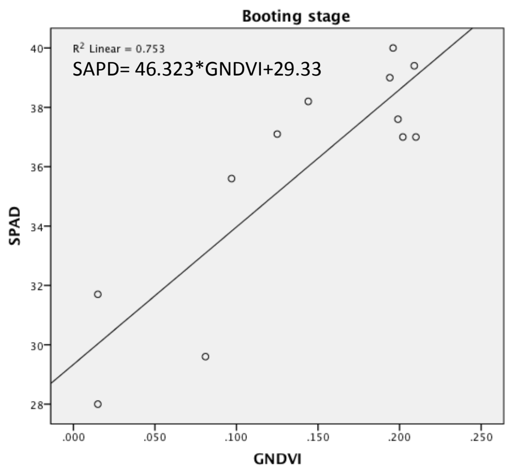
(c)


Booting stage
R2 Linear = 0.719
SAPD= 40.412*NDVI+29.76
SPAD
NDVI

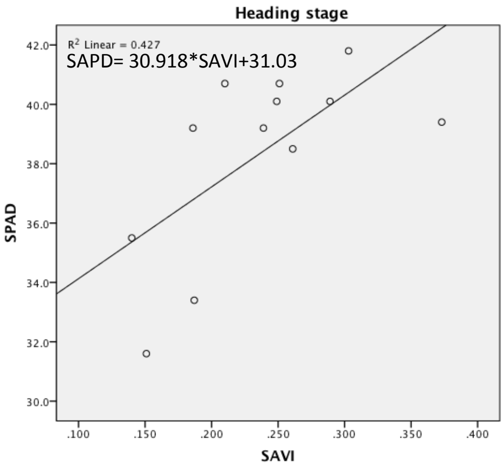
(d)


Booting stage
R2 Linear = 0.777
SAPD= 41.956*SAVI+29.40
SPAD
SAVI

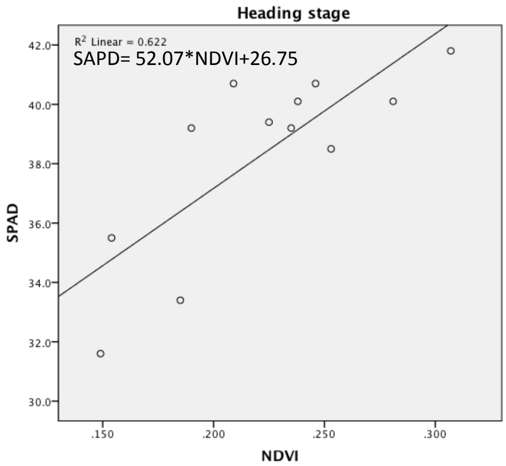
(e)


Booting stage
R2 Linear = 0.753
SAPD= 46.323*GNDVI+29.33
SPAD
GNDVI

(f)



(g)



(h)

CONCLUSION

Tetracam ADC was used for capturing multi-spectral images over rice canopy to estimate the chlorophyll content, N and grain yield. This study found that Tetracam ADC can be a promising sensor for capturing images to determine N status in rice. The relation between VIs and SPAD readings also showed the applicability of the Tetracam ADC images for determining the status of N for rice. A linear regression model demonstrated a good fit (R^2= 0.78) for estimating N for rice using Tetracam ADC based on NDVI and GNDVI. This study confirmed that the best growth stage for measuring the status of N in rice would be the panicle initiation and booting stage, respectively. This study should be extended for evaluating the capability of other nutrients, which have important roles at different growth stages of rice in the paddy fields.

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