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Assessment of Nutrient Status of Lowland Irrigated Rice (*Oryza sativa* L.) using Low Altitude Remote Sensing

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ABSTRACT

Low altitude remote sensing provides near real-time information on crop nutrient status with higher spatial resolution compared to airborne and spaceborne systems. In this study, an Unmanned Aerial Vehicle System (UAVS) with on-board multispectral camera was deployed to determine the normalized difference vegetation index (NDVI) of lowland irrigated rice under different fertilizer treatments. Relationship between UAV-based NDVI and ground measurements from Soil Plant Analysis Development (SPAD) chlorophyll meter at different rice growth stages were also established. The results showed that experimental plots with high nitrogen fertilization had significantly higher SPAD and NDVI values compared with plots without nitrogen fertilization. Strong correlation between SPAD readings and NDVI values ($p<0.001$) was also observed as early as panicle initiation stage ($r=0.7372$). Hence, low altitude remote sensing can be a rapid and non-destructive tool for site-specific rice nutrient management. The use of low altitude remote sensing technique as evaluated in this study offers a practical approach in spot- or field-level application of nitrogen fertilizer during panicle initiation to enhance uniform spikelet development, and during flowering (few days before or after) to promote grain filling using foliar fertilizers.

Keywords: *Low altitude remote sensing; UAVS; NDVI*

INTRODUCTION

Rice remains as the top agricultural commodity with economic significance in the Philippines. About 11.5 million farmers and family members rely on rice farming as their source of income and employment (FAO, 2000). With the increasing trend in the country's population, there is also increasing demand for rice (Sebastian *et al*., 2006). Despite of many technologies available to meet the demand, rice productivity is still lower than the maximum potential due to some production constraints like declining soil fertility and socio-economic constraints due to farmer's limited management capabilities in making best decision to increase yield. With the goal of producing more rice, farmers tend to over apply fertilizer without knowing the actual nutrient status of the crop in the field. Thus, there is a need for a reliable protocol to give the farmers the right information needed for the best nutrient management strategy on a site-specific basis.

Nitrogen is one of the important nutrients needed by crops in greatest amounts (Taiz and Zeiger, 2002). Nitrogen is responsible for rapid plant growth, vigor, and improves grain quality and yield through higher tillering, leaf area development, grain formation, grain filling, and protein synthesis (Aguera *et al*., 2011). Improper nitrogen fertilization increases rice farming cost, reduces grain yield and contributes to global warming (Peng *et al*., 2010). Thus, proper nitrogen management is needed to optimize fertilizer application and maximize the rice yields.

Assessment of leaf radiation has the potential to detect nitrogen deficiency and is a promising tool for nitrogen management and monitoring. The chlorophyll content of a plant is a good indicator of nitrogen content. The relationship between nitrogen and chlorophyll content arises from the fact that nitrogen stress reduces the production of the chlorophyll that is involved in the production of the reduced compounds that are responsible for carbon dioxide fixation (Pettorreli, 2013). Reduced chlorophyll content leads to increased reflectance of photosynthetically active radiation, that is the reason why nitrogen-stressed plants appear yellow. The NDVI is an indicator of photosynthetic activity. Several studies showed strong correlation between NDVI and plant nitrogen content using hand-held sensors and satellite-based information (Daughtry *et al*., 2000, Hunt *et al*., 2013, Jones *et al*., 2007, Zhu *et al*., 2007, Bell *et al*., 2004 and Saberioon *et al*., 2013). Thus, accurately estimating plant chlorophyll concentration can give farmers valuable information to make decisions on nitrogen management.

Satellite-based remote sensing can be used to monitor crop health on a larger scale but with certain limitations such as higher cost of images, lower resolution, cloud contamination, and soil background noises (Saberion *et al*., 2013). Low altitude remote sensing offers much greater flexibility than satellite platforms because it can operate under clouds and it has finer spatial resolution (Lamb and Brown, 2011). Data acquisition from manned aircraft can be an option, although expensive compared to other types of imagery (Hunt *et al*., 2008). Unmanned Aerial vehicle (UAV) equipped with NDVI sensor can facilitate rapid and non-destructive vegetation analysis. Hence, this study explored the use of UAV-acquired NDVI images in determining the nutrient status of lowland irrigated rice.

MATERIALS AND METHODS

Study Site

The study was conducted during the dry cropping season of rice. Ground data and images were collected from a 1500 m2 irrigated lowland irrigated rice field located at the long-term experimental site at UPLB (121°15'N, 14°10'E), Los Baños, Laguna. The experiment was laid out in a split-plot randomized completely block design with three replicates. A nutrient omission plot technique was used in the experiment. The treatments used in the study were NPK-limited (0-0-0 kg/ha NPK), N-limited (0-30-30 kg/ha NPK), P-limited (90-0-30 kg/ha NPK), K-limited (90-30-0 kg/ha NPK) and without N, P or K limitation (90-30-30 kg/ha N-P-K). Nitrogen fertilizer was applied in two splits (one basal and one at panicle initiation) and the P and K were both applied basal. The study used five (5) rice cultivars, namely: NSIC Rc202 H, NSIC Rc302, NSIC Rc222, PSB Rc82, and PSB Rc18.

Unmanned Aerial Vehicle (UAV) System

A rotary-wing hexacopter drone was used in this study to capture aerial images of the experimental plots. The drone was mounted with a Canon SX260 HS camera, professionally converted by Event38 (2013) to capture NGB (near-infrared-green-blue) images. Camera modification was done by replacing the IR filter such that the red channel records NIR above 700 nm and the green and blue channels still record green and blue (Event38, 2013).

The camera has 12.1 Megapixel and has an on-board GPS, allowing for each image to be geo-tagged with GPS coordinates that is important for orthomosaicing. The camera was set to capture nadir images every three second to ensure sufficient overlap at approximately 25 m height and controlled speed. White balance was set to cloudy to reduce unrealistic color casts under wider range of lightning condition. Images were captured at maximum wide angle, ISO value 1/2150 s shutter speed to avoid blur.

Data Collection

Field data collection was done during tillering (42 DAT), panicle initiation (61 DAT), flowering (75 DAT), and grain filling (82 DAT) stages of rice. Aerial images of experimental plots were acquired at 25 m height between 1300-1400H under a clear sky and sunny day to ensure good quality image. The ground-based leaf chlorophyll content was measured using a SPAD 502 (Konica Minolta, Inc.) chlorophyll meter. Chlorophyll meter readings were done following the procedure of Peng *et al*. (1999). The measurements at each sampling date were taken from three randomly selected hills of each subplot, three tillers per hill and its three youngest fully expanded leaf. The measurements were taken around the midpoint of each leaf blade, 30 mm apart, on one side of the midrib. Leaf chlorophyll measurements were synchronized with aerial image acquisition.

Image Processing

The geo-tagged images captured by the UAVS were stitched using the trial version of Agisoft PhotoScan. The software utilizes structure from motion algorithm hence, orthomosaicing despite unknown camera positions is possible. Image processing was done based on the workflow shown in Figure 1.

Poor quality images especially the blurred images were deleted before loading to Agisoft Photoscan to reduce processing time and come up with good orthomosaic. The orthomosaic was generated and then exported as .tiff file for analysis in QGIS.

Orthomosaics were processed using QGIS, a user friendly Open Source Geographic Information System that can create, edit, visualize, analyze and publish geospatial information. Georeferencing of these orthomosaics was done using ground control

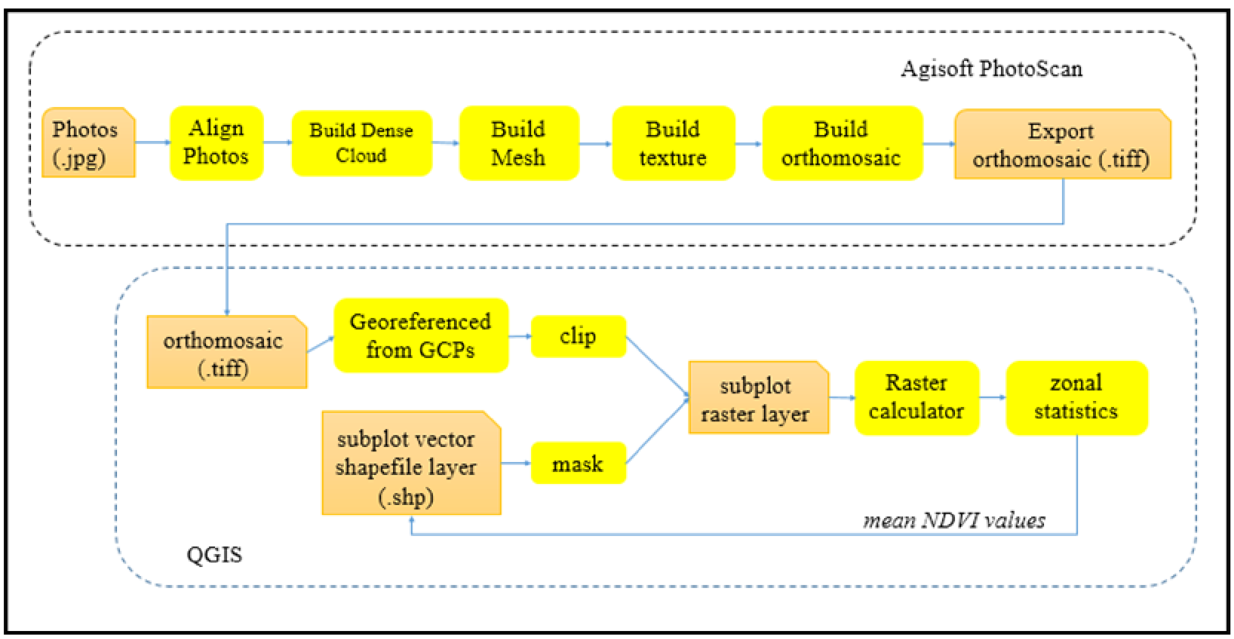

Figure 1. Image processing workflow for generation of NDVI values from NGB aerial images.

point's coordinates and markers visible on the orthomosaic.

A new shapefile layer (vector layer) was created adding each 75 subplots as a new feature on the layer. This was used as mask layer for clipping the areas of interest for computing NDVI. The output of this step was a new raster file containing the subplots only. Then, pixel-wise calculation was made using raster calculator function of the QGIS software to generate NDVI maps. The equation used for computing NDVI (Rasmussen *et al*, 2015) is shown below as:

$$NDVI = \frac{NIR - B}{NIR + B} \qquad \textbf{\textit{Equation 1}}$$

where,

NIR: Reflectance value for Near-infrared band
B: Reflectance value for Blue band.

Zonal statistics were performed to compute the mean NDVI values for each masked subplot. The mean NDVI values for each subplot were loaded accordingly into the vector layer.

Statistical Analysis

Pearson product-moment correlation was used to measure the relationship between SPAD readings and NDVI values. Analysis of variance (ANOVA) for leaf chlorophyll content and NDVI at different growth stages was also performed to determine if the different fertilizer rates and varieties for each measurement were significantly different. To evaluate whether treatment means were ranked in the same order or considered different, comparisons were carried out using least significant difference tests (LSD) at 95% level of confidence. All statistical analyses were performed using STAR statistical software. Percent differences were also used in comparing the treatment effects on leaf chlorophyll content and NDVI.

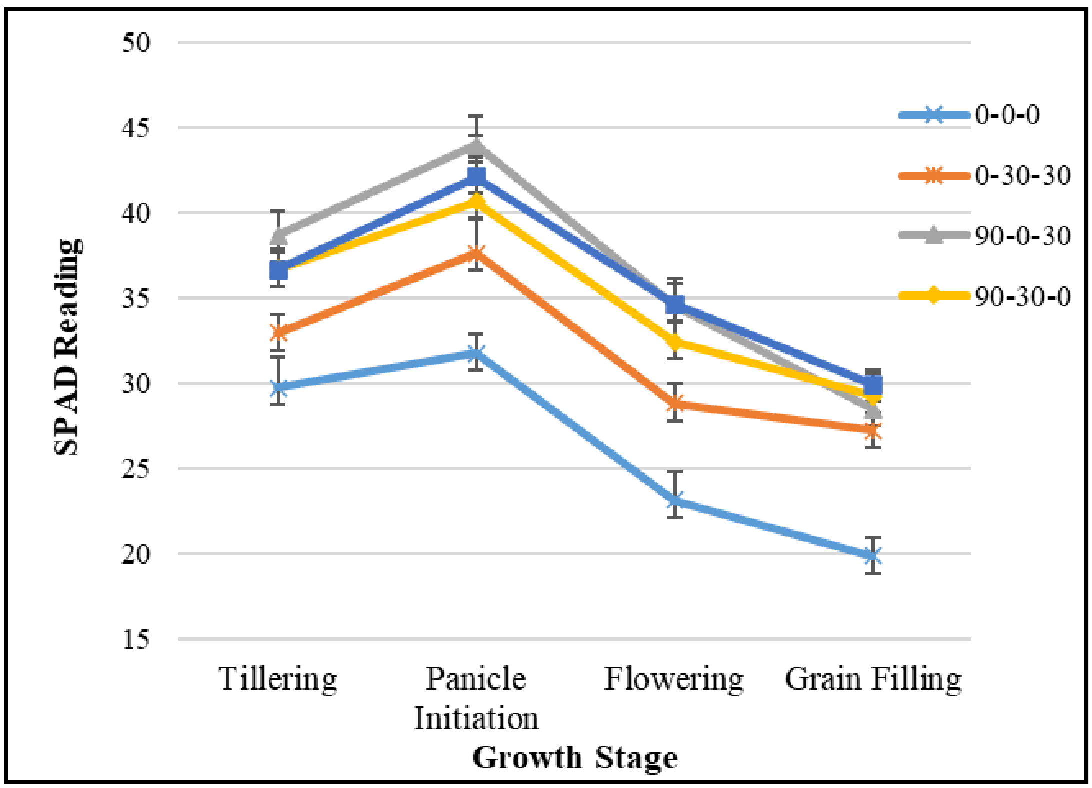

Figure 2. Changes in SPAD readings under different fertilizer treatments.

RESULTS AND DISCUSSION

Temporal Changes in Leaf Chlorophyll Content under Different Fertilizer Rates

The ANOVA test revealed no significant differences among cultivars. The leaf chlorophyll contents of five rice cultivars at different growth stages under varying fertilizer treatments are shown in Figure 2. The SPAD values increased from tillering to panicle initiation stage in all plots with varying fertilizer treatments. However, SPAD values decreased from panicle initiation to grain filling stage. The decrease in leaf chlorophyll, as represented by SPAD readings, is caused by the leaves that begin to wither and die as it reaches senescence (Wang Lin *et al*., 2014).

Non-fertilized plants (0-0-0 kg NPK/ha) exhibited the lowest SPAD value. Significant differences (95% level of confidence) were observed for the different fertilizer treatments and at different growth stages of the crop. Plants applied with 90-0-30, 90-30-0 and 90-30-30 kg NPK/ha had significantly higher SPAD readings compared with those applied with 0-0-0 and 0-30-30 kg NPK/ha.

Plants applied with 90-0-30 and 90-30-0 kg NPK/ha, i. e. without phosphorus and potassium applications respectively, had slight SPAD differences ranging 5-7% across rice growth stages. This is consistent with the earlier findings of Peng *et al*. (1999), wherein SPAD values are not significantly affected by potassium deficiency or non-application of potassium. The same is true under phosphorus deficiency condition or non-

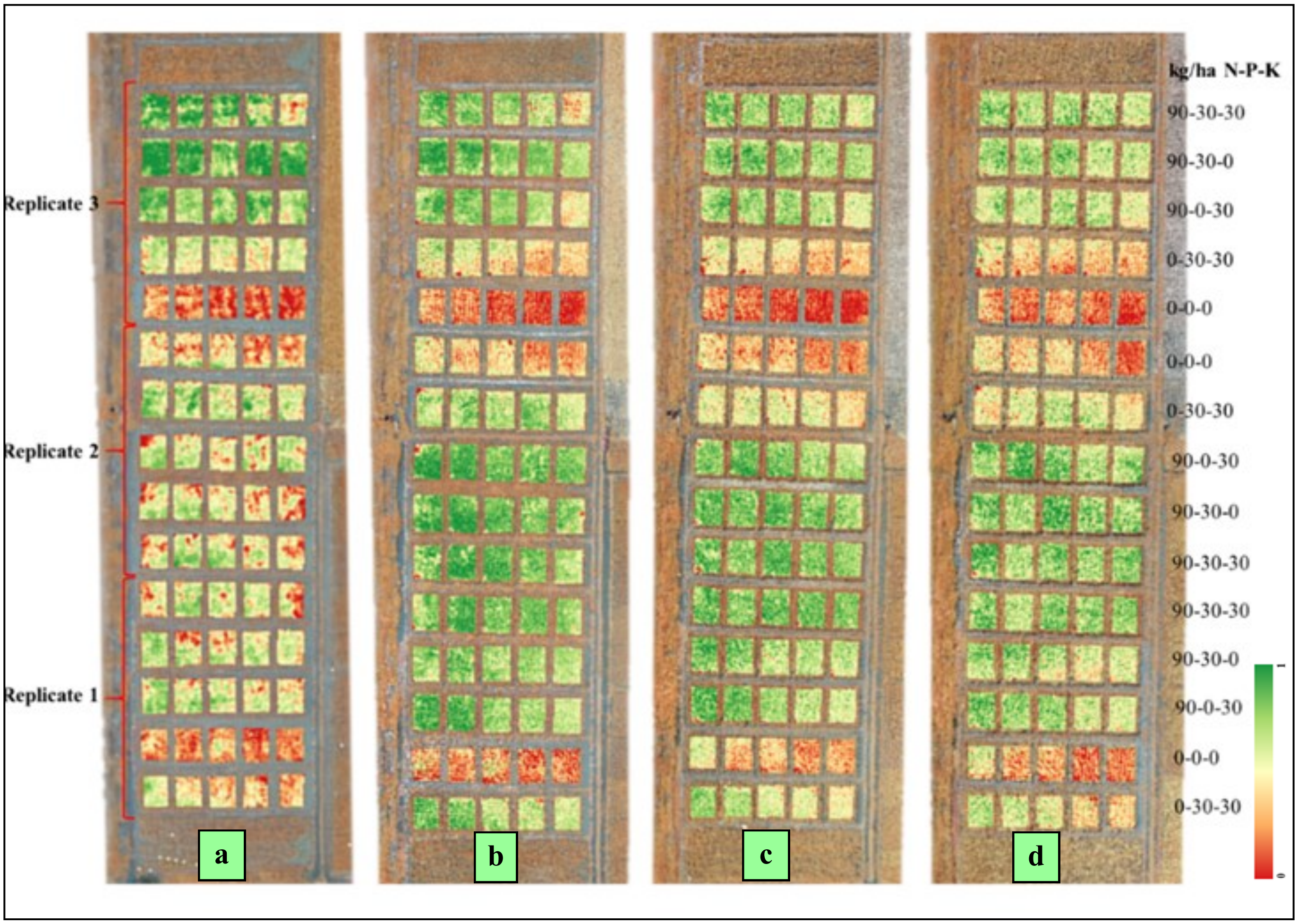

Figure 3. NDVI map of the rice field during (a) tillering (b) panicle initiation (c) flowering, and (d) grain filling stage.

application of phosphorus fertilizer. Further, leaf nitrogen concentration during the tillering stage is reduced when phosphorus is limiting, but it causes increase in nitrogen concentration during panicle initiation stage.

In the present study however, SPAD values obtained from 90-0-30 kg NPK/ha applied plants were 5% higher than 90-30-30 kg/ha. Plants with phosphorus deficiency usually have dark green leaves, which resulted in higher SPAD readings (Peng *et al*., 1999). However, large percent differences in SPAD values ranging 9-18% were observed in nitrogen-limited plants in the present study. Plants with not applied with NPK had the highest percent differences ranging 21-40%. Highest percentage difference was observed during the rice flowering stage.

Spatial and Temporal Changes in NDVI under Different Fertilizer Rates

Figure 3 shows the generated NDVI map of the rice field during (a) tillering, (b) panicle initiation, (c) flowering, and (d) grain filling stages. By visual interpretation, it is apparent that plots with

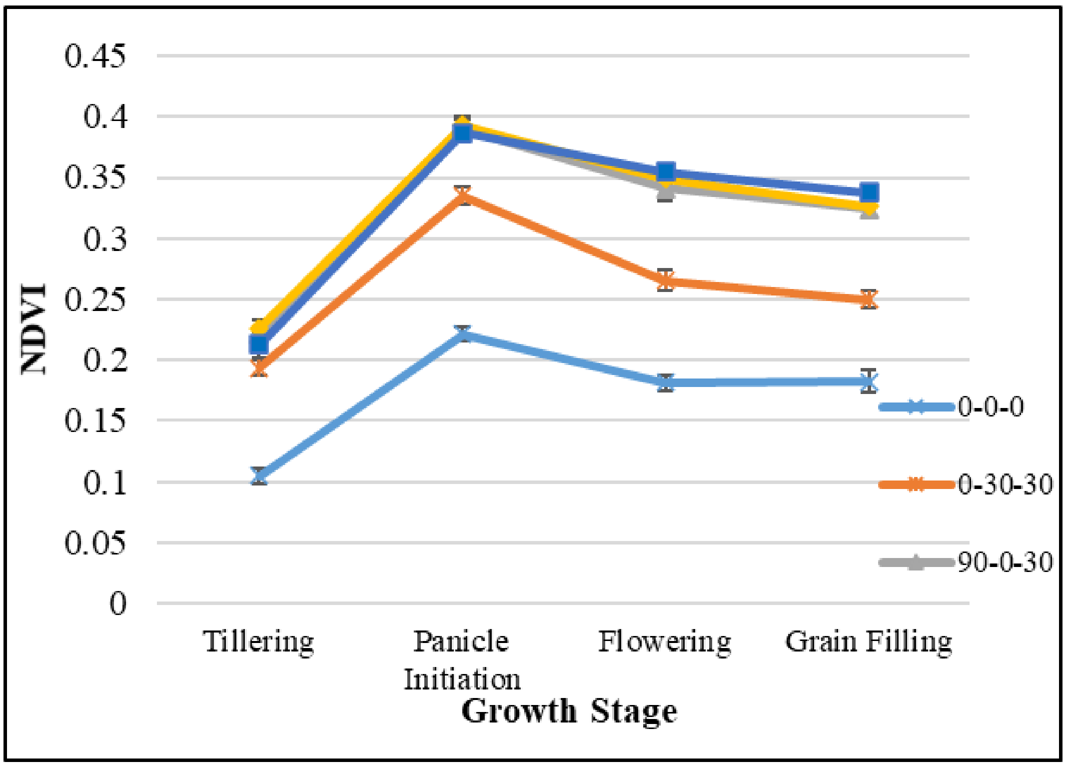

Figure 4. Changes in NDVI under different fertilizer treatments.

Table 1. Correlation coefficients between leaf chlorophyll content and NDVI of rice at different growth stages.

STAGE	r value	p value
Tillering	0.4834**	<0.0001
Panicle initiation	0.7372**	<0.0001
Flowering	0.8028**	<0.0001
Grain filling	0.7471**	<0.0001

***significant at 1% probability level*

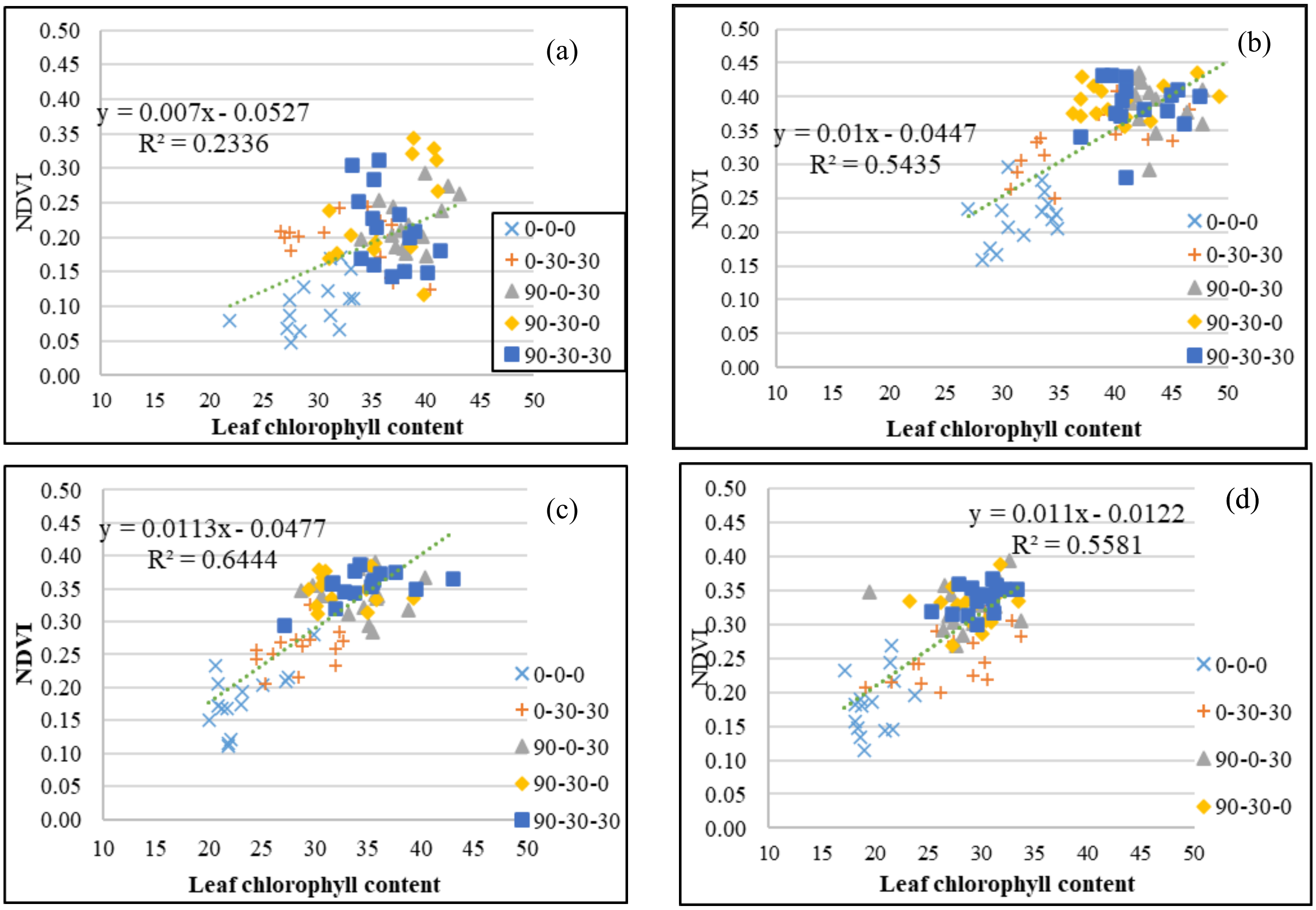

Figure 5. Scatter plots indicating the relationship between leaf chlorophyll content and NDVI during (a) tillering, (b) panicle initiation, (c) flowering, and (d) grain filling.

no nitrogen fertilization (0-0-0 and 0-30-30,kg/ha) were dominantly dark red and light green areas, indicating very low NDVI values. The red areas in the map are exposed water surfaces suggesting low crop cover for nitrogen-deficient plots. On the other hand, plots applied with nitrogen were mostly covered by dark green leaves suggesting very high NDVI values and had full canopy cover.

ANOVA for split-plot RCBD revealed no significant differences among varieties and blocks. Therefore, NDVI values were averaged according to varieties. Figure 4 shows the NDVI values of rice at different growth stages and at varying fertilizer applications. Differences in NDVI tends to increase in nitrogen-limited plots. Among the comparison groups, 0-0-0 and 90-0-30 kg NPK/ha applied plots had the highest differences ranging 56-73%. This suggests that plots with limiting phosphorus have the highest percentage of NDVI difference. Lowest percent difference was observed during panicle initiation stage, while highest at tillering stage. Among fertilizer treatments, relatively larger differences in NDVI values were observed between plots applied with nitrogen and those not applied with NPK fertilizer.

As shown in Figure 4, NDVI values at tillering stage were lower compared to other growth stages due to the exposed water surfaces while canopy crop closure was not attained yet at this stage. Water occupies large portion of the paddy field and the reflectance measured is represented by the mixture of water and green leaves of rice crop. A significant increase (95% level of confidence) in NDVI was observed from tillering to panicle initiation stages. Similarly, Wang Lin *et al*. (2014) reported that the NDVI of rice plants peaks during panicle initiation. This represents the stage where the crop needs more water and fertilizer. On the other hand, a significant decrease in NDVI values were observed from panicle initiation to grain filling stage. Lower NDVI during grain filling can be attributed to leaf senescence and loss of green color of the grains during ripening stage. This non-synchronous pattern of greenness has a great impact on the canopy reflectance of rice (Zhu *et al*., 2007).

Relationships between Leaf Chlorophyll Content and NDVI

Table 1 shows the result of linear correlation analysis (Table 1) between SPAD and NDVI at different rice growth stages for each variety. Considering the pooled data of 75 pairs, the leaf chlorophyll content and NDVI values were found to be positively correlated ($p<0.001$) in all stages of rice crop. Flowering stage (Figure 5b) showed a very strong linear relationship, while during panicle initiation (Figure 5a) and grain filling (Figure 5c) stages, leaf chlorophyll content and NDVI had strong linear relationship. Significant moderate positive correlation was expected during tillering stage (Figure 5d) due to the influence of the water background at this early stage. Correlation coefficients were highest during the flowering stage. The NVDI at the different stages of rice was as good as the leaf chlorophyll content as shown from the positive correlation.

The UAV-based NVDI monitoring appears to be applicable to plots with N deficiency only and cannot delineate deficiencies due to phosphorus and potassium. Findings from the present study will be useful in assessing the nitrogen status of the crop, particularly during panicle initiation and flowering stages, in which nitrogen applications at these stages are crucial in enhancing spikelet formation and grain filling processes. Monitoring of phosphorus and potassium deficiencies using NDVI-based AUV needs further studies.

CONCLUSION AND RECOMMENDATIONS

This study demonstrated the use of low altitude remote sensing as a rapid and non-destructive method of assesing nutrient status of lowland rice. Strong positive correlation between the leaf chlorophyll content and derived NDVI values was observed as early as panicle initiation stage. ANOVA test results for both leaf chlorophyll content and NDVI showed that nitrogen deficient plots were significantly different from plots that were applied with nitrogen. There was no significant difference in NDVI for plots applied with N at all growth stages. Therefore, the NDVI images used in the study is accurate enough to detect nitrogen deficiency for lowland rice.

Low altitude remote sensing can provide near real-time information on nutrient status of rice during critical growth stages. This information is very crucial in implementing spot- or site-specific rice nutrient management. Application of nitrogen during panicle initiation as needed is crucially important to enhance spikelet development, and during flowering (few days before or after) to promote grain filling using foliar fertilizers. Monitoring of phosphorus and potassium status in plants and the needed amount of nutrients for application in relation to UAV-based NDVI need further research.

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