Quantifying nitrogen status of rice using low altitude UAV-mounted system and object-oriented segmentation methodology

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ABSTRACT
Nitrogen deficiency can seriously reduce yield, while over-fertilization can result problems such as excess nutrient runoff and groundwater pollution. Hence, efficient methods for assessing crop nitrogen status are needed to enable more optimal fertilizer management. The ability to quantify the different nitrogen application rates by crops using digital images taken from an unmanned aerial vehicle (UAV) was investigated in comparison with ground-based hyperspectral reflectance and chlorophyll content data from 140 plots on a managed field. This research utilized new UAV system, comprised of remote-controlled helicopter (Hercules II) and digital camera (EOS 30D), was used to characterize spatial and temporal variation in crop production. Digital information was extracted based on an object-oriented segmentation method, and the color parameter was reduced and represented using principal component analysis (PCA). An estimating model was established after analyzing the relationship between the optimal color parameter and ground-based measurements. Model testing demonstrated that unknown samples could be associated with the controlled nitrogen application rates (0, 60, 90, and 120 kg N·hm$^{-2}$): 91.6% %; N1( 60 kg N·hm$^{-2}$): 70.83%; N2( 90 kg N·hm$^{-2}$): 86.7%; N3( 120 kg N·hm$^{-2}$): 95%. Overall, this result proved to provide a cost-effective and accurate way and the UAV was an exploratory and predictive tool when applied to quantify different status of nitrogen. In addition, it indicated that the application of digital image from UAV to the problem of estimating different nitrogen rates is promising.

1 INTRODUCTION
Over-application of nitrogen fertilizer in rice production is common in Southeast China and many other agricultural regions globally, while nitrogen deficiency reduces crop yield, over-application leads to potential environmental problems, including surface water and groundwater pollution and aquatic habitat degradation. In addition to fertilizer quantity, the timing of applications is critical to minimize nitrogen loss and increase recovery (Becker et al., 1994). Thus, a challenge facing farmers is to more effectively observe plant nitrogen status and manage applications both temporally and spatially.

While instrumentation, such as chlorophyll meters, are widely applied to support field crop nitrogen management, they are limited to provide leaf- or plant-scale information and are not practical field- to regional scale assessments. Remote sensing techniques have the potential to quantify the nitrogen status in a timely and cost-effective way relative to traditional chemical methods (REF). However, while satellite remote sensing provides an ideal platform for obtaining regional crop information, this approach can suffers from spatial resolution limitations and is subject to the influence of weather.

Intermediate scale remote sensing techniques can overcome some of the limitations to satellite-based sensing (Everitt et al., 1995). Such techniques enable greater deployment flexibility with respect to cloud cover, and offer finer spatial resolution than satellite remote sensing products (Lamb and Brown, 2001). Buerkert et al. (1996) and Boike et al. (2003) demonstrated the potential of low level aerial photography captured from kite and balloon platforms. Inoue and Morinaga (2000) did the research on monitoring of plant variables using a blimp-based remote sensing system. Ries and Marzolff (2003) monitored gully erosion by large-scale aerial photography taken from a remotely controlled blimp. Baker adopted a cable-supported helium balloon platform to record temporal changes in surficial environments (Baker et al., 2004).

Recent investigations have employed remote-control helicopters (Sugiura et al., 2005) and model aircraft (Hunt et al., 2005) platforms in attempts to map crop biomass and nitrogen status. Furthermore, a high altitude unmanned aerial
vehicle (UAV) was employed to map crop ripeness and weeds in a coffee plantation (Herwitz et al., 2004). No work to date has assessed the potential for quantifying different nitrogen application rates to rice using this technology.

The objective of this study is to assess the feasibility of employing digital imagery collected using an UAV platform to quantify the effect of different nitrogen rates on crop. This capability would enable optimizing nitrogen inputs in order to decrease costs and minimize environmental degradation. The analysis here is based on the digital image recorded from a UAV image acquisition system, which could be controlled from the ground using commercially available components, and on the manually collected plant spectral reflectance and nitrogen concentration data.

2 SITE DESCRIPTION AND METHODS

2.1 Site Description

The field experiment was conducted at Fuyang Farm, situated in the north of Zhejiang Province, near to the southwestern periphery of the city of Hangzhou. The county is located approximately within 119°2′00″N 120°19′30″E, 29°44′45″N 30°11′58.5″N. The area is characterized by a monsoon climate with a hot summers and cool winters, marked by seasonal variations in precipitation. The location of the study area depict in Fig. 1.

![Fig. 1 Location of the study area](image)

The cultivars of Xiushui110 of rice were grown subject to four nitrogen application rates: null nitrogen fertilizer (N0), 240 kg urea per hectare (N1), 360 kg urea per hectare (N2), and 480 kg urea per hectare (N3). The nitrogen fertilization was applied at three different times, 15% at the three leaf stage, 50% at the seven leaf stage, and 35% at the head stage.

The experiment design used four blocks with thirty-five plots each (140 total plots), with 2m × 3m location in each plot. Each plot was replicated three times and completed in three lines, where each line consisted of twelve rows separated 50 cm. Eighty-five plots were selected randomly as the training sample and the remaining were selected as the test sample. Sampling granularity was 1m × 1m sampling location per square meter and each location was at the center of the plot as determined by GPS. Time-course ground measurements were taken on canopy spectral reflectance, leaf chlorophyll concentration, and leaf total nitrogen concentrations at the elongation stage.

2.2 Aerial Imagery from UAV

A remotely-controlled helicopter (Hercules II) was chosen as the monitoring platform and a digital camera (EOS 30D) was used to capture the canopy information due to its lightweight and low cost. The control mechanisms consisted of a black-and-white analogue video camera and a radio-controlled receiver and transmitter. The video camera transmitted images to the group for use as a guide to monitor the field of view of the main camera. The receiver was used to trigger the camera to take an image and the most appropriate images were then selected for further processing. The camera system was shown in Fig. 2.

![Fig. 2 Equipment of helicopter remote sensing](image)

The photographs were taken using UAV on September 1, 2007 at noon to minimize shadow effects. The helicopter flight was stable over a range of wind conditions. Image resolution is directly related to the altitude of the camera.

With this UAV system used in this trial, we obtained a resolution of approximately 0.02 m² covering 0.125 ha at 60m altitude, a pixel area of 0.02 m² using images of 1610×1746 pixels with no image compression in the interest area. The color camera could store 200 images. Images were saved as TIFF or high-resolution JPG files. Photographs responded to the blue, green and red bands. The scanner produced a RGB digital image with 8-bit color and every pixel in the image showed RGB digital counts ranging from 0-255. A sample image is shown in Fig. 3. Twenty ground control points were collected simultaneously using GPS as reference data for the image geo-correction, which was accomplished using ERDAS Imaging 8.7 software (Leica Geosystems GIS & Mapping LLC, Norcross, GA, USA) using the 20 ground control points.
2.3 Measurements of canopy hyperspectral

Canopy hyperspectral reflectance of the rice crop was measured using a spectrometer (ASD Field Spec FR, Analytical Spectral Devices, Inc., Boulder, CO, USA). This spectrometer was fitted with a 25° field of view fiber optics, operated in the 350-2500 nm spectral region with sampling intervals of 1.4 nm between 350-1000, and 2 nm between 1000-2500 nm; The spectral resolutions were 3 nm and 10 nm respectively. For each measurement ten scans were performed and these measurements were averaged to represent the canopy reflectance of each plot. The reflectance of the target was calculated with the calibration measurements of dark current and a BaSO\(_4\) calibration panel was used for calculating the black and baseline reflectance with known reflectance properties (ASD User’s Guide 2002). The sensor was held at approximately 1.7 m above ground at the nadir position to obtain the best regression coefficient for the targeted spectral parameter. The spectral measurement was repeated at 10 sites per treatment where 3 plants were sampled at each plot. The measurements were conducted under clear and cloudless skies between 11:00 and 13:00 local time in the year 2007.

2.4 Determination of agronomy parameters

Representative above-ground plants were destructively sampled almost synchronously in each plot with canopy spectral reflectance measurements. All plant samples were pulled out with roots and some soil intact in order to keep them alive. The samples were transported immediately to the laboratory, separated from the stems, put into an oven to dry with at 105 °C for half an hour and at 70 °C to achieve a constant weight. Then the dry matter was ground, weighed, and quantified for Kjeldahl-N. The results were expressed in mg nitrogen g-1 leaf dry weight.

Rice leaf chlorophyll content was measured using a SPAD (Soil and Plant Analyzer Development, Minolta, Inc., Japan) chlorophyll meter at mid-length of the fully expanded leaf from 3 randomly selected plants per plot.

2.5 Image segmentation and Data analysis

The aerial images were analyzed using eCognition software (V4.0 Defieniens AG, Germany) which used an object-oriented image segmentation method to eliminate the infection from background. The image was broken into unique objects, maintaining internal homogeneity of the objects and exhibiting the external heterogeneity of the image. Each pixel group of the object was composed of similar digital values and possessed an intrinsic relationship to the real-world scene component it modeled. Objects could be generated by altering the parameters, such as shape features, compactness as well as smoothness of the spatial image units. The cell size of objects was stipulated to be the same as field sample scale when the relationship between image information and ground measurements was analyzed. Cell size was determined by \(7 \times 7\) pixels (equal to 1.05 m\(^2\)) around each 1 m\(^2\) field sample area. Then the best represented object was chosen from the area composed of \(7 \times 7\) pixels.

Regression analysis was used to find the best functional form relating image information and ground measurements. The determination coefficient (R\(^2\)) was used to identify significant correlation. The statistical analysis was done using SPSS 13.0. Eighty five of the original 140 plots were subjected to a principal component analysis (PCA), which will be applied as data reducing and representation.

3 RESULTS

3.1 Canopy hyperspectral reflectance under different nitrogen rates

The hyperspectral reflectance of canopy was markedly differently under different nitrogen rates. Fig. 4 displayed the response patterns of canopy reflectance spectra to the different nitrogen application rates at the elongation stage.

Reflectance decreased with increasing nitrogen application in the ultraviolet-visible wavebands (350-710nm). The peak and trough of the wave were described by green (500-560nm) and blue bands (350-400nm), respectively. It was the same as color parameters obtained from the canopy image (Fig.5).
3.2 Estimating model for quantifying effects of different nitrogen rates

The Dark Green Color Index (DGCI) was created to measure the relative dark green color of an image (Douglas, 2003). A good relationship was found between DGCI and the leaf nitrogen content (LNC).

<table>
<thead>
<tr>
<th>G</th>
<th>B</th>
<th>b</th>
<th>g</th>
<th>B/r</th>
<th>b/g</th>
<th>H</th>
<th>S</th>
<th>DGCI</th>
<th>N</th>
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<td>S</td>
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*, ** indicating significant difference at 5% and 1% probability respectively. n=85

Overall, ten optimum color characteristic parameters were identified (see Table 1) as sensitive to the effects of different nitrogen applications rates on rice based on their high correlation coefficient of the LNC.

The different status of nitrogen was subjected to a principal component analysis (PCA). The relationship between the principal component and LNC is summarized in Tab.2. With regards to LNC, PC1+PC2 were the most significant predictor because it was highly corrected with LNC and the coefficient of variance (CV) was the greatest.

<table>
<thead>
<tr>
<th></th>
<th>total N concentrations</th>
<th>CV</th>
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<tr>
<td>PC1</td>
<td>-0.42**</td>
<td>-1.54</td>
</tr>
<tr>
<td>PC2</td>
<td>0.84**</td>
<td>1.88</td>
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<tr>
<td>PC1+PC2</td>
<td>0.81**</td>
<td>8.28</td>
</tr>
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</table>

The color property used in this research was $C_b$ which was directly adopted from the color model used in the transmission of television signals (Bulanon, 2002). The relationship between the color property $C_b$ and LNC was pronounced ($R^2=0.879$, $p = 0.05$), and explained the majority of variance and exhibited high relationship with LNC. The principal component PC2 yielded comparable but lower CV, while the first component PC1 was significantly inferior. For those three components investigated, the component of PC1+PC2 outperformed the other components. It exhibited moderately strong correlation with LNC ($R^2=0.81$, $p = 0.05$). Consequently, $C_b$ was chosen to identify the nonlinear relationships with the relatively good indicators (principal components PC1+PC2) in 85 training samples. Overall, the best-fitting model of quantifying the different nitrogen rates was produced as follows:

$$Y=0.1207*X^2+0.3368*X-20.559$$

with the greatest $R^2$ value of 0.8656 (Fig.6).

Fig. 6 Modeling between the principal component and $C_b$ (F1+F2 indicating PC1+PC2)

3.3 Modeling test
The results from the remaining 55 testing samples were plotted in Fig. 7. The test results exhibited a modest comparison under different nitrogen rates on this estimating model. The result was markedly decreased with the increasing nitrogen rates. Of the original grouped cases, 95% were correctly classified as the normal style as N3. And the sensors were able to predict the area of N0 with 91.6%, where the nutrient was deficient and the plant available nitrogen had decreased. There were difficulties to predict the nitrogen rates of N1 and N2, with the accuracy percentage of 70.83% and N2 86.7% respectively.

![Fig. 7 Distribution of the result](image)

**ANOVA Analysis of LSD** illustrated that treatments under different nitrogen rates on this estimating model had significant differences. In addition, the mean difference under different nitrogen rates on this estimating model had significant differences. The homogeneity of the variance test got the notable F (F=82.881).

**4 DISCUSSIONS**

According to Blackmer and Schepers (1996), the collection of ground data and the inclusion of known reference conditions within a photograph are necessary to verify in principle whether differences in canopy reflectance of rice indeed mirror differences in the soil’s N supply. The agronomic parameters varied greatly under different N application rates, and total leaf N concentration (LNC) was therefore chosen as the primary property in this study. This is a reasonable result considering infield variability at the study sites, and that SPAD values generally vary across the landscape while LNC was relatively stable. Hence LNC was tested for its possible relationship with color parameters.

In this research, the relationship between the dynamic change patterns of canopy reflectance and the parameters of digital image were used to analyze and construct quantitative relationships for rice under different nitrogen rates. Ideally, such relationships might significantly reflect the effectiveness of photosynthesis of the rice under varied nitrogen application rates. The first issue is that there was a high correlation between the principal component and LNC, a finding that is in accord with the theoretical expectations and with some other related research (Yao, 2007). In addition, a good relationship between canopy reflectance in the visible part of the spectrum and the LNC was achieved, a finding that is consistent with Blackmer (1994), who identified good correlations between leaf reflectance in the visible part of the spectrum using chlorophyll meter readings and LNC and grain yield.

There were no significant correlations between absolute color values and LNC. No previous reports exist of a change in the proportion of red, green and blue reflectance as induced by different nitrogen application rates. As seen in Table 1, significantly strong linear correlations were obtained between relative values of red, green and blue light derived from aerial photographs and LNC. Relative reflectance of the rice canopy decreased with increasing nitrogen rates, a finding similar to previous results for corn (Blackmer et al. 1994; Scharf and Lory, 2002). Additionally, after comparing the correlation coefficient between the changed style of color parameters and LNC, the study confirmed that using the different ratios would help to find the optimum relationship under different nitrogen rates in this region. The parameters B and b derived from photography were identified as the optimum parameter. This result was consistent with the previous study as Scharf and Lory, (2002), successfully used aerial photography to predict the side-dressed N rate for optimum crop growth from the green or blue color spectrum at V6-V7 growth stage of corn.

Another issue confounded was the investigated color property $c_s$, which was suggested by Awcock and Thomas (1996), and which is widely used in the transmission of television signals. The model obviously quantifying the
different rates of nitrogen had attained the comparable accuracy with Strachan et al. (2002) who used reflectance data with overall success rates varying from 70 to 93%. The N1 level in this research had a slightly lower accuracy with the percentage of 70.83. It may have been caused by the little difference under deficiency nitrogen rates. More work is needed to verify the result. This research focus on the relationship of image-derived reflectance intensities with LNC, and site-specific fertilizer recommendation should receive more attention in further research.

5 CONCLUSIONS

This study was the first attempt to quantify the effects of different nitrogen application rates using the canopy image acquired from a new platform of UAV, composed of remote-controlled helicopter and digital camera (EOS 30D). This constitutes a relatively simple system to set up and apply in agricultural areas. The digital image obtained from this platform was quite good. The boundary between different fields was clear and the variety of light was obvious.

The results from this study are relevant to modern efforts aimed at quantifying the effects of different nitrogen application rates on crop productivity. The method and model for estimating the effects for rice was established under different nitrogen application rates (0, 60, 90, and 120 kg N·hm-2), with the accuracy of N0 (%): 70.83; N1 (60 kg N·hm-2): 70.83 %; N2 (90 kg N·hm-2): 86.7%; N3 (120 kg N·hm-2): 95%, indicating that the N1 level had a slightly lower accuracy with the percentage of 70.83. More work is needed to verify the result.

The results from this work suggest that the aerial photography from UAV has the potential to provide important information for managing fields so as to allow increases in yield and decreases in environmental problems in future.

ACKNOWLEDGMENTS

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