Estimation of plant nitrogen content using digital image processing

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Abstract: A manually operated four wheel test trolley was designed and developed for acquiring outdoor color images of plant under controlled illumination to predict crop nitrogen content in field. This set up consists of a camera to capture the plant image, four lights to control illumination and a laptop for processing the signal. The developed unit was evaluated rigorously for paddy crop for four observations at fifteen days interval after transplantation. The results were compared with the chlorophyll content of the crop measured by SPAD meter and the chemical analysis of plant leaf. The processing of the color plant image was done in MATLAB 7.0 program. Various features such as R, G, B, normalized 'r' and normalized 'g' were analyzed for both the processes. Regression models were developed and evaluated between various image feature and the plant nitrogen content and observed that, the minimum accuracy was found to be 65% with an average accuracy of 75% (Standard Deviation ±1.9), actual and predicted values of nitrogen percent were linearly correlated with R^2 value (0.948), this showed that the plant nitrogen content can be successfully estimated by its color image feature.

Keywords: precision agriculture, digital image processing, site specific nitrogen application

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1 Introduction

Precision agriculture (PA) is conceptualized by a system approach to re-organize the total system of agriculture towards a low-input, higher-efficiency, higher profit, and sustainable agriculture (Zhang et al., 2002). Among all Precision Crop Management (PCM) activities, nitrogen (N) management, which determines the optimal amount of nitrogen for a specific location based on the yield potential, is the most frequently practiced operation. Nitrogen is the most important and essential element for crop growth and development, its accurate assessment in plants is a key to nutrient management. Plants normally contain between 1%-5% nitrogen by weight (Lee et al., 1999; Arregui et al., 2006). Nitrogen is a major component of the chlorophyll molecule that enhances photosynthesis (Tumbo et al., 2002). The idea of applying 'as much is exactly needed' is termed as site specific nitrogen application (SSNA). However, the efficiency and effectiveness of variable-rate use is heavily relied on the capability of detecting crop nitrogen deficiency variations in the field during the application. Various methods of indirect sensing of the plant reflectance can be classified as the ground based remote sensing, air borne remote sensing, and satellite based remote sensing techniques (El-Shikha et al., 2007; Gitelson et al., 1997). Borhan et al., (2004) developed two laboratory based multispectral imaging systems, the image features from color (red, green, and blue) and multispectral bands (550, 710, and 810 nm) were evaluated in predicting chlorophyll and nitrate contents of potato leaves grown in the greenhouse. Although these methodologies are used in agriculture but consists numbers of shortcomings like high cost, difficulty to apply remote sensing and inability to sue SPAD meter for real time variable rate nitrogen application. Noh et al. (2005) used a multispectral image sensor to detect corn

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plant nitrogen deficiency in real-time for supporting sensor-based variable-rate nitrogen site dressing. Leaf color is usually the most sensitive indicator of deficient nutrient levels (Pagola et al., 2009). Chlorophyll content and concentration may be used to evaluate the overall photosynthetic capacity or productivity of the plant canopy. So to determine the nitrogen content level in the plant, it can be proved very useful. This put forward a requirement of any cheap and straight forward technique. Few researchers tried and were partially successful, but the main constraints found were the difficulty of discriminating plant image and soil due to their almost reflectance in visible range and the absence of near infra red spectrum in color image, which is used to calculate the N.D.V.I. (Normalized Difference Vegetation Index) and which strongly correlates with the plant N content, therefore any index which can be derived from color image and that strongly correlates with plant nitrogen and a technique to discriminate the plant image and soil background would be a cheaper and simple solution to determine plant nitrogen content. Therefore it is very crucial to determine the exact amount of nitrogen content in the leaf of crops. Keeping this in view, an attempt was made to investigate the color plant image features and to determine the plant nitrogen content using digital image processing (DIP) techniques in the field conditions for site-specific nitrogen availability to development of crop chlorophyll content and nitrogen content.

2 Materials and Methods

2.1 Field experimental design

The field experiments were conducted to evaluate the nitrogen content of the crop; a paddy crop cultivated in the field fertilized with nitrogen at different rates was selected in this study. The paddy variety used in this study was 'Kranti' (120 day). An area of 700 m^2 field was used in the research farm of Agricultural and Food Engineering Department at IIT Kharagpur. Total land was subdivided into 28 plots of 25 m^2 sizes; six different nitrogen fertilizer treatments were applied, with four replicates per treatment. Boundary ridges between plots (1 m in width) were separated by a plastic film. Every plot received a specific amount of nitrogen based on its designed treatment level at each application. The nitrogen was provided by applying different amount of UREA (46% N) fertilizer. The nitrogen level varied as control, 50, 100, 150, 200, 250 and 300 kg ha^{-1}, with four replications of each plot for paddy crop and control received none in three split doses of 50, 20 and 30 percent were applied at a ratio of 50% for basal fertilizer, 20% for tillering fertilizer, and 30% for panicle fertilizer to reduce N leaching. K_2O and P_2O_5 were applied at 160 and 95 kg ha^{-1} before transplanting, respectively. Irrigation was supplied by flood irrigation method.

2.2 Experimental setup

Simple color image of plants acquired by high mega-pixel digital camera was selected to develop cheap solution for predicting the nitrogen content of leaf. A set-up was designed to acquire the color image of plant in outdoor situation under controlled illumination conditions (Kim et al., 2001). Provision was made for increasing and decreasing the width (400-700 mm), and height (100-1,500 mm) in the experimental setup for different crops under field conditions. In the present study the dimension of camera captured area is about 400×700 mm and the height of camera was 500 mm and the travel speed of the cage was 1.2 km hr^{-1}. Also, there was an arrangement for changing the position of camera in vertical as well as in horizontal direction, to achieve the apparent picture of plant in different crop height conditions. Chevron lug arrangement was selected for the cage wheels of the width 100 mm to reduce the wheel sinkage and for the easy movement in wet soil (Salokhe et al., 1994).

2.3 Image collection

In color image, it's not possible to distinguish the plant with soil because it has only RBG spectrums which do not discriminate between reflectance of plant and soil (Scotford and Miller (2005). As a solution, in this experimental setup, a provision was made to capture the front view of plant image with constant black background surface, which can be easily removed in color image with image processing to obtain an exclusive plant image. A 5.1 mega pixel camera (SAMSUNG DIGIMAX S600) was used to capture the plants image, the image acquisition was in continuous mode and camera was triggered in wire mode. The setup was covered with a black cloth all around and inside, with artificial lighting arrangement provided by fluorescent tubes (5000 lumen) and a design of the setup is shown in Figure 1. Parallel with the image capture, the same leaves were used to determine SPAD reading (Jongschaap and Booij, 2004) by using SPAD meter(SPAD-502 Model, Konica Minolta company, Features: small enough to fit in a pocket and is extremely light weight (225 g), measuring area is about 2×3 mm and having high accuracy of ±1.0). The field view of SPAD meter is shown in Figure 2. A system was used to measure fourth leaves from top of the randomly selected plant in each plot and calculated an average SPAD value for each plot at each sample time. At the same time the leaves sample of same plants were collected for chemical analysis of Kjeldahl Method (Chapman and Pratt, 1961) to estimate the plant nitrogen content. Total eighty observations of the SPAD were collected at each time, five data from each plot and one sample was prepared by same plant leaves from one plot. Two thousand and three hundred images were acquired covering the entire plot.

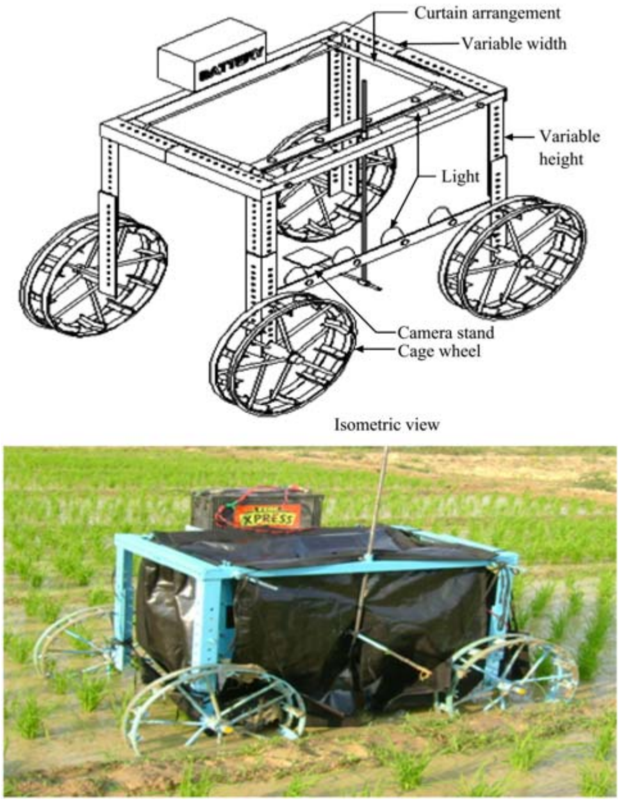

Figure 1 Fabricated setup for capturing the plant image in field condition

Figure 2 Fields view of SPAD meter

2.4 Determination of Plant Nitrogen Content Using Kjeldahl Method

The Kjeldahl method (Chapman and Pratt, 1961) was used for quantitative determination of nitrogen in chemical substances developed by Johan Kjeldahl. Initially a leaf sample of 0.2 g was oven dried for 72 hrs and then properly crushed. The sample was then mixed with 5 mL H_2SO_4 in the presence of K_2SO_4 and $CUSO_4$ and then heated in the digestion flask on the heater for 4 hrs. Heating the substance with sulphuric acid decomposes the organic nitrogen to ammonium sulphate. In this step potassium sulphate was added in order to increase the boiling point of the medium (from 337℃ to 373℃). Chemical decomposition of the sample is supposed to be completed after the medium (initially very dark) become clear and colorless.

The solution was distilled with sodium hydroxide (added in small quantities approximately 10 ml) to convert the ammonium salt into ammonia. The amount of ammonia present (hence the amount of nitrogen present in the sample) was determined by back titration. The end of the condenser was dipped into a solution of hydrochloric acid or sulphuric acid of precisely known concentration (generally 0.2 to 0.4 N). The ammonia reacted with the acid and the remainder of the acid was then titrated with a sodium carbonate solution with a methyl orange pH indicator. Percentage Nitrogen was calculated using the following formula as in Equation (1). The apparatus used for the estimation of plant nitrogen content is shown in Figure 3.

$$\%\,\text{Nitrogen} = \frac{(0.014 \times \text{Volume of } H_2SO_4 \text{ required} \times \text{Normality of the } H_2SO_4)}{\text{Sample weight of the collected leaves}} \quad (1)$$

Figure 3 Kjeldahl apparatus for plant nitrogen estimation

2.5 Digital image processing

Digital image processing, as a tool to analyze the color plant image and extract the important features of the image, was used in the current study. Modern digital technology has made it possible to manipulate multi-dimensional signals with systems that range from simple digital circuits to advanced parallel computers. It is an improvement of pictorial information for human interpretation and processing of image data for storage, transmission, and representation for autonomous machine perception.

A digital image a [m, n] described in 2D discrete space is derived from an analog images a (x, y) in a 2D continuous space through a sampling process that is frequently referred to as digitization. The 2D continuous image a (x, y) is divided into rows (N) and columns (M). The value assigned to the integer coordinates [m, n] with {m = 0,1,2,...,M-1} and {n = 0,1,2,...,N-1} is a [m, n]. In fact, in most cases a (x, y) which we might consider to be the physical signal that impinges on the face of a 2D sensor, is actually a function of many variables including depth (z), color (λ), and time (t). Commonly encountered value of rows (N) and columns (M) are 256, 512, 525, 625, 1024, 1035 {M=N=2^K where (K = 8, 9, 10)}. The number of distinct gray levels is usually a power of two, that is, $L=2^B$ where B is the number of bits in the binary representation of the brightness levels. The images were captured in the field condition; they were processed in MATLAB 7.0 platform. Initially, preprocessing of all images was done to enhance their visual quality, further to achieve the various features of color images and to transform color (RGB) images into normalized r, g, and b chromaticity coordinates. The composite color images were decomposed into red spectrum image (R), green spectrum image (G), and blue spectrum image (B) components. Subsequently, the images were also converted into hue, saturation, and intensity (HIS) coordinates to extract the

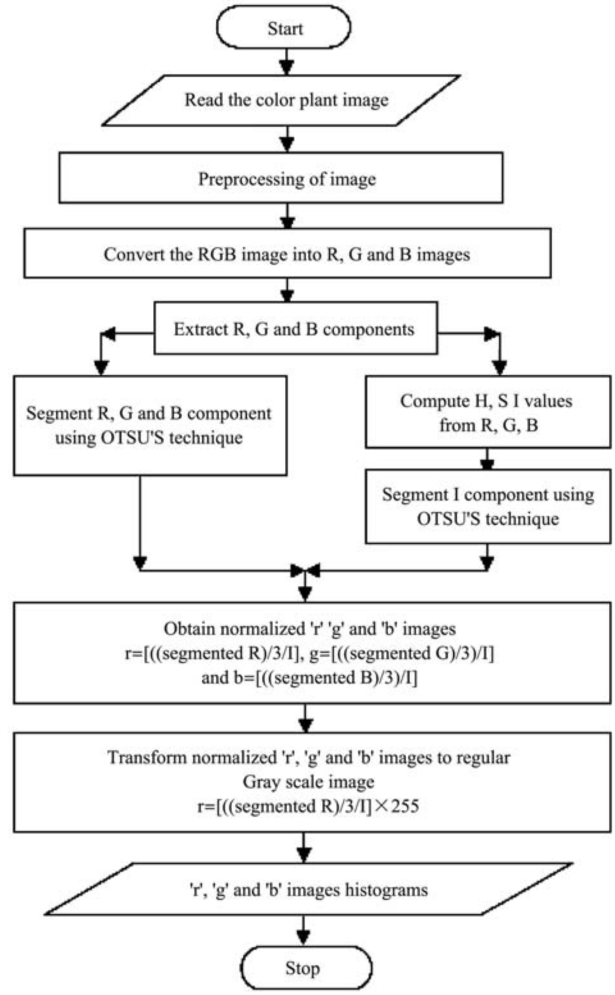

Figure 4 Flow chart of the embedded image processing

intensity component (Ahmad et al., 1999). In order to extract the color information and to obtain different features, the entire image features were segmented from its background using an automatic segmentation technique based on a modification of Otsu's algorithm (Otsu, 1979). The automatic threshold technique selects a threshold to segment the background from the object. Thus segmented images were used to calculate the mean values of images. Four image features (mean, variance, average energy, and entropy) from each normalized 'r' and 'g' segmented image histogram of paddy leaves were calculated. Figure 4 shows the flow chart for extracting the color image features.

3 Results and discussion

The results are discussed with regard to, correlation between different image features of plant and plant chlorophyll content using SPAD meter reading and the plant nitrogen content estimated by the micro-Kjeldahl procedure (Chapman and Pratt, 1961). In paddy, the first observation was collected for fifteen days after transplantation, where the images were captured and the plant samples were taken for chemical analysis. At the time of SPAD meter observations, plant images were also taken at constant illumination and then various image features were extracted using the image processing techniques. After these features were extracted, their mean values were correlated with the SPAD meter (Jongschaap and Booij, 2004) readings and the collected leaf sample values to determine the nitrogen content. Similar observations were made for 30, 45 and 60 days after transplantation. Chemical analysis of the soil nutrients distribution in the field, collected from the experimental farm, was done to estimate the amount of the nitrogen fertilizer required in different plots to maintain the required fertility level.

3.1 Relation between different image features

Paddy leafs are green in color and its intensity is represented between black (minimum) and white (maximum) so the minimum and maximum values of RGB colors never attain the minimum value (0) or maximum value (255) with the lowest standard deviation. Minimum and maximum value of normalize 'r' was 138.023 at 0 kg ha^{-1} and 187.903 at 300 kg ha^{-1} at 214 N dose respectively. The properties of the images in RGB color space context is shown in Table 2. It was also observed that the R, G and normalized image features of the plant have the highest correlation with the SPAD value which was expected because the maximum absorption of the light to the chlorophyll content as shown in Table 3. In paddy, the correlation coefficients between image features and the SPAD meter reading was observed to increase from first to second observation, second to third and then almost constant trends were observed between third to fourth observations. This was because the paddy had acquired the flowering stage and the crop chlorophyll content acquired almost constant state. But it can be clearly seen that R, G, and

Table 2 Nitrogen level Image features and SPAD value of paddy

Nitrogen Level /kg ha^{-1}	Red	Green	Blue	Norm 'r'	Norm 'g'	Avg. SPAD
0	120.268	144.67	112.111	138.023	152.413	27.3
50	133.353	155.585	126.381	149.75	165.135	29.87
100	143.437	177.633	116.426	155.618	182.593	32.23
150	154.055	185.485	131.653	164.502	189.34	32.78
200	169.461	195.777	139.662	176.737	194.044	35.85
250	177.755	202.354	150.494	180.405	199.853	37.73
300	193.735	216.952	177.473	187.903	209.732	39.15

Table 3 Correlation coefficients between different image features and the SPAD meter readings for Paddy (Kawashima el al., 1998)

Image features	15 days after transplanting	30 days after transplanting	45 days after transplanting	60 days after transplanting
R	0.71	0.8	0.79	0.78
G	0.76	0.71	0.77	0.77
B	0.55	0.54	0.52	0.5
R/(R+G+B)	0.46	0.51	0.5	0.48
G/(R+G+B)	0.48	0.42	0.47	0.44
B/(R+G+B)	0.27	0.31	0.32	0.33
R-G	-0.42	-0.44	-0.43	-0.43
R-B	0.43	0.45	0.42	0.42
G-B	0.5	0.49	0.53	0.52
(R-G)/(R+G)	-0.13	-0.15	-0.18	-0.16
(R-B)/(R+B)	0.6	0.62	0.61	0.66
(G-B)/(G+B)	0.26	0.32	0.34	0.33
(R-G)/(R+G+B)	-0.14	-0.16	-0.15	-0.14
(R-B)/(R+G+B)	0.27	0.29	0.33	0.32
(G-B)/(R+G+B)	0.26	0.28	0.29	0.28
NORMALISED 'r'	0.69	0.75	0.77	0.79
NORMALISED 'g'	0.71	0.73	0.74	0.76

normalized ‘r’ and normalized ‘g’ were the four features had the highest value of the correlation coefficients, and hence these features were selected to develop the regression model between image features and the plant nitrogen content, estimated using micro-Kjeldahl method (Chapman and Pratt, 1961).

3.2 Development of histogram

The histogram shown in Figures 5 and 6, clearly indicate variation present in the grayscale values of all kinds of leaves visual texture. The histogram of paddy

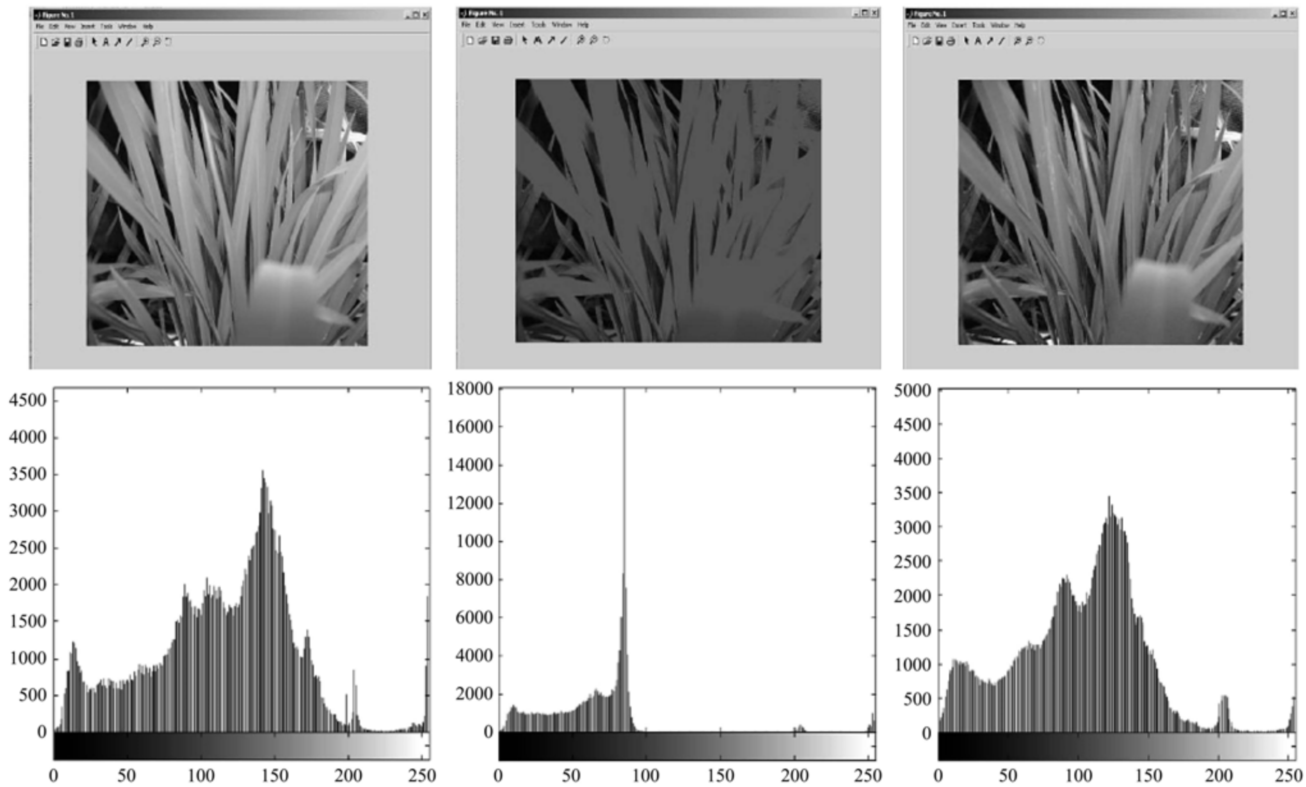

Figure 5 Original image, ‘R’ image and ‘G’ image of paddy plant

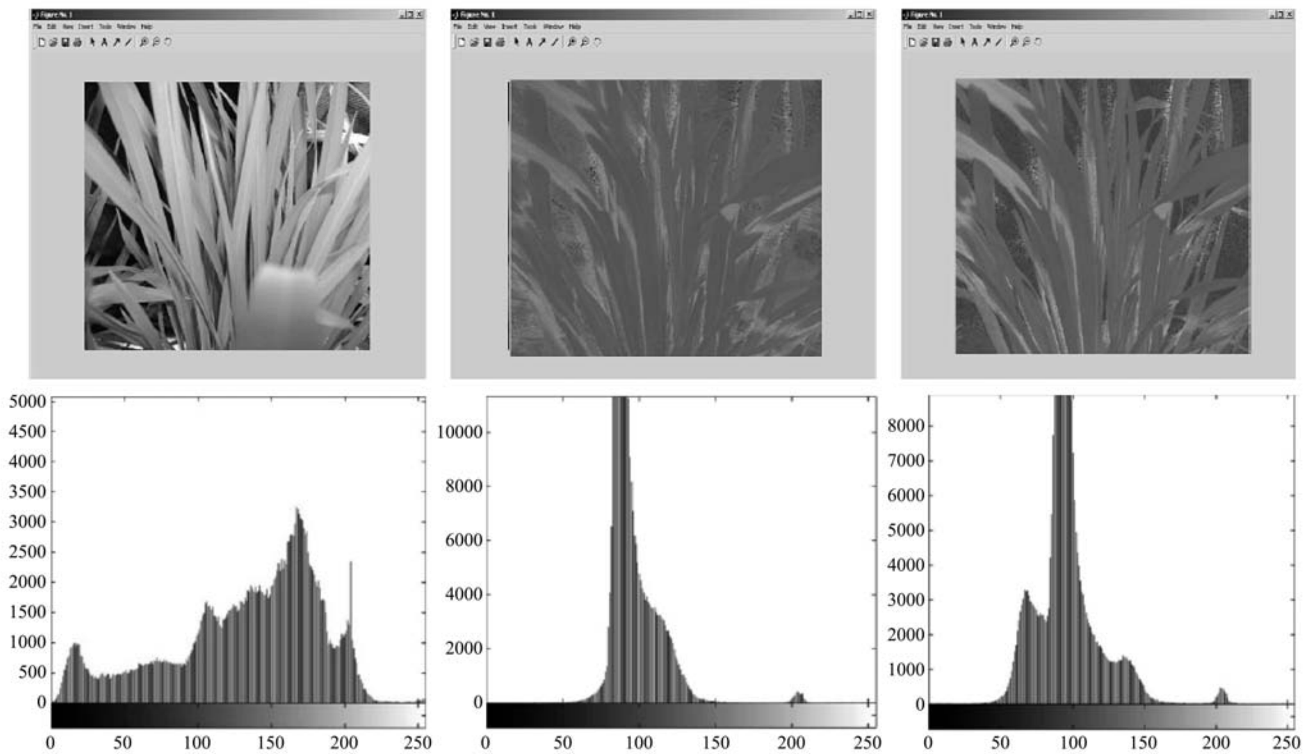

Figure 6 ‘B’ image, Normalized ‘r’ and Normalized ‘g’ image of paddy plant images can be easily separated by the features of image. First-order statistics can be computed from the histogram of pixel intensities in the image. These are the common outcomes on the basis of image histogram. Various features were successfully extracted in Matlab platform and these image features were used to estimate the plant nitrogen content.

3.3 Prediction of plant nitrogen content using regression model

Regression models were developed between image feature and the plant nitrogen content, estimated by chemical analysis with micro-Kjeldahl method. After preprocessing of the image, they were converted into the R, G, B, normalized ‘r’ and normalized ‘g’ image. Various image properties with the help of histogram developed for various image features were calculated such as mean, variance, average energy and entropy. Among various features, the mean value of the different image features was found to be best correlated with the plant nitrogen content. Regression equations between the plant nitrogen content and different image features were developed. Most successful models were between normalized ‘r’ vs. percent nitrogen content and normalized ‘g’ vs. percent nitrogen content by a second order polynomial equation. After fifteen DAT, the best related feature was the normalized ‘r’, which yielded R^2 value of 0.842 at 5% significant level, when correlated with the mean of the image and the nitrogen content. At this stage the plant nitrogen varied from 0.405% to 0.449%. The mean value of the normalized ‘r’ and ‘g’ varied from 168.28 to 172.95 and from 189.3 to 194 respectively. Thirty DAT, the best related feature was the normalized ‘r’, which yielded R^2 value of 0.894 with second order polynomial equation, at 5% significant level, when correlated with the mean of the image and the nitrogen content at this stage the plant nitrogen varied from 0.401% to 0.449%. The values of mean value of the normalized ‘r’ and ‘g’ varied from 168.9 to 173.1 and from 189.3 to 192.5 respectively. It was observed that even though the nitrogen percent and the image values have not increased but the R^2 value has increased, this could be because at the time of second observation the plant had grown sufficiently, which gave a good quality picture in comparison of the first observation. And thus the image features could be drawn even more successfully. In case of the third and fourth observations (forty five and sixty DAT), the same trend was observed and the value of R^2 increased in comparison to the second observation, which also suggest that as plants grow, it becomes easy to extract the image feature and thus the value of R^2 also increases. The R^2 was 0.944 at sixty DAT. Also there is a definite increase in the percent Nitrogen content which shows that the quantity of the Nitrogen increases with the growth stage of the plant. This way we find that for all the observations, the normalized ’r’ showed the highest value of R^2, in relation to the % Nitrogen. When all the observations were considered simultaneously (Figures 7 - 8), the value of R^2 was found to be (0.883) with normalized ‘r’ and (0.746) with normalized ‘g’, with a five percent confidence interval. Thus normalized ‘r’ was selected for the estimation of plant nitrogen content, by model. Total 140 samples were used to develop the prediction model, five data points from each plot. Eighty samples were used to validate the model.

$$\text{Nitrogen Percent} = 8\times10^{-5}\times(r^2) - 0.0162\times(r) + 0.8778 \tag{2}$$

When this equation was used to estimate the plant nitrogen content, results shown (Figure 9) the average accuracy was above 75% (Standard Deviation ±1.9).

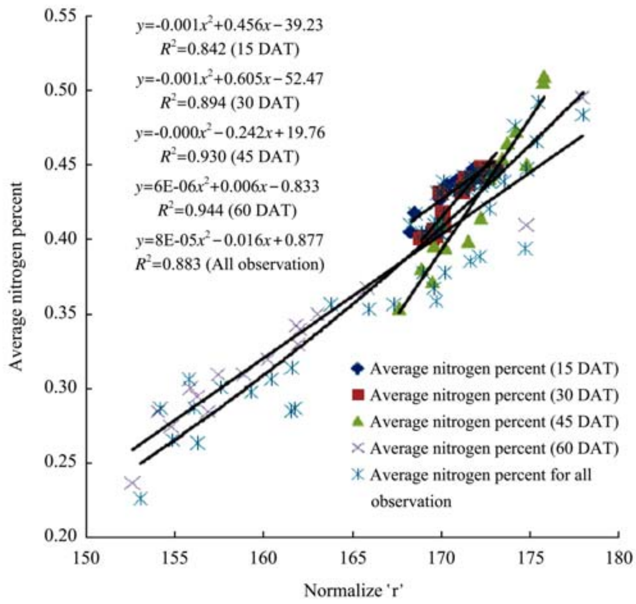

Figure 7 Normalized ‘r’ vs. % nitrogen for all observations for paddy at different time interval

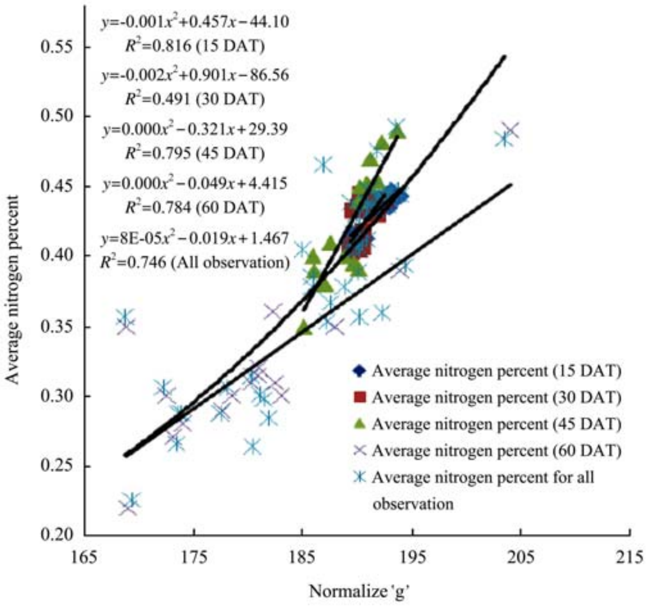

Figure 8 Normalized 'g' vs. % nitrogen for all observations for paddy at different time interval

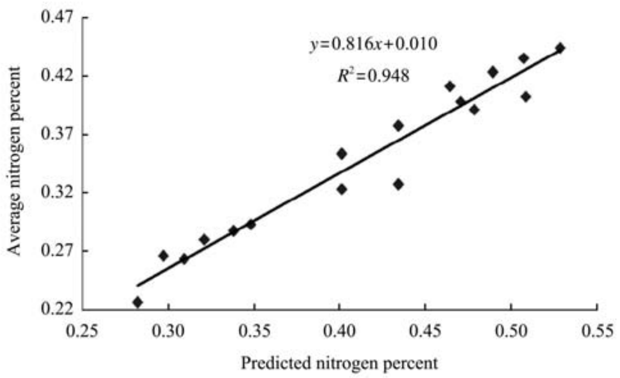

Figure 9 Actual and predicted nitrogen percent in paddy

3.4 Actual and predicted nitrogen content for paddy

When actual and predicted percent nitrogen values were observed, they were found to be linearly related with R^2 value of 0.95. The minimum prediction accuracy was 67% and the maximum prediction accuracy of 88%, which gives an average accuracy of prediction above 75% (Standard Deviation ±1.9) (Figure 9).

4 Conclusions

This research was basically undertaken to estimate the status of the plant nitrogen content / chlorophyll content in the field condition, so as to avoid the intricacies involved in other method such as chemical analysis. Digital image processing was selected as the tool to estimate plant nitrogen content in field. An experimental setup was developed to fulfill both the requirements in field condition; this was able to produce the constant illumination (artificial) and a uniform background for the image. Various image features such as RGB, normalized 'r' and normalized 'g' were taken. These features were correlated with SPAD reading, which represent nitrogen / chlorophyll content of plant. R, G and normalized 'r' and 'g' were found to be the most closely related with SPAD readings, normalized 'r' was found to have the highest value of R^2. Regression model were developed between various image feature and the plant nitrogen content. When this model was tested, the minimum accuracy was found to be 65% with an average accuracy of 75%, actual and predicted values of nitrogen percent were linearly correlated with R^2 value (0.948). These results show that the plant nitrogen content can be successfully estimated using its color image feature.

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