



Assessment of rice leaf chlorophyll content using visible bands at different growth stages at both the leaf and canopy scale



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ABSTRACT

Nitrogen is an important variable for paddy farming management. The objectives of this study were to develop and test a new method to determine the status of nitrogen and chlorophyll content in rice leaf by analysing and considering all visible bands derived from images captured using a conventional digital camera. The images from the 6-pannel leaf colour chart were acquired using Basler Scout sCA640-70fc under light-emitting diode lighting, in which principal component analysis was used to retain the lower order principal component to develop a new index. Digital photographs of the upper most collared leaf of rice (*Oryza sativa* L.), grown over a range of soils with different nitrogen treatments, were processed into 11 indices and I_{PCA} through six growth stages. Also a conventional digital camera mounted to an unmanned aerial vehicle was used to acquire images over the rice canopy for the purpose of verification. The result indicated that the conventional digital camera at the both leaf ($r = -0.81$) and the canopy ($r = 0.78$) scale could be used as a sensor to determine the status of chlorophyll content in rice plants through different growth stages. This indicates that conventional low-cost digital cameras can be used for determining chlorophyll content and consequently for monitoring nitrogen content of the growing rice plant, thus offering a potentially inexpensive, fast, accurate and suitable tool for rice growers. Additionally, results confirmed that a low cost LARS system would be well suited for high spatial and temporal resolution images and data analysis for proper assessment of key nutrients in rice farming in a fast, inexpensive and non-destructive way.

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Introduction

Knowledge of the nitrogen (N) status of crops is essential for sustainable management of nitrogen fertilizer; it helps with the application of N fertilizer to crops based on site-specific requirements. Currently several different, direct and indirect methods and instruments are available for assessing N status in crops and manage the amount of N fertilizer applied to crops based on site-specific requirements such as tissue and chemical analysis, leaf colour chart (LCC), chlorophyll meters (van den Berg and Perkins, 2004; Gholizadeh et al., 2011), Dualex (Cartelat et al., 2005), Greenseeker (Johanson et al., 2002), crop circle ACD-210 and crop circle ACD-470 (Cao et al., 2013) and Yara passive N sensor. However, all of

the above-mentioned methods have been proven to be costly, time consuming and in some cases destructive and labour intensive.

Recently, remote sensing (RS) has become an attractive technique for crop nutrient determination (Link and Reusch, 2006). RS provides a rapid estimate of nutrient status using high spatial resolution for vast areas, which can be used for variable rate fertilizer application (Olfs et al., 2005). RS has been proposed as a cost-effective alternative to other methods for rapidly detecting nutrient deficiency, in particular N deficiency across farm fields (Wright et al., 2003; Meisinger et al., 2008). The most common RS is mainly from aerial and satellite platforms, which are equipped with a various types of sensors such as multispectral, hyperspectral cameras.

Satellite imagery (Zhang et al., 2006; Shou et al., 2007; Eitel et al., 2007), aerial photography (Williams et al., 2010) and hyperspectral remote sensing (Hansen and Schjoerring, 2003; Inoue et al., 2012) have been used widely for determining status of nitrogen in plants. However, these types of imageries have low temporal and easily

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affected by low resolution and variation in soil background (Broge and Leblanc, 2001). Moreover, they are still costly especially when repeated data acquisition needs at critical growth stages.

Among the different RS platforms, the low altitude remote sensing (LARS) system is currently attractive to researchers and agriculturists, which includes precision farming (PF) as one of the most promising platforms for monitoring crops. Various LARS platforms are now available, such as tractor driven crane mounted systems (Samseemounget al., 2012), kites (Aber et al., 2002), blimps (Vericat et al., 2008), balloons (Jensen et al., 2007; Seang, 2006), unmanned helicopters (Swain et al., 2010), unmanned aerial planes (Hunt et al., 2005), powered gliders (Lelong et al., 2008) and quadrocopters (Primicerio et al., 2012) to capture images for agricultural applications. All of these platforms are equipped with a variety of types of remotely sensed sensors such as film cameras (Hunt et al., 2003) or commercial digital cameras (Lelong et al., 2008; Teoh et al., 2012) and global navigation satellite systems (GNSS), which can acquire images with high resolution over the farms. In other words, the LARS system can be used to obtain high spatial resolution images below the cloud cover and near the field for providing better details of crops. Moreover, in spite of satellite and aerial platforms, the LARS system has potential to be used at any required setting time over the agriculture fields, which provides crop details for farmers near to real time (Hunt et al., 2002).

Among the different LARS platforms, imagery using digital cameras, attached to UAV has attracted researchers the most. Aerial photography using UAV can be made at a very low cost, with higher spatial and temporal resolution compared to airborne and satellite platforms (Quilter and Anderson, 2000; Hunt et al., 2005).

The development of low cost digital cameras together with coupled charged device (CCD) arrays allows for easy and rapid capturing of images. Images can be easily transferred to a computer for processing and analysing. All these benefits combined with their ease of use and non-destructive functionality make this system ideal for farmers as a potential sensor for crop management and monitoring (McMurtrey et al., 1994). For example, Adamsen et al. (1999) used a colour digital camera to measure the greenness of a wheat canopy at the plot level by calculating the ratio of green to red. Dymond and Trotter (1997) used a CCD array to obtain colour images of forest and pasture targets from an aircraft. They were able to calibrate the camera system and use it to evaluate the bi-directional reflectance properties of different targets. Lukina et al. (1999) used digital images captured by a colour digital camera to estimate the vegetation coverage and biomass of wheat. The digital camera has also been used by Sakamoto et al. (2012) to continue the monitoring of crop biophysical parameters during day and night. Some have also used digital cameras and image processing to determine vegetation dynamics such as nutrient deficiency, as well as pest and disease diagnosis in crops (Yao et al., 2010; Hairuddin et al., 2011) or weed detection (Perez et al., 2000). Digital cameras have also been used to estimate nutrient status in crops. For example, Hunt et al. (2005) used a digital camera attached to an aerobatic model aircraft to estimate N status and biomass of corn, alfalfa and soybean, and they found a linear correlation between an index derived from the digital camera and biomass and N. Zhu et al. (2009) examined the feasibility of employing digital imagery collected using an UAV platform to quantify the effect of different nitrogen rate in paddy fields. They found digital imagery using UAV not only has potential to provide input in support of crop decision making but also this type of approach minimized field sampling efforts, saving both time and money while enabling accurate assessment of different N application rates.

Visible spectral reflectance of the plant canopy has also been found to be useful for analysing crop growth and yield. For example, Blackmer and Schepers (1995) and Xue et al. (2004) have proven that green reflectance at 550 nm has a robust relationship with leaf

N concentration ($r^2 = 0.96$) and chlorophyll content ($r^2 = 0.90$). Eitel et al. (2008) showed that increasing leaf chlorophyll content would cause a smaller change in red reflectance because of the strong absorbance of red wavelengths by chlorophyll.

Hence, digital images, which can measure the intensity of reflectance in the red, green and blue (RGB) bands, have the capacity to evaluate the status of N and chlorophyll content in different types of crops.

Researchers have examined digital colour images by measuring different parameters, such as greenness (Richardson et al., 2002), intensity of G and R (Gitelson et al., 2002), normalized green intensity (Jia et al., 2007), canopy cover (Li et al., 2010) and growth (Lee and Lee, 2013). Some studies have also attempted to find the relationship between different colour systems and N. For example, Mercado-Luna et al. (2010) used the RGB colour space to determine the N deficiency in tomato seedlings, while Hairuddin et al. (2011) proposed a new reliable method for using RGB next to hue, saturation and value (HSV) colour spaces to determine N deficiency, and other main nutrients in oil palm leaves. Meanwhile, Graeff et al. (2008) found a correlation between N concentration and CIELa*b* chromaticity parameters in broccoli plants. Vegetation indices calculated from the combination of visible bands have also been studied. For example, normalized green red difference index (NGRDI) shows the correlation with chlorophyll content at the leaf scale (Hunt et al., 2005). Kawashima index (I_{KAW}) was developed and used to estimate the chlorophyll content in rice leaves (Kawashima and Nakatani, 1998; Saberioon et al., 2013). Hunt et al. (2011) developed the triangular greenness index based on visible bands for determining the status of chlorophyll content in crops ($r^2 = 0.85$).

Most indices are calculated using the ratio or normalized difference of two bands, which may not consider all three bands in the visible wavelengths. The main objective of this study was to develop and test a new index to determine the status of N and chlorophyll content in rice leaf by analysing and considering all visible bands derived from images captured using the conventional digital camera and principal component analysis. This research were partly consistent with previous work by Pagola et al. (2009), who proposed that PCA could be used to develop a robust index for determining N and chlorophyll content over the various N treatments in barley at the leaf scale. Pagola et al. (2009) used various images of barley leaves with different nutritional status according to the N supply dosage to develop the index. In the present study, the 6-panel LCC was used as a proven tool (which arranged based on the best match of the spectral reflectance of plant leaves (Fairhurst et al., 2007)) to determine N in rice leaves to develop I_{PCA} . Moreover, as Hunt et al. (2005) indicated, indices, which usually show good performance at the leaf scale, do not perform well at the canopy scale. Another objective of this experiment was to explore the LARS system using an unmanned aerial vehicle to acquire images in visible bands for determining the chlorophyll content status of rice plant at the canopy scale. The LARS system was also used to examine and verify the application of I_{PCA} over the canopy of paddy fields. Moreover, based on our knowledge, no research has been done on examining I_{PCA} in canopy scale.

Materials and methods

Field preparation for leaf data

The experiment for capturing leaf data was conducted at a farm (out side of greenhouse) at Universiti Putra Malaysia, Serdang, Selangor, Malaysia (Latitude $3^{\circ}05'N$ and Longitude $101^{\circ}42'E$). The soil, which was placed in 16 pots (Medium 15 cm (diameter) round

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