Spectral reflectance of rice leaves and leaf color charts for N management

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Abstract

A leaf color chart (LCC) offers substantial opportunities for farmers to detect plant nitrogen (N) demand in real time for efficient fertilizer use and high rice yields. There are several LCCs available for irrigated rice, but colors and color ranges vary greatly among charts. A systematic analysis using a Minolta CM 3700-d spectrophotometer showed a tight relationship between leaf color measured by spectral reflectance (SR) and leaf N content in a two-season field experiment with ten rice varieties grown at three different N levels in the Philippines in 2001. Based on actual SR measurements performed on rice leaves, criteria and target patterns of SR were established for the evaluation of five existing leaf color charts. Color panels were subjected to reflectance measurements, which confirmed the visual observation that color charts vary greatly in color, color ranges, and consistencies in color among panels of each chart. Despite technical limitations in achieving a perfect match between leaf and plastic color, the LCCs developed by the University of California Cooperative Extension (UCCE) and the International Rice Research Institute (IRRI) in collaboration with UCCE met the established criteria reasonably well. The two charts have consistent reflectance patterns among their color panels and appear to successfully capture the relevant color range observed for rice varieties commonly grown in California (UCCE) and Asia (IRRI). The leaf color charts of UCCE and IRRI are currently tested and evaluated by rice growers.

Media summary

Two high-quality leaf color charts for efficient N management in rice capture the relevant color range observed for rice varieties in California and Asia.

Key Words

Rice (Oryza sativa), leaf N, spectrophotometer

Introduction

A rapid and accurate estimation of leaf nitrogen (N) content under field conditions is of equal usefulness in rice research on N nutrition and extension of improved N management strategies. Farmers need real-time information on the plant's need for N to manage climate associated risks such as lodging and achieve high yields and efficient fertilizer use. The scientific basis for need based N management was developed with the introduction of the chlorophyll (SPAD) meter (Peng et al 1996, Balasubramanian et al 1999). Recognizing the limitations of the costly SPAD meter as an on-farm tool, leaf color charts have been developed to guide rice farmers in assessing the crop demand for N. In both SPAD and LCC based approaches, the leaf N status is periodically assessed and application of fertilizer N is delayed until (near) N deficiency symptoms appear. Several leaf color charts exist that differ in size, number, and color of their panels. Leaf color charts were first developed in Japan (Furuya 1987) and China (by Prof. Tao Qinnan, Zhejiang University, Zhejiang, P.R. China, late 1980ies). Modified from these early prototypes, the most widely distributed LCC in Asia was developed through collaboration between IRRI and the Philippine Rice Research Institute (IRRI 1999). More than 500,000 units of the IRRI-PhilRice LCC have been fabricated and distributed to farmers through collaboration with National Agricultural Research and Extension

Systems (NARES) in a number of Asian countries. However, manufacturers of the IRRI-PhilRice LCC were not able to maintain the quality of the chart so that refinements were required. In the late 1990s, the University of California Cooperative Extension (UCCE) released a LCC that was developed for the most common rice varieties in California based on spectral reflectance measurements of rice leaves. In 2004, IRRI released a new, standardized LCC that was developed for Asian rice varieties based on a modified approach using spectral reflectance measurements of rice leaves in collaboration with UCCE. Although earlier research has shown that fertilizer N can be managed efficiently with any of the currently available LCCs (Yang et al 2003), there is a need to establish technical criteria for the identification of most suitable LCCs in rice. The specific objectives of this paper were to establish the relationship between leaf N content and color using spectral reflectance measurements, to use actual measurements for the development of target spectral reflectance patterns for a theoretical LCC, and to compare currently existing LCCs with the target patterns.

Methods

Field experiments

Two field experiments were conducted at IRRI, Los Ba?os, Philippines, in the 2001 dry (DS) and wet (WS) seasons. Ten modern high-yielding varieties (four indica inbreds, two new plant type [NPT], two NPT x indica, and two hybrids) were grown at three N levels (zero, medium, high). A split-plot randomized complete block design was used with four replicates with N treatment as main plot and cultivar as subplots. Seedlings (14 d) were transplanted on 15 Feb 2001 (DS) and 2 Jul 2001 (WS) with 2-3 seedlings per hill at 0.2- x 0.2-m hill spacing. All plots received 40 kg P2O5, 40 kg K2O, and 12 kg ZnSO4 prior to transplanting. Fertilizer N was applied in four splits as basal dose (20%) and at 7 days before mid-tillering (25%), panicle initiation (40%), and booting (15%).

Plant measurements

Measurements were made 1 wk after each fertilizer N application starting at 21 d after transplanting. Ten hills were randomly selected from each plot where the uppermost, fully expanded (healthy) leaf was subjected to spectral reflectance measurements in 10-nm bandwidths from 400 to 700 nm wavelength using a Minolta CM-3700d spectrophotometer

Leaves were then detached and pooled for measuring leaf area, dry weight, and N content. Leaf N content was determined using the micro-Kjeldahl digestion and distillation method and expressed as the amount of N per unit dry weight (Ndw).

Comparison of leaf color charts

Color panels of five leaf color charts were subjected to spectral reflectance measurements in 10-nm bandwidths from 400 to 700 nm wavelength using a Minolta CM-3700d spectrophotometer. Spectral reflectance measurements of each chart were compared with actual reflectance measurements of rice leaves.

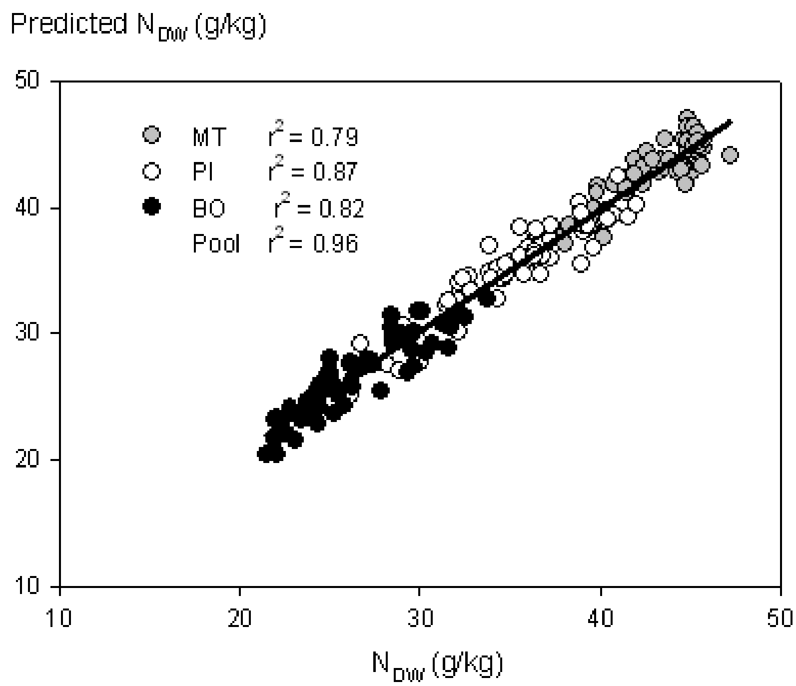

Figure 1. Predicted and measured leaf N content, 2001 DS and WS. N_{dw} = leaf N per unit dry weight, MT = mid tillering, PI = panicle initiation, BO = booting.

Results

Leaf N content as predicted by spectral reflectance measurements

Despite differences in spectral reflectance of leaves among treatments, spectral *patterns* were not affected by variety, N rate, and season (data not shown). Using the statistical software SAS V.8.02, a model for predicting leaf N content using partial least squares (PLS) regression was constructed using all visible spectral data (400-700 nm) without variable selection. Using data from the 2001 DS and WS season experiments, a model having 15 latent variables was able to account for more than 99% of the predictor variation (reflectance) and more than 96% of the response variation (leaf N content) (Figure 1).

Target and actual reflectance patterns of leaf color charts

The relationship between leaf N content and spectral reflectance patterns was used to develop target spectral reflectance patterns for a theoretical LCC that would cover the major range of leaf N contents in Asian rice varieties (Figure 2A). Typical reflectance patterns of rice leaves would have the greatest reflectance and sensitivity at 550 nm (green). Spectral reflectance of rice leaves with different N content would therefore differ greatly at 550 nm, while differences in reflectance would decrease towards both ends of the spectrum.

Based on the actual spectral reflectance patterns of rice leaves, an optimal LCC should have 1) color panels with maximum reflectance at 550 nm with decreasing reflectance towards both ends of the spectrum, 2) greatest differences in reflectance among color panels at 550 nm and small differences towards both ends of the spectrum (400 and 675 nm), and 3) equidistant reflectance among color panels at 550 nm. Recognizing technical limitations, a perfect match between leaf and plastic color was not expected. However, there were great differences among existing LCCs with regard to the above given criteria. Greatest reflectance of color panels at 550 nm was not always achieved (Figure 2BCD). Only the LCCs of UCCE and IRRI that were developed using an approach based on spectral reflectance measurements (Figure 2EF) provided color panels with equidistant spacing of reflectance patters meeting all criteria. The LCC of UCCE has eight, larger color panels covering a color range of yellowish green to green developed for the most common rice varieties in California, while the IRRI chart has four, smaller color panels and covers a darker range of greens suitable for Asian rice varieties. Consequently, the LCC of UCCE had generally higher spectral reflectance than the IRRI chart.

Conclusion

Leaf color measured by spectral reflectance provides an instant and reliable estimate of leaf N content without destructive plant sampling. Because of the tight relationship between leaf N content and spectral reflectance patterns, target patterns of spectral reflectance can be developed for color panels of a theoretical LCC. The target patterns were used to develop criteria for the evaluation of five existing leaf color charts. Despite technical limitations in achieving a perfect match between leaf and plastic color, only the LCCs from UCCE and IRRI met the established criteria reasonably well. The two charts have consistent reflectance patterns among their color panels and appear to successfully capture the relevant color range observed for rice varieties commonly grown in California (UCCE) and Asia (IRRI). We conclude that spectral reflectance measurements are useful in the development and evaluation of LCCs to achieve a consistent set of color panels suitable for the rice varieties commonly grown in the area of interest. The leaf color charts of UCCE and IRRI are currently tested and evaluated by rice growers.

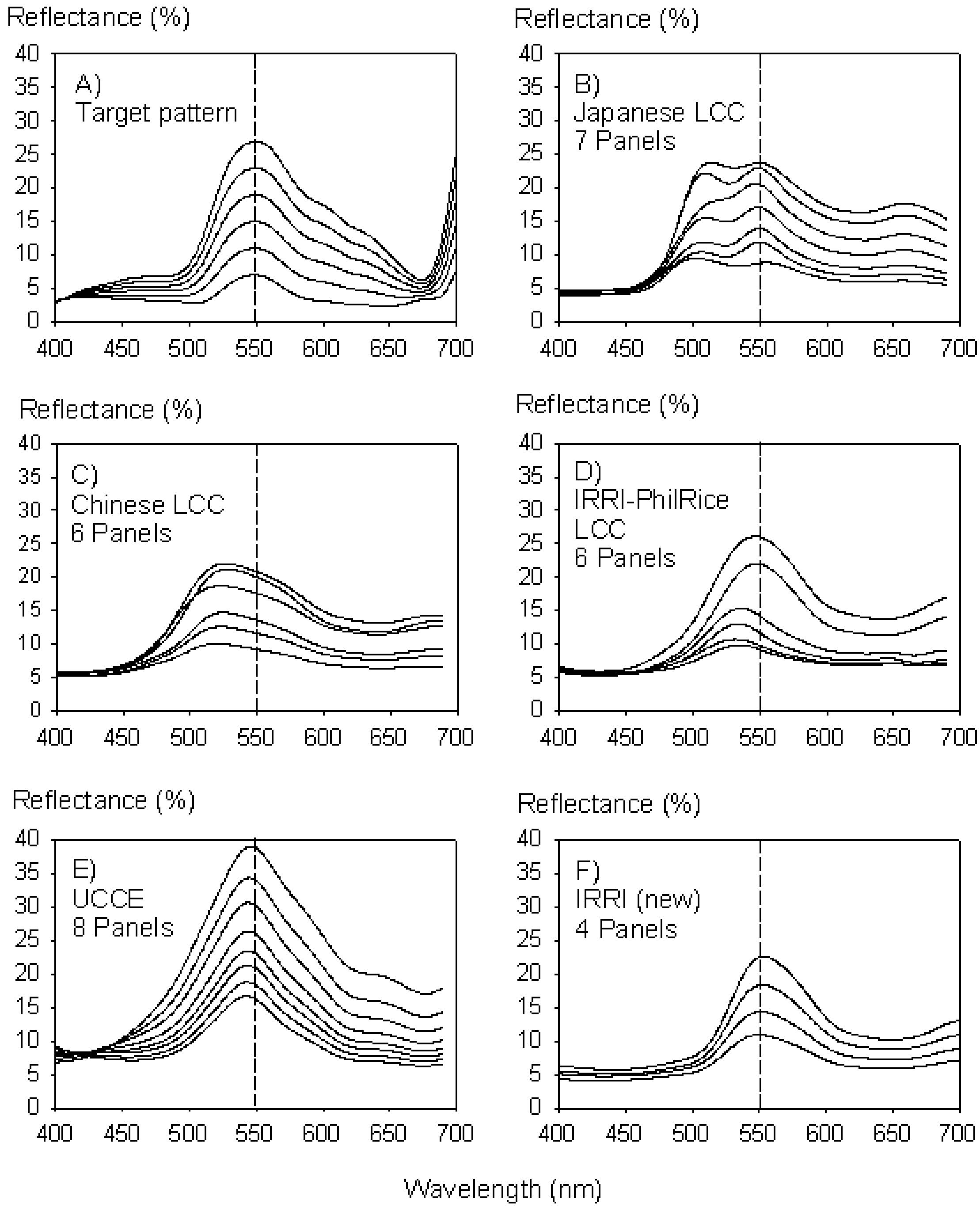

Figure 2. Target spectral reflectance patterns for a theoretical leaf color chart (LCC) based on actual reflectance measurements performed on rice leaves of major rice varieties in Asia (A), and actual reflectance patterns for different LCCs from Japan (B), China (C), IRRI-PhilRice (D), UCCE (E), and IRRI (F). The dotted line at 550 nm (green) reflects the maximum reflectance of actual rice leaves in the visible spectrum. The top line in each chart represents the lightest green, while the lowest line represents the darkest green.

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