Choosing a near infrared instrument and a sample presentation option for plant and soil analysis

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Introduction

In Australia the yields of rice crops are amongst the highest in the world. A record average yield of 9.6 t ha^{-1} was achieved in the 2000–2001 season. Individual growers regularly achieve 12 t ha^{-1} (data provided by the Ricegrowers' Co-operative Limited, Leeton Australia). The average input of nitrogen fertilizer is 120 kg N ha^{-1} but when rice is grown after several rice crops as much as 240 kg N ha^{-1} may be applied.[1,2]

The cost of fertilizer together with the water used to grow rice and the declining price of rice are encouraging rice growers to adopt management practices which lead to higher yield ha^{-1}, higher yield kg N^{-1} applied, higher yield ML^{-1} water used to grow the crop and grain of marketable quality while exerting minimal impact on the environment.

Near infrared (NIR)-based analysis of rice crop shoot N status was developed as an aid to crop fertilizer management in the 1980's and provides a quantitative system to improve efficiency in the terms specified above.[3,4] We have reported on this application of NIR spectroscopy at previous NIR Conferences.[5,6]

The success of the shoot tissue testing service for rice has led to its adoption by over 40% of rice growers.[7] The benefits to the industry include an estimated 5% higher yield for those who have crops tested, reduced waste of fertilizer by those whose crops acquire adequate nitrogen (a saving to the industry and also protection of the environment from excess fertilization) and more marketable grain (slightly lower protein content). There are considerable flow-on benefits to farmers who do not use the testing services through a better understanding of crops requirements. The estimated benefits are some A$10 million per year to the industry at a cost of only about A$50,000 per year or a return of 100 : 1.

New developments

The present NIR-based plant shoot analysis services for rice and wheat depend on growers sampling their crops at defined physiological growth stages and collecting samples from up to nine small areas of crop. The total area sampled is < 1 m^2 from 20 to 30 ha of crop. This sampling intensity was chosen[8] after an examination of the variability in some crops. The current NIR testing procedure in-

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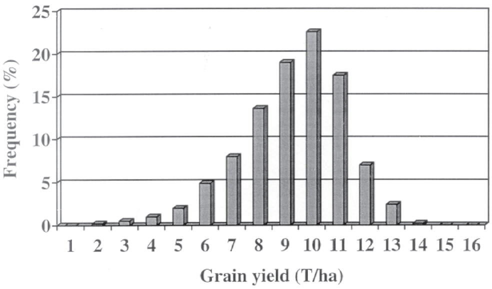

Figure 1. Yield range and distribution in a rice crop with an average yield of 10 t ha^{-1}. (Source—J. Lacy, personal communication).

cludes presenting the sample to the NIR instrument in a standard sample cup. The NIR instrument, therefore, only senses about 1 g of tissue taken from 20 to 30 ha of crop. Using larger cells, or the presentation system available on the Perten DA7000 instrument, would increase the amount of sample exposed to the instrument but would not reduce the error associated with sampling the crop in the field.

As we enter the 21st century, farmers are becoming familiar with yield maps which show the extent of crop variability. In a field of rice which yields an average of 10 t ha^{-1}, only 25% of the area will yield 10 t. The other 75% of the area will yield less or more than the average, possibly within the range of < 1 to 14 t ha^{-1} (Figure 1). Yield maps are a first step into the new 'precision farming' approach to crop management. To be of real benefit to farm managers, precision farming tools must provide information about variability within a field which is cost effective to obtain, is in absolute (not relative) units, indicates reasons for the variation; and can be collected in time to allow decisions about the current crop.

Crops are being assessed during vegetative phases of development using satellite or air-borne imaging systems with electromagnetic energy of visible and near infrared wavelengths.[9–12] To calibrate these images into actual data values, such as dry matter ha^{-1}, much field data recording work is necessary. In many situations the images from satellites cannot be obtained at the appropriate time or cost for timely crop management decisions to be made. Images of crops collected from an aircraft flying at an altitude between 1,000 and 3,000 m above the land surface may be more reliable and less expensive.

We have advanced the prediction of actual crop dry matter yields from a 4-camera airborne video system.[13] Each camera contains a 740 × 576 pixel array and is fitted with a 12 mm focal length lens. At 1524 m above the ground, this system achieves a resolution on 1 m (1 m × 1 m pixels) and an image area of 43.2 ha. Each camera acquires information in a preset spectral band governed by an interchangeable filter (25 nm band-pass). An on-board computer, fitted with a 4-channel frame-grabber board, captures and digitises the images from the cameras. In this study images were captured using filters with 440, 550, 650 and 770 nm wavelengths.

Images of the rice crops reported here were obtained between 11 am and 2 pm Australian Eastern Standard time at an altitude of 1400 m. Standard reference panels were imaged during each flight. Pre-processing of each image included shear correction, band-to-band registration and elimination of geometric and radiometric distortion. The normalised difference vegetation index or NDVI for each pixel was determined as follows:

NDVI = (red – infrared) / (red + infrared)

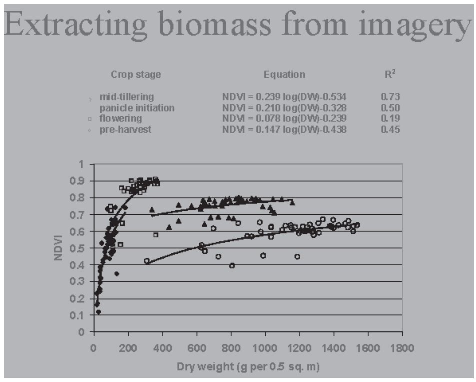

Figure 2. Correlations between normalised difference vegetation index (NDVI) and rice crop dry matter at four plant growth stages.

NDVI was found to be correlated with biomass at several crop stages (Figure 2). Final yield was estimated from mid-tillering NDVI with an error of < 1 t ha^{-1}. The correlations between NDVI obtained here and crop biomass at final grain yield are comparable with similar data reported by Ruan *et al.*[14] The stronger correlations between NDVI and dry matter during the earlier vegetative stages of crop development partly reflect the shoot to water ratio of the rice crop.

Future developments

At this time, the NDVI images are being used by rice growers to decide where to take samples for PI N tests and to indicate where nitrogen fertilizer rate should vary. In Australian rice crops deficiency of nitrogen is the dominant cause of low yields but sub-optimal yields due to inadequate phosphorus and zinc and now evident from recent reports by Batten *et al.*[2] and Dang *et al.* (2001, unpublished data). Extrapolation from NDVI data to biomass estimates may be valuable when calculating potential crop yields but further work is essential to predict the appropriate fertilizer type and amount to be applied.

A study by Brian Dunn (2000; personal communication) revealed that the final yield of a crop is explained largely by dry matter at the panicle initiation stage of development ($R^2 = 0.74$), while shoot nitrogen is a more informative predictor of final yield ($R^2 = 0.80$). Analysis of nitrogen, and also non-structural carbohydrate,[6] would provide a basis for more appropriate fertilizer recommendations. If crop composition data were made available, in conjunction with NDVI maps, crop managers could be in a better position to determine the appropriate fertilizers and the optimal rates of fertilizer, for small areas within crops.

NIR science and technology has much to offer in these new expectations of food producers who must continue to feed the current population of the world which will rapidly increase towards 8 billion over the next 25 years.

Conclusions

Techniques which detect the extent of variation within crops will enhance the average yields achieved by producers. Current sampling and subsequent analysis using NIR has been profitable for rice growers in Australia but large area surveys of crop dry matter variation, together with NIR analysis of crop nitrogen status, is suggested as essential to improving crop production on a larger number of rice farms. Yield-limiting factors (such as soil pH, salinity, nutrient deficiencies, water logging, disease, pests), must be understood before recommendations are made on fertilizer requirements.

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