# Using a handheld multispectral radiometer to forecast grain protein in northern Australia

**Rob Kelly**[1], John Cooper[1], Greg Thomas[2], Wayne Strong[1], David Butler[1] and Armando Apan[3]

[1] Department of Primary Industries and Fisheries, PO Box 102, Toowoomba, QLD 4350. www.dpi.qld.gov.au. Email rob.kelly@dpi.qld.gov.au.
[2] Department of Natural Resources, Mines and Energy, PO Box 2282, Toowoomba, QLD 4350. www.nrm.qld.gov.au.
[3] Geospatial Information and Remote Sensing Group, Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba, QLD 4350. www.usq.edu.au/users/apana.

## Abstract

A handheld 8-channel multispectral radiometer was used to capture canopy spectral signatures on wheat grown in a long-term tillage and fertilizer experiment during 2002 and 2003 in southern Queensland. The experiment was designed, among other things, to measure long-term responses to nitrogen (N) application at 0, 30 and 90 kg/ha.year. We used the radiometer to collect canopy spectral responses at several dates during the growing season which corresponded to tillering, pre-anthesis, anthesis and post-anthesis. In 2002, grain protein was best explained by capturing the reflectance at 710 and 810 nm of the crop canopy at 118 days after sowing ($r^2$=0.59). In 2003, the same wavelengths were closely related to observed grain protein, but at 98 days after sowing ($r^2$=0.56). The close relationship between grain protein and tissue N concentration at anthesis may be why spectral-based prediction of grain protein can take place. Further testing of this model in subsequent years under varying conditions will allow a more robust model to be developed for region-wide grain quality prediction.

## Media summary

Canopy reflectance offers promise as a means to forecast grain protein of wheat ahead of harvest, and may allow regional forecasting systems to be developed.

## Key Words

Spectral reflectance, remote sensing, nitrogen content, forecasting systems.

## Introduction

Grain quality remains an important determinant, along with grain yield, of crop performance. Grain protein, when interpreted alongside grain yield, can identify the effectiveness of nitrogen (N) application strategies for cereal crops (Strong and Holford 1997). In addition, appropriate N application can enhance the chances of a cereal crop reaching a premium quality grade, such as Prime Hard for wheat. This in turn can boost crop returns by up to 30% in some years. This economic incentive has assisted in the adoption of sound N application strategies in the northern region, and created opportunities by which these strategies can be reviewed (Lawrence *et al*. 2000).

Significant variation in grain protein content exists within grain fields (Strong *et al*. 2003, Stewart *et al*. 2002), and this has similarly allowed for the site-specific assessment of N strategies (Kelly *et al*. 2004). However, retrospective analysis precludes the immediate segregation of grain at harvest to take advantage of price premiums. Remote sensing of canopy reflectance prior to harvest has been demonstrated as a way to forecast grain yield and quality of barley (Basnet *et al*. 2003; Hansen *et al*. 2002). We investigated proximal sensing of wheat on a long-term fertiliser experiment over two seasons to see if spectral properties related with final grain yield and grain protein content.

## Methods

*Experimental site and design*

A trial site, established in 1969 at the Hermitage Research Station (28.21?S, 152.10?E) near Warwick, was used for the capture of reflectance data. The site is located on a black Vertosol. The experiment comprises 12 factorial treatments made up of two fallow tillage methods (zero-tillage or conventional tillage), two stubble management methods (stubble retention or stubble burned), and three N fertiliser rates (0, 30, 90 kg N/ha, N1/N2/N3). Fertiliser N was applied as urea (46% N) between rows at sowing. The treatments were replicated four times among randomised blocks, providing a total of 192 plots. Each plot was ca. 40 m long and 5 m wide.

*Crop management and data collection in 2002*

In 2002, wheat (*Triticum aestivum* cv. Baxter) was sown on 26 June into 0.25 m row spacings. Plant establishment was inconsistent within the fourth replicate block due to a blocked planting tyne, and so only the first three replicates were considered in subsequent analysis. Canopy reflectance was determined using an MSR87 radiometer (www.cropscan.com) capable of measuring reflectance at 460, 510, 560, 610, 660, 710, 760 and 810 nm from a diameter of 0.7 m. Reflectance measurements were taken at 98, 104, 111, and 118 DAS with four duplicated readings taken per plot. Readings (recorded as mV) were taken within 2 h of noon to maximise solar irradiance and reflectance. These readings were then corrected with a sun-angle cosine factor to account for sun movement (based on date, time, latitude and longitude), then converted into percent reflectance. At mid-anthesis (15 October, or 111 DAS), two samples of wheat were harvested at ground level from each plot from an area of 0.3 $m^2$. Total biomass was oven-dried to determine total above-ground biomass. These samples were then ground and measured for N concentration using a near infrared (NIR) spectrophotometer. The experiment was harvested on 20 November (147 DAS) with a plot harvester. Each plot was split into four subplots to align with the reflectance readings. Grain yield was taken on site, and a sample was processed by the spectrophotometer to measure grain protein and moisture content.

*Crop management and data collection in 2003*

In 2003, wheat (cv. Baxter) was sown on 19 June. Canopy reflectance was taken at 69, 85, 98 and 112 DAS on all four replicates. A severe frost in August caused minor dieback on the southern edge of the plots. At mid-anthesis (15 October, or 118 DAS), plant cuts were taken in a similar fashion and dried, ground and analysed by the NIR for tissue N. Harvest was conducted on 2 December (166 DAS) as for 2002. Grain yield and grain protein content were calculated for each subsample within each plot, and corrected to 12.5% moisture.

*Data analysis and statistical procedures*

Statistical analyses were carried out using Genstat (Lawes Agricultural Trust 2002). Principal components analysis (PCA) was undertaken on the reflectance data to reduce the data size and maximise data orthogonality. Vegetation indices were also derived from the 8 bands (Table 1). Analysis of variance (ANOVA) was applied on all data sets to establish significance of response, and subset regression analysis was conducted to identify the strength of parameter combinations on yield and protein. Grain N was the product of yield (t/ha), protein (%), and the factor 1.75. We present results relating to N treatments only.

**Table 1. Vegetation indices derived from canopy reflectance data.**

| Indices | Derivation |
|---|---|
| NR1 | W760/W660 |
| NR2 | W810/W510 |

| | |
|---|---|
| NG | W760/W510 |
| NDVI | (W810-W710)/(W810+W710) |

**Results**

*Plant response to N treatment*

Both grain yield and grain protein content responded significantly to the influence of N fertiliser ($P<0.001$) in 2002 but not in 2003 (Table 1). Yields were negatively impacted from drought conditions in 2002 when compared with those of 2003 (e.g. 1.67 *v*. 2.61 t/ha for N3 in 2002 and 2003). This is reflected in the reduced concentrations of N in plant tissue at anthesis in 2003 as soil supplies were diluted into a larger canopy (Table 2). Almost double the N was removed as grain in 2002 for the N3 treatment than the N1 treatment (26.6 *v*. 40.8 kg/ha), but similar amounts were removed in 2003 for all treatments (mean of 62.5 kg/ha).

**Table 1. Response to N treatments by grain yield and grain protein content of wheat at Hermitage Research Station in 2002 and 2003.**

| Level | 2002 | | 2003 | |
|---|---|---|---|---|
| | Yield (t/ha) | Grain protein (%) | Yield (t/ha) | Grain protein (%) |
| 0 | 1.33 a | 11.50 a | 2.14 a | 12.30 a |
| 30 | 1.50 b | 13.12 b | 2.79 b | 13.82 b |
| 90 | 1.67 c | 13.96 c | 2.95 c | 14.37 c |
| l.s.d. ($P<0.05$) | 0.06 | 0.13 | 0.11 | 0.14 |

ns=not significant

**Table 2. Response to N treatments by tissue N and grain protein content of wheat at Hermitage Research Station in 2002 and 2003.**

| Level | 2002 | | 2003 | |
|---|---|---|---|---|
| | Tissue N (%) | Grain N (kg/ha) | Tissue N (%) | Grain N (kg/ha) |
| 0 | 1.27 a | 26.6 a | 1.16 a | 46.0 a |
| 30 | 1.73 b | 34.4 b | 1.54 b | 67.4 b |

| | | | | |
|---|---|---|---|---|
| 90 | 2.00 c | 40.8 c | 1.69 c | 74.0 c |
| l.s.d. (*P*<0.05) | 0.03 | 0.6 | 0.05 | 2.9 |

ns=not significant

*Relationship between reflectance and grain yield and protein content*

In 2002, grain yield was correlated with individual near/mid-infrared wavelengths (i.e. *W*760, *W*810) and PC1 (*r*=0.89-0.91) on the latest two sampling times (Table 3). Grain protein was also related to individual wavelengths found in the green/red/near infrared region (i.e. *W*460-*W*710) at both samplings. Over 60% of the variation in grain protein observed was explained by PC2 at both samplings (Table 3).

**Table 3. Correlation (*r*) between grain yield and grain protein content at harvest and selected canopy reflectance readings of wheat at Hermitage Research Station in 2002 and 2003.**

| Spectral variable | 2002 | | | | 2003 | | | |
|---|---|---|---|---|---|---|---|---|
| | *111 DAS* | | *118 DAS* | | *98 DAS* | | *112 DAS* | |
| | Yield | Protein | Yield | Protein | Yield | Protein | Yield | Protein |
| *W*460 | -0.06 | -0.76 | -0.10 | -0.72 | -0.48 | -0.58 | -0.49 | -0.67 |
| *W*510 | -0.04 | -0.82 | -0.04 | -0.72 | -0.56 | -0.71 | -0.64 | -0.73 |
| *W*560 | 0.16 | -0.72 | 0.15 | -0.70 | -0.47 | -0.65 | -0.54 | -0.68 |
| *W*610 | -0.10 | -0.83 | -0.06 | -0.76 | -0.70 | -0.71 | -0.68 | -0.68 |
| *W*660 | -0.17 | -0.86 | -0.09 | -0.74 | -0.71 | -0.76 | -0.75 | -0.69 |
| *W*710 | 0.23 | -0.72 | 0.24 | -0.71 | -0.55 | -0.68 | -0.31 | -0.53 |
| *W*760 | 0.80 | 0.32 | 0.83 | 0.22 | 0.67 | 0.64 | 0.83 | 0.59 |
| *W*810 | 0.80 | 0.34 | 0.83 | 0.24 | 0.66 | 0.66 | 0.82 | 0.59 |
| NDVI | 0.67 | 0.76 | 0.74 | 0.73 | 0.71 | 0.79 | 0.82 | 0.72 |
| NR | 0.74 | 0.70 | 0.80 | 0.69 | 0.65 | 0.60 | 0.80 | 0.59 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| NG | 0.72 | 0.66 | 0.80 | 0.59 | 0.64 | 0.66 | 0.79 | 0.64 |
| PC1 | 0.89 | 0.33 | 0.91 | 0.22 | 0.67 | 0.66 | 0.83 | 0.60 |
| PC2 | -0.11 | 0.81 | 0.09 | 0.78 | 0.32 | 0.49 | 0.07 | 0.43 |

The most parsimonious relationship between reflectance captured for individual wavelengths (*W*) and grain protein (GP), at 118 DAS, was described:

$$GP = 16.68 - 0.728 \cdot W710 + 0.134 \cdot W810$$ (*P*<0.001; *n*=96; $r^2$=0.59)

In 2003, these relationships were as evident as in 2002, although the degree of correlation varied between wavelengths (Table 3). Grain yield was closely correlated to NDVI at both dates (*r*=0.71 and 0.82) as well as to individual wavelengths (e.g. *r*=0.83 and 0.82 for *W*760 and *W*810, respectively, at 112 DAS). Grain protein was related to wavelengths in the red/near infrared region (i.e. *W*510 and *W*660). In 2003, the most parsimonious relationship was observed at 98 DAS, where:

$$GP = 16.86 - 0.708 \cdot W710 + 0.0809 \cdot W810$$ (*P*<0.001; *n*=186; $r^2$=0.56)

*Relationships between grain protein and tissue N*

The relationship between grain protein and whole tissue N at anthesis was consistent between years (Figure 1). In 2002, between 17 and 60 kg N/ha was removed in grain while in 2003, between 31 and 106 kg/ha was removed (data not shown). Evidently, residual N applied in 2002 was available for plant uptake in 2003, such that antecedent N supplies in 2003 were around double those available in 2002. Nevertheless, at these higher supplies, the relationship between tissue N and grain protein in 2003 was consistent with that observed in 2002 (Figure 1).

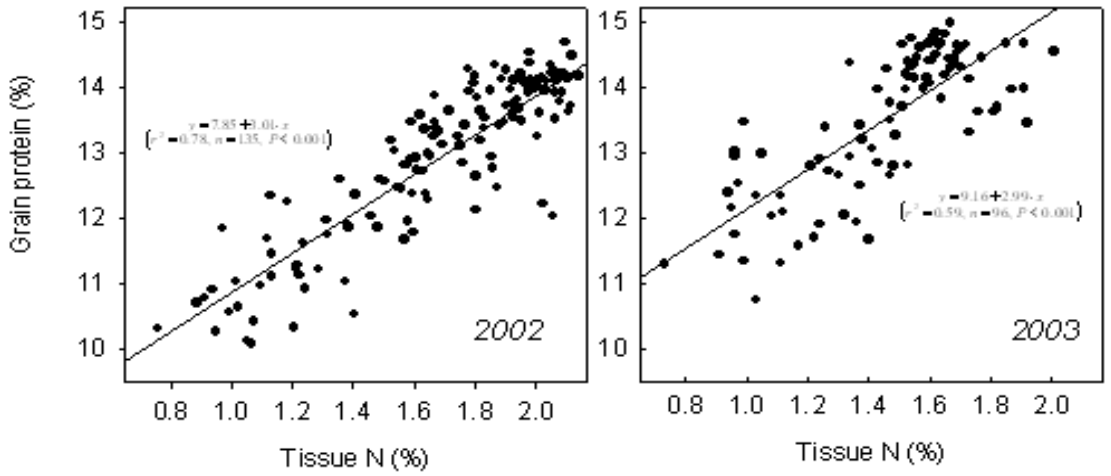


**Figure 1. Relationship between whole tissue N at anthesis and final grain protein for wheat at Hermitage Research Station in 2002 and 2003.**

**Conclusions**

These results show there is considerable promise in using canopy reflectance to forecast grain quality for wheat, presumably due to the close relationship between tissue N at anthesis and final grain protein. These results simplify those developed under European conditions, without any significant loss in model accuracy (Hansen *et al*. 2002). Algorithms remain season-dependent, although the same wavelengths (*W*710 and *W*810) produced the best prediction model for both years. The 2002 model was able to explain 43% of the variation in grain protein observed in 2003 (data not shown). Further testing of this model in subsequent years under varying conditions will allow a more robust model to be developed for region-wide grain quality prediction.

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