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## **Managing Grain Protein in Wheat Using Remote Sensing**

Dennis L. Wright Jr., Glen Ritchie, V. Philip Rasmussen, R. Douglas Ramsey, and Doran Baker

### **Introduction**

Protein premiums for high quality hard spring wheat have producers concerned with maximizing grain protein levels to capture higher prices. Wheat quality is based primarily on protein content, and nitrogen is a principal component of protein (Brown, 2000). Thus nitrogen (N), available from the soil and from applied fertilizers, must be in sufficient supply in order to obtain high protein levels and economical wheat yields (Wuest and Cassman, 1992).

In addition to N status, grain protein is determined by other factors. These include variety, fertility, water, and temperature (Teman, et al., 1969, Stark et al., 2001).

Nitrogen, however, is the most cost efficient and practical factor to manage. Nitrogen applied before stem elongation in wheat can increase yield if the crop is N deficient, while applications of N fertilizer after stem elongation may increase protein (Fisher et al., 1993). Whitfield and Smith (1992) found that three extremes can be attributed to the response of yield and protein to moisture and N: (i) high protein content, low yield under conditions of adequate N and water stress, (ii) moderate protein content and high yield under conditions of adequate N and adequate moisture, and (iii) poor yield and low protein content under conditions of N stress and adequate moisture. Although wheat cultivar, soil type, and growing environments influence the protein content in wheat

grain, protein content will consistently increase with N applications at anthesis, indicating that this effect is consistent across a range of conditions (Rawluk, et al., 2000).

Nitrogen status and therefore grain protein content may be successfully evaluated using crop spectral reflectance from aerial and satellite platforms. Crop spectral reflectance has been correlated to such parameters as leaf area index (LAI) (Asrar et al., 1985), ground cover (Boissard et al., 1992), total dry-matter accumulation (Tucker et al., 1981), plant greenness (Pinter et al., 1987), water status, (Jackson et al., 1983) and N status (Hinzman et al., 1986). Many crop reflectance studies have used spectral vegetation indices to normalize the data and determine these parameters. A vegetation index relates crop spectral reflectance to the quantity and/or quality of vegetation on the surface and is mathematically derived from the combination of two or more spectral bands.

Experimentation of various spectral vegetation indices would be important in determining midseason N application requirements.

Increasing grain protein with a midseason application of N on stressed areas of a crop may provide a demonstrable solution to a real-world problem by using remote sensing to increase revenue for farmers in a sustainable, cost-effective way. The objectives of this study were as follows: (i) to determine the relationship between plant tissue N and spectral reflectance recorded in aerial and satellite images, (ii) to test various vegetation indices (normalizations) on remote sensing imagery to identify the best vegetation indices for crop stress determination in a high-yielding wheat cultivar, and (iii) to determine

whether remote sensing can be used to predict the final grain protein response to midseason N application.

## **Methods and Materials**

A field experiment was conducted within a 50 ha farm field under center-pivot irrigation near Minidoka, Idaho (42°46' N, 113°28' W) during the 2002 growing season. Soils included on the study site are generally uniform, alluvial and loess deposits of silt loam. The surface soil layer of the study site is Minidoka silt loam (coarse-silty, mixed superactive, mesic Xerollic Durorthid) with minor intrusions of Portneuf silt loam (coarse-silty, mixed, superactive, mesic Durixerollic Calciothid). These soils are generally shallow (150 cm or less) and overlay basalt uplands.

The wheat variety was Westbred 936 hard red spring wheat. According to the Idaho Agriculture Statistics Service, Westbred 936 was the second most popular wheat variety in Idaho and accounted for 12.4% of all wheat grown in the state in 2002 (IASS 2002). Westbred is a white-chaffed, awned, early season, semidwarf variety released by Western Plant Breeders in 1993. Westbred 936 has stiff straw with a high test weight/yield potential and is tolerant to stripe rust and moderately tolerant to stem/leaf rust, but susceptible to powdery mildew (Aberdeen Extension, 2000). Westbred 936 has excellent yield potential, straw strength, uniformity, good stress tolerance, very good test weight, and high protein percent (Western Plant Breeders, 2000).

Seven transects, each 21 m wide, were established across the center of the field. Four different rates of N (0, 72, 180, and 234 kg N ha<sup>-1</sup>) were incorporated at planting, and

each rate was replicated twice except the 0 N control. The control was not replicated in order to minimize yield loss to the farmer. The farmer-cooperator applied 180 kg N ha<sup>-1</sup> on the rest of the field as his optimal rate; hence, the rates of 0, 72, and 234 kg n ha<sup>-1</sup> were used to represent N deficient and excessive wheat stands. Three plots were randomly selected within each transect to collect soil, plant, and grain samples, and to extract spectral characteristics from airborne and satellite based imagery. At anthesis, half of the transects received 54 kg of nitrogen through the pivot in the form of liquid nitrogen (URAN).

Flag leaf samples were collected before heading (June 24, 2002) and analyzed using nitric acid/hydrogen peroxide digestion followed by Inductively Coupled Plasma Emission Spectrophotometry (ICP-ES) method for micro- and macro-nutrients. Wheat was harvested at each of the sampling locations using a hand sickle. The wheat was then dried and threshed to separate grain from chaff. Protein concentration in the grain was estimated at Utah State University using a combustion analyzer (LECO CHN-1000, LECO Corp., St. Joseph, MI).

Imagery was collected from both satellite-based and aerial-based sensors. Quickbird satellite imagery was collected on June 25, 2002 and consisted of 2.5 m multispectral (0.45-0.52  $\mu$ m, 0.52-0.60  $\mu$ m, 0.63-0.69  $\mu$ m, and 0.76-0.90  $\mu$ m) and 0.7 m panchromatic bands. Aerial imagery was acquired on June 28, 2002 with a Piper Seneca II twin-engine turboprop plane equipped with 3 Kodak 420i digital cameras capturing 3 multispectral bands (0.45 – 0.55  $\mu$ m, 0.63 – 0.73  $\mu$ m, 0.63-0.69  $\mu$ m, and 0.79 – 0.82  $\mu$ m) with 1 m

resolution. Satellite imagery was radiometrically corrected for scan angle and sensor attitude variations by the provider, and aerial imagery was radiometrically corrected using a hand-held radiometer. Image geo-rectification, spectral vegetation index generation, and vegetation sample correlation with spectral data were performed using ERDAS Imagine. Because imagery was not compared temporally or with other imagery, atmospheric corrections were not performed (Song et al., 2001). Spectral vegetation indices (i.e. NDVI, Green NDVI, DVI, RVI), and NIR and reflectance values (Table 1) were derived from imagery brightness values and were compared with initial N treatments, mid-season N treatments, and plant tissue analyses.

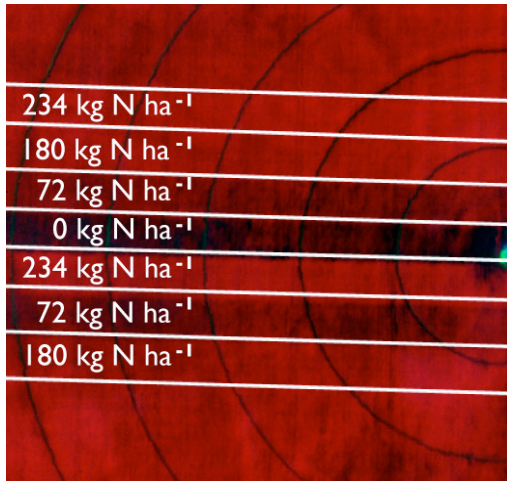
**Table 1. Broadband vegetation indices used for imagery analysis.**

Abbreviation	Name	Vegetation Index	Reference
RVI	Ratio Vegetation Index	$RVI = \frac{NIR}{RED}$	(Jordan, 1969)
NDVI	Normalized Difference Vegetation Index	$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$	(Rouse et al., 1973)
DVI	Difference Vegetation Index	$DVI = NIR - RED$	(Tucker, 1979)
GNDVI	Green Normalized Difference Vegetation Index	$GNDVI = \frac{(NIR - GREEN)}{(NIR + GREEN)}$	(Gitelson and Merzlyak, 1998)
NIR	Near Infrared Reflectance	$NIR\ Reflectance = \frac{NIR\ Digital\ Number}{highest\ possible\ pixel\ values}$	

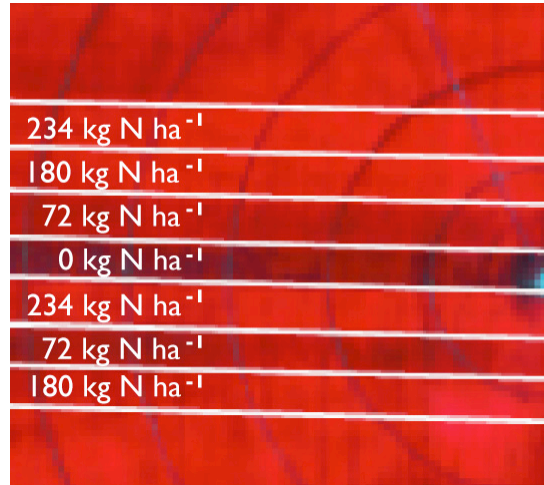
## Results and Discussion

Nitrogen treatments were easily distinguished in the false color NIR satellite and aerial images as dark strips running from left to right on the aerial and satellite imagery (Figures 1 and 2). The dark strip with no applied N was the most visible feature in the

field followed by the two plots with 72 kg N ha<sup>-1</sup>. No visible differences were observed on the false color images for plots with 180 and 234 kg N ha<sup>-1</sup>. The plots with 72 lbs N ha<sup>-1</sup> are a little darker than the treatments with sufficient N (180 and 234 kg N ha<sup>-1</sup>).

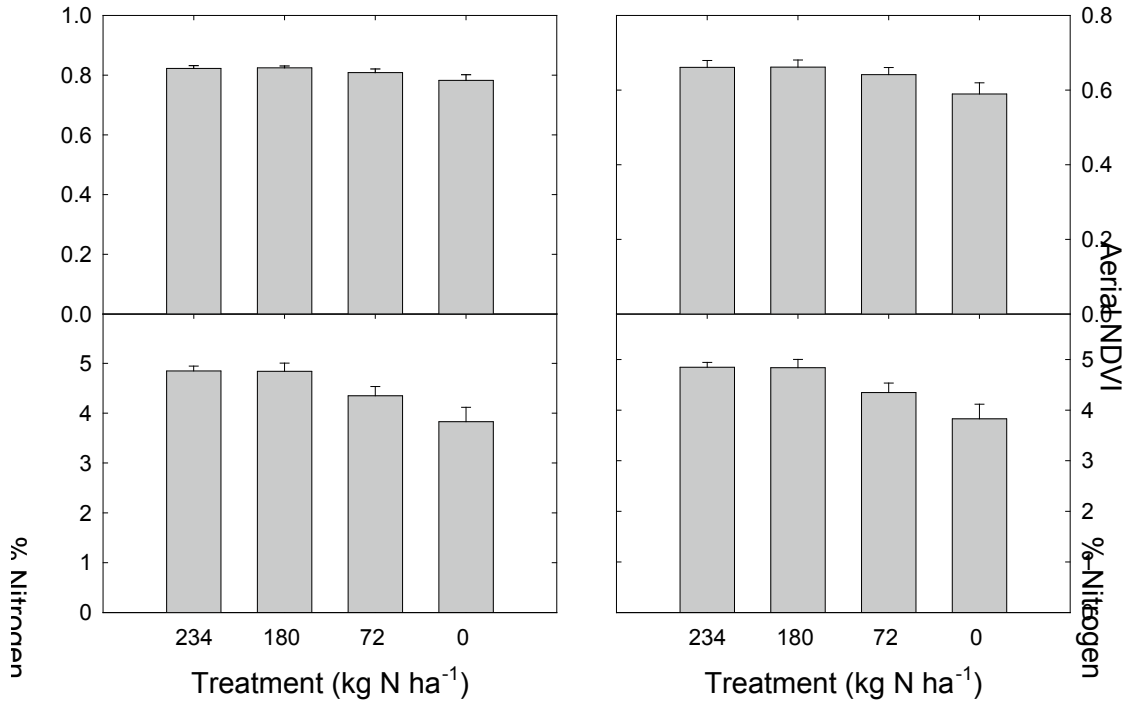


**Figure 1. NIR false color composite of multispectral aerial imagery from June 28, 2002 with**

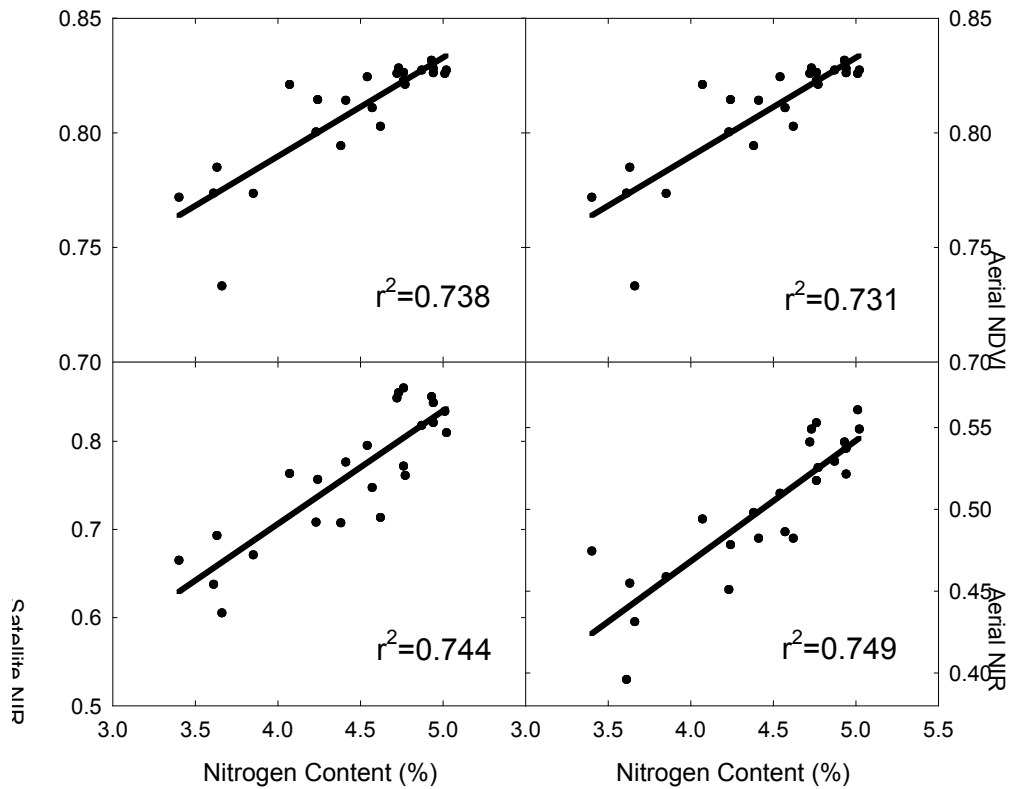


**Figure 2. Multispectral satellite image captured on June 25, 2002 with plot scheme overlaid.**

Percent plant tissue N and image-based NDVI means both decreased as N application decreased from 234 to 0 kg N ha<sup>-1</sup>, while standard deviation in NDVI increased (Figure 3). Satellite and aerial NIR reflectance correlated to plant N as well as the more complex vegetation indices (Figure 4).



**Figure 3. Plot means from tissue sampling, aerial imagery and satellite imagery. Error bars indicate standard deviation.**



**Figure 4. Correlation between Nitrogen Content and 2.5 m Satellite and 1m Aerial NIR reflectance and NDVI.**



Spectral vegetation indices for both satellite and aerial imagery correlated well with N treatments and plant tissue N, but had lower correlation with grain protein (Table 2). Correlations for satellite imagery and N treatments were similar to our findings on previous studies on whole-field plots (Wright et al., 2001, Wright et al., 2002). Aerial NDVI, GNDVI, and RVI indices correlated less to N treatments than did DVI and NIR. These relationships are secondary correlations with total surface leaf. These results are preliminary, and further experimentation will be needed before conclusions can be drawn.

**Table 2. Coefficient of determination ( $r^2$ ) values for satellite and aerial imagery indices and preseason N, plant tissue N, and protein at P = 0.05.**

	Satellite Imagery					Aerial Imagery				
	NDVI	GNDVI	RVI	DVI	NIR	NDVI	GNDVI	RVI	DVI	NIR
<b>N Treatments</b>	.675	.726	.757	.793	.798	.590	.583	.584	.801	.828
<b>Plant Tissue</b>	.738	.782	.780	.754	.744	.731	.705	.707	.757	.749
<b>Protein</b>	.328	.324	.350	.350	.294	.223	.240	.198	.332	.362

Average grain protein increased with a midseason application of N during anthesis in all the topdressed plots except the control (Figure 5). Grain protein increased from 12.55% to 14.43% in the N stressed plots (72 kg N ha<sup>-1</sup>) that received an additional 54 kg of N ha<sup>-1</sup> at anthesis. Grain from plots with sufficient N (234 and 180 kg N ha<sup>-1</sup>) exhibited increased protein content of 0.3% -0.4%. The plot with 0 N showed no increase in grain protein because the wheat matured faster and was already entering seed filling at application, causing decreased plant uptake of the additional N.

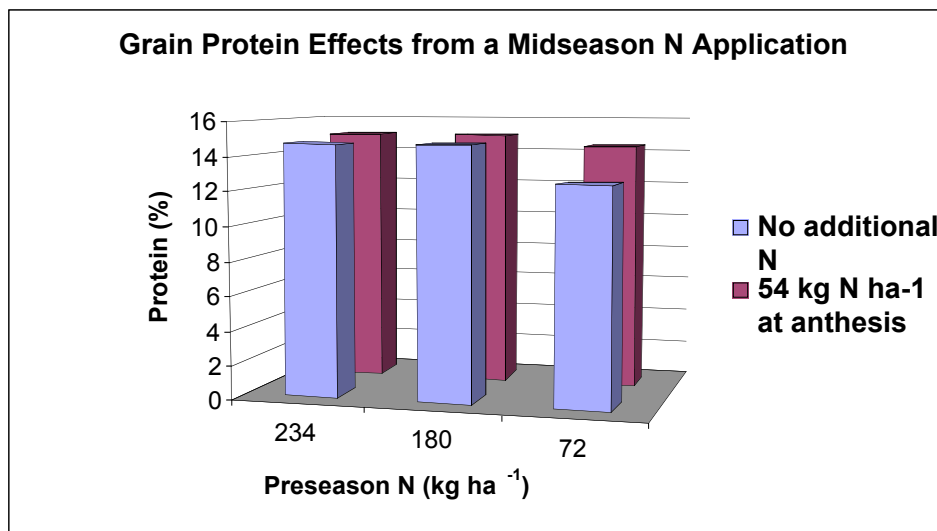


Figure 5. Average grain protein increase with a second application at anthesis.

## Conclusions

Remote sensing derived vegetation indices and plant tissue analysis correlated well with each other ( $r^2=0.58-0.82$ ) for stressed and unstressed plots, suggesting that remote sensing can be used to determine N nutrition status in wheat. Spectral vegetation indices calculated from satellite imagery exhibited similar correlation with N treatments, plant tissue N, and protein, while DVI and NIR reflectance had the highest  $r^2$  values for aerial imagery.

A midseason N application at anthesis increased grain protein in all plots with sufficient N by 0.3%-0.4%, and increased grain protein from the nitrogen-stressed plots almost 2%. The Portland market for Hard Red Spring Wheat allows for a 4-6 cent per quarter percent protein premium with protein higher than 14% and a dockage of 7-11 cents for every quarter percent under 14% per 50 kg for wheat (Western Seed 2002). The 72 kg N ha<sup>-1</sup> plot with no additional N had an average protein level of 12.55%. Assuming an average

yield of 6000 kg ha<sup>-1</sup> wheat, the 72 kg N ha<sup>-1</sup> plot would have been docked \$53-\$79 ha<sup>-1</sup> for low protein. The midseason application of N increased the protein for the 72 kg N ha<sup>-1</sup> almost 2% to 14.43%, which equates to a premium of \$8-\$13 ha<sup>-1</sup>. During normal price years, the increase to the farmer would have been \$61-\$92 ha<sup>-1</sup> on these N stressed areas. Wheat N stress detected with help of properly timed satellite and aerial imagery could help growers manage N properly and thus increase revenue and decrease N over-application. Regression analysis of data from many study areas will be needed to determine if these results will hold under varying weather patterns in different locations.

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