Using Remote Sensing to Manage Wheat Grain Protein

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Executive Summary

Improving grain quality can help growers increase revenue and retain customers. Remote sensing is a valuable tool to assist in managing in-season nitrogen applications during the growing season to improve grain quality. Our objective was to obtain spectral signatures of wheat under various N rates (0, 72, 180, 254 kg N ha\(^{-1}\)) and the response to a midseason N application (54 kg N ha\(^{-1}\)) at heading. Spectral data from satellite and aerial platforms were compared with pre-anthesis tissue samples and post-harvest grain quality. Imagery and tissue samples correlated significantly with each other with and preseason N applications (P<.0001). A second application of N at heading improved protein only marginally for wheat with sufficient N, but almost 2% in areas of stress, which could mean an increase in the selling price of up to 25%. Wheat stress identified data from satellite and aerial sensors could help growers increase revenue and decrease N over-application.
1.0 Introduction

Today’s farmers and ranchers face an array of ever changing economic, environmental, and market conditions. What was once a regional or national market structure is now a large global trading system with international events controlling local commodity prices. Concomitantly, the producer now faces a marketplace that is increasingly price-sensitive to crop quality. Wheat growers are now, more than ever before, concerned with measurable protein, as well as yield. Premium prices are paid for high protein, high quality wheat. This can, literally, mean the difference between profit and loss at the farm level. The major component of high quality wheat is protein (essential amino acids), which are rich in nitrogen. Nitrogen is the most abundant element in our atmosphere. However, plants cannot utilize the gaseous form of nitrogen. Hence, growing crops need adequate supplies of mineral nitrogen from the soil or both yield and quality will suffer.

Nitrogen is a vital component of grain development in wheat. Nitrogen abundance is usually manifest through the “greenness” of the wheat crop. Researchers from the earliest recorded wheat research in the western United States have observed this phenomenon, and continue to do so (Widtsoe and Merrill, 1902 and 1905; Widstoe, 1919; Bracken et al., 1930; and, Bennett et al., 1954). Large-scale chlorosis, or the absence of chlorophyll and carotenoids, is easily identifiable with an adequate view of the crop (leaf) canopy. Chlorosis can be caused by deficiencies in vital nutrients such as nitrogen, iron, sulfur, and magnesium or by the competitive action of specific ions at the root-soil interface. It can also be caused by disease and other crop stresses. However, field-scale chlorosis is usually attributed to nitrogen deficiencies, while spotty chlorosis is usually attributed to disease or other crop stresses (Wescott, 1998).

Grain protein is an indicator of the quality of hard wheat varieties and growers receive premiums for grain protein over 14% and a dockage for protein below 14%. Factors affecting the protein in wheat include variety, fertility, water, and temperature (Teman et al., 1969, Stark et al., 2001). Nitrogen applied before stem elongation in wheat can increase yield if the crop is lacking in N while applications of N fertilizer after stem elongation may increase protein (Fisher et al., 1993). Whitfield and Smith (1992) found that three extremes could be attributed to the response of yield and protein to moisture and N: (1) high protein content, low yield under conditions of adequate N and low moisture, (2) moderate protein content and high yield under conditions of adequate N and minimal water stress and (3) poor yield and low protein content under conditions of low N. Although wheat cultivar, soil type, and growing environments have affects on 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).

More recent research showed flag leaf N was significantly correlated with protein ($r^2 = .85$) and that the rate of topdressed N rate was significantly correlated with grain protein, flour protein, and loaf volume Stark et al. (2001). Horneck et al. (2001) found that an application of late season N to increase protein is usually cost effective in hard red spring wheat and that testing for flag leaf N facilitates a better estimate for the necessary rate of N. Westcott et al. (2001) suggested a remote sensing approach to protein enhancement using aerial imagery.
Many researchers have analyzed remote sensing for general agronomic problems, but have only investigated as far as crop parameter identification. 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 that utilizes remote sensing to increase revenue for farmers in a sustainable, cost-effective way. This method of N management could also decrease environmental impacts by improving N efficiency throughout the growing season. Hence, the objectives of this study were to (i) observe correlation between plant tissue nitrogen and reflectance from aerial and satellite images, (ii) test various vegetation-index methods on remote sensing imagery to qualify the best vegetation normalization for identifying crop stress in high-yielding wheat cultivars, and (iii) quantify the protein response of a midseason application of 54 kg N ha⁻¹ to each of these treatments.

2.0 Methods and Materials

Research was conducted at Minidoka, Idaho (42°46’ N, 113°28’ W) during the 2002 summer growing season. Soils included in the study site are generally uniform, alluvial and loess deposits of silt loam. Most of the soil is Minidoka silt loam, a coarse-silty, mixed superactive, mesic Xerollic Durorthid with a color of 10YR 6/3, 10YR 4/2 moist, with minor intrusions of Portneuf silt loam, coarse-silty, mixed, superactive, mesic Durixerollic Calciorthid 10YR 6/2, 10YR 4/2 moist. These soils are generally shallow (150 cm or less) and overlay basalt uplands.

The wheat chosen by the farmer-cooperator was the Westbred 936 variety of 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 (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 has excellent yield potential, straw strength, and uniformity. It also has good stress tolerance, very good test weight, and high protein percentage (Western Plant Breeders, 2000).

Seven transects, each 21 m wide, were established across the center of a standard 50 ha center-pivot field. Four different rates of N as urea were incorporated (0, 72, 180, 254 kg N ha⁻¹) and each rate was replicated except the control. The farmer-cooperator applied 180 kg N ha⁻¹ on the rest field as his optimal rate; hence, the rates of 0, 72 and 180 kg n ha⁻¹ were used to represent N deficient and excessive wheat stands. Within each transect, four plots were randomly selected for soil, plant, grain, and imagery analysis. At anthesis, half of the plots received 54 kg of nitrogen through the pivot in the form of liquid nitrogen (URAN).

Soil and plant tissue samples were analyzed at MDS Harris laboratories in Lincoln, Nebraska. Soil samples were collected before planting at each of the 28 sampling plots and analyzed for organic matter, pH, and macro- and micro-nutrients. Flag leaf samples were collected before heading (June 24, 2002) and analyzed the using Inductively Coupled Plasma (ICP) method for micro- and macro-nutrients and Kjeldahl method for nitrogen. Grain was harvested at each of
the 28 locations, weighed, and sent to the Aberdeen Wheat Quality Laboratory for quality analysis. Protein was estimated at Utah State University pf Agriculture and Applied Science using a combustion analyzer (LECO). Harvest data were estimated with an Ag Leader yield monitor with a Differential Global Positioning System (DGPS).

Imagery was collected from both satellite and an aerial sensors. Quickbird satellite imagery includes 2.5 m multispectral (.45-.52 µm, .52-.60 µm, .63-.69 µm, and .76-.90 µm), and .7 m panchromatic bands. Aerial imagery was provided by Environmental Mapping and Remote Sensing (EMARS). EMARS has a Piper Seneca II twin engine aircraft with 3 Kodak 420i digital cameras. The aerial sensor bandwidths occur in 10 nm widths in the green, red, and near infrared (NIR) portion of the electromagnetic spectrum and imagery was collected at a 1 m scale. Image geo-rectification, modeling, and vector correlation were performed using ArcView, Arc/Info, and ERDAS Imagine. NDVI, Green NDVI, DVI, RVI, and NIR reflectance values (Table 1) from the imagery were compared with preseason N treatments, midseason N treatments and plant tissue ICP results. Satellite imagery was collected on June 25, 2002 and aerial imagery was collected 3 days later on June 28, 2002.

Table 1. Broadband vegetation indices used for imagery analysis.

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

3.0 Results and Discussion

Nitrogen treatments were easily distinguished in the false color NIR satellite and aerial images as the dark strips running from left to right on the 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\(^{-1}\) that lie directly above the 0 N plot and a plot two plots below the 0 applied N plot. The plots with 180 and 254 kg N ha\(^{-1}\) were no different on the false color images than with the naked eye. The reflectance in the near infrared region isn’t as high and therefore shows up darker. The plots with 72 lbs N ha\(^{-1}\) show up a little darker
Mean values of laboratory-calculated plant total N, and satellite and aerial NDVI, GNDVI, DVI, RVI, and NIR are given in Table 2. Plots with 254 and 180 kg N ha\(^{-1}\) (above normal and normal application rates) had sufficient N and differences in mean values for all tests were not statistically different between these two transacts for both imagery and tissue analysis. Means for tissue samples within plots with 72 kg N ha\(^{-1}\) (below normal application rate) were statistically significant between other plots for tissue analysis and all of the vegetation indices except the aerial NDVI, and RVI. The cause of this phenomenon is due to the high red reflectance values for the red band in the aerial imagery. The unusually high reflectance in the red band causes lower NDVI and RVI values that have small variability and in turn, affect the statistical separability between plots. The plot with no applied N was significantly different from all other plots in both tissue analysis and remote sensing methods.

Table 2. Average values for plant N and satellite and aerial imagery vegetation index values for the 2002 growing season.

<table>
<thead>
<tr>
<th>Tissue N*</th>
<th>Satellite</th>
<th>Aerial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NDVI</td>
<td>GNDVI</td>
</tr>
<tr>
<td>LSD</td>
<td>.246f</td>
<td>.0126</td>
</tr>
<tr>
<td>254</td>
<td>4.84a†</td>
<td>.825a</td>
</tr>
<tr>
<td>180</td>
<td>4.82a</td>
<td>.822a</td>
</tr>
<tr>
<td>72</td>
<td>4.38b</td>
<td>.808b</td>
</tr>
<tr>
<td>0</td>
<td>3.73c</td>
<td>.783c</td>
</tr>
</tbody>
</table>

* Total N is expressed in percent N of total plant tissue. Satellite and aerial imagery values are unitless.  
† Means followed by the same letter within column are not significantly different at P = 0.05 using Fisher’s LSD multiple range test.

The sensitivity of the NIR reflectance values for both aerial and satellite imagery was not expected. Both satellite and aerial imagery NIR values showed significant differences between plots. The satellite and aerial NIR bands had similar correlation coefficients to plant N as the broadband indices and were significantly correlated with the GNDVI for both satellite and aerial
imagery (Figure 3). The use of one wavelength of imagery for N management in wheat would cut costs significantly in imagery acquisition, image processing, and technical support.

Figure 3. Correlation between nitrogen content and satellite and aerial NIR and GNDVI.

Broadband Indices for both satellite and aerial imagery correlated well with preseason N and ICP plant tissue analysis, but had lower correlation with protein (Tables 3 and 4). Coefficients of determination for satellite imagery were consistent with previous studies on whole-field plots (Wright et al, 2001, Wright et al, 2002). Aerial NDVI, GNDVI, and RVI indices had lower correlation coefficients with preseason N than DVI and NIR but more analysis must be performed in future experiments to determine if these findings are significant.

Table 3. Pearson r values for satellite imagery indices and preseason N, plant tissue N, and protein.

<table>
<thead>
<tr>
<th>NDVI</th>
<th>GNDVI</th>
<th>RVI</th>
<th>DVI</th>
<th>NIR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Pearson r values for aerial imagery indices and preseason N, plant tissue N, and protein.

<table>
<thead>
<tr>
<th></th>
<th>NDVI</th>
<th>GNDVI</th>
<th>RVI</th>
<th>DVI</th>
<th>NIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preseason N</td>
<td>.768</td>
<td>.763</td>
<td>.764</td>
<td>.895</td>
<td>.910</td>
</tr>
<tr>
<td>Plant Tissue</td>
<td>.855</td>
<td>.839</td>
<td>.841</td>
<td>.870</td>
<td>.861</td>
</tr>
<tr>
<td>Protein</td>
<td>.472</td>
<td>.490</td>
<td>.445</td>
<td>.576</td>
<td>.602</td>
</tr>
</tbody>
</table>

Average protein increased with a midseason application of N during anthesis in all the plots (Figure 4). Grain protein increased between plots with no additional N and plots with 54 kg ha\(^{-1}\) applied at anthesis from 13.66% to 14.55%. The plot with 0 N showed no increase because the wheat matured faster and was beyond the point return on N investment when additional N was applied. Mill prices allow for a 4-6 cent quarter percent premium per 50 kg for wheat with protein higher than 14% and a dockage of 7-11 cents for every quarter percent under 14%. The 72 kg N ha\(^{-1}\) plot with no additional N had an average protein level of 12.55%. Assuming an average yield of 6000 kg ha\(^{-1}\) wheat, the 72 kg N ha\(^{-1}\) plot would have been docked $53-$79 ha\(^{-1}\) for low protein. The midseason application of N increased the protein for the 72 kg N ha\(^{-1}\) almost 2% to 14.43%, which equates to a premium of $8-$13 ha\(^{-1}\). During normal years, the increase to the grower would have been $61-$92 ha\(^{-1}\) on these stressed areas. This year, however, the drought in the Midwest increased the nation’s wheat protein causing a mere 2 cent per quarter protein over 14% and a dockage of only 4-6 cents per 50 kg of wheat (Western Seed, 2002) increasing profit to the farmer by $30-$46 ha\(^{-1}\).

![Grain Protein Effects from a Midseason N Application](image)

Figure 4. Average grain protein increase with a second application at anthesis.

4.0 Conclusions

The objectives of this study were (i) to observe correlation between plant tissue nitrogen and reflectance from aerial and satellite images, (ii) to test various vegetation-index methods on
remote sensing imagery to qualify the best vegetation normalization for identifying crop stress in high-yielding wheat cultivars, and (iii) to quantify the protein response of a midseason application of 54 kg N ha-1 to each of these treatments. Remote sensing and laboratory analyses on plant tissue showed similar trends between the statistical means of stressed and unstressed plots at anthesis, suggesting that remote sensing can indeed be used to ascertain vegetation health. Broadband vegetation indices tested in this study exhibited similar correlation to preseason N, plant tissue N, and protein. The NIR band was as sensitive to crop health as many of the broad-band vegetation indices and could significantly reduce remote sensing cost to farmers due to its simplicity. A midseason nitrogen application at anthesis increased grain protein from the unstressed plots only slightly, but increased grain protein from the nitrogen-stressed plots almost 16% from 12.55% - 14.43%. Wheat stress detected with help from satellite and aerial platforms could help growers increase revenue and decrease N over-application. Timing should be considered with remote sensing to estimate application needs.

5.0 Acknowledgements

Special thanks are expressed Duane Grant for allowing us to use his land and to Mike Larsen, our contact for the farm operation.

6.0 References


