Research Question

Objectives:

1) Determine if light reflectance from the wheat canopy at one or more vegetative growth stages can be used to predict grain yield and grain protein.
2) Identify the growth stage of hard spring wheat for obtaining maximum accuracy for prediction of grain yield and grain protein.

Results

General Information

Fertilizer application and the wheat planting occurred in a timely manner at both locations. Wheat was planted April 26 at NWROC and May 3 at WCROC. Weather conditions were quite different between the two experimental sites. At WCROC, over an inch of precipitation fell within two days after planting. However, only about 3-inches of rain fell the entire growing season at WCROC. At NWROC, growing conditions were more favorable with about 10-inches of precipitation during the growing season. At both locations wheat emergence, stand, and plant vigor were good. Other than the dry conditions at WCROC no other yield limiting factors can be identified.

Grain Yield and Protein

The effects of N rates and Varieties on spring wheat grain yield and protein were highly significant at both locations (Table 1). At NWROC there were significant interactions of N rate by Variety on grain yield. This indicates that varieties responded differently to the increasing N rates. Knudsen grain yields increased nearly 25 bu A\(^{-1}\) over the range of N rates compared to about 10 bu A\(^{-1}\) for Alsen (Fig 1). Nitrogen Source and a N rate by N Source interaction on grain yield were also significant. Within varieties, maximum yield occurred at approximately the same N rate regardless of N Source, but yields were always greater when ESN was applied compared to urea (Fig 1). At WCROC, there was no grain yield difference between N Source and both varieties increased yield over the entire range of N rates (Fig 2). Nitrogen source had no effect on grain protein at either location, but protein tended to increase over the entire range of N rates (Fig 3). At both locations, Knudsen had greater grain yields and lower grain protein that Alsen, as expected. Grain yields were greater at NWROC compared to that at WCROC, but protein was greater at WCROC.

Greenseeker Readings

Greenseeker (GS) readings were easier to do NWROC than WCROC due to distance. The NDVI calculated by the Greenseeker is related to green biomass which is related to the health, vigor, and growth development of the crop which is related to many factors not the least of which is nitrogen. Figure 4 shows NDVI relationships to urea-N rates for both varieties in the NWROC trial averaged over replications. Each line represents a different reading. NDVI of both varieties increased when N was applied suggesting increased green biomass with N, which is consistent with visual observations. As the wheat crop developed, NDVI increased (solid lines in Fig 4) until a maximum NDVI was reached on the June 12\(^{th}\) reading. This corresponds to the flag leaf growth stage or Zadoks 37-39. The NDVI held relatively constant over the next week or two then began to decline (dashed lines in Fig 4). The June 15th GS reading at WCROC corresponded to a similar wheat growth stage as that on June 12\(^{th}\) at NWROC. I reasoned that if the GS and its calculated NDVI could be used to predict hard red spring wheat grain or protein yield, it should be able to do it by the flag leaf when NDVI maximum occurred.

Predictor Indices

Three different Predictor Indices were calculated using the NDVI and compared to grain yield and protein. The three Prediction Indices are described in the Materials and Methods.

Index #1

Several index values using NDVI from various
combinations of paired GS readings and the GDD accumulating between those readings were calculated and compared to wheat grain yield or grain protein. These comparisons yielded scattered or vertical data alignment in which many different yield or protein measurements occurred at the same or similar index values. There was no discernable pattern between the various calculated index values and grain yield or grain protein. Figure 5 illustrates various calculated index values and grain yield relationships.

Index #2
Comparisons of Index #2 to grain yield or protein revealed some patterns that may be useful. The data in Figure 6 used the index calculated from the June 12 and June 15 GS readings at NWROC and WCROC, respectively. Of the index values calculated from various GSr readings, those from the June 12 and June 15 readings appeared to be the most promising for the reason stated above. At NWROC, an exponential function and a quadratic function best described the relationship between the index value and the grain yield or grain protein, respectively (Fig 6). However, it was clear that the function equations were quite different between the two varieties. At WCROC, similar functions were applied to the data (Fig 6). Though the WCROC data was more variable than at NWROC, probably partially caused by the extremely dry weather conditions, it is still obvious the function equations are different between the two varieties.

Index #3
As with Index #2, Index #3 values calculated from GS readings on June 12 and June 15 at NWROC and WCROC, respectively, had the strongest relationship to grain yield or grain protein. The primary difference between Index #3 and Index #2 is the denominator. Index #2 uses GDD, which will somewhat reflect climatic conditions from planting to the when the GS reading occurred. Index #3 uses DAP and will not directly reflect climatic conditions except those that might be normal for this time of year. Nevertheless, the relationships between the index value and grain yield or grain protein in Fig 7 are quite similar to those in Fig 6 (Index #2). Like Index #2, there are two distinctly different function equations for the two varieties in Index #3.

Application/Use
Previous research has clearly shown that sufficient preplant N application of N fertilizer is the most reliable management strategy for spring wheat production in Minnesota. However, N application is based on yield goal. If the N is applied to achieve a specific and realistic yield goal, but yield potential exceeds that goal, is additional N necessary to maintain an acceptable grain protein level. My overall objective was to determine if the Greenseeker could be used to predict grain yield or perhaps grain protein at a time when growers could make the decision as to whether additional N fertilizer should be applied to improve the grain protein content. The data suggest the best potential for using the Greenseeker is at or around flag leaf to boot, which corresponds closely to when growers apply fungicide to control Fusarium Head Blight. The Greenseeker could be mounted on the sprayer unit and readings taken during the spraying operation.

I could find no potential predictive capability of Index #1 from this data due to little discernable relationships between the calculated index values and grain yield or grain protein. Indices #2 and #3 were quite similar in their discernable relationships between the calculated index values and grain yield or grain protein. However, neither of these indices was capable of distinguishing the grain yield or grain protein difference between the two varieties; each variety seemed to have its own best fit function equation. Within varieties, there was a general increase in grain yield or grain protein as the index value increased. However, neither of these indices was capable of distinguishing the yield differences that occurred between the two N sources (Fig 1, Fig 6 and 7: open versus closed symbols for each variety) which were as much as 7 to 10 bu A⁻¹ at NWROC.

Growers and researchers are always striving to improve N fertilizer use efficiency to increase the ‘bang for the buck’ and to decrease the threat of excess N to the environment. At this time, I do not see the Greenseeker as a tool to increase N use efficiency in hard red spring wheat production systems in Northwest Minnesota or Eastern North Dakota. Perhaps a larger data set than I currently have available would improve its chances. Taking GS readings is fairly easy and cheap so data can continue to be collected on other spring wheat experiments. But, I do not think further intensive and specific investigations in this monitoring tool are warranted.
Materials and Methods

Field experiments were established at two locations in western Minnesota, the University of Minnesota’s Northwest Research and Outreach Center near Crookston (NWROC) and West Central Research and Outreach Center near Morris (WCROC). Soybean was the previous crop at both locations.

The experiment design used in these experiments was randomized complete block with a 2 by 2 by 5 factorial treatment design and four replications. One factor included two hard red spring wheat varieties, Alsen and Knudsen. Alsen was selected for its high protein potential and Knudsen was selected for its high yield potential. The second factor was two nitrogen (N) sources. A product by Agrium Inc. called ESN, a slow release N source, was compared to urea. The final factor was six N rates in 20 lbs N A⁻¹ increments from 0 to 100 lbs N A⁻¹.

A Greenseeker (GS) instrument was used to measure red and near infrared light reflectance from the wheat canopy. Each reading measures the reflectance of red and NIR light reflected from the crop canopy and compares this to that emitted from a source mounted in the GS instrument head and calculates a ratio of red and NIR reflected to red and NIR emitted. This ratio is referred to as the Normalized Difference Vegetative Index (NDVI) and is directly related to the green biomass of the crop. The hand held GS measures reflectance in an oblong oval shape and was adjusted so that the long axis of the oval was perpendicular to the direction of the wheat rows. Reflectance was measured by holding the instrument about 2 ft above the canopy of the center rows of the plot and walking at a steady gate over the entire length of the plot (about 25 ft). The GS typically takes 50 to 60 readings per plot depending on walking speed. For this report I used average NDVI of the 50 to 60 readings per plot. Greenseeker readings were taken twice weekly, when possible, at NWROC starting at the tillering growing stage and continuing into early soft dough. Only four GS readings were taken at WCROC during these same growth periods.

Three separate Prediction Indices were calculated using the NDVI values calculated by the Greenseeker at each GS reading. They are:

Index #1:

\[
[(T1+T2) \text{NDVI}/(T2-T1)\text{GDD}] \text{ where the NDVI calculated from two different GS readings were summed and divided GDD accumulated between those GS readings.}
\]

Index #2:

\[
[(T1)\text{NDVI}/\text{GDD}] \text{ where the NDVI calculated for at a single GS reading is divided by the GDD accumulated from planting to the time of the GS reading.}
\]

Index #3:

\[
[(T1)\text{NDVI}/\text{DAP}] \text{ where the NDVI calculated at a single GS reading is divided by DAP when the reading occurred.}
\]

Growing Degree Days (GDD) were calculated according to Wiersma and Ransom (2005). Maximum and minimum temperatures were obtained from weather recorders on the respective research and outreach centers. The NDVI Index was then related to final grain yields and protein produced in the plots.

Days After Planting (DAP) is the calendar days that have passed since the wheat crop was planted to the time the GS reading was taken.

The index values calculated using the three indices described above were compared to measured grain yield and grain protein from the individual plots. Various regression functions were applied to the index value and grain yield or grain protein relationship data starting with the exponential function, which was used by Raun et al. (2001). Additional regression functions were applied to the data in an attempt to improve the correlation coefficient (R²). The regression function with the highest correlation coefficient is shown in each graph in Figures 5 through 7. Attempts were made to maintain the same regression function for similar data comparisons at both locations. If, however, the correlations coefficient could be improved by more than 10% with a different function, then different functions were adapted to the data without regard to location.

Wheat was harvested with a small plot combine to determine wheat yield and an NRI instrument was used to determine grain protein.

Economic Benefit to a Typical 500 Acre Wheat Enterprise

None at this time
Related Research

The wheat crop relies on fertilizer N and non-fertilizer N sources such as residual soil N, climatic N deposition, and N mineralized from the soil organic matter. The magnitude of the wheat response to applied fertilizer N greatly depends on the availability of non-fertilizer N sources. Residual soil N is measured with soil testing prior to planting, but climatic N deposition and N mineralization vary considerably from year to year and are difficult to predict. At any given point in time during the growing season the growth of the wheat crop is the result of integration of all the environmental factors the crop has been exposed to, including N availability. If the early season growth patterns can be used to estimate season ending grain yield and quality potential, then management decisions can be made as to how much N needs to be available to support that potential. The grower will know how much fertilizer N was applied prior to planting and how much residual soil N is available. Combining estimates of yield and quality potential and known N availability, the grower can now determine if additional fertilizer N should be applied to support that potential. Remote sensing of early season wheat canopy can be a tool that can be used to estimate grain yield and quality potential.

Remote sensing of wheat canopies can be done through many methodologies, but the reflectance of light from the canopy is the underlying principle in all of them. Technologies are available to measure incoming red and near infrared light and compare that to the red and near infrared light reflected from the crop canopy. Through a series of algorithms, these measurements are used to develop a Normalized Difference Vegetative Index (NDVI). The NDVI provides a relative quantity of biomass reflecting the light.

Plant biomass is a product of many factors affecting growing conditions of the plant. Nitrogen availability is one of those factors. Reeves et al. (1993) used direct in-season total N uptake (dry biomass X N concentration) at Feekes growth stage 5 to predict winter wheat grain yields. Aase and Siddoway (1981) found a relationship between in-season NDVI and the final winter wheat grain yields. Smith et al (1995) reported that two in-season canopy reflectance readings combined through linear modeling improved the NDVI – Wheat grain yield relationship compared to only one NDVI reading. Raun et al (2001) measured NDVI at two growth stages of winter wheat soon after winter dormancy broke. They found that the average of the two NDVI readings divided by the growing degree days (GDD) accumulated between the two reading dates provided an estimated yield prediction that was highly correlated to the actual grain yield harvested.

References


Recommended Future Research

The quest to improve N fertilizer use efficiency is an absolute necessity from both an economical and environmental standpoint. Substantial increases in the cost of N fertilizer in recent years, and the likelihood it will continue to increase, makes this vitally important from a producer standpoint. How can the producer recover as much of his/her N fertilizer investment as possible? While substantial research has been done in the past, there are still many questions. Research to improve N fertilizer use efficiency should continue down various avenues. I do not recommend further specific investment in GreenSeeker research to achieve this goal except perhaps as a rider on other experiments with their own specific objectives. I think there are other more promising avenues that should be researched. Polycoated urea may be one such avenue.
Appendix

Table 1. Statistical analysis of spring wheat grain yield and protein response to N rates, N source, and variety at two locations in 2007.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>NWROC Grain</th>
<th>WCROC Grain</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield</td>
<td>Protein</td>
<td>Yield</td>
<td>Protein</td>
</tr>
<tr>
<td>N rate</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Linear (Lin)</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Quadratic (Quad)</td>
<td>***</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>N Source</td>
<td>***</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Variety</td>
<td>***</td>
<td>**</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>N rate by N Source</td>
<td>**</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Lin by Source</td>
<td>***</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Quad by Source</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>N rate by Variety</td>
<td>***</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Lin by Variety</td>
<td>***</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Quad by Variety</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>N Source by Variety</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

§ ***, **, *, and ns represent significant levels of PR>F of 0.001, 0.001, 0.05, and non-significant, respectively.

Figure 1. 2007 Grain yield response of two spring wheat varieties to N supplied by two N sources at NWROC.
Figure 2. 2007 Spring wheat grain yield response of two spring wheat varieties to N supplied by two N sources at WCROC. A linear N rate response was highly significant with no significant difference between N sources. Linear regression was applied to individual treatment means with R^2 values of 0.594 and 0.760 when N source was ESN and 0.762 and 0.990 when N source was urea for Alsen and Knudsen wheat varieties, respectively.

Figure 3. Spring wheat grain protein response to N rates, N sources, and varieties at two locations, NWROC (left) and WCROC (right) in the 2007 growing season.
Figure 4. NDVI response to increasing rates of urea-N on two hard red spring wheat varieties on selected reading dates in the 2007 growing season at NWROC.

Figure 5. Graphical representation of spring wheat grain yield compared to a Predictive Index #1 [(T1+T2)NDVI/(T2-T1)GDD] in the 2007 growing season at NWROC (left) and WCROC (right). (T1+T2)NDVI is the sum of Greenseeker calculated NDVI from two GS readings taken at two points in time during the growing season. (T2-T1)GDD is the GDD accumulation the interval between the two GS readings.

Figure 6. Continued on next page
Figure 6. Graphical representation of spring wheat grain yield (top) and protein (Bottom) compared to a Predictive Index #2 [(T1)NDVI/GDD] in the 2007 growing season at NWROC (left) and WCROC (right). (T1)NDVI is the Greenseeker calculated NDVI on the June 12 (NWROC) and June 15 (WCROC) GS readings. GDD is the Growing Degree Days accumulated during the growing season to the date of the GS reading.

Figure 7. Graphical representation of spring wheat grain yield (top) and protein (Bottom) compared to a Predictive Index #3 [(T1)NDVI/DAP] in the 2007 growing season at NWROC (left) and WCROC (right). (T1)NDVI is the Greenseeker calculated NDVI reading on the June 12 (NWROC) and June 15 (WCROC) GS readings. DAP is the Days After Planting the GS reading occurred.