Evaluation of an on-combine wheat protein analyzer on Montana hard red spring wheat

D. Long¹ and T. Rosenthal²
¹USDA-ARS, Pendleton, Oregon 97801, USA
²Zeltex, Inc., Hagerstown, Maryland 21740, USA
dan.long@oregonstate.edu

Abstract

The objective of this study was to evaluate a new optical near infrared transmitter analyzer for automatically sensing the protein concentration of wheat on the combine during actual harvest. In 2004, the Zeltex AccuHarvest Analyzer was mounted on the clean grain elevator of a Case IH combine harvester and linked with the GPS. The protein content of spring wheat was then measured and mapped in two dryland fields in northern Montana. At the same time, grain samples were collected on the AccuHarvest during actual harvest and saved for whole grain laboratory analysis. Calibration results of linear regression showed sensor-based measurements of grain protein to be correlated with reference measurements of grain protein ($R^2 = 0.86$, SEP = $\pm 0.49\%$). Grain protein could be predicted to within 0.66% when the calibration model was applied to a validation dataset. Interpolated maps of sensed- and referenced-protein were visually related. These results are sufficiently promising to suggest that on-combine spectroscopic sensing for mapping purposes is technically feasible.

Keywords: on-combine sensing, wheat, grain protein concentration, near infrared transmittance.

Introduction

Grain protein concentration is an important determinant of the quality of wheat and thus the economic value of this major cereal commodity. Today, the rapid, quantitative analysis of protein concentration of whole grain is undertaken at grain elevators and terminals by means of laboratory near infrared (NIR) spectroscopy. Typically, whole grain NIR analyzers operate based on the principle of near infrared transmittance. A sampling mechanism feeds a small quantity of grain into a sampling chamber where this grain is exposed to a broadband source of near infrared light, usually a quartz-tungsten lamp. Some of the total light is absorbed and some is transmitted through the grain. The analyzer measures the portion that is transmitted and infers that the amount absorbed corresponds with the concentration of protein in the grain.
Yield monitors and GPS receivers are commercially available for mapping grain yields from the combine during actual harvest. There is strong interest in expanding the mapping capabilities to include grain protein concentration. Some manufacturing firms have responded by attempting to adapt the NIR spectroscopic technology for use on combine harvesters (Von Rosenberg et al., 2000; Thylén et al., 1999). The results reported by these studies were limited to laboratory conditions and did not indicate how well this technology would work in measuring and mapping the protein concentration of grain from the combine under actual harvest conditions.

Maps of grain protein concentration would have considerable application in precision agriculture. For example, mapped values of wheat yield and protein, and a geographic information system (GIS) have been used to compute the amount of nitrogen (N) needed to replace that removed in the grain at harvest and raise protein in the following wheat crop to a certain target level (Engel et al., 1999; Long et al., 2000). The rationale is that crops are excellent indicators of soil conditions in the root zone, and grain protein is highly correlated with N nutrition adequacy. Furthermore, grain yield and protein maps have been found to be useful in calculating straw yield, which is another important factor in the determination of N recommendations (Engel et al., 2003).

To date, no spectroscopic NIR sensor is commercially available for automatically obtaining site-specific measurements of grain protein levels as needed to implement the aforementioned mapping methods. The objective of this study was to evaluate the performance of an NIR sensor for measuring and mapping the protein concentration of grain as it is being harvested with a combine harvester. The spectroscopic sensor tested was a prototype version of the AccuHarvest Analyzer (US Patent No. 09/844,698) developed by Zeltex, Inc. (Hagerstown, Maryland, USA).

Materials and methods

The AccuHarvest Analyzer consists of a base analyzer unit, with combined sampling mechanism and sampling chamber. The AccuHarvest easily mounts to the side of a combine’s clean grain elevator (Fig. 1 left). A handheld computer with special Windows CE software is installed in the cab of the combine for displaying the protein readings and recording data for later download to a personal computer (Fig. 1 right).
The AccuHarvest sensor operates in transmittance mode between wavelengths of 893-nm and 1045-nm. These wavelengths are generated by a series of 14 NIR light emitting diodes (IREDs) behind narrow band filters (Fig. 2). A major advantage of IREDs is that they permit spectroscopic measurements using a single, inexpensive silicon detector without the need for moving filters or gratings. Sample presentation is by means of a gravity-filled, quartz-windowed chamber and a mechanical sampling system of inlet and outlet ports that permit the grain to flow into and out of the sensor. Sample size is about 200-g of whole-wheat kernels.
Figure 2. Configuration of infrared emitting diodes, narrow band filters, and silicon detector within the Zeltex AccuHarvest Analyzer.

A Case-IH model 1660 combine, equipped with a GPS receiver, yield monitor, and AccuHarvest Analyzer, was used to harvest two 40-ha dryland fields of hard red spring wheat near Malta, Montana, USA. The same grain that entered the sensor could be retrieved for later laboratory testing because an outlet port was available for capturing that grain when it exited the sampling chamber. A person riding on the side of the combine next to the instrument manually collected the grain samples after each reading (Fig. 3). When each sample was collected, the GPS time was recorded on the sampling bag. Therefore, each sample could be tied to its corresponding AccuHarvest reading that also had been referenced in space and time by means of the combine’s GPS receiver.
Figure 3. Positioning a person next to the AccuHarvest Analyzer on the combine during actual harvest allowed for the collection reference grain samples.

More than 600 samples of grain were collected by hand from the sensor on the combine. Of these, 189 were acquired in Field 1 for calibration model development and 85 in Field 2 for validation. Reference testing of grain samples was carried out in the laboratory using a Foss Infratec model 1225 whole grain NIR analyzer. Protein concentrations were not converted to a 12% moisture basis, but instead were reported on an “as is” basis in accordance with the output from AccuHarvest Analyzer.

There was no time to calibrate the instrument before harvest and so the calibration was carried out afterwards at the factory. Multiple linear regression was used to develop a linear model relating the spectral data that had been saved to the handheld computer with the 189 reference grain protein values from Field 1. Statistics for evaluating the field calibration included the coefficient of multiple determination ($R^2$) and the standard error of calibration (SEC). The resulting calibration model was used to predict protein content in the validation sample set consisting of 85 protein values from Field 2. Validation statistics included the $R^2$ and the standard error of validation (SEV).
Results and Discussion

Protein concentration varied widely within the calibration and validation sample sets of hard red spring wheat, specifically dark northern spring wheat, within Field 1 and Field 2 (Table 1). The mean protein concentration of the 189 calibration samples was 14.54% and the standard deviation was ±1.21%. Grain protein concentration ranged from 11.08% to 17.54%. The mean protein concentration of the 85 validation samples was 14.56% and the standard deviation was ±1.06%. Proteins ranged from 11.63% to 16.81%.

Table 1. Descriptive statistics for the calibration sample set obtained from Field 1 and validation sample set obtained from Field 2.

<table>
<thead>
<tr>
<th>Sample Set</th>
<th>n</th>
<th>mean</th>
<th>sd</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field 1 (calibration)</td>
<td>189</td>
<td>14.54</td>
<td>1.21</td>
<td>11.08</td>
<td>17.54</td>
</tr>
<tr>
<td>Field 2 (validation)</td>
<td>85</td>
<td>14.56</td>
<td>1.06</td>
<td>11.63</td>
<td>16.81</td>
</tr>
</tbody>
</table>

A scatter plot (Fig. 5) shows a strong linear response over a wide range of protein values. There is good agreement between predicted and reference protein (R²=0.86) based on the calibration at the factory after harvest. The line slope relating predicted- to observed-protein is 0.86 and the 1:1 line indicates bias towards slight underestimation of protein below a grain concentration of 16%. The standard error of calibration (SEC) is 0.49%, which equals the company specifications that targeted <0.5%. Harsh operating conditions of heat, dust, and vibration, and possibility for foreign material in the grain are factors that may negatively influence the instrument’s precision when used on the combine.

The accuracy of the calibration model diminished on the validation data set obtained from Field 2 (Fig. 6). There was more scatter in the data points compared with the calibration relationship for Field 1 thus the standard error of validation (SEP) is greater than the error observed for the calibration data set (0.66% vs. 0.49%). However, the relationship between predicted and reference protein shows a linear response (R²=0.65) and slope near unity (0.90) suggesting that the calibration model may be transferable to other fields. As observation number appears in the denominator of the standard error, it is possible that accuracy would have been more acceptable if a greater number of samples had been available in the validation data set.
Figure 4. Relationship between reference protein and AccuHarvest protein based on factory prediction model.

Figure 5. Relationship between reference protein and predicted protein as predicted by the AccuHarvest Analyzer for the validation data set in Field 2.
The geostatistical interpolation procedure of kriging, available in the mapping software package Surfer (Golden Software, Inc.), was used to develop maps of reference protein and AccuHarvest protein. Experimental semi-variograms were computed for the calibration data set in Field 1 and the validation data set in Field 2 (Fig. 6). Exponential models were fitted to the experimental semi-variograms for both reference protein and AccuHarvest protein in Fields 1 and 2.

Figure 6. Exponential (Field 1) and spherical (Field 2) models fitted to experimental semi-variograms of reference protein and AccuHarvest protein.
The maps of grain protein for reference protein and AccuHarvest protein in Field 1 are visually similar (Fig. 7). High and low areas of grain protein concentration are consistent from map to map. That the maps are statistically related is also revealed by a correlation coefficient \( r \) of 0.95 (\( P<0.05 \)). In Field 2, the maps of reference protein and AccuHarvest protein are similar in the upper two thirds of the field, but there are some inconsistencies in the remaining lower third of the field (Fig. 8).

Thus, the AccuHarvest Analyzer is sensitive to spatial variability in grain protein levels and is potentially useful for field mapping purposes. Based on reports in the literature, grain quality differences result from spatial patterns in soil N fertility, plant available water, and other environmental factors (Fiez et al., 1994; Stewart et al., 2002).

Figure 7. Maps of reference grain protein and AccuHarvest protein derived by kriging the calibration data set in Field 1. Sample locations marked by “+”.
Figure 8. Maps of reference protein and AccuHarvest protein derived by kriging the validation data set in Field 2. Sample locations denoted by “+”.

Conclusions

Testing of the AccuHarvest Analyzer on a combine harvester in the field revealed that the instrument was able to predict grain protein to within 0.49% when calibrated to hard red spring wheat (n=189) and within 0.66% when the calibration model was applied to a validation data set (n=85). Mapped output from the AccuHarvest was highly correlated with maps of reference grain protein. These results are sufficiently promising to suggest that spectroscopic sensing and mapping of grain protein concentration are technically feasible from an operating
combine harvester. Grain producers could be the first to benefit from this new technology in precision agriculture mapping applications that have been described in the literature: namely, site-specific management of N fertilizers (Engel et al., 1999; Long et al., 2000), and crop residues (Engel et al., 2003).

Acknowledgements

The authors express thanks to Karl Mavencamp and Wes Anderson for allowing access to their farm fields where the AccuHarvest Analyzer was evaluated. Appreciation goes to Jeff Whitmus and Terry Grass for able technical assistance in installing and operating the Analyzer, and collecting and analyzing grain reference samples.

Disclaimer

Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

References