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On-Combine Sensing and Mapping of Wheat Protein Concentration

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Abstract

Site-specific measurements of grain protein concentration, in addition to grain yield, are potentially useful for assessing spatial variability in cereal crop production as needed in precision agriculture. This study investigated an on-combine spectroscopic sensor for mapping grain protein levels within farm fields. The optical, near-infrared sensor was calibrated in the laboratory to test samples of hard red spring wheat (r^2 = 0.99, SEC = 0.081%). Grain protein data for spring wheat were then acquired for a 45-acre dryland wheat field, and compared with test samples that had been manually sampled from the combine□s exit auger. The ability of the sensor to predict protein values declined in the field (r^2 = 0.55, SEP = 0.66%). However, a map of grain protein concentration derived from on-combine sensing was highly correlated with a test map of grain protein (r = 0.93). The results are sufficiently promising to suggest that on-combine spectroscopic sensing of grain protein concentration for mapping purposes is technically feasible.

Introduction

Protein concentration is an important determinant of grain quality and ultimately the economic value of cereal grains that qualify for price premiums. Spectroscopic analysis by near-infrared transmission (NIT) and near-infrared reflectance (NIR) is often used in the laboratory to determine the protein concentration and moisture content of whole grain samples with a precision of < 0.1% (15). With the commercialization of the Global Positioning System (GPS) and crop yield sensors, there is potential for adapting NIT/NIR spectroscopy for use on combine harvesters and grain augers.

The ability to sense cereal grain protein in-stream could lead to changes in harvesting/grain handing procedures. In-stream sensing would allow segregation of grain into fractions of low or high quality as needed to blend the grain to meet certain contract specifications of grain buyers. In addition, this technology would allow protein mapping of cereal grain fields. Protein maps, in conjunction with yield data, provide information on nitrogen (N) use and removal, which is also useful for variable-rate application of N fertilizer in crop production (3).

A recent example of a spectroscopic instrument that was developed for combines is the ProSpectra Grain Analyzer that measures protein concentration in a grain stream as it passes over an optical NIR sensor (14). Investigators in Montana evaluated this experimental sensor, but were unsuccessful in using it to develop protein maps of farm fields (11). Researchers in Sweden mapped grain protein using a sampling device designed to control the flow of grain through an NIT-based sensor (13). Laboratory tests showed that the instrument□s precision was < 0.36%, but apparently no tests have been performed to indicate the instrument□s precision under field conditions on a combine.

Independent testing is needed to check whether the on-combine grain quality sensors perform as expected and thus, speed the commercial release of this technology for use in grain quality monitoring. This project evaluated a prototype version of the Cropscan 2000H Spectrometer manufactured by NIR Technologies Australia, Inc. (Bankstown, NSW, AU). Specific objectives were: (i) to evaluate the accuracy of the optical sensor for determining within-field variability in grain protein concentration, (ii) to generate protein yield maps from the optical sensor for a selected farm field, and (iii) to illustrate practical uses of protein maps in precision agriculture.

Sensor Description

The Cropscan instrument is designed to measure NIT through whole kernels using the 720 to 1100 nm region of the light spectrum. The instrument consists of a remote sampling device and fiber optic cable (Fig. 1), and spectrometer with control panel and remote display module. The remote sampling device, consisting of sample cell with mechanical plunger, fiber optic cable, and light emitting tungsten lamp, is mounted in the housing of the exit auger within the bulk tank of a combine harvester. As grain passes the opening of the sampling device, the plunger lowers to draw approximately 50 g of grain into a windowed sample cell. Light emitted from the tungsten lamp passes through the sampled grain. A fiber optic pickup cable transmits the spectra to a detector in the remote display module located within the cab of the combine.

Fig. 1. Remote sampling device (with cables) mounted to the exit auger in the bulk tank of a Case-IH model 1660 combine harvester.

When the measurement is finished, the plunger is driven upwards to return the grain to the exit auger. Each grain sample is collected and scanned within a 6-s period. A 100% transmittance reference scan is taken after every five scans as needed to recalibrate the instrument. Up to 10 measurements can be combined to provide a moving average of protein and moisture data, and thereby smooth the variability in the collected data. The remote display module shows the instantaneous and average values of protein and moisture during harvesting operations. Controls are available for starting, stopping, and resetting the instrument. Up to 4000 measurements may be stored in memory before downloading to a personal computer for mapping purposes. Thus, combine operators have about 6.5 h of scanning time before data retrieval.

Testing the Sensor in the Laboratory

Reference grain samples (n = 30) representing a wide range in protein concentration were obtained from an N fertility□water gradient trial with hard red spring wheat conducted at the Montana State University Northern Agricultural Research Center near Havre. Interested readers may wish to consult Engel et al. (4) for details on the experimental setup and cultural practices. Chemical analysis for N was performed in the laboratory using a LECO CNS-2000 combustion analyzer (12). Grain protein concentration was computed by multiplying grain N concentration by 5.7 (8) and correcting to 12% moisture.

In the laboratory, each grain sample was poured into the instrument□s sampling device. At the start of the measurement cycle, the instrument takes an initial 100% reference scan and then allows the rectangular sampling chamber to fill with grain. Five protein scans are taken per sample then another 100% reference is taken and this process is repeated. These results, including the spectral data, are saved in the instrument□s memory. After scanning all samples, data were downloaded to a personal computer and analyzed using SAS (SAS Institute, Cary, NC).

Regression analysis was used to develop a calibration model relating grain protein concentration to spectra collected with the Cropscan instrument. Statistics for evaluating the prediction included the coefficient of determination (R^2) and standard error of calibration (SEC). A scatter plot (Fig. 2) shows excellent agreement between protein derived by LECO analysis and that derived by the online NIT sensor. The line slope and intercept relating predicted to observed grain protein concentration was close to 1.0

and 0.0, respectively. In addition, the SEC was less than the Federal Grain Inspection Service (FGIS) standard (± 0.15% mean deviation) for NIT instruments that are calibrated to the combustion method.

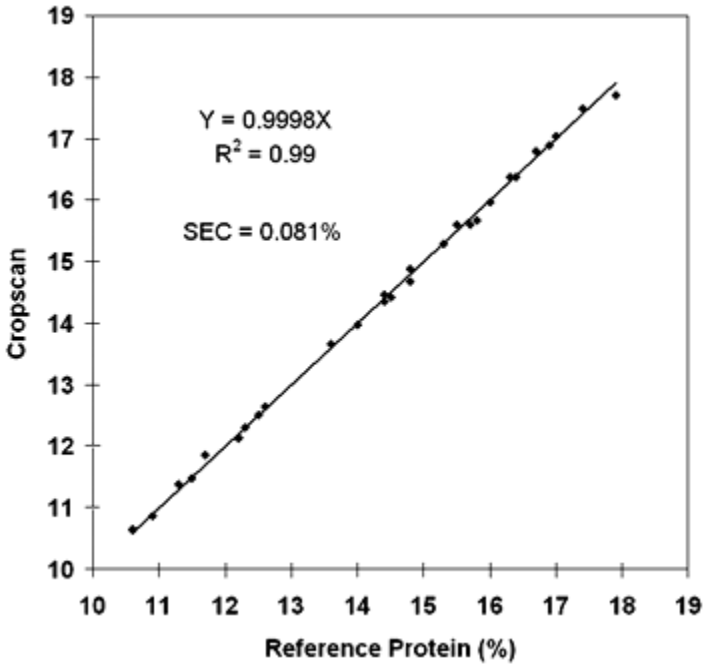

Fig. 2. Calibration line through the plotted points of the relationship between sensor-derived protein and test samples of protein.

Testing the Sensor in the Field

A Case-IH 1660 combine, equipped with a GPS receiver, yield monitor, and a CropScan grain quality monitor, was used to harvest a 45-acre dryland field of hard red spring wheat in northern Montana. More than 500 hand samples were collected manually from the exit auger of the clean grain elevator at 30-s intervals as the grain was harvested. Distance of separation between the grain samples was 176 ft based on combine ground speed of 5.87 fps (4 mph) and the 30-s sampling rate. During the sampling process, the unique GPS-time of collection was noted and written onto each bag that received a sample.

A whole grain near-infrared analyzer (Foss Infratec 1225) was used to determine the reference protein concentration of each hand sample. The grain samples had been cleaned of foreign materials as needed for the analyzer to operate properly. Protein concentrations were corrected to a 12% moisture basis. Values of protein from the hand samples and sensor were used to develop protein maps for the study site. Geographic positioning of a protein measurement was accomplished in the following two steps: (i) subtracting 11 s from the GPS time of sample collection as needed to compensate for the time from when the crop was cut to when the threshed grain reached the sensor at the top of the elevator, and (ii) matching this lagged time with the same GPS time and its corresponding geographic coordinates that had been recorded in the data file created by the combine□s yield monitor and GPS receiver.

In the field, it was not possible to manually collect the same grain that was sampled by the Cropscan sensor because of the plunger design, which did not include a separate outlet port for grain exiting the sampling chamber. Hand sampling could not be coordinated with the sensor because of difficulty in knowing when the sensor was taking a reading during the measurement cycle. Instead, a sensor measurement was paired with a reference protein measurement if they were located within 5 m, or equal to the combine□s header width. This procedure created 32 pairs of observation for statistically evaluating the linear relationship between Cropscan and reference protein values.

Though the relationship between the on-combine sensor and reference protein is linear, as indicated by the scatter diagram presented in Figure 3, the regression line of reference protein accounts for only 55% of the statistical variation ($R^2 = 0.55$) in Cropscan protein. In addition, the laboratory calibration predicted the protein level in spring wheat with an SEP of 0.66%, which is well outside of the 0.15% specification set by FGIS. Comparison of the mean laboratory results ($x = 14.1\%$) with the Cropscan ($x =$

16.4%) indicated that its readings were negatively biased, or overestimated grain protein by 2.3%. Further, the slope of the regression equation is 0.832 (Fig. 3) and significantly differs from unity thus showing that the relationship is not 1:1 in the population.

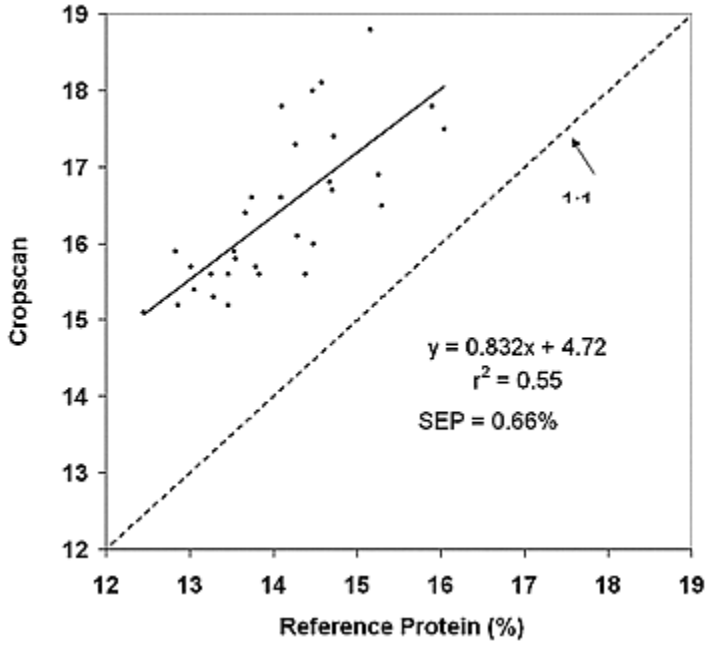

Fig. 3. Relationship between grain protein measurements obtained on the combine with the Cropscan sensor and those obtained in the laboratory with whole grain NIR analysis of reference samples.

It is hypothesized that the deviation and bias between the protein measures result from the presence of foreign material in the threshed grain. Meier (11) evaluated the accuracy of the ProSpectra Grain Analyzer and showed that the R^2 decreased from 0.81 to 0.71, and absolute bias increased from 1.81 to 3.36% as the content of foreign material in the grain increased from zero to 2.5% (by weight). Foreign material consisted of roughage such as chaff, straw, and threshed wheat heads. Therefore, a bias-slope adjustment would likely be required for different cylinder or rotor speeds, airflow rates, grain moisture contents, and other factors that influence grain cleanliness during machine harvest. Fortunately, the instrument can easily be adjusted for slope and bias on the combine provided a limited number of reference grain samples are available for matching with the sensed protein values.

The geostatistical interpolation procedure of kriging and the mapping software Surfer (Golden Software, Inc., Golden, CO) were used to create maps of sensed protein and reference protein (Fig. 4). To enable their visual comparison, a normalization procedure was used to adjust the interpolated map values to the each measurement scale. The equation: Normalized Protein = (Map Value / Mean), derives the percentage of the mean of the data series at each location in the field. In evaluating the equation, the computer substitutes a map value for a field location, completes the calculation, stores the result, and then repeats the process for all other map locations (1).

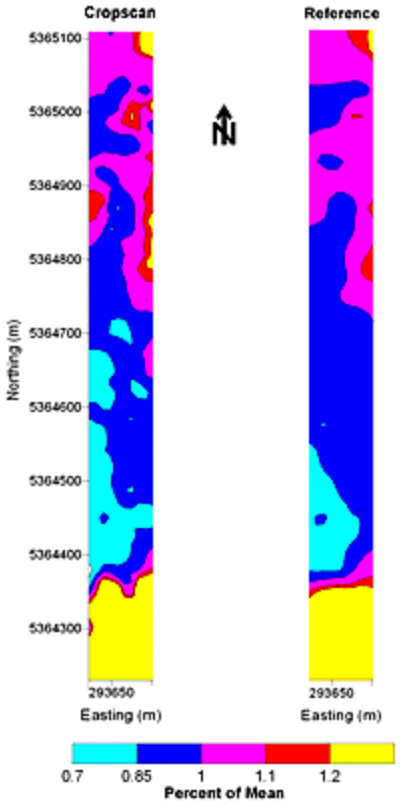

Fig. 4. Visual comparison of maps of normalized grain protein concentration as for on-combine measurements and laboratory measurements of test samples.

The maps of normalized grain protein for on-combine sensing and laboratory analysis of hand samples appear similar. High and low areas of grain protein concentration are consistent from map to map. The maps are statistically related as indicated by a correlation coefficient (r) of 0.93 ($P < 0.05$). Thus, protein measurements achieved with the Cropscan may be useful for distinguishing protein differences for field mapping purposes. Based on the authors☐ experience, the grain quality differences result from spatial variability in N fertility, plant available water, and other environmental factors.

Practical Uses of Protein Maps

Due to the correlation between grain protein and plant N nutrition, growers may be able to use grain protein maps to assess spatial variability in soil N fertility levels (4). This could lead to improved soil sampling protocols that direct sampling to areas of a field that are deficient in N. As a compliment to soil tests for N, grain protein concentration can be a useful post-harvest indicator of whether N supply was sufficient for optimum wheat yields (7). For example, protein at 11.5% indicated the transition between N-sufficient and N-deficient dryland winter wheat in Colorado (6). Yields of dryland spring wheat in Montana with protein concentration below 13.2% were frequently depressed by inadequate N (4). Hence, a protein map could be viewed as a map showing areas of a field where N is either sufficient or deficient for grain yield (Fig. 5).

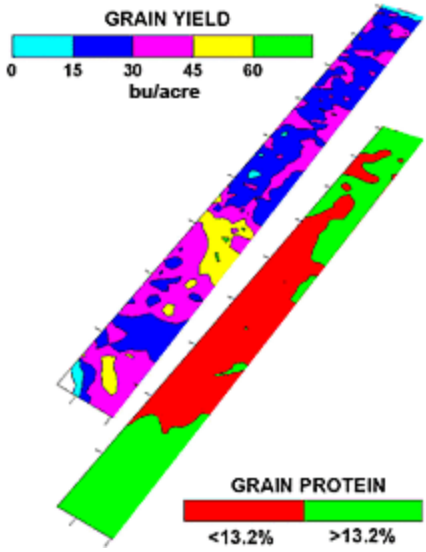

Fig. 5. Spatial variability in the mapped values of grain yield and grain protein within the 45-acre spring wheat field in Montana.

Further, maps of grain yield and grain protein allow for the computation of crop N removal and crop N deficit, which are factors used in identifying management zones for precision N management (9,10). They can be estimated on a site-specific basis using a geographic information system, mapped values of grain yield and grain protein, and simple models relating grain protein to available N, and N removal to wheat yield and grain protein (Fig. 6). The rationale for this approach is that crops are indicators of soil conditions in the root zone and that spatial patterns in grain protein are correlated with patterns in soil profile N.

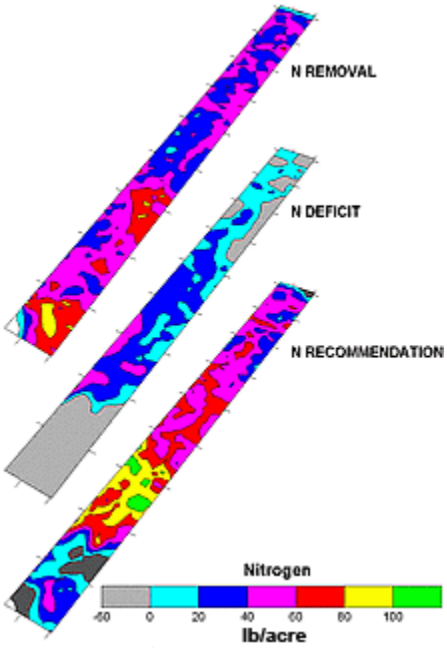

Fig. 6. Maps of N removal, N deficit, and N recommendation derived from the arithmetic combination of maps of grain yield and grain protein in a geographic information system.

Plot and field work by Montana State University showed success in using grain yield and grain protein to quantify straw yield production (5). The relationship between straw yield and grain yield or grain protein is based upon the correlation between grain and straw (2), and presumed correlation between grain protein and straw N. Thus, on-combine sensing of grain yield and protein may provide a rapid, accurate way to quantify and map crop residue cover across farm fields (Fig. 7) versus windshield surveys and line transects that are subjective, labor intensive, or time consuming. Straw yield maps derived from on-combine sensing would increase the accuracy of USDA-NRCS crop residue survey programs, improve soil erosion and carbon management models that use crop residue cover as an input, and provide a means for monitoring compliance for the Conservation Security Program.

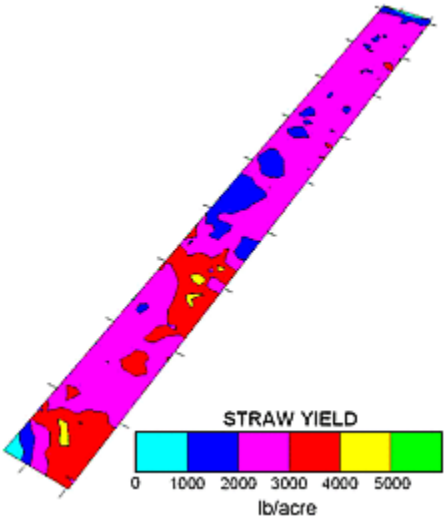

Fig. 7. Map of straw yield computed from mapped values of grain yield and grain protein concentration.

Summary and Conclusions

The Cropscan sensor operated from a combine produced results with deviations that were likely too large for establishing the market value of grain based on protein concentration. However, the mapped output from this optical NIR instrument revealed spatial patterns that were consistent with spatial variability in measured observations of grain protein. One of the main benefits of grain protein maps is ability to better identify N fertility patterns and N management zones within farm fields. To facilitate use of this information, however, manufacturers of on-combine NIR optical sensors will need to develop simple, rapid calibration procedures that farmers find easy to implement in the field. Ideally, such procedures would require only a few grain samples representing a wide range in composition and spectral variance. Further improvements in instrument design may be expected to improve sensor accuracy and reduce requirements for slope/bias correction thus further enhancing growers☐ ability to segregate grain either on a moving combine during harvest, or on a stationary auger during a grain transfer operation. This has implications for new identity-preserved marketing systems, which are forcing growers to produce high quality wheat that meets buyers☐ specifications and document the end-use quality of what they have produced.

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