USING THE NEAR INFRARED ANALYSIS SYSTEM TO PREDICT HAY QUALITY

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Infrared spectroscopy has been an important analytical tool for the chemist since commercial instruments were introduced in 1944. The first use of this technology was for qualitative analysis of liquids using infrared light transmitted through the substance. The near infrared (NIR) portion of the spectra, although rich with information, was not used because of the complex mathematical computations needed to extract the information from the spectra. Reflectance rather than transmission measurements were needed to generate NIR spectra for solid agricultural products such as hay and grain. Successful quantification of the NIR spectra involves chemistry, electronics, and computer technology. Three companies, Dickey-john, Technicon, and Neotec, are currently manufacturing instruments for agricultural application.

Advantages of NIR

The major advantage of NIR reflectance is rapid analysis of multiple constituents. After the instrument is properly calibrated for a particular substance such as hay or hay crop silage, analysis of successive samples requires only seconds per sample. It usually requires more time to open the sample container and place the sample in the holder than to do the analysis.

Other advantages are simplicity of sample preparation and ease of instrument operation. All that is required for sample preparation is grinding the sample. In addition, chemicals or reagents are not used, eliminating the associated safety hazards and pollution problems. The instrument can be operated by a relatively unskilled technician, using a very small work space.

Disadvantages of NIR

The major disadvantage of NIR is instrument calibration. Representative samples with accurate wet chemistry data must be obtained to calibrate the instrument. This critical step has a large influence on the accuracy of predictions. The best way to overcome the problem is to have a State or Federal agency accumulate an official calibration set of samples and provide them to laboratories or private individuals providing NIR analysis.

Prediction of Hay Quality

A number of studies have been conducted to test the prediction of hay quality with NIR. Hay grown under Pennsylvania conditions contains many different mixtures of grass and legume species harvested at different stages of maturity. Table 1 lists the lowest NIR prediction errors published for hay. This represents the potential accuracy of the technology.

Table 1. Prediction errors for hay using near infrared reflectance (NIR) analysis.

Analysis	NIR Standard Errors of Prediction
Protein	0.66
Acid detergent fiber	1.02
Neutral detergent fiber	1.97
Lignin	0.59
In vitro digestion	1.80
Dry matter	0.35
Calcium	0.16
Phosphorus	0.04

These NIR prediction errors for hay were of the same general magnitude as the errors we have found among laboratories using the standard wet chemistry procedures. These results are possible with 1) a high quality scanning instrument, 2) careful control of sample processing, 3) proper selection of calibration samples, and 4) appropriate computer software to select wavelengths and develop prediction equations. These are the 4 keys to successful results with NIR.

Pennsylvania Hay Marketing Study

We attended three hay auctions in Pennsylvania to evaluate the nutrient variation in loads of hay, investigate sampling techniques, and become acquainted with the logistics of providing NIR analyses under local marketing condition. Hay samples were taken at the market and returned to the University for analysis by both wet chemistry and NIR. An average load of hay consisted of approximately 100 (50 to 60 lb) bales. The variation of quality parameters within a load was about twice the variation within a single bale (Table 2).

Table 2. Errors of sampling individual bales of hay and variation in hay loads (standard deviations).

Source of Variation	Protein	Acid Detergent Fiber	Neutral Detergent Fiber
Individual bales	0.65	1.41	1.68
Hay loads	1.54	2.41	4.17

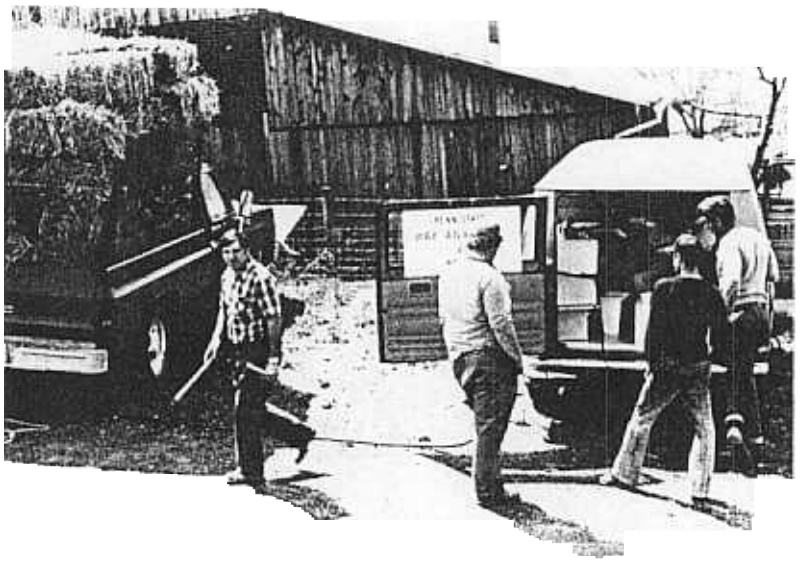
The limiting factor in sampling was the time required to take the sample. Using the Penn State hay sampler (a 24-inch x 3/4-inch core sampler attached to a 1/2-inch battery-powered electric drill), at least two minutes were required to collect a composite sample from five bales chosen at random from the load. If this sample were analyzed by current wet chemistry procedures, the standard error of the load determinations based on one composite sample would be ±0.8% for protein, ±1.2% for ADF, and ±2.1% for NDF. If an NIR instrument were used, the errors would be ±1.0% for protein, ±1.9% for ADF, and ±2.6% for NDF. This higher error for NIR would be easily offset by the speed of analysis and availability of the information.

A comparison was made of the price paid for hay and its quality as determined by NIR analysis. The correlation of this relationship over the 385 loads of hay was +.63. Only 40% of the variation in the price paid for hay could be attributed to hay quality. We concluded that the NIR procedure would be fast enough to operate under working conditions at the market and accurate enough for decision making. Furthermore, the potential savings to the buyers and sellers made a self-supporting analysis system seem economically feasible. Since the NIR analysis for this study was not conducted at the hay markets, it was decided to develop a mobile NIR analytical system to interact directly with the farmers at these hay auctions.

The NIR Van

The NIR instrument and computer were mounted in a standard size van along with a grinder to prepare the sample for analysis. This analytical system was taken to the hay market auction at Belleville, PA for testing (see picture on following page). Hay loads were sampled, analyzed, and the results posted on the load before the sale. Analyses displayed included crude protein, TDN, and hay grade determined by the computer from the equations developed by the American Forage and Grassland Council.

The response by the farmers to this analysis and grading program changed throughout the five weeks of the study. In the first two weeks, little attention was paid to the posted information beyond expressions of curiosity. By the third week, farmers bringing hay from the same field and same harvest were finding the analyses to be very repeatable.



NIR Van at hay market auction -- Belleville, PA

This began to build confidence in the analyses. Buyers were beginning to study the analyses as well as the hay on the truck. Some farmers selling low quality hay began to refuse analysis and buyers showed little interest in purchasing their hay. During the fourth week some sellers with high quality hay wanted us to continue the service; and by the fifth week more farmers were requesting that we continue the service. At this point the program was discontinued because of other planned research activities.

Our accomplishments during the five week period can be summarized as follows. First, we learned how to make the van system function efficiently. Second, we demonstrated that NIR analysis of hay under marketing conditions can be accomplished without disrupting the sale in any way. Third, we found that NIR analysis does not give the buyer or the seller an advantage in the market but does provide a basis upon which the auction can function more equitably, and fourth, we found a great lack of knowledge among farmers about hay quality and how to use this information in their feeding program.

Expanding the Van Concept

Having developed a satisfactory mobile hay analysis system, we proceeded to devise a method for analyzing high moisture samples of corn silage, hay crop silage, high moisture corn, and green chop. Samples were dried 5-7 minutes in a microwave oven giving a rapid turnaround time for high moisture analysis. NIR prediction errors were not enlarged due to microwave drying if the instrument was calibrated using microwave dried samples. A computer program for ration formulation was then added to complete the mobile analytical and ration formulation system.

The items required for this mobile system were a grinder-vacuum device for grinding samples and cleaning sample holders, a microwave oven to dry high moisture samples, an electronic balance to determine "as is" moisture in high moisture samples, a scanning filter Neotec 51 NIR instrument, DEC computer, terminals, air conditioner-heater combination for winter and summer operation, a self-contained electrical power system and customized computer software for instrument control, nutrient prediction, and ration formulation The equipment was available "off-the-shelf" from various suppliers and the computer software was a PSU/USDA development. The van complete is available from P.A.G.E., Allentown, PA.

Extension of Concepts to Hay Analysis in Western States

Our research with hay has led to the adoption of NIR as an acceptable method of determining hay quality by two commercial laboratories in Pennsylvania. These laboratories

analyze hundreds of hay samples from farms and livestock feeders from all over northeastern United States. However, NIR is not limited to the prediction of hay quality for mixed hay grown in the northeast. In fact, since most all hay produced in the western states consists mainly of alfalfa, NIR should be able to predict the quality of this hay with even greater accuracy. It has been shown that prediction errors of hay quality are generally lower for pure species than mixtures.

There is no reason to believe that NIR could not be used to predict modified crude fiber (MCF) as well as acid detergent fiber if the NIR instrument is properly calibrated. The advantage of NIR is that in the same few seconds required to predict MCF, an accurate prediction of protein and other nutrients can be obtained.

The computer used to control the NIR instrument is under the complete control of the operator. It can be programmed for any hay grading or ration formulation scheme desired. Hay is marketed differently in the West than in Pennsylvania; this represents a new challenge for the application of NIR to these conditions.

Both mobile and stationary NIR systems could be used for hay analyses in the western states. The best choice can only be made after a thorough understanding of each application. The important point is that both types of systems have been developed and are commercially available if needed. In Pennsylvania we estimate that one NIR system operated by a full-time person trained in analysis and ration formulation could be a profitable enterprise for the hay producers, instrument operators, and dairymen if it supports 3,000 dairy cows. We do not know if these estimates are appropriate for California and other western states, but we do believe that NIR will be a useful technology for the entire hay and dairy industry of this country.

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