Prediction of as-is barley silage dry matter by near infrared reflectance spectroscopy

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STORY IN BRIEF

The objective of this study was to evaluate the use of near infrared reflectance spectroscopy **(NIR)** technology in determining the DM of barley silage. Two separate NIR equations were built in an effort to improve DM prediction accuracy using the technology. First, a commodity specific equation with only barley silage samples included in the equation was developed. Second, a broad based equation was developed, where both barley silage and barley straw samples were included in the equation. Fifteen samples of barley silage and straw were utilized and split into groups: water added **(WTR)** and fresh. Water was added to WTR to broaden the DM range. Samples were weighed, scanned (InfraXact, FOSS North America) and dried (55°C) in twelve, 4 hour intervals. DM was calculated and correlated to NIR spectra at each interval. Silage samples were blocked by DM and randomized to validation (n = 128) or calibration (n = 639) sets. A commodity specific equation **(SIL)** was developed from the silage calibration set [SE of calibration (SEC) = 3.77, $R^2 = 0.98$]. A broad based equation **(SIL-STR)** was derived (SEC = 2.93, $R^2 = 0.98$) using a calibration set (n = 1,406) consisting of the silage calibration set (n = 639) and straw samples (n = 767). The R^2 and SE of prediction **(SEP)** for the validation of SIL and SIL-STR, using the independent validation set, were 0.98 and 3.78, 0.98 and 3.96, respectively. Barley silage DM content can be accurately predicted using NIR with broad based or commodity specific calibrations.

Key Words: barley, near infrared reflectance spectroscopy, silage

INTRODUCTION

Silage is a major commodity used throughout feedlots in Western Canada and the United States. Feedlots are including silage in rations at significant rates; therefore, understanding the composition of this feedstuff is important. Understanding the moisture contained in a commodity is important for producers when they determine storage conditions, the cost of the commodity, and ultimately converting nutrients to a DM basis (Thiex and Richardson, 2003). Traditional laboratory DM analysis utilizes a "loss on drying" where moisture is evaporated from a sample. This analysis can be susceptible to several errors including weighing errors, humidity fluctuations, drying time, and temperature uniformity. In addition, this analysis requires specific sample preparation and a long drying time which can make it less than ideal for speedy analysis (Thiex and Richardson, 2003).

NIR technology is a non-destructive and rapid analysis method that has been demonstrated to provide accurate DM and quality trait predictions for various commodities (de Boever et al., 1995). One limitation of previous NIR analysis has been that samples must be dried and ground prior to scanning. This causes additional processing for feedlots and additional sources of error in scanning results. It was identified that using NIR technology to characterize silage on an "as-is" basis would be a beneficial advancement throughout the feedlot industry.

NIR technology has often been used in single commodity applications, where individual commodity equations must be built for each new application. However, to increase NIR's usefulness as an analysis tool, and to decrease laboratory costs, selected calibrations have been built to include several commodities. These "broad based" calibrations would be more robust and could lead to more advanced and diverse uses of the technology if prediction accuracy can be maintained. The study examined the use of an as-is calibration for barley silage DM, where both broad based and commodity specific equations were developed to test prediction accuracy using both equation development methods.

MATERIALS AND METHODS

Sample Collection. Samples used for this project were 15 barley silage samples taken from four different feedlot locations, and 15 barley straw samples originating from three feedlot locations in western Canada. Each sample was split and duplicates put into two groups: water added (WTR) and fresh. Samples in the WTR group had water added to them prior to scanning and drying to increase their moisture content and broaden the DM range based on the publication by Schroeder (2004). NIR spectra was collected using commercially available technology (InfraXact, FOSS North America, Eden Prairie, MN).

Samples were refrigerated for 24 h prior to the start of oven drying to allow those in the WTR group to absorb the moisture. Samples and trays were weighed and scanned prior to the start of drying. Samples were put into the drying oven set at 55 °C for 48 h. Samples were removed from the oven every 4 h and left to cool at room temperature for 1 h. Following cooling all samples were individually weighed and scanned.
DM was calculated for each 4 h interval as:

$$\text{DM \%} = (\text{Sample Weight at interval} / \text{Initial Sample Weight}) * 100$$

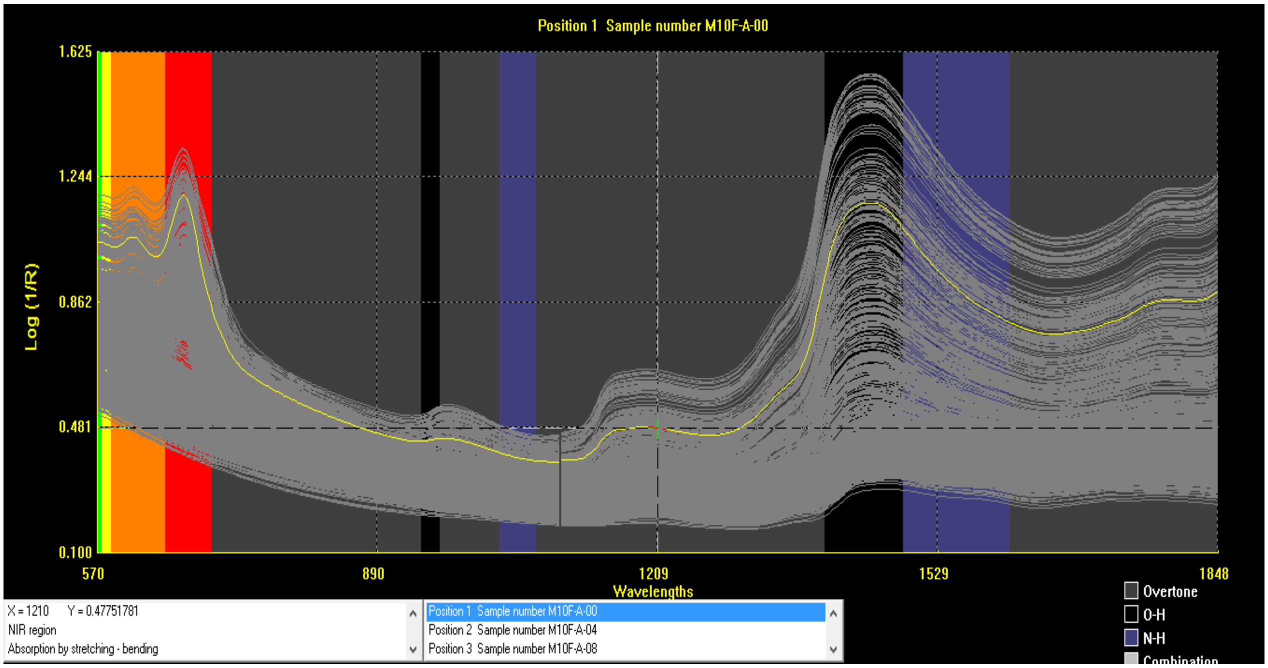
Calibration Development and Statistical Analysis. DM data and spectra were correlated using WINISI software (FOSS North America, Eden Prairie, MN) utilizing wavelengths 1100-1848 nm. Barley silage spectra and calculated DM values were blocked by the calculated DM value and randomized into either the validation set or calibration set. A commodity specific equation (SIL) was developed using only the barley silage spectra and calculated DM results. A broad based equation (SIL-STR) was developed using the spectra and calculated DM values of the barley silage samples from the calibration set combined with the spectra and calculated DM values of the barley straw samples. Equations were developed using WINISI software using optimal math conversions and treatments (Aufrere et al., 1996 and Hervera et al., 2012).

Linear regression analysis was conducted to establish the relationship between the NIR predicted values and the oven determined DM values. The spectrum from the independent barley silage validation set was passed through each developed equation to obtain predicted DM values. For each equation, those predicted DM values were correlated to the determined DM values using PROC REG of SAS (SAS Inc., Cary, NC).

RESULTS AND DISCUSSION

Sample Characteristics. Figure 1 shows the spectral representation of all the samples included in the study. A peak at 1472 nm corresponds with the water absorption bands (Hervera et al., 2012).

Table 1 shows the simple statistics associated with those samples allotted into each calibration set and the independent validation set. This demonstrates that a similar range was achieved in both calibration sets as well as the validation sets. This allows one to test each calibration across a broad range of DM values using the validation set. From this it can be seen that including straw samples in the SIL-STR equation increased the robustness of the calibration to include 1406 observations compared to the 639 of the commodity specific equation. Equation statistics are displayed in Table 2. A high coefficient of determination value ($R^2 = 0.98$) for both equations was observed in equation development. This R^2 value is the same as that seen in equations built by Abrams et al. (1987) for silage DM using various silage types including alfalfa, orchard-grass, timothy, and bromegrass mixtures. From these results it appears that building an as-is calibration for barley silage is a viable option with NIR technology.



X = 1210   Y = 0.47751781
NIR region
Absorption by stretching - bending

Position 1 Sample number M10F-A-00
Position 2 Sample number M10F-A-04
Position 3 Sample number M10F-A-08

Figure 1. Spectra representation of all barley silage and barley straw samples.

Table 1. Simple statistics for samples included in calibration and validation sets

		Calibration Set	
Statistic	Validation Set	SIL	SIL-STR
N	128	639	1406
Min.	22.55	22.87	22.87
Max.	100.00	100.00	100.00
SD	26.28	26.00	21.26
Mean	76.39	76.68	86.83

Table 2. Equation statistics for commodity specific or broad based barley silage calibrations

Equation	n[a]	SEC[b]	R^2	SECV[c]
SIL	634	3.77	0.98	3.89
SIL-STR	1384	2.93	0.98	2.96

[a] Samples were removed from SIL (5) and SIL-STR (16) equations after being determined spectral outliers
[b] SEC = Standard error of calibration
[c] SECV = Standard error of cross validation using 5 groups for cross validation

Prediction of Validation Set. Figures 2 and 3 display the regression analysis results from the predictions using the SIL and SIL-STR equations, respectively. A high coefficient of determination ($R^2 = 0.98$, $P < 0.05$) was achieved utilizing the independent validation set and both equations. These figures display that the validation set tested across a broad range of DM values (25% to 100%) which would make it suitable for a wide range application in testing DM of barley silage as-is.

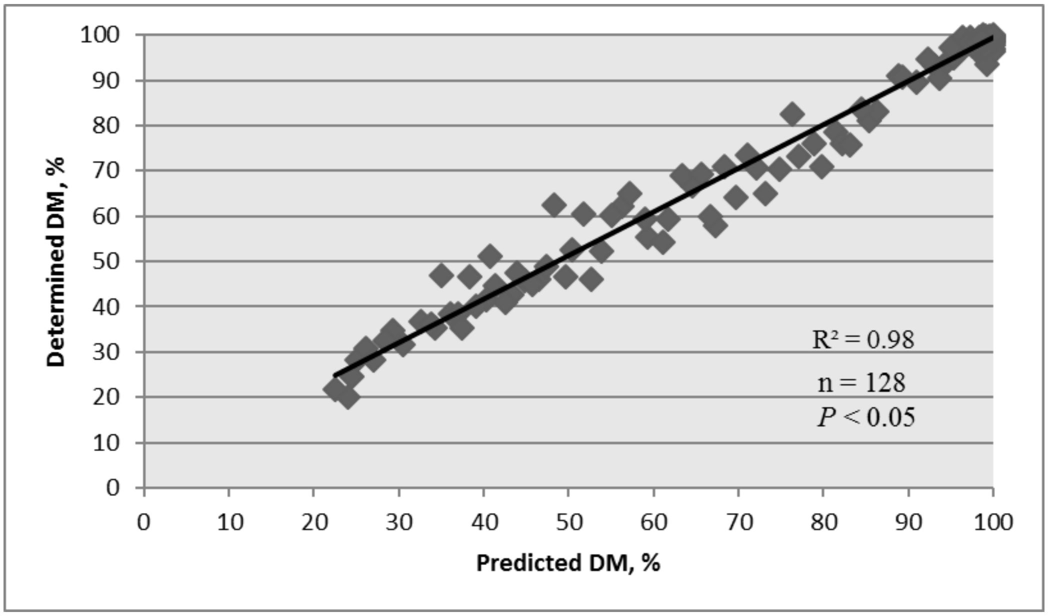


Figure 2. Commodity specific NIR equation (SIL) predictions of independent validation set (n = 128).

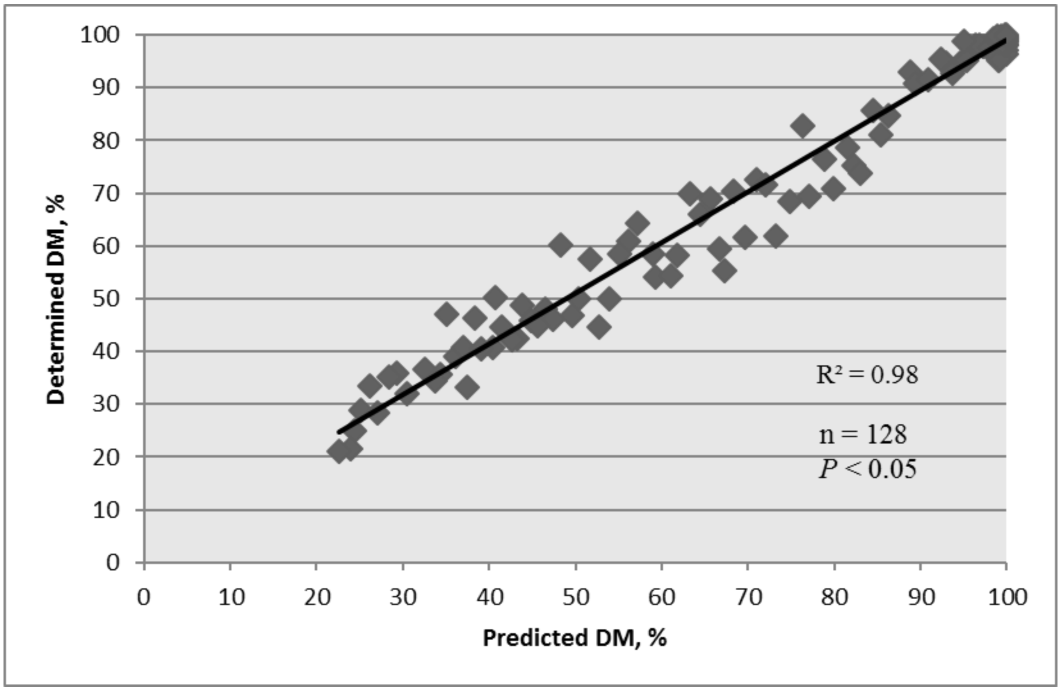


Figure 3. Broad based NIR equation (SIL-STR) predictions of independent validation set (n = 128).

These results demonstrate that by including several commodities into one NIR equation the robustness of a calibration increases and prediction accuracy is not compromised. These results are in keeping with Brown et al. (1990), who also concluded that broad based equations provide the advantage of reducing the need to build individual commodity calibrations. Ultimately these results can allow for wider spread applications of NIR technology in forage DM analysis.

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