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Predictability of growth performance in feedlot cattle using fecal near infrared spectroscopy[1]

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ABSTRACT: Near infrared spectroscopy (NIRS) was used to predict nutrients and apparent total tract digestibility (aTTD) of nutrients and gross energy (GE) using 282 pooled pen-floor dried ground fecal samples collected monthly over 13-mo from 6 feedlots in Southern Alberta. Mixed-model regression was used to examine relationships between fecal composition, digestibility, DMI, ADG, and G:F. Lower ($P < 0.01$) fecal starch, greater ($P \leq 0.04$) fecal NDF, and greater ($P \leq 0.01$) aTTD of DM, OM, starch and GE were observed in cattle fed tempered versus dry rolled barley, with no differences in DMI, ADG, or G:F. Compared to cattle fed barley, those fed a wheat-barley grain mixture had greater ($P \leq 0.02$) fecal starch and aTTD of DM, OM, as well as greater ADG, and G:F. Heifers had a lower ($P \geq 0.05$) aTTD of DM and GE than steers. A quadratic relationship was observed between fecal starch and G:F, with sex and average BW at time of sampling as additional variables (rho = 0.75, $P < 0.01$). Our data indicate that NIRS predictions using the feces of feedlot cattle have potential in predicting G:F when variables such as BW and sex are included in the equation.

Key words: digestibility**,** fecal composition, feces, feedlot cattle, growth performance, near infrared spectroscopy

INTRODUCTION

Cereal grains are a major ingredient in diets for finishing cattle, and given the high proportion of starch in grains, predictions have been developed to rapidly estimate starch digestibility using fecal starch concentration (Zinn et al. 2002; Corona et al. 2005; Zinn et al. 2007). Research by Owens and Zinn has shown that the accuracy of starch digestibility predictions can be improved by including additional variables such as fecal N (Zinn et al. 2011), DM or OM digestibility, and starch intake (Owens et al. 2016). Methods to predict other nutrient digestibilities, particularly NDF, from their fecal concentrations have been examined (Fredin et al. 2014; Jancewicz et al. 2016; Owens et al. 2016), as well as indirect relationships between OM digestibility and fecal CP (Lukas et al. 2005). Since fecal samples contain information relevant to feed digestion, monitoring how efficiently cattle are utilizing nutrients could directly benefit the efficiency and profitability of feedlot cattle production. For such predictive approaches to be commercially applied, they need to be practical and accurately reflect impacts on performance efficiency, rather than just digestibility.

Near infrared spectroscopy (NIRS) is a rapid alternative to wet chemistry and can successfully predict nutrient composition and diet digestibility using dried ground fecal samples collected from the pen floor of feedlot cattle (Jancewicz et al. 2017a; 2017b). The initial process of developing calibration equations for NIRS requires laboratory analysis, but once calibrations are developed, NIRS is capable of the simultaneous estimation of multiple constituents within a sample. Multivariate regression analysis is used in calibration development to describe the relationship between the concentration of an analyte and its spectrophotometric response. Near infrared spectroscopy calibrations have been directly applied to identifying associations between measured fecal parameters and performance, and to predicting ADG and G:F using small

datasets where grain type, processing, or grain proportion were deliberately altered (Jancewicz et al. 2017b). These results suggest that the use of NIRS may have merit in predicting growth performance in commercial feedlot cattle, if calibrations are relevant to the samples collected. However, the commercial feedlot industry encounters many challenges that do not occur in typical feedlot research studies. Feedlot managers are faced with implementing management decisions that require changes in the type and proportion of ingredients in the diet, grain processing, sorting of cattle into production lots for marketing and adjusting the shipping dates prior to slaughter. All of these actions introduce variables that are not easily anticipated, potentially making equations developed for specific diets less reliable.

The first objective of this study was to use previously developed NIRS calibrations to predict fecal composition and digestibility in dried ground fecal samples collected from commercial feedlots. Principal component analysis was used to qualitatively visualize the differences in the spectral populations of samples in the calibration sets and those to be analyzed. Secondly, the impact of variables including grain type, grain inclusion rate, processing method, processing index, forage to concentration ratio (F:C; included grain and other concentrates), sex, season, and average BW of the cattle at the time of sampling on NIRS predicted fecal nutrients and digestibility was examined. Lastly, NIRS of feces was assessed for its ability to predict DMI, ADG, and G:F within groups of commercial feedlot cattle.

MATERIALS AND METHODS

All sampling procedures used in this study were reviewed and approved by the Animal Care Committee at the Lethbridge Research Centre of Agriculture and Agri-Food Canada, which operates under the guidelines of the Canadian Council on Animal Care (2009).

Description and development of feedlot fecal database

A database was constructed by collecting and analyzing monthly fecal samples from 6 feedlots from the floor of pens over a consecutive 13-mo period (May 2013-May 2014). The feedlots in the database were located in southern Alberta. Cattle were housed in outdoor pens with dirt floors. All pens were enclosed with porosity fencing on at least two sides. Cattle were bedded by placing barley straw in the middle of the pen as required. Pens were either steers (228 pens) or heifers (54 pens) of primarily British or Continental cross breeds. Steers and heifers were separated by sex, and housed at an average density of 167 ± 71.6 hd/pen, with a range of 26 to 438 hd/pen. Pen areas also varied, but provided approximately 13.8 to 16.6 m^2/hd, and 22 to 26 cm of bunk space/hd.

Each month, four fecal pats from approximately four pens were composited by pen on an equal wet weight basis. Cattle within a pen were observed until defecation occurred so that fresh samples could be collected from different cattle. Samples were collected from the center of the fresh fecal pats and contamination with dirt or bedding was avoided, as described in Jancewicz et al. (2017b). Samples were collected between 0800 to 1300 h, and were stored in separate plastic bags and kept in coolers until collection from all pens was complete. Samples within the same pen were composited on an equal wet weight basis (≈100 g each). Due to a low number of pens of cattle fed finishing diets at certain times, there were months when fewer than 4 pens were sampled at some of the feedlots. In addition, one monthly collection was missed for one of the feedlots because of issues with frothy bloat, and two from a second feedlot due to difficulty in coordinating a suitable sampling day with the feedlot manager. Pens of cattle on finishing diets were sampled randomly, therefore over the 13-mo period some pens were sampled only once

whereas others were sampled up to 6 times. Once sampling was completed, there were a total of 282 composite fecal samples collected from a total of 140 different pens. Each composite sample was dried at 55ºC for a minimum of 72 h, followed by DM determination, and grinding through 0.75 mm screen using a Retsch grinder (Verder Scientific, Inc, Newton, PA).

Each dried ground pooled fecal sample was associated with appropriate linked measurements including: feedlot identification (1 to 6), diet (ingredients, grain type, dietary grain inclusion rate, grain processing, processing index, forage to concentrate [F:C] ratio), average BW of cattle, sex, season (Summer; June to August, Fall; September to November, Winter; December to February, and Spring; March to May), fecal DM, NIRS predicted fecal composition, and NIRS predicted nutrient and GE digestibility. The pooled fecal samples were also associated to each pen they were collected from and to the performance measures at the end of the feeding period for the particular lot of cattle housed within that pen.

Depending on the feedlot, grain in the diet consisted of barley or a mixture of barley and wheat. Grain was processed on site in a feedmill located at each feedlot. The processing methods included grain that was either dry- or temper rolled, and the method varied based on feedlot and season. For example, one feedlot used both processing methods with dry rolling used in the winter and temper rolling in other seasons. Processing index was calculated as the bushel weight of the grain after dry rolling or temper rolling divided by the bushel weight of the whole grain before processing. Temper-rolled grain was dried prior to this measurement. Among feedlots, the amount of grain in the diet ranged from 52% to 90% of DM, and the processing index from 52% to 97%. Two feedlots fed potato waste at 3% to 15% of diet DM as an additional source of starch. None of the feedlots that fed wheat or dry rolled grain fed waste potatoes. Therefore, additional dietary starch from potatoes was only relevant to feedlots that fed temper-rolled

barley. The F:C accounted for concentrates other than grain included in the diet, such as dried distillers grains, potato waste, grain screenings, and supplement. Samples were collected from both heifers and steers in four feedlots, and from only steers at the remaining two. The diet composition, processing methods, and overall performance for each feedlot at the end of the 13-mo period are summarized in Table 1.

Feed offered and sampling

Feed was delivered in the morning at all feedlots using a feed truck with a mixer, in 2 primary passes (twice/day) with pens of cattle being fed to appetite. In some feedlots, three feedings per day occurred occasionally, but was rare. Cattle were fed to appetite, with refusals kept to a minimum. Only cattle that had been fed a finishing diet for a minimum of 5 d or the final step-up diet for a period of 3 wks were sampled. In all 6 feedlots, a supplement was included at 2.3% of diet DM and provided 33 - 48 ppm monensin (Rumensin 200®, Elanco Animal Health, Indianapolis, IN) and 11 ppm tylosin phosphate (Tylan 40; Elanco Animal Health, Indianapolis, IN). The heifer supplement also contained MGA 100 (Zoetis Inc, Parsippany, NJ) targeted at delivering 0.4 mg of melengesterol acetate hd/d. Optaflexx (Elanco Animal Health, Indianapolis, IN) was provided through a separate supplement during the final 20 to 40 days of the feeding period targeting an intake of 200 to 300 mg of ractopamine hd/d to pens of steers at all 6 feedlots. Ingredients and their proportions in the finishing diet were changed based on pricing, availability, and manager preference. Diet adjustments were made as frequently as weekly, or infrequently with ingredients remaining the same for a month or more. Grain samples (4 L) were collected before and after processing the same day as feces were

collected from the pen floors at each feedlot, ensuring that the grain was from the same original bin.

Analysis using NIRS

The dried ground pooled fecal samples (n=282; minimum 250 g) were packed into small quartz ring cups (25 g) and scanned in duplicate (two repacks; where the second scan was a different subsample from the first) using a SpectraStar Near-Infrared analyzer 2400 RTW (Unity Scientific, Brookfield, CT). Spectral information was collected at wavelengths between 1100 and 2400 nm in 1-nm increments, and trimmed between 1250 to 2350 nm to reduce noise peaks above and below this range. Duplicate spectra of each sample were averaged, and fecal OM, starch, N, NDF, ADF, ADL, ether extract (EE) and aTTD of DM, OM, starch, CPD, NDF, ADF, and GE were predicted using previously derived NIRS calibrations as developed by Jancewicz et al. (2017a).

In order to expand the original calibration to encompass samples from the current study, all commercial feedlot samples predicted using the initial NIRS calibrations were ranked from the highest to lowest for each constituent (% of fecal DM). Samples were selected to include the entire concentration range of each constituent of interest, while ensuring that representative samples from each feedlot were included in the dataset. Validation of the calibration included not only samples from the current study, but also from other feedlot studies as described in Jancewicz et al. (2017a). Fecal starch, NDF, and ADL were selected as the key nutrients of interest based on results from regression models (described below), and previous studies (Jancewicz et al. 2017b; Owens et al. 2016). Reference analysis consisting of wet chemistry for OM, starch, N, NDF, ADF, ADL, and EE (AOAC 2005), was conducted on a subset of fecal

samples from each feedlot (24 from the current study) and the samples whose neighborhood distance (ND) was above a certain threshold (0.60) were used to expand the original calibration. A similar approach could not be used for calibrations for digestibility as this parameter could not be realistically measured for the commercial feedlot samples. Details of calibration development for digestibility are described in Jancewicz et al. (2017a).

Principal component analysis (PCA) was used in Unscrambler® X version 10.3 (CAMO Software, Oslo, Norway) to visualize the differences in spectral populations of the commercial feedlot dataset and the calibration set. The export function in Ucal was used to convert spectra into a JCAMP format that could be imported in Unscrambler® X to generate PCA graphs. The full spectra were used with no trimming (1100 to 2400 nm). Raw spectra were transformed using a standard normal variate and detrending procedure, followed by first derivatization using Savitsky Golay with three points. A scatter plot of principal component (PC) scores for each sample from the feedlot dataset, and within the calibration dataset were plotted along the first two PC factors (x axis = Factor 1, y axis= Factor 2). Outliers were visually identified using the Hotelling's T^2 distribution as per its application in identifying differences in population means in multivariate statistics. The samples outside of the defined Hotelling's T^2 ellipses were considered strong outliers from the population at a confidence level of 95%.

Performance measurements

For this study, close out performance data were obtained for groups of cattle that remained together as a single lot from arrival until slaughter. Lots of cattle were weighed together on trucks, at the start and end of the finishing feeding period, primarily for billing and inventory purposes. The 282 fecal samples (pool of 4 as described above) were collected from a

total of 140 pens corresponding to 90 lots of cattle where DMI, ADG, and G:F could be obtained. Of these lots, 70 contained steers, and 20 contained heifers. Measures of interest (i.e. fecal composition, digestibility, grain percent, F:C, grain processing) were averaged if samples were collected from the same lot more than once. The frequency of fecal collections within a feeding period for each lot was recorded.

Close out DMI was estimated by the amount of feed offered to a lot (adding the total feed offered to each pen within a lot) over the full feeding period, divided by the number of days on feed and the number of cattle in the lot. Close out ADG and G:F were calculated assuming 4% shrink. Close out data were calculated by subtracting average initial weight from the average final shrunk body weight with dead animals removed. This difference was divided by the number of cattle, and the days on feed for each pen, as described by Gaylean et al. (2010). The pen G:F was calculated as ADG divided by DMI.

Statistical Analysis

The Mixed procedure in SAS v. 9.1. (SAS Inst. Inc., Cary, NC, USA) was used to determine the differences in management strategies (grain percent, F:C, processing index), in NIRS predicted fecal composition and digestibility, and performance, observed among the six feedlots. The number of samples collected from each pen varied because of differences in the time that cattle were shipped for slaughter and because the distribution of cattle within pens varied among feedlots and with month. A compound symmetry structure was used to model repeated measures on individual pens sampled on more than one day as it exhibited best fit for convergence. In addition to fecal starch and fecal NDF, aTTD of DM, OM, and starch were selected as key interests for digestibility based on previous investigations (Jancewicz et al.

2017b; Owens et al. 2016). The aTTD of GE (%) was also selected because of its relationship to net energy of gain (Jancewicz et al. 2017b). The model used was $Y_{ij} = \beta_{0ij} + \beta_1 feedlot_{ij} + \beta_2 day_{ij} + \mu_j + \varepsilon_{ij}$, where β_0 was the average y-intercept or overall mean for management factors, fecal chemical composition, digestibility, BW, DMI, ADG, or G:F when all terms in the equation are equal to 0, i was the individual observation of day within pen, j was feedlot, μ_j was the residual associated with feedlot and ε_{ij} was the residual error associated with each observation. Least square means of the treatments were separated using PDIFF statement, with significance declared at $P < 0.05$.

Pen was considered the experimental unit and the Mixed procedure was then used to determine the effect of grain type, processing method, and sex on NIRS predicted fecal composition, digestibility and growth performance, adjusting for differences among feedlots as a random intercept. Interactions were not examined in this observational study because of the large number of variables examined, unequal numbers of pens per lot and feedlot, and missing data. The model used was $Y_{ij} = \beta_{0ij} + \beta_1 grain\ type_{ij} + \beta_2 processing\ method_{ij} + \beta_3 sex_{ij} + \beta_4 season_{ij} + \beta_5 day_{ij} + \mu_j + \varepsilon_{ij}$, where β_0 was the average y-intercept or overall mean for fecal chemical composition, digestibility, DMI, ADG, or G:F when all terms in the equation are equal to 0, i was the individual observation of day within pen, j was feedlot, μ_j was the residual associated with feedlot and ε_{ij} was the residual error associated with each observation. Least square means of the treatments were separated using PDIFF statement, with significance declared at $P < 0.05$.

A third series of regression models were used to examine the bivariate associations between each of fecal nutrients and digestibility measures, and each measure of performance, including DMI, ADG, and G:F at each lot. Lot of cattle was considered the experimental unit for this analysis, and if multiple fecal collections occurred within the same lot of cattle, fecal

nutrients and digestibility measures were averaged before inclusion in the regression. Manual backward stepwise regression was used to generate multivariable equations to predict DMI, ADG, or G:F for each lot of cattle using information on fecal nutrients and NIRS predicted digestibility, with a p-value for bivariate association of < 0.20 suggesting a potential association. The mixed linear regression model included a random effect for feedlot and fixed effects for grain type, grain percent, processing method, processing index, F:C, sex, season, and average BW of the cattle at the time of sampling.

The correlations between all pairs of variables that were significantly associated with an outcome of interest were assessed using PROC CORR. Where variables were highly correlated ($r \geq 0.90$, $P < 0.01$), the variable from the pair with the greatest *P* value was removed before consideration in building the final multivariable model. A strong correlation ($r = 0.99$, $P < 0.01$) was only observed between aTTD of DM and aTTD of OM. The linearity assumption was examined for each of the continuous measures of fecal nutrient concentrations and digestibilities in these models. Differences were declared significant at $P < 0.05$, and trends at $P < 0.10$ for all models.

The concordance correlation coefficient (CCC) (rho; Lin 1989; 2000) was used to calculate the concordance between observed and predicted DMI, ADG, and G:F. The CCC reflects the agreement between two sets of results with a value of 1 indicating perfect agreement between the results. Differences were declared significant at $P < 0.05$, and trends at $P < 0.10$ for all models.

Results and Discussion

Accuracy of NIRS predictions of fecal samples

A pre-requisite for successful NIRS of feces is that the spectral variability of samples to be analyzed is encompassed by the calibration database (Landau et al. 2015), a requirement satisfied by the calibrations in the present study. Calibrations should not be static, but rather continuously evolve as new datasets become available. To expand previous calibrations, data selection methods such as random selection, manual selection, and discriminant analysis by wavelength selection or PCA can be used (Shenk and Westerhaus 1991). These methods recognize outlier samples that are identified using *H* (or Mahalanhobis) distances, Hotelling's T^2 distribution (WinISI 1.50, Infrasoft International, Silver Spring, MD), Global and Neighborhood distances (Ucal, Unity Scientific, 2010), and *T* statistics (Ucal), depending on the type of software employed. In the current study, we used manual selection to expand the original calibration by including a subset of commercial feedlot samples that were selected based on NIRS predicted constituent concentrations. We then examined ND in the validation set, and added samples with ND > 0.60. Prior to adding the subset of samples into the initial calibration for chemical composition, the coefficients of determination of validation (R^2_{val}) was 0.94 for fecal starch, $0.70 \leq R^2_{val} \leq 0.80$ for fecal OM, N, NDF, ADL, and $R^2_{val} = 0.25$ for fecal ADF, and EE (Jancewicz et al. 2017a). We did not perform a second validation or additional reference analysis after initial calibration expansion, but it is likely that this step improved predictability. The coefficients of determination of cross-validation increased, or remained high (except for EE), and the standard errors of cross validation did not change dramatically (Jancewicz et al. 2017a). Obviously, total tract digestibility could not be measured in commercial feedlot cattle. Consequently, all samples in the calibration set used to predict digestibility were collected from cattle housed indoors during metabolism experiments (Jancewicz et al. 2017a) and none of the commercial feedlot samples could be used to expand the digestibility calibration set.

Discriminant analysis (PCA) was used to visualize and compare spectral populations as a whole using the Hotelling's T^2 distribution. Samples outside of the defined Hotelling's T^2 ellipses were identified as outliers from the population to a confidence level of 95%. Principal component analysis demonstrated substantial overlap along PC 1 and PC 2 between the calibration set for fecal chemical composition and the samples collected from the commercial feedlots (Figure 1A). Principal components 1 and 2 explained 64% of the variation in the calibration samples, and 41% in the feedlot samples. The only samples from the feedlot dataset that were considered outliers according to the Hotelling's T^2 distribution were samples collected in January. There was much less overlap between the calibration sets for digestibility and those collected from the commercial feedlots, and two separate populations were evident (Figure 1B). The first two PCs still explained a large proportion of the spectral variability in both datasets (67% for the calibration samples, and 44% for the feedlot samples) and feedlot samples collected in January were again identified as outliers, as well as a few samples collected in November and December. It is possible that the cold temperatures that cattle were exposed to during this period may have altered the composition of feces as compared to those used in the development of digestibility equations which were all collected indoors at room temperature. This is consistent with previous work by Coates and Dixon (2011) where calibrations for predicting diet digestibility in ruminants were developed using samples collected over 10 years using various sampling methods. They demonstrated that experimental site and sampling method often had important effects on calibration statistics and performance. Landau et al (2015) also developed NIRS calibrations of feces for predicting dietary composition in beef cattle in east Mediterranean rangelands, and found that seasonal trends in pasture quality and responses to management practices impacted estimates. This would explain the differences shown in the PCA graphs

between spectra collected from metabolism studies in Jancewicz et al. 2017a, and those collected from the commercial feedlots in the current study.

Characterization of fecal samples

There is a limited number of studies where NIRS was used to predict performance in commercial feedlot cattle (Allen et al. 2011; Hussey 2012). This study is the first to examine the extent to which NIRS of the feces can be directly used to predict fecal composition, diet digestibility and growth performance of commercial feedlot cattle fed a variety of diets. The average fecal DM, and NIRS predicted fecal composition and digestibility estimates (Table 2) were comparable to estimates from a previous study (Jancewicz et al. 2017a). The previous datasets were compiled from fecal samples representing over 60 diets from both research feedlot and metabolism studies. Although none of the average fecal concentrations reported in the commercial feedlot samples appeared unusual, the largest discrepancy identified occurred with fecal NDF, which was on average 3% lower than previous estimates from research feedlot studies. This is not likely due to an error with NIRS as the average fecal NDF in a subset of these samples that were analyzed using wet chemistry was also lower than reported in previous studies (46.0 ± 8.02%; Jancewicz et al. 2016). As we did not analyze the diets that were fed to the commercial feedlot cattle, it was impossible to determine if the lower fecal NDF was a result of lower NDF intake.

The commercial feedlot fecal samples possessed individual samples with unusually low and high estimates of starch concentration. For example, 5 fecal samples had predicted starch concentrations of less than 1% starch. These samples came from separate pens collected within the same month from two feedlots that were feeding temper-rolled barley. The standard error in

the calibration for starch was 1.67%, which indicates an error of ±1.67% fecal starch DM in 68% of samples (based on a normal Gaussian distribution), and ±3.34% in 95% of the samples. In a previous study, NIRS was used to predict starch in fecal samples collected from backgrounding cattle, and if starch levels in feces were low (≤ 2%), the average C.V. for duplicate samples were much higher than wet chemistry estimates (0.33 versus 0.055; Jancewicz et al. 2016). In the finishing period, fecal starch concentrations were higher and the average C.V. for NIRS analysis were only slightly higher than wet chemistry (0.067 versus 0.053; Jancewicz et al. 2016). All of the fecal samples with starch values > 16% originated from a single feedlot that exhibited the highest processing index.

The nutrient and GE digestibility values in the 6 commercial feedlots were higher than those reported in previous studies (Jancewicz et al. 2017a) and unrealistically high (up to 100%) estimates in aTTD of GE were observed (Table 2). The reason for this high variability in prediction in field as compared to our previous research studies is unknown. In commercial feedlots, competition among cattle for feed can be intense if meal delivery is delayed or if bunk space is limiting. Competition is known to increase consumption rates and reduce eating time (Olofsson 1999), factors that can affect digestibility. Furthermore, because dominant and subordinate cattle are penned together, eating behaviours of these cattle differ from the individually housed cattle (Striklin and Gonyou 1981) that were used in metabolism studies to develop the NIRS calibrations to predict digestibility. If the feedlot manager performs sorting of cattle to various pens to ensure similar frame and body weight, and uses good practice related to bunk space and feed delivery, such variability could be reduced. Strengthening of the calibration equations through the addition of data from a broader range of digestibility studies may help improve our estimates by increasing precision.

Since the PCA graphs show different populations, it is also possible that the NIRS predictions lacked accuracy, and were over-predicting actual values. Despite the ability of NIRS to be less predictive of digestibility as compared to the chemical composition of feces, the current method has value in terms of its potential to estimate diet digestibility in group-penned feedlot cattle without using markers or total collection techniques. Jancewicz et al. (2017a) reported that even though predictions of certain digestibility coefficients using NIRS were not identical to estimates obtained from total collection, expected changes in digestibility in response to dietary changes could be predicted, illustrating the merit of this approach.

Variation in fecal chemical composition and diet digestibility among different individual cattle is important to address when attempting to predict outcomes from a population of cattle without sampling all of them. Consistent with Jancewicz et al. (2017b), where fecal starch values within a pen varied substantially, a high degree of variation was also observed in fecal starch (C.V. = 55%) in the commercial feedlot samples. In contrast, all other fecal constituents were reported to have C.V. of 12% or less (Table 2). The greatest variability in digestibility was observed for aTTD of ADF, an outcome that was attributed to the relatively poor linearity and accuracy of predicting this fecal constituent (Jancewicz et al. 2017a).

Differences between feedlots and management practices

Beef cattle performance is dependent on many factors including the initial BW, age, sex, body condition, health record (Reinhardt et al. 2009; McMeniman et al. 2010; Galyean et al. 2010), animal behaviour, hierarchical behaviour, diet, inclusion of feed additives and anabolic agents, as well as season and temperature (NASEM, 2016). Our sample size was limited (6 feedlots and 4 pens per feedlot) and therefore we did not have sufficient statistical power to

investigate interactions among production parameters. The factors that we could account for such as grain type, grain processing method, sex, season, and day were adjusted for in the analysis. Other factors such as the effects of grain inclusion rate, F:C ratio, and diet ingredients were reported as well. For example, grain percent was quite low for feedlots 1 (69.2 ± 5.08) and 6 (64.7±5.10) in relation to others (all ≥ 77.6%), with feedlot 1 also having the highest F:C ratio (0.16 versus ≤ 0.11 for the remaining five feedlots; Table 3). Without any additional information, we could expect that cattle in this feedlot would have the poorest performance because of the lower energy density of these diets. However, this was not the case as the DMI was the greatest for feedlot 1, resulting in increased energy intake. Also, the degree of grain processing and method utilized must also be considered as the least vigorous grain processing occurred in feedlot 5 (84.3±8.27; Table 3). This likely explains why cattle in feedlot 5 exhibited the lowest ($P \leq 0.01$) ADG (1.19 kg BW/d) and G:F (0.110), the highest ($P \leq 0.01$) fecal starch (11.6% of fecal DM) and the lowest ($P \leq 0.01$) fecal NDF (45.7% of fecal DM) concentration of the feedlots examined (Table 3).

There has been considerable discussion on the advantages and disadvantages of specific processing methods since the type and severity of grain processing has varying results on feeding value and feedlot cattle performance. Changes in ADG, DMI, and feed efficiency vary from significant increases, to no effect, to decreases, depending on the grain type and processing method (Theurer 1986; Owens et al. 1997; Zinn et al. 2011). Reported improvements in finishing feedlot cattle performance as a result of processing have been attributed to an increase in aTTD of starch (Owens et al. 1997; Theurer 1986; Beauchemin et al. 2001). Extensive processing maximizes starch digestibility, but is also associated with greater risk for digestive upset and can result in reductions in performance. Rapid starch digestion can cause abnormal rumen function

and variable feed intake which can lead to severe health related problems in cattle such as acidosis, bloat, laminitis, and liver abscesses (Nagaraja et al. 2007). Increasing the proportion of forage in the diet is one approach to alleviating or reducing digestive disorders in cattle (Koenig and Beauchemin, 2011). Additionally, the type and chop length of forage in the diet influence ruminal health, and therefore animal performance (Beauchemin et al 2011). This is in part due to the effect of peNDF on chewing, rumination time, and rumen pH (Bailey 1961; Beauchemin 2001; Koenig and Beauchemin et al 2011). Although we did not measure peNDF or monitor chewing rates, the differences in forage type and processing, and not just F:C or processing index of grains may have played a role in differences in fecal starch, DM digestibility, and overall performance observed.

To clarify other discrepancies, despite feedlot 1 having the lowest percentage of grain in the diet, and greatest F:C, performance was not compromised. In times of poor weather or low DMI as a result of rapid diet changes, feedlot 1 fed cattle a finishing diet with lower levels of grain for long periods of time. This occurred over the course of several sampling times, and would have resulted in the lower grain percentage and higher F:C ratio reported. Feedlot 6 always temper-rolled grain and included potatoes in the diet, both of which would increase the energy content of the diet. Feedlot 5 was the most obvious outlier, where processing index and fecal starch concentration were exceptionally high, and digestibility coefficients low, factors that likely contributed to the reduced growth performance of cattle at this location.

Many western Canadian feedlots use barley or wheat that is processed by dry or temper rolling (McAllister et al. 2011). When grain is dry-rolled, the degree of fracturing of the grain kernel is dependent on the adjustable distance between two rollers. This processing method is sufficient for barley and wheat, but can result in greater variability in particle size including the

generation of fine particles and dust (Wang et al. 2003; McAllister et al. 2011). Fines (particles less than 1 mm diameter) have been shown to increase the occurrence of digestive dysfunction due to starch digestion being too rapid, resulting in acid accumulation in the rumen (Mathison, 2000). Temper rolling involves application of water for 8 to 24 h prior to rolling, enabling more control over the degree of fracture of the kernel and reducing the generation of fine particles. Industry standards for processing index of dry rolled barley grain ranges between 65 and 82% (Yang et al. 2000), whereas temper rolled barley ranges from 70 to 95% (Beauchemin et al. 2001). Over the 13-mo period, only feedlot 5 exceeded the upper range of the recommended PI for dry rolling.

Cereal grain processing acts to increase ruminal digestion of all nutrients, especially starch, by first disrupting the pericarp (and hull in hulled grains) and secondly by reducing the grain particle size, accelerating microbial colonization and fermentation (McAllister et al. 2011). If grain is processed more vigorously, measured as a lower processing index, exposure of the starch to microbes will increase. Our results show that compared to temper rolled grain, dry rolled grain was processed less vigorously (75.4 ± 9.33 versus 66.0 ± 4.08). However, temper rolled grain has a higher moisture content (17 to 25%) and greater malleability, allowing for less severe processing. Therefore, the processing indices for the two methods should not be directly compared. As expected, cattle fed dry rolled grain had greater ($P < 0.01$) fecal starch concentrations, and lower ($P \leq 0.04$) fecal NDF, and lower ($P \leq 0.01$) aTTD of DM, OM, starch and GE (Table 4). However, those fed temper rolled grains did not differ in DMI or growth performance compared to those fed dry rolled grain. The lack of effect on performance is consistent with Bradshaw et al (1996), who found no difference in ADG and G:F of growing and finishing feedlot cattle fed tempered vs dry rolled barley. This confirms that many other factors,

in addition to nutrient digestibility impact ADG and G:F. Had we examined the interactions between feedlot, grain processing, processing method, and grain type, we may have identified other factors that contributed to differences in the growth performance of feedlot cattle.

When processing grains, we must also consider grain type as differences have been found in the responses of barley and wheat to processing (Jancewicz et al. 2017b). Size and composition of the starch granules, moisture content, size and shape of the kernels (McAllister et al. 2011), and kernel hardness (Campbell et al. 2007) can all influence the efficiency of grain processing. When barley and wheat were fed together, we observed a 2.2% increase ($P < 0.01$) in fecal starch, which may have been due to the 3.8% greater grain proportion, and 6.8% greater processing index of the grain. Despite the increase in fecal starch, and less vigorous processing, there was still an increase ($P \leq 0.02$) in aTTD of DM, OM, ADG, and G:F for cattle fed barley and wheat. Compared to barley, wheat has higher starch content [on average 10% more; based on a range of 56.5-65.6% starch in barley (Engstrom et al. 1992), and 61.6-73.9% in wheat (McAllister and Sultana 2011)], and requires less vigorous processing to expose the endosperm (McAllister et al. 2011; Jancewicz et al. 2017b). This may have contributed to the higher aTTD of DM that we observed when wheat and barley grain were fed together (Table 4). We cannot attribute increases in performance to be solely due to feeding wheat, when in fact cattle in feedlot 5 were fed both wheat and barley, but had the numerically lowest ADG and G:F. Grains differ in their ruminal availability of DM, protein, and starch. These differences could play a role in synchronizing degradation of protein and starch in the rumen that may influence microbial protein synthesis and growth performance. With similar processing, the protein and starch in wheat is more ruminally available than in barley (Herrera-Saldana et al. 1990).

We also found differences in fecal starch, digestibility and growth performance based on the sex of the cattle. Several studies have documented differences in fecal starch excretion (Caetano 2008) as well as in intake and feeding patterns (Owens et al. 1985; Hicks et al. 1990; Schwartzkopf-Genswein et al. 2002) between heifers and steers. In contrast to Caetano (2008), who found higher fecal starch in steers compared to heifers, we found a tendency ($P = 0.07$) for greater fecal starch in heifers compared to steers. We also found greater ($P = 0.05$) aTTD of DM in steers ($P \leq 0.05$), and a tendency ($P = 0.07$) for greater aTTD of GE in steers compared to heifers (Table 4). Eating behavior can affect nutrient excretion and digestibility. For example, higher intake, rate of intake, and lower feeding frequency are associated with lower digestibility. Schwartzkopf-Genswein et al. (2002) reported that heifers visited the feed bunk more frequently and spent more time there than did steers, however, Chirase et al. (1991) found that steers spent more time eating than heifers, but with a similar visitation frequency. Since we did not record feeding patterns, stocking density, or hierarchical behaviour in the current study, we can only attribute differences to data that was measured. For example, small dietary variances may have biased our results, particularly the higher processing index of grain for heifers than steers (73.5 ± 10.10 versus 68.7 ± 7.17; ignoring processing method), and the lower proportion of pens of heifers fed temper rolled grain compared to steers (59% versus 64%).

Using pen-averaged data, Owens et al. (1985) and Hicks et al. (1990) reported that steers consumed up to 3% more DM than heifers, but we found no differences ($P = 0.20$) in DMI, despite a 18.6 kg greater average BW of steers. Once again, the less vigorous processing of grain may have contributed to heifers consuming more feed so as to increase their energy consumption. As expected, steers exhibited greater ADG and G:F than heifers (Table 4). Differences in fattening patterns among sexes reflect the fact that heifers exhibit a more rapid

rate of fat deposition and fatten at a lighter weight than steers (Berg et al 1979). Even when at the same weight, heifers display a much greater percent body fat and a lower percent body protein then steers (NASEM 2016), resulting in lower gains and G:F.

Relationships between fecal starch, processing index, and G:F averaged among feedlot

When averaged by feedlot, processing index predicted fecal starch concentration using the equation: fecal starch (%, DM) = 0.36 × processing index - 18.38 (R^2 = 0.97, P < 0.01; Figure 2A). A weaker relationship (R^2 = 0.79, P < 0.01; Figure 2B) was found between fecal starch concentration and G:F. This strong linear relationship was only identified when data were averaged across feedlots, confirming that factors other than processing index and fecal starch concentration affected these predictions. Considering some feedlots feed up to 15,000 kg of grain per day, it would be difficult to always sample the exact grain at the feed mill that was fed to a particular pen of cattle. In the present study, we assumed that the grain variety and processing method would not change drastically within 1 to 2 d. The histogram of fecal starch concentration as predicted in all samples indicated that fecal starch concentration ranged from < 1 % to > 25%, with 40% of the fecal samples containing between 5 and 7% starch. If feedlot 5 was excluded from the data set due to its high processing index, the average processing index of feedlots declined from 69.6 ± 8.01% to 67.2% ± 4.96% and average concentrations of fecal starch declined from 7.0 ± 3.87% to 6.2 ± 2.96% (Figure 3). These results provide processing indices and associated fecal starch levels that can be used as a benchmark for well-processed grains in barley-based finishing diets.

Associations between and predictions of performance in lots of cattle using NIRS

The use of NIRS by the livestock industry has permitted nutritional information of the diet (primarily of grazing ruminants) to be obtained from feces, allowing researchers and nutritionists to rapidly improve management strategies. Currently most reports for predicting performance of cattle using NIRS are restricted to free-ranging cattle (Dixon and Coates 2009; Tolleson and Schaffer 2014), but recently fecal NIRS has been used to predict NEg and ADG in feedlot cattle (Jancewicz et al. 2017b). Near infrared spectroscopy calibrations have also been directly applied to finding associations between measured fecal parameters and performance, and to predicting ADG and G:F using small datasets where grain type, processing, or grain proportion were deliberately altered (Jancewicz et al. 2017b). Consistent with previous work, many associations were found between DMI, ADG, and G:F. The regression slopes and standard errors for the individual associations between cattle BW, grain percentage in the diet, fecal nutrients, aTTD of nutrients, and DMI, ADG, and G:F for lots of cattle are reported in Table 5. Increasing values of grain percent, NIRS-predicted ADL, aTTD of DM, OM (aTTD of DM and OM had correlation coefficients of r = 0.99, $P < 0.01$), and GE, were associated with decreasing values of DMI ($P \leq 0.04$). Increasing values of BW, fecal DM, NDF, and ether extract (EE) were also associated with increasing DMI ($P \leq 0.04$). For ADG, a tendency ($P = 0.08$) for a negative association was observed with fecal starch, and positive associations with fecal NDF, ADF, aTTD of CP, NDF, and GE ($P \leq 0.05$). Average BW, fecal OM, starch, and EE were negatively associated with G:F ($P \leq 0.04$). Fecal ADF, ADL, ash, aTTD of DM, OM, and GE were positively associated ($P \leq 0.04$) with G:F and there was a tendency ($P = 0.09$) for a positive association between G:F and aTTD of starch. All associations were linear, except for those between fecal starch and ADG and G:F, and between aTTD of NDF and ADG.

Digestibility coefficients including aTTD of DM, OM, and GE, were negatively associated with DMI. Apparent TTD of CP, NDF, and GE were positively associated with ADG, and aTTD of DM, OM, starch, and GE were positively associated with G:F. This result is expected, since greater digestibility would indicate more energy available to the cattle, and gains could still increase with lower feed consumption. Similar to previous work, a non-linear association was found for fecal starch and G:F, and a positive association was observed between fecal NDF and ADG (Jancewicz et al. 2017b). The reason for greater fecal NDF being associated with greater ADG is unknown, but it may simply reflect an increase in fecal NDF as the contribution of starch to fecal DM decreases.

Multivariable models including fecal chemical composition and digestibility were developed for DMI, ADG, and G:F, after randomly splitting the data set in half, ensuring equal number of heifers and steers lots were represented in each, and accounting for study design variables (Table 6). Average BW at the time of sampling was included in the regression models for both DMI and G:F, and sex was accounted for in predictions of ADG and G:F. Greater fecal NDF resulted in an increase in both DMI and ADG. The concordance between observed versus predicted DMI and ADG were poor (rho = 0.14, $P < 0.01$ for DMI, Figure 4A; and rho = 0.41, $P < 0.01$ for ADG, Figure 4B) relative to G:F (rho = 0.75, $P < 0.01$; Figure 4C). The final model for G:F incorporated BW, sex, and a quadratic term for fecal starch.

Unlike G:F, multivariable models between predicted and observed DMI and ADG displayed poor concordance or agreement. A positive linear relationship was observed for DMI, but the predicted values were about 2% greater than observed. Average daily gain depends on the energy density of the diet as well as DMI and as a result not considering these factors would be expected to generate poor predictions. It would be difficult to develop an equation to predict

DMI accurately that would encompass all diets and management conditions in commercial feedlots, since total energy intake varies considerably. However the prediction capacity of these models could be improved as more data points are added to the calibration equations. It is likely that the improved prediction of G:F is a reflection that DMI and ADG are both taken into account in the formula for G:F. Consequently, having ADG and DMI in the numerator and denominator of G:F permits us to consider both values at the same time. As reported in other work, the stage of maturity of the cattle resulted in different equations for predicting net energy, ADG, and G:F (Jancewicz et al. 2017b). In the current study, the prediction of G:F includes the average BW at the time of sampling, as well as sex, as reported in equations 1 and 2. The quadratic relationship for fecal starch implies that the maximum G:F obtained for steers and heifers weighing 550 kg, would be obtained when fecal starch levels were 4.4%.

$$G:F = 0.21-0.00010\times BW+0.0028\times fecalstarch - 0.00032\times fecalstarch^2 \text{ for steers} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$G:F = 0.19-0.00010\times BW+0.0028\times fecalstarch - 0.00032\times fecalstarch^2 \text{ for heifers} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

We have shown that fecal starch is dependent on dietary starch concentration, source of starch, degree of grain processing and DMI. Thus, a lower fecal starch concentration does not always indicate increased G:F. In fact, highly fermentable diets and extensive processing of grain increases the risk of bloat and acidosis by allowing for too rapid fermentation and increased acid production in the rumen and lower tract (Wang et al. 2012; Aschenbach et al. 2011). Currently we do not know the detailed nutrient characteristics of fecal samples collected from acidotic cattle, but fecal pH is depressed, and volatile fatty acid concentrations increased (Gressley et al. 2011; Mao et al. 2012;). As a result of damage to the gut epithelium, watery or foamy feces that

contain mucin casts are typical for identifying hindgut acidosis (Gressley et al. 2011). It is likely that fecal starch concentration will be lower than normal in these abnormal fecal samples.

Starch digestibility predicted using NIRS did not generate strong associations to ADG and G:F as fecal starch measurements, despite their close relationship. This is likely because large changes in fecal starch do not result in as large differences in aTTD of starch. Our results show that in addition to measuring fecal starch, NIRS predicted aTTD of DM or OM, and DE could also be monitored, since these values were also associated with improved growth performance.

The residual graphs depict a cone shape (Figure 5) for all performance parameters. This indicates that as more samples are collected per lot of cattle, the difference between predicted and observed performance measurements becomes less. The greatest differences between predicted and observed estimates occurred when pooled samples were collected once or twice over the feeding period from the same lot of cattle. Residuals are almost 0 when 16 pooled samples were collected over the full feeding period. It is difficult to assess results from the residual graphs since many sampling points are missing because we did not design the study to sample lots of cattle over a range of set frequencies. However, the graphs do show that as more samples were taken over the feeding period, less deviation occurred between predicted and observed values. We must consider that as sampling frequency increases, the practicality of our approach decreases, especially if samples are collected at the end of the feeding period, when predictions of G:F are no longer useful in terms of being used for immediate management decisions.

Conclusions

We have found that the composition of fecal samples can predict ADG and G:F under some circumstances, but is not a universal predictor due to the myriad of factors that can influence feedlot cattle production. Increasing the frequency of collection during the feeding period and number of fecal samples collected per pen, could be strategies to improve the predictive abilities of NIRS. However, it may not be reasonable to collect fecal samples this frequently under commercial production conditions. For feedlots that choose to keep diets and practices fairly constant, there is more value in using NIRS for predictive purposes. Using the recommendations for processing index and maximum fecal starch concentrations, combined with monitoring digestibility of DM, OM or GE and the predictive equation for G:F, it may be possible to identify poor management practices that can be alleviated so as to improve production outcomes.

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Table 1: Summary of variables associated with fecal samples collected from pens of cattle housed in six commercial feedlots over a 13-month period

Item	Feedlot[a]					
	1	2	3	4	5	6
No samples	52	52	46	51	39	42
Management[b]						
Sex	Steers	Steers and Heifers	Steers	Steers and Heifers	Steers and Heifers	Steers and Heifers
Grain	Barley	Barley	Barley and Wheat	Barley and Wheat	Barley and Wheat	Barley
Processing	Dry rolled	Temper rolled	Temper rolled	Dry and Temper rolled	Dry rolled	Temper rolled
Grain percent	58.5-73.7 (69.2±5.08)	65.1-86.5 (78.0±5.94)	52.5-88.7 (81.2±11.62)	54.7-89.7 (81.3±11.48)	62.8-85.9 (80.0±6.67)	56.7-73.7 (64.7±5.10)
F:C	0.10-0.38 (0.16±0.090)	0.08-0.19 (0.11±0.025)	0.09-0.11 (0.10±0.009)	0.07-0.11 (0.10±0.012)	0.11-0.24 (0.11±0.021)	0.10-0.23 (0.11±0.042)
PI	63.6-82.6 (70.6±6.12)	58.9-69.4 (64.7±3.48)	51.7-76.1 (66.1±5.42)	65.8-74.8 (69.5±2.63)	71.2-96.9 (84.3±8.27)	58.7-71.0 (65.8±3.52)
Ingredients[c]						
Dry rolled barley	58-74 [12]			60-85 [4]	51-86 [12]	
Tempered barley		65-85 [12]	27-89 [12]	15-88 [8]		57-74 [12]
Dry rolled wheat				10 [4]	11-17 [8]	
Tempered wheat			25-43 [6]	33-40 [4]		
Corn DDGS	12-15 [12]	7-20 [8]	10-20 [3]	20 [2]		12-20 [12]
Corn silage		7-16 [12]	9-10 [6]	4-10 [10]		5 [12]
Barley silage			6-9 [6]	4-10 [3]	10-19 [12]	
Wheat silage			10-12 [4]			
Grass silage	9-27 [12]					
Triticale silage						2.3 [12]
Straw			2 [1]	3 [1]		
Grain screenings			15 [2]	15 [2]		
M.Sprouts/Millrun				11-23 [6]		
Potatoes		3-6 [3]				5-15 [12]
Performance[b]						
BW, kg	474-680 (628±37.9)	421-687 (546±77.5)	363-636 (487±73.3)	364-614 (494±61.0)	474-740 (586±63.3)	462-599 (519±45.0)
DMI, kg DM/d	9.0-12.7 (10.7±1.05)	8.7-11.1 (10.0±0.98)	8.0-11.3 (9.5±1.04)	8.0-10.9 (10.0±0.66)	9.4-11.7 (10.7±0.78)	8.7-11.0 (9.7±0.86)
ADG, kg BW/d	1.41-1.91 (1.66±0.145)	1.36-1.74 (1.51±0.102)	1.42-1.74 (1.60±0.104)	1.24-1.78 (1.52±0.181)	0.86-1.64 (1.19±0.212)	1.43-1.76 (1.56±0.125)
G:F, kg/kg	0.14-0.17 (0.16±0.009)	0.13-0.16 (0.15±0.010)	0.14-0.18 (0.17±0.012)	0.13-0.19 (0.15±0.014)	0.08-0.16 (0.11±0.026)	0.14-0.18 (0.16±0.013)

Note: F:C = forage to concentrate ratio; PI = processing index of grain.

[a]A total of 282 fecal samples are represented in the table. Data is missing for F:C (n = 269), BW (n = 242), and grain percent (n = 272).

[b]Numbers in parentheses represent the mean ± standard deviation

[c] Numbers in square brackets represent the frequency out of 12 months that each ingredient was fed.

Table 2: Simple descriptive statistics for fecal DM and NIRS predicted fecal composition and apparent total tract digestibility derived from pen composite fecal samples collected from feedlot cattle fed in six commercial feedlots (n=282 pens) over a 13 month period

Item	Measurement[1]			
	Mean±SD	C.V. (%)	Min	Max
Fecal composition, % of fecal DM				
Dry matter	18.9±2.31	12.2	13.6	27.0
Organic matter	83.8±3.58	4.27	67.5	89.4
Starch	7.0±3.87	55.3	0.00	25.1
Nitrogen	2.36±0.215	9.11	1.83	3.00
Neutral detergent fiber	50.4±4.78	9.48	33.2	60.5
Acid detergent fiber	29.3±3.18	10.8	19.9	36.2
Acid detergent lignin	5.41±0.939	17.3	3.29	8.03
Ether extract	1.50±0.183	12.2	0.849	1.912
Digestibility, % of intake				
Dry matter	82.0±3.28	4.00	70.4	89.2
Organic matter	81.6±3.53	4.32	70.0	89.3
Starch	95.0±2.14	2.25	86.2	99.5
Crude protein	77.6±3.04	3.92	68.4	85.0
Neutral detergent fiber	62.0±3.56	5.74	53.5	73.5
Acid detergent fiber	46.9±5.10	10.9	27.8	63.6
Gross energy	88.0±5.19	5.90	74.6	100

Note: SD = standard deviation; C.V. = coefficient of variation (SD/mean)

Table 3: Comparisons of NIRS predicted fecal starch and NDF, digestibility of DM and OM, performance, and management strategies among six commercial feedlots over a 13 month period (n=282) with the least squared means reported and standard error in parentheses.

Item	Feedlot[a]						*P* value
	1 (n=52)	2[b] (n=51)	3 (n=46)	4 (n=51)	5 (n=39)	6[c] (n=42)	
Management							
Grain %	69.2 (1.209)c	77.6 (1.317)b	80.7 (1.363)ab	81.4 (1.26)a	80.7 (1.49)ab	64.6 (1.63)d	<0.01
F:C	0.16 (0.006)a	0.11 (0.005)b	0.096 (0.0066)b	0.10 (0.006)b	0.11 (0.008)b	0.11 (0.007)b	<0.01
PI	70.7 (0.77)b	64.6 (0.89)c	65.4 (0.90)c	69.4 (0.82)b	84.2 (0.98)a	65.6 (0.98)c	<0.01
Processing methods	Dry rolled	Temper rolled	Temper rolled	Dry/Temper rolled	Dry rolled	Temper rolled	n/a
Composition, % of fecal DM							
Starch	7.90 (0.449)b	4.84 (0.494)c	5.46 (0.509)c	7.53 (0.471)b	11.60 (0.555)a	5.20 (0.544)c	<0.01
Neutral detergent fiber	50.6 (0.63)ab	51.0 (0.72)ab	51.5 (0.73)ab	52.4 (0.67)a	45.7 (0.80)c	50.1 (0.79)b	<0.01
Digestibility, % of intake							
Dry matter	79.9 (0.41)c	82.4 (0.44)b	83.8 (0.46)a	82.9 (0.43)ab	79.7 (0.51)c	82.7 (0.49)b	<0.01
Organic matter	79.4 (0.47)c	81.4 (0.51)b	83.4 (0.53)a	83.1 (10.49)a	80.9 (0.58)b	80.9 (0.56)b	<0.01
Starch	94.3 (0.30)bc	95.4 (0.33)a	95.6 (0.34)a	95.5 (0.31)a	93.8 (0.37)c	95.1 (0.37)ab	<0.01
Gross energy	86.9 (0.66)c	88.8 (0.67)b	90.9 (0.71)a	87.1 (0.67)bc	83.7 (0.78)d	90.5 (0.73)a	<0.01
Performance							
BW, kg[d]	629.9 (9.15)a	550.3 (10.59)c	491.7 (10.54)d	489.9 (9.69)d	583.2 (12.05)b	520.0 (20.60)cd	<0.01
DMI, kg/d	10.7 (0.14)a	10.1 (0.17)bcd	9.69 (0.170)d	9.96 (0.152)cd	10.5 (0.18)ab	9.94 (0.184)cd	<0.01
ADG, kg/d	1.66 (0.022)a	1.52 (0.027)bc	1.60 (0.027)ab	1.51 (0.025)c	1.19 (0.029)d	1.56 (0.030)bc	<0.01
G:F, kg/kg DM	0.155 (0.0022)bc	0.151 (0.0026)bc	0.167 (0.0026)a	0.151 (0.0023)c	0.115 (0.0028)d	0.159 (0.0028)b	<0.01

Note: F:C = forage to concentrate ratio; PI = processing index of grain. Values with lowercased letters represent significant differences ($P < 0.05$).

[a]A total of 282 fecal samples are represented in the table. Data is missing for F:C (n = 269), BW (n = 242), and grain percent (n = 272). Numbers in parentheses represent the standard error of the mean.

[b]Included potatoes as a source of starch during 3 of the sampling days

[c]Included potatoes as a source of starch all year

[d]Average body weight of cattle in pens at time of sampling

Table 4: Comparisons of NIRS predicted fecal starch and NDF, digestibility of DM, OM, performance, and management strategies for dry rolled grain versus temper rolled, barley versus barley and wheat diets, and heifers versus steers (n=282) with standard error of the mean shown in parentheses.

Item	Processing Method		
Management	DR (n=107)	TR (n=174)	*P* value
Grain %	75.6 ± 8.39	76.4 ± 11.35	
F:C	0.134 ± 0.0675	0.106 ± 0.0247	
PI	75.4 ± 9.33	66.0 ± 4.08	
Composition, % of fecal DM			
Starch	10.4 (0.64)	6.5 (0.55)	<0.01
NDF	46.5 (1.25)	49.2 (1.09)	0.04
Digestibility, % of intake			
DM	80.0 (0.58)	82.9 (0.50)	<0.01
OM	80.1 (0.75)	82.4 (0.64)	0.01
Starch	93.4 (0.39)	94.9 (0.33)	<0.01
GE	85.8 (1.05)	89.3 (0.91)	<0.01
Performance			
BW, kg	593.7 ± 68.82	511.2 ± 74.64	
DMI, kg/d	10.2 (0.25)	10.0 (0.21)	0.50
ADG, kg/d	1.47 (0.074)	1.53 (0.070)	0.22
G:F, kg/kg DM	0.146 (0.0079)	0.150 (0.0076)	0.32
	Grain type		
Management	B (n=202)	BW (n=79)	*P* value
Grain %	75.0 ± 9.59	78.8 ± 11.40	
F:C	0.123 ± 0.0563	0.103 ± 0.0125	
PI	67.7 ± 5.64	74.5 ± 10.74	
Composition, % of fecal DM			
Starch	7.2 (0.50)	9.4 (0.66)	<0.01
NDF	47.6 (1.03)	48.1 (1.15)	0.54
Digestibility, % of intake			
DM	80.8 (0.50)	82.1 (0.57)	0.02
OM	80.3 (0.63)	82.1 (0.73)	<0.01
Starch	94.2 (0.35)	94.2 (0.39)	0.89
GE	87.6 (0.87)	87.5 (0.99)	0.92
Performance			
BW, kg	562.2 ± 81.42	510.9 ± 75.10	
DMI, kg/d	10.1 (0.20)	10.1 (0.22)	0.83
ADG, kg/d	1.46 (0.068)	1.54 (0.071)	<0.01
G:F, kg/kg DM	0.144 (0.0075)	0.151 (0.0077)	<0.01
	Sex		
Management	Heifer (n=53)	Steer (n=228)	*P* value
Grain %	76.5 ± 9.47	76.0 ± 10.48	
F:C	0.114 ± 0.0318	0.118 ± 0.0518	
PI	73.5 ± 10.10	68.7 ± 7.17	
Composition, % of fecal DM			
Starch	8.9 (0.65)	8.0 (0.50)	0.07
NDF	47.4 (1.14)	48.3 (0.98)	0.20
Digestibility, % of intake			
DM	81.0 (0.59)	81.9 (0.45)	0.05
OM	80.9 (0.74)	81.5 (0.57)	0.29
Starch	94.0 (0.42)	94.4 (0.31)	0.21
GE	86.9 (0.99)	88.1 (0.81)	0.07
Performance			
BW, kg	530.8 ± 82.96	549.4 ± 82.64	
DMI, kg/d	10.0 (0.21)	10.2 (0.19)	0.20
ADG, kg/d	1.45 (0.070)	1.55 (0.068)	<0.01
G:F, kg/kg DM	0.142 (0.0077)	0.153 (0.0075)	<0.01

Note: F:C = forage to concentrate ratio; PI = processing index; B = barley; BW = barley and wheat. Numbers in parentheses represent the standard error of the mean. Diets containing potatoes were only included in temper rolled and barley diets.

Table 5: Linear regression equation coefficients examining the individual associations between near infrared spectroscopy predicted fecal constituent concentrations, digestibilities, and observed growth performance of feedlot cattle (n=90 groups) housed within 6 commercial feedlots.

Equation Variables				
Dependent	Independent	Coefficient/slope (β)	SE	*P*
DMI, kg/d	BW	0.0091	0.00098	<0.01
	Grain%	-0.025	0.0107	0.02
	DM[a]	0.105	0.0565	0.06
	NDF	0.057	0.0279	0.04
	ADL	-0.33	0.121	<0.01
	EE	1.60	0.705	0.03
	aTTD of DM	-0.11	0.037	<0.01
	aTTD of OM[c]	-0.094	0.0340	<0.01
	aTTD of GE	-0.051	0.0246	0.04
ADG, kg/d	Starch[b]	-0.010	0.0058	0.08
	NDF	0.012	0.0048	0.01
	ADF	0.016	0.0073	0.03
	aTTD of CP	0.023	0.0071	<0.01
	aTTD of NDF[b]	0.012	0.0057	0.04
	aTTD of GE	0.0087	0.00433	0.05
G:F kg/kg	BW	-0.00010	0.000030	<0.01
	OM	-0.0012	0.00052	0.03
	Starch[b]	-0.0014	0.00057	0.02
	ADF	0.0021	0.00070	<0.01
	ADL	0.0043	0.00204	0.04
	EE	-0.030	0.0117	0.01
	aTTD of DM	0.0021	0.00063	<0.01
	aTTD of OM	0.0012	0.00058	0.04
	aTTD of starch	0.0017	0.00101	0.09
	aTTD of GE	0.0015	0.00040	<0.01

Note: aTTD = apparent total tract digestibility.
[a] Fecal DM was determined using actual DM and not NIRS predictions.
[b] There was a non-linear association between independent variable and performance addressed by the introduction of a squared term into the model.
[c] correlated with aTTD of DM r=0.99.

Table 6. Multivariable regression equation coefficients examining the joint associations between near infrared spectroscopy predicted fecal constituents, digestibilities, and observed performance of feedlot cattle (n=45 pens) in 6 commercial feedlots.

Equation Variables[2]				
Dependent	Independent	Coefficient/slope (β)	SE	*P*
DMI, kg/d	Intercept	21.6	7.94	0.04
	BW	0.0096	0.00127	<0.01
	NDF	0.10	0.038	0.01
	aTTD of OM	-0.23	0.094	0.02
ADG, kg/d	Intercept	0.22	0.396	0.60
	Heifer	-0.18	0.064	<0.01
	Steer	0		
	NDF	0.026	0.0077	<0.01
G:F, kg/kg	Intercept	0.21	0.017	<0.01
	BW	-0.00010	0.00029	<0.01
	Heifer	-0.019	0.0053	<0.01
	Steer	0		
	Starch	0.0028	0.00167	0.10
	Starch*Starch[a]	-0.00032	0.000095	<0.01

Note: aTTD = apparent total tract digestibility.
[a]There was a non-linear association between Starch and performance in two of the models addressed by the introduction of a squared term into the model.

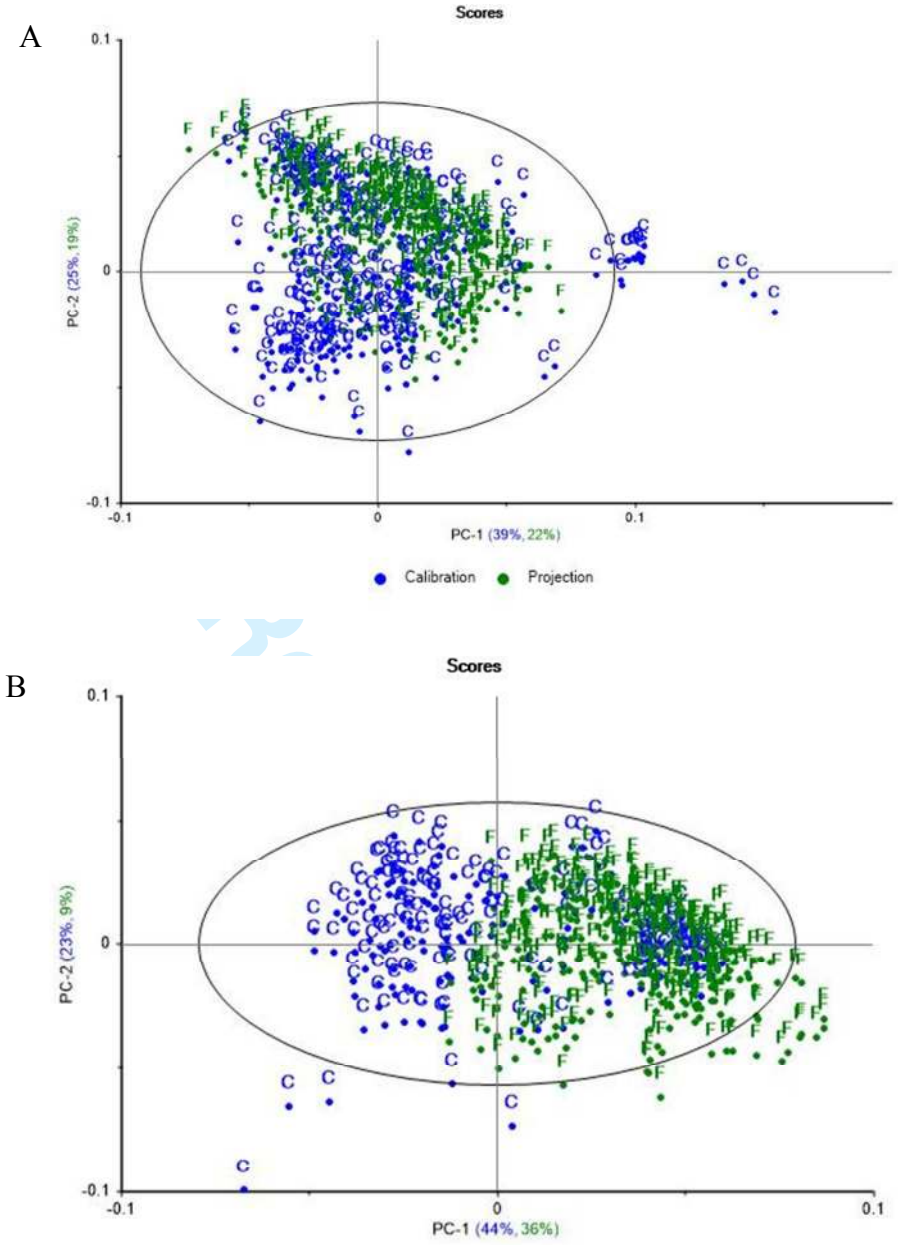

Figure 1: Principal component graph displaying the spectra of fecal samples collected from commercial feedlots over a 13 month period in relation to the fecal samples in the NIRS calibration set for chemical composition along the first two principal components (A); and the spectra of fecal samples collected from six commercial feedlots over a 13 month period in relation to the fecal samples in the NIRS calibration set to estimate digestibility along the first two principal components (B). Samples outside of the defined Hotelling's T^2 ellipses are considered outliers from the population to a confidence level of 95%.

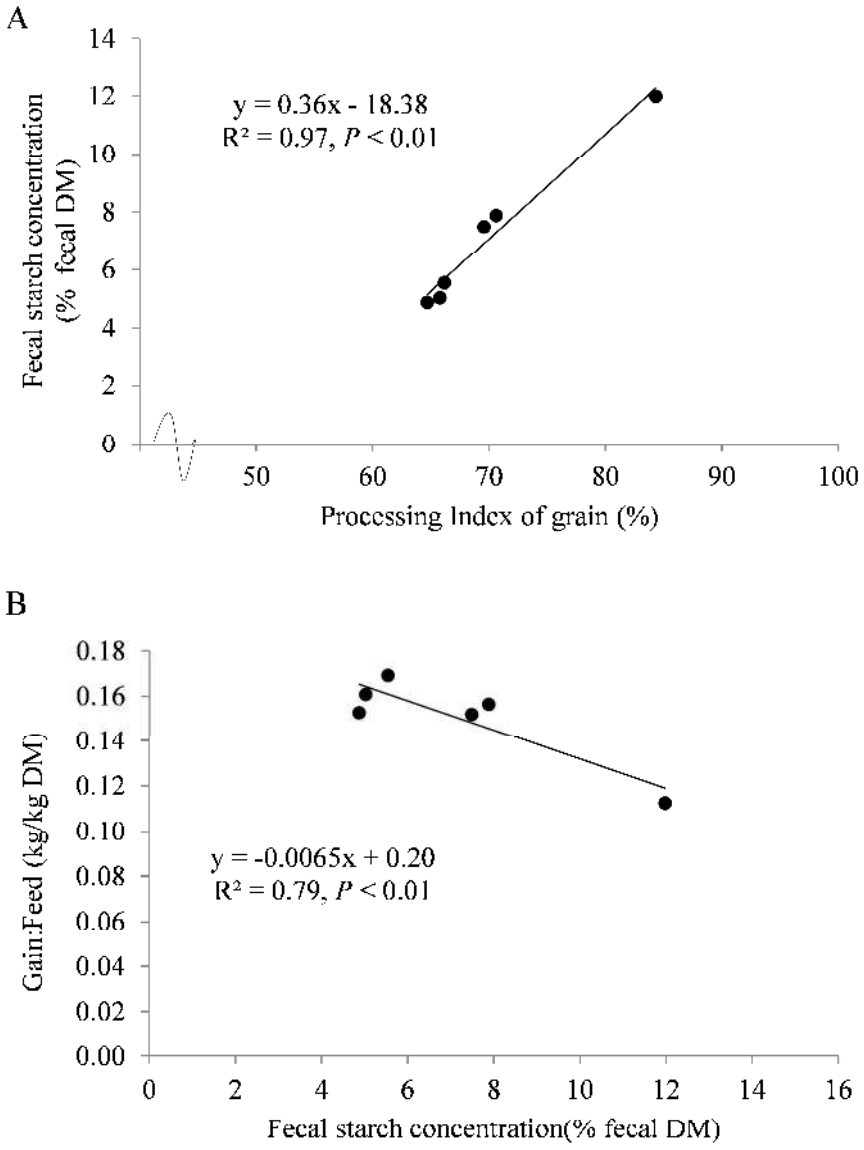

Figure 2. Relationship between processing index and fecal starch concentration (A); and fecal starch concentration and gain:feed (B), when fecal samples collected monthly from six feedlots are averaged over 13 months.

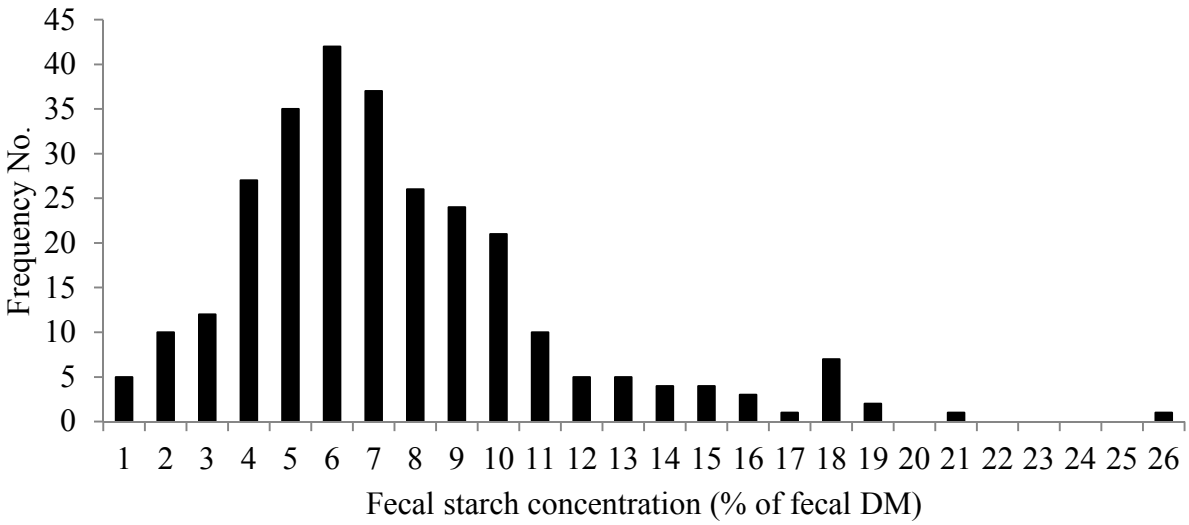

Figure 3: Histogram of NIRS predicted fecal starch concentration found in pooled feces collected monthly from 4 animals per pen from 6 commercial feedlots over a 13 month period. The mean and standard deviation was 7.0 ± 3.86%.

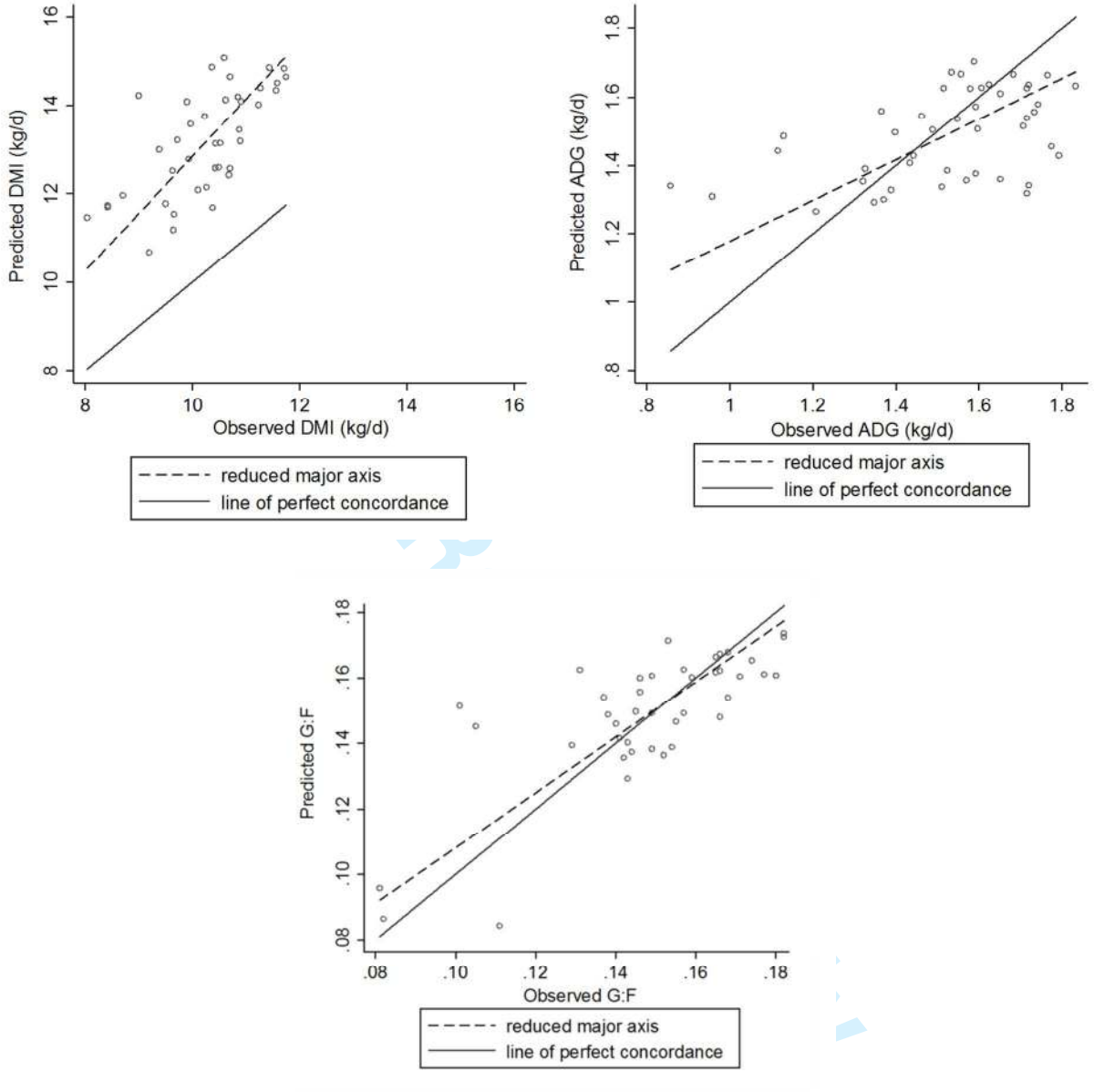

Figure 4: Observed versus predicted graphs for DMI (top left); ADG (top right); and G :F (bottom). Concordance correlation coefficients (Lin, 1989, 2000) are rho=0.145 (SEM = 0.036), P<0.01, Pearson's r = 0.702. Average difference=2.94 for DMI, rho=0.416 (SEM = 0.106), P<0.01, Pearson's r = 0.481. Average difference=-0.032 for ADG, and rho=0.753 (SEM = 0.067), P<0.01, Pearson's r = 0.764. Average difference=0.001 for G :F.

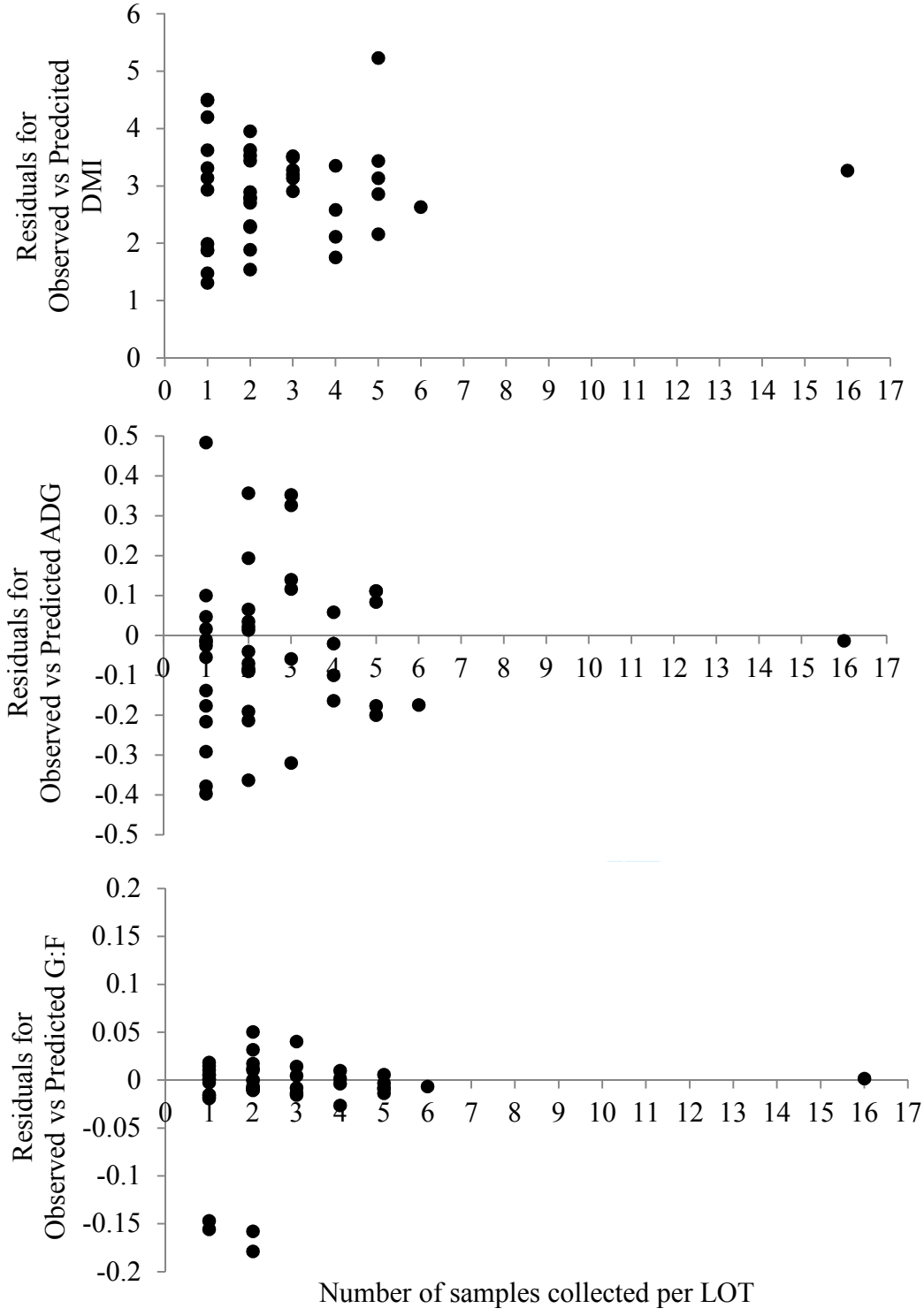

Figure 5: Residuals (Predicted – Observed; y-axis) for each group of cattle with the number of samples collected per group displayed on the x-axis for DMI, ADG, and G:F (in order from top to bottom).