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Does a NIR system provide low-cost alternative to on-farm feed and forage testing? A Techno-economic analysis

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ABSTRACT. *Improperly balanced diet not only impacts the quality of animal products but also the quantity of profits of a livestock operation. Typically, the nutrient and chemical content of feed ingredients and forages are determined using well-established wet chemistry tests. However, these tests can be expensive and time-consuming. Moreover, the increasing use of distiller's by-products which are known to have large variations in chemical and nutrient content warrants a real-time on-farm feed and forage testing system. Near Infra-Red (NIR) spectroscopy systems have been documented as a quick and effective on-site testing tool across several industries. While NIR systems are being adopted for on-farm feed and forage testing, very little is known about the economic impacts of such an investment for a livestock operator. This study developed a baseline model and an excel based spreadsheet application for performing Return On Investment (ROI) analysis to determine the feasibility of using an on-farm NIR testing system. ROI was calculated based on the nutrient cost saved or spent determined from the difference of estimated nutrient content and actual calculated value. Assumptions were made for the cost of NIR system, calibration and labor expenses. What-if analyses were also performed to determine the impact of variation in nutrient content on the ROI. The finding of this study will help promote low-cost alternatives for on-farm feed and forage testing, thus positively impacting the quality of animal product and minimizing costs.*

Keywords. *data analytics, feed processing, nutrient management, what-if analysis, spectroscopy, testing.*

Introduction

The impact of feed rations on the yield of the animal products as well as the profitability of the livestock operation have been well documented (Ball et al., 2001; Palmquist, Beaulieu, & Barbano, 1993; Pesti & Miller, 1997; Sova, LeBlanc, McBride, & DeVries, 2014). Yet, the feed rations formulated on-farm have been found to be significantly different from the original specifications (Sova et al., 2014). One main reason for this inconsistency of the feed rations is the variation in the nutrient content of the individual ingredients that make up these feed ration (Mikus & Diamond, 2012). While nutrient variation in traditional ingredients such as corn, soybean and other grains are minimal, most of the variations in feed rations are due to the increased usage of Biofuels by-products and other "poorly defined" ingredients (Weiss, 2004). For example, the variation of fat content in by-products such as distillers dried grains with solubles (DDGS) is five times that in corn, and that of crude proteins in DDGS is 16 times than that in corn (Belyea et al., 2010; Belyea, Rausch, & Tumbleson, 2004; Kajikawa et al., 2012).

Variation in the individual nutrient content results in the livestock consuming a feed ration that is quite different than what is prescribed by the nutritionist (Sova et al., 2014). Feeding animals with a diet that is deficient or excessive have huge costs implications (Weiss, 2004). Insufficient nutrients reduce animal products yield while excessive nutrients are money wasted (Belyea et al., 2004). Since feed costs are the biggest expense of any livestock operations, compensating for nutrient deficiencies and excesses could push these costs even higher (Beever & Doyle, 2007; Belyea et al., 2010; Sova et al., 2014). Hence, this variation in nutrient contents must be appropriately measured and controlled.

The chemical composition of feed rations is typically determined by using either well-established wet chemistry tests or by Near Infrared Spectroscopy (NIR) (Ball et al., 2001; Cozzolino & Moron, 2004; Givens & Deaville, 1999). Conventional wet chemistry analysis is time-consuming, labor-intensive and expensive (Osborne, Fearn, & Hindle, 1993). In contrast, NIR is a quick analytical testing alternative successfully used for on-site testing in food, bio-products and bio-energy industries worldwide (Kulmyrzaev, Karoui, De Baerdemaeker, & Dufour, 2007; Lorenzo, Garde-Cerdán, Pedroza, Alonso, & Salinas, 2009; Schut et al., 2006). Several previous works have highlighted the effectiveness of NIR testing in determining nutrients and chemical content of feed (Cozzolino & Moron, 2004; Deaville & Flinn, 2000; Harding, 2014). Yet, very little work has explored the techno-economic aspects of using a NIR system for on-farm feed testing.

The aim of this study is to establish the baseline economics for using the NIR system to test feed rations formulated on the farm. A return on investment (ROI) analysis was performed to determine if the investment to purchase the NIR system and its operating costs can be offset by the savings in feed costs. The time-frame used in this for the ROI analysis was two years. This study also developed a Microsoft excel based spreadsheet where user can input various costs and determine the feasibility of using an on-farm NIR testing system. The difference in costs of feed based on the variation in nutrient content (i.e. supplier specified vs. actual) as measured by the NIR system were used to calculate the return on investment. Appropriate assumptions were made for the cost of the NIR system, the calibration, and the labor expenses.

This study will help promote the benefits of using on-farm NIR systems for rapid and inexpensive feed nutrient and chemical analysis. Rapid and inexpensive testing are important to measure the daily difference in feed composition based on the actual and expected values. The findings of this study will positively impact the quality of the animal products and help minimize the costs for a livestock operation.

Background

DDGS are the main by-products of ethanol plants that use dry-milling to grind the raw material (Shurson & Noll, 2005). The rapid growth of the Biofuels industry in the last decade has also enabled extensive marketing and use of DDGS in animal feed (Wood, Rosentrater, & Muthukumarappan, 2014). Besides availability, the fact that DDGS costs can sometimes be lower than the cost of the grain is also a factor for its increasing adoption in feed rations (Kim et al., 2008). Since feed costs are the single largest variable cost associated with livestock operations, substituting high-cost ingredients with less expensive DDGS helps maximize profits. While DDGS has similar nutrients when compared to grains like in corn or soybean, the major challenge is the variation of these nutrients in DDGS. Feed-rations prepared by substituting corn or soybean with DDGS would be highly economical. However, the wide variation in feed nutrients in DDGS could add other challenges such as; over-use to avoid nutrient deficiency, or use fewer nutrients feed that causes a decrease in animal product yield (Belyea et al., 2010; Belyea et al., 2004). Wide variation in nutrient content, moisture levels and nutrient excesses and deficiencies are key limitations of using ethanol co-products (Bernard, 2013; Mathews Jr & McConnell, 2009).

On-farm feed rations are formulated by mixing ingredients such as grains, DDGS, and other ingredients to achieve a certain proportions of the dry matter (DM), crude protein (CP), fiber, total digestible nutrients (TDN) and the net energy content (Rasby, Kononoff, & Anderson, 2008; Stallings, 2009). Most feed rations mixed on-farm are balanced using average values or “book values” indicated by the feed tag provided by the respective ingredients supplier (Bernard, 2013; Rasby et al., 2008). Since, book values are mostly indicative and are not an accurate reflection of nutrient concentration, balancing feed rations by average nutrient values alone can result in over or under feeding of certain critical nutrients (Rasby et al., 2008). Nutritional quality of on-farm formulated feed can only be determined by testing (Undersander, 2007). Important parameters that determine feed quality are: dry matter, pH, crude protein, available protein, nitrogen content, acid detergent fiber (ADF), neutral detergent fiber (NDF), Amino acids such as Lysine and ash (Ball et al., 2001; Rasby et al., 2008; Undersander, 2007). According to Baltrop et al. (2012), the availability of accurate, reliable and reproducible analytical data is imperative for determining proper feed formulation and quality. Methods used for feed analysis are a physical or sensory evaluation, traditional wet chemistry and nondestructive tests using near infrared spectroscopy (Ball et al., 2001; Fulgueira, Amigot, Gaggiotti, Romero, & Basílico, 2007; Rasby et al., 2008).

Physical Testing

Physical evaluation of feed is based on sensory perceptions of smell, sight, and touch (Cherney & Hall, 2000; Fulgueira et al., 2007). Physical testing is highly subjective but provides some general information on physical parameters such as color, maturity, order, purity and palatability (Fulgueira et al., 2007). Though physical testing is quick and easy, it has significant limitations in determining feed and forage quality. Cherney & Hall (2000) stated that when forage producers were asked to rank hay bales based on a visual appraisal, a good majority of them picked the bale that ranked lowest in relative feed value (RFV) determined by more objective chemical analysis. Hence assessment by physical evaluation remains highly subjective and is very difficult to standardize (Schroeder, 2004).

Wet Chemistry Testing

Traditional chemical analysis is presently the most widely used method for determining the nutritive value of feed (Ball et al., 2001; Cherney & Hall, 2000; Fulgueira et al., 2007). Wet chemistry testing uses standardized well-established methods that involve chemical, drying and burning procedures to determine quantity of protein, fiber, fat and minerals (Fulgueira et al., 2007; Stallings, 2009)

The nutritional components typically evaluated by these tests are: Dry Matter (DM) which is a measure of amount feed that is not water; crude protein (CP) which is a measure of all forms of nitrogen including nitrates, amino acids, non-protein nitrogen and nitrogen in the form of protein; fibers in feed and forage a measure important in preparing feed rations for ruminants; fats and minerals (Ball et al., 2001; Newman, Lambert, & Muir, 2006). The measures for energy such as net energy (NE), total digestible nutrients (TDN) and relative feed value (RFV) are calculated from core analyses (Stokes & Prostko, 1998)

The concentration of nutrients are typically expressed as a percentage either on actual “as-is” basis or on dry matter (DM) basis (Ball et al., 2001; Stallings, 2009). Nutrient values in the feed industry are typically expressed in “as-is” basis on the feed tag which is always less than the value on dry matter basis (Stallings, 2009). Hence, it is critical to interpret the nutrient concentration values correctly when preparing feed formulations.

Chemical analysis of feed and forage nutrients provide the most accurate results but take a considerable amount of time to complete (Fulgueira et al., 2007). According to Berzaghi et al. (2011), even in best case scenario chemical analysis of feed and forage takes anywhere from a few days to a few weeks potentially resulting in the feed and forage consumed before the tests results arrive. Also tests need to be done with multiple samples frequently to profile a complete silo of feed and forage, which could impact operating costs. In the last few years, nondestructive testing methods such as Near Infrared Spectroscopy (NIR) has gained popularity for feed testing due to its rapid and inexpensive characteristics (Fulgueira et al., 2007; Givens & Deaville, 1999; Rasby et al., 2008; Undersander, 2007)

Near Infrared Spectroscopy (NIR) testing

Chemical analysis of feed is time consuming and expensive. Near Infrared Spectroscopy (NIR) is a non-destructive testing method that combines spectroscopy, statistics and computing to provide nutritional information in a very short amount of time (Fulgueira et al., 2007). This method uses near infrared region of electromagnetic spectrum i.e. from 800nm to 2500 nm to estimate the chemical concentration of feed and forage (Undersander, 2007). Over the last few years, NIR instruments have has been perfected to quickly, economically and accurately measure nutrient content of the feed and forage samples (Stallings, 2009). One major advantage of this method is that it is non-destructive with minimal or no requirement for sample preparation (Fulgueira et al., 2007). In 2002 the National Forage Testing Association approved NIR testing method as accepted and accurate method of feed analysis. Recent improvements and evolution of NIR instruments have reduced the size and weight of these instruments and are easily portable (Berzaghi, Serva, Piombino, Mirisola, & Benozzo, 2010). Despite numerous advantages and applicability of this method, limited research has thus far evaluated the technical and economic feasibility of using NIR in testing no-farm feed formulations.

Material and Methods

Technical analysis to assess the feasibility of using a NIR machine was conducted using the review of research literature. For the economic evaluation, a Microsoft Excel based spreadsheet analysis was used. The data for nutrient concentration and variation was collected from the data published by Dairy One Labs located in Ithaca New York. The University of Missouri Extension's by-product feed price listing website was used to collect the latest prices of various commonly used feed ingredients. This study collected nutrient variation and feed data for the following 23 types of ingredients: corn, barley, wheat, soybean (dry), soybean meal, soybean (roasted), extruded soy, cottonseed, oats, dry distillers grain, distillers condensed soluble, corn gluten feed, corn gluten meal, blood meal, meat meal (dry), meat and bone meal, fish meal (dry), alfalfa cubes, linseed meal, animal byproducts (wet), animal byproducts (dry), potato byproduct, soy byproduct. The initial fixed cost for buying an NIR system was assumed to be $25,000 based on the prices of some of the popular models in the market. The variable cost was calculated based on the data from Iowa State University Grain Quality Lab test and fees webpage. The details are shown in Table 1.

Table 1. NIR fixed and variable cost

Fixed cost	
Cost of NIR system	$25,000.00
Initial cost of calibration	$5000
Total fixed cost	$ 30,000.00
Variable costs	
Labor / hr.	$15.00
Labor/Sample	$0.67
Labor for 10 Samples	$6.67
Calibration verification for 10 samples	$10.00
Subtotal/truck	$16.67

Assumptions: 10 samples tested each hour

Ten samples per truck load

Economic Model Design

The Microsoft Excel model consisted of three parts. The first part consisted of price values for protein, dry matter and Total Digestible Nutrients (TDN) for all 23 feed ingredients calculated based on the mean and standard deviation values. A typical livestock operation sources feed based on the guaranteed tag value of protein, dry matter, and TDN. However, data published by Dairy One Labs suggested that there is a considerable variation in the nutrient composition from the guaranteed tag value. When the composition of nutrient values is greater than the tag value less quantity of that feed which results in lowering cost of feed. In this project, the variation of one standard deviation above the mean was used as a criterion for calculating the savings if feed cost.

The second part of the spreadsheet consists of NIR fixed costs and variable costs data. An assumption was made that the number of samples required to test a truckload of raw material was ten samples. Based on this the variable cost for testing samples for each truckload was calculated. The sum of fixed and variable cost was used as the required break even value. The third part of the spreadsheet consists of the breakeven analysis for each of the ingredients protein, dry matter, and TDN. A what-if analysis was performed in five truckload increments for each of the three ingredients.

Calculating ROI is the main objective of the whole program, the cost of ingredients, fixed cost of NIR and variable cost can all be user input and the program would automatically calculate the ROI for each ingredient based on the variation in protein, dry matter, and TDN. The model used to calculate the ROI is shown in Figure 1 below.

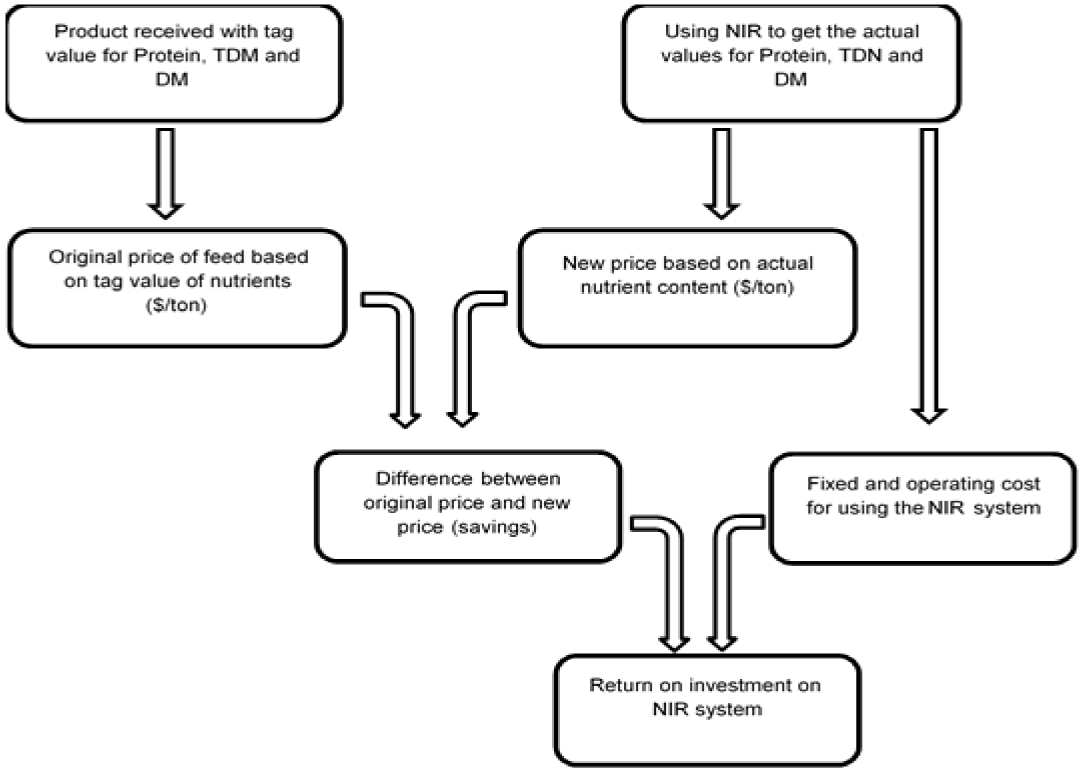

Figure 1: Return on Investment Model (ROI)

Results and Discussion

To determine if the NIR systems can provide reliable information to measure variation in nutrient composition, a review of research literature was conducted. The review focused on studies that used NIR systems to measure either feed or forage. Also, the emphasis was on studies that used on-farm portable instruments. The literature review was by no means extensive since the primary goal was to validate if there is sufficient evidence suggesting the use of NIR systems for on-farm applications. The studies listed in the Table 2 below suggest that NIR systems can predict the nutrient components of a variety of feed samples with the fairly high degree to accuracy.

Since it is technically possible to use NIR system for onsite and on-farm feed nutrient analysis, the economic aspect becomes necessary. To evaluate the economic aspects of using a NIR system, a Microsoft Excel based spreadsheet analysis was used.

Table 2. *Literature Review results*

Study	Instrument	Type of feed	Measured components
Berzaghi et al.(2010)	Zeiss Corona 45 NIR	Maize Silage	Crude protein and fiber
González-Martín et al.(2007)	Foss NIR Systems 5000-6500	Various animal feed and fodder	Crude protein , ether extract and fiber
Cozzolino et al.(2004)	Foss NIR Systems 5000-6500	Maize Silage	Dry matter, crude protein , fiber, and pH
Shen et al. (2016)	Spotlight400, Perkin Elmer	Soybean meal	Non-protein nitrogen

Typically, the incoming feed quality is assessed based on the specification mentioned in the feed tag. It is common industry practice to price feed based on the percentage of certain nutrients in the feed, especially in the case of co-products. The Excel program developed enables the user to enter the prices per ton for each type of feed. Users then enter the tag value of the nutrients components. The spreadsheet is pre-programmed with standard deviations for each type of feed so users can get an idea of how much the tag values can vary.

Once the price and tag values are entered for each feed ingredient the spreadsheet calculates the deviations from the mean values. Large deviations from the average values would result in less quantity of feed used to achieve the balanced diet. This is translated into savings that are calculated by the spreadsheet program.

The savings amount is calculated for one standard deviation increase from the mean. When the feed has more than the specified amount of nutrient, then less quantity of that ingredient is required. The difference in quantity is multiplied by unit price shown in Table 2, to calculate the cost savings. This savings amount is then multiplied with the probability that there is at least one standard deviation from the mean. Based on the normal distribution there is a 16% chance that the nutrient content is at least one standard deviation above the average. In other words, one out of every seven truck loads of a particular ingredient would contain ingredient where the nutrient content is at least one standard deviation above the mean.

Results showed that the savings per truckload when the ingredients are at least one standard deviation above the average are greatest for fish meal followed by potato by-product and soy byproducts. The lowest savings were for grain based feeds like corn, wheat and barley. The amount of savings per truckload of each feed type was then used to conduct a what-if analysis for calculating the ROI. Increments of five were used to calculate the number of truckloads of each feed type is required to break even

For this study variation in only protein, dry matter and TDN only were considered as they are the top three metrics considered for balancing feed rations. The cost, average nutrient values and the results of the ROI analysis for protein, dry matter and total digestible nutrients (TDN) are shown in the below Table 3 and Tables 4.

Table 3: Unit cost, average and standard deviation of nutrients

Ingredient	Original price/ton	Average protein	Std. Dev (SD)	Average Dry Matter (DM)	Std. Dev (DM)	Average TDN	Std. Dev (TDN)
Corn	$150	9.0%	1.5%	88.9%	3.5%	88.1%	2.3%
Barley	$160	11.9%	2.3%	89.5%	2.6%	80.9%	3.4%
Wheat	$170	13.6%	2.6%	89.0%	1.8%	83.8%	2.6%
Soybean (Dry)	$403	39.9%	5.0%	92.7%	3.0%	97.5%	4.2%
Soybean Meal	$630	51.2%	4.8%	90.3%	2.2%	80.0%	4.1%
Soybean (roasted)	$725	40.5%	3.8%	93.3%	2.4%	97.6%	4.6%
Extruded Soy	$500	44.4%	4.4%	92.4%	2.8%	93.9%	6.5%
Cottonseed	$275	24.3%	4.3%	91.4%	2.1%	77.2%	10.6%
Oats	$150	12.5%	2.0%	90.1%	1.9%	80.3%	5.1%
Distillers Condensed Soluble	$225	20.4%	5.4%	32.0%	9.9%	99.4%	14.4%
Corn Gluten Feed	$160	24.0%	7.2%	89.2%	2.6%	73.3%	2.7%
Corn Gluten Meal	$610	67.1%	8.2%	90.9%	2.1%	87.0%	3.1%
Blood Meal	$900	99.7%	7.6%	90.0%	2.5%	72.0%	3.1%
Meat Meal (dry)	$385	57.2%	3.0%	95.7%	1.2%	68.0%	5.6%
Meat and Bone Meal	$390	58.5%	14.0%	94.3%	2.1%	68.3%	6.8%
Fish Meal (dry)	$1,775	60.4%	14.1%	91.6%	2.5%	76.8%	16.2%
Alfalfa Cubes	$375	18.3%	3.1%	91.1%	1.3%	56.7%	3.7%
Linseed Meal	$245	36.4%	6.3%	90.4%	2.3%	71.8%	7.8%
Animal Byproducts (wet)	$500	55.4%	14.5%	33.1%	13.9%	105.2%	22.6%
Animal Byproducts (dry)	$500	73.1%	18.2%	91.8%	5.2%	79.4%	14.0%
Potato Byproduct	$500	16.5%	21.5%	86.4%	17.9%	79.6%	14.0%
Soy Byproduct	$500	34.5%	15.9%	90.3%	12.8%	83.9%	13.1%

1 ton = 2000 lbs. Cost information from The University of Missouri Extension’s website

Nutrient data from Dairy One Labs, Ithaca, New York

Table 4. # of truckloads required for break-even

Ingredient	Protein	Dry Matter	TDN
Fish Meal (dry)	25	180	25
Potato Byproduct	30	95	110
Soy Byproduct	50	130	120
Animal Byproducts (wet)	80	55	90
Animal Byproducts (dry)	80	335	110
Meat and Bone Meal	110	Above 500	240
Corn Gluten Meal	120	Above 500	Above 500
Soybean (roasted)	130	Above 500	265
Blood Meal	130	375	230
Soybean Meal	155	Above 500	285
Alfalfa Cubes	155	Above 500	405
Distillers Condensed Soluble	175	155	310
Extruded Soy	185	Above 500	265
Soybean (Dry)	190	Above 500	Above 500
Cottonseed	200	Above 500	260
Corn Gluten Feed	230	Above 500	Above 500
Linseed Meal	235	Above 500	380
Meat Meal (dry)	279	Above 500	300
Wheat	330	Above 500	Above 500
Barley	350	Above 500	Above 500
Corn	425	Above 500	Above 500
Oats	455	Above 500	Above 500

1 ton = 2000 lbs.

1 truck load = 25 tons

Conclusion

Protein is one of the expensive nutrients in feed rations. For livestock operations that use feed material known to have a wide nutrient variation, the NIR system is very beneficial. Especially when the feed material is expensive such as fish meal or soy byproducts or other protein-rich feeds. Variation in other nutrients such as Dry matter or TDN is not as beneficial as compared to variation in protein. This study was a baseline techno-economic analysis where variation in single nutrient only was considered each time. Further work can extend this finding to multiple feed nutrients all considered simultaneously.

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