The Impact of Feed Management Software on Whole-Farm Nutrient Balance on Virginia Dairy Farms

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ABSTRACT

Agricultural runoff is the largest source of nitrogen and phosphorus pollution entering the Chesapeake Bay, contributing 38% of nitrogen and 45% of phosphorus (USEPA, 2010). Since agricultural runoff is the number one contributing source of nitrogen and phosphorus entering the Chesapeake Bay, action needs to be taken to reduce nitrogen and phosphorus on agriculture production facilities, such as dairy farms. The impact of feed management software on whole-farm nutrient balance was studied on 18 dairy farms located in Virginia from 2006 to 2010. Nine farms began using the TMR Tracker feed management software in 2006 and were compared to 9 control farms not using feed management software. Each of the treatment farms were visited on a monthly basis to collect ration and feed ingredient samples and feed management data. Whole-farm nutrient balance was calculated using University of Nebraska software. Herd sizes and crop hectares averaged 314 and 366 for treatment and 298 and 261 for control farms. Milk production averaged 3,226 and 2,650 tonnes per year respectively. Measures of surplus (input-output) and use efficiency (input/output) for nitrogen and phosphorus were analyzed over a four year time span and did not differ between treatment and control farms whether expressed on a per farms, cow or hectare basis. Due to the large variation in feeding accuracy within farms, the use of feed management software did not influence whole-farm nutrient balance. Sources of variation that contributed to loading errors were investigated within the feed management data. Percent load deviation increased over time from 2007 to 2009 from 0.94 ± 0.53 to 2.37 ± 0.50 percent of the actual load weight. Effects of month, day of the week and time of day on percent load deviation were not significant. There was no effect of percent load deviation on milk production. No relationship was observed between percent load deviation and whole-farm nutrient balance.

Keywords: (nitrogen, phosphorus, precision feeding, whole-farm nutrient balance)

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Table of Contents

List of Figures

List of Tables

Introduction

Eutrophication has been a major concern for the Chesapeake Bay. Eutrophication occurs when nutrients from non-point and point sources enter a body of water. Nutrients, specifically nitrogen and phosphorus, enter bodies of water in run-off from sources such as agricultural farms, power plants and urban areas. Concern over the condition of the Chesapeake Bay led to the enactment of the 1987 Chesapeake Bay Agreement to regulate water quality and reduce nitrogen and phosphorus in the bay waters by 22% and 33% by the year 2000 (Chesapeake Bay Program, 1987). Since the goals set in 1987 and 2000 were not achieved, the commitment was reaffirmed to reduce nitrogen by 47 million kg and phosphorus by 3 million kg per year by 2010 (Chesapeake Bay Program, 2000).

In October 2009, Chesapeake Bay Program leadership placed a cap on load allocations for nitrogen, at 91 million kg per year, and phosphorus, at 7 million kg per year, entering the Chesapeake Bay. Bay-wide total maximum daily loads were established in December 2010 to restore the Chesapeake Bay to healthy water quality conditions (USEPA, 2010). Each state was assigned a water implementation plan that indicates how pollution reductions will occur. Nitrogen and phosphorus allocations for Virginia are 24 and 2 million kg per year (USEPA, 2010; DCR, 2010). If the states located within the Chesapeake Bay watershed do not make progress, the U.S. Environmental Protection Agency has the authority from the Clean Water Act to impose consequences.

There are various avenues to identify and reduce the amount of nutrients that enter the Chesapeake Bay watershed. Agricultural runoff was the largest source of nitrogen and phosphorus pollution entering the Chesapeake Bay, contributing 38% of nitrogen and 45% of phosphorus (USEPA, 2010). Of agricultural P contributions, 58% are from manure and 42% from chemical fertilizer (Chesapeake Bay Program, 2007). Since agricultural runoff is the number one contributing source of nitrogen and phosphorus entering the Chesapeake Bay, action needs to be taken to reduce nitrogen and phosphorus run-off from agriculture production facilities, such as dairy farms.

Whole-farm nutrient balance is a way to estimate nitrogen and phosphorus surplus from farms. Nitrogen and phosphorus surplus may be reduced by feeding cows closer to their requirements and monitoring loading and delivery accuracy of the ration to the cows. Nutrient requirements established by the National Research Council (NRC, 2001) are used to create dairy rations although work by Wu and Satter (2000) indicates that phosphorus requirements might be set too high for some stages of lactation. However, some nutritionists, dairy producers and veterinarians include higher amounts of phosphorus in the diet than recommended by the NRC (Satter and Wu, 1999; Wu and Satter, 2000).

Knowledge of variability of nutrient content of feed ingredients is important to enable balancing rations according to animal nutrient requirements. If a feed ingredient has high nutrient variability, the nutritionist incorporates a higher “safety” margin to ensure that the ration meets the animal’s nutrient requirements. Forages are known to vary widely in nutrient content and therefore require timely analysis. However, by-products are usually purchased without knowledge of the precise nutrient content. By-product and forage sampling, nutrient analysis, nutrient content of all ration components, loading and mixing and the final delivery of the TMR are contributors to the delivery of desired nutrients to groups of dairy cattle on the farm. Obtaining representative samples of feeds for timely nutrient analysis and the accurate loading and delivery of rations are contributors to delivery of desired nutrients to groups of dairy cattle on the farm. Accuracy and precision in feeding management is necessary for minimization of overfeeding and achieving whole-farm nutrient balance.

Chapter 1: Literature Review

Eutrophication and Pollution of the Chesapeake Bay

Eutrophication of the Chesapeake Bay has been a major concern recently, although it has been a major problem ever since settlers migrated to the United States (Chesapeake Bay Program, 2009). Eutrophication occurs when nutrients from non-point and point sources enter the watershed of any body of water. Nutrients, specifically nitrogen and phosphorus, enter bodies of water in run-off from sources such as agricultural farms, power plants and urban areas. Excess nutrients allow algae present to thrive, leading to algae blooms, which block the sunlight from entering the lower depths of the water. The net result is impairment of Chesapeake Bay aquatic health.

The population of oysters serves as an indication of the health of the Chesapeake Bay. Oysters are filter feeders, meaning they can decrease the population of algae and nutrients. Groups of oysters form large reefs providing a habitat for aquatic life. Their presence is critical to the survival of the Bay since they aid in removing excessive nutrients and algae from the water. The oyster population has decreased dramatically over the past centuries due to overharvesting. It is estimated that the oyster population is between one and two percent of the Bay's original population in the 17^{th} century (Chesapeake Bay Foundation, 2010). The oyster population in the Chesapeake Bay is currently being replenished by introducing more oysters to reduce excessive loads of nitrogen and phosphorus.

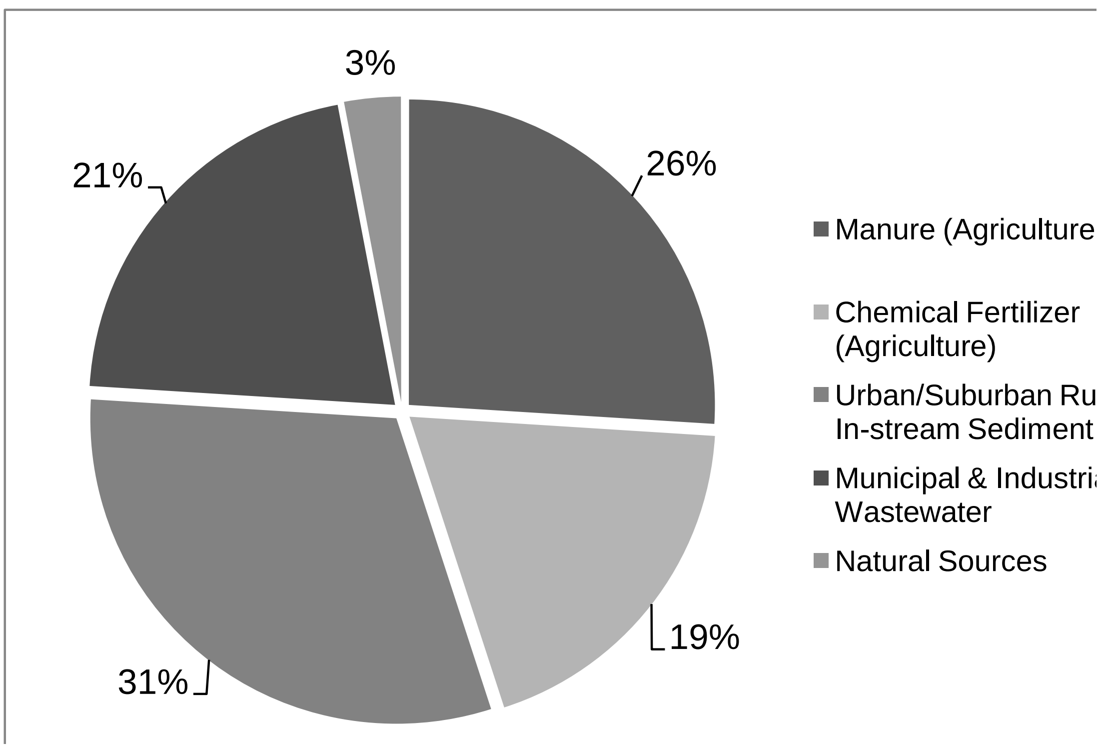
Numerous sources contribute to nutrient pollution in the Chesapeake Bay. Point source pollution discharges such as wastewater treatment plants are less difficult to control than non-point source pollution from agriculture because the pathways of nutrient loss are more numerous for non-point source pollution (Maguire et al., 2009).

Concern over the condition of the Chesapeake Bay led to the enactment of the 1987 Chesapeake Bay Agreement to regulate water quality and reduce nitrogen and phosphorus in the bay waters by 22% and 33% (Chesapeake Bay Program, 1987). Computer models estimated that nitrogen and phosphorus loads entering the Bay were decreased by 24 and 4 million kg, respectively, indicating that the goal of decreasing nutrient loads of nitrogen and phosphorus were short by 11 and 1 million kg. Since the goals set in 1987 and 2000 were not met by 2010, the commitment was reaffirmed in hopes to reduce nitrogen by 47 million kg and phosphorus by 3 million kg per year (Chesapeake Bay Program, 2000). In October 2009, Chesapeake Bay

Program leadership placed a cap on load allocations for nitrogen, at 91 million kg per year, and phosphorus, at 7 million kg per year entering the Chesapeake Bay.

Sources of phosphorus that enter the Chesapeake Bay are shown in Figure 1.1. Agricultural runoff was the largest source of nitrogen and phosphorus pollution entering the Chesapeake Bay, contributing 38% of nitrogen and 45% of phosphorus (USEPA, 2010). Phosphorus sources entering the Chesapeake Bay from agriculture are manure (26%) and chemical fertilizer (19%) (Chesapeake Bay Foundation, 2007). Since agricultural runoff is the number one contributing source of nitrogen and phosphorus entering the Chesapeake Bay, action needs to be taken to reduce nitrogen and phosphorus run-off from agriculture production facilities, such as dairy farms.

Figure 1.1 Sources of phosphorus entering the Chesapeake Bay



[1]Adapted from Chesapeake Bay Program Phase 4.3 Watershed Model 2007 Simulation (http://www.chesapeakebay.net/status_phosphorusloads.aspx?menuitem=19801)

Whole-farm nutrient balance and precision feeding

Whole-farm nutrient balance is a way to estimate nitrogen and phosphorus surplus on farms that is susceptible to exiting the farms as runoff and entering the Chesapeake Bay (Klausner, 1995; Koelsch et al., 1999; Lanyon and Beegle, 1989). Nitrogen and phosphorus surpluses documented on dairies and beef lots indicate potential for these nutrients to leave these farms as runoff and enter bodies of water, such as the Chesapeake Bay. Nutrient inputs consisted of purchased feed, fertilizer, animals, nitrogen in irrigation water and biologically fixed nitrogen. Nutrient outputs consisted of animals, crops and manure that are sold or taken off the farm. Nitrogen surplus on Nebraska livestock operations ranged from 8,000 to 466,000 kg per year and phosphorus surplus ranged from 600 to 60,000 kg per year depending on herd size (Koelsch et al., 1999). On average, one unit of phosphorus left the farms for every three units of phosphorus that entered the farm remains and could be considered as a potential nonpoint source of pollution (Koelsch, 2005).

Nitrogen surpluses as a portion of total inputs were 84% for a Pennsylvania dairy (Lanyon and Beegle, 1989), 86% on a Dutch dairy (Aarts et al., 1992) and ranged between 59 and 79% for 17 New York dairies (Klausner, 1995). In a study of New York dairies, 65 to 85% of annual imported phosphorus was from purchased feeds (Cerosaletti et al., 1998). Other studies showed that 42 to 63% of phosphorus imported onto farms remains there as sources of potential run-off (Rotz et al., 2002; Cerosaletti et al., 2004).

Whole-farm nitrogen and phosphorus balance on 41 farms in the western U.S was evaluated by Spears et al (2003a, 2003b). Farms had an average herd size of 466 cows and milk production of 10,254 kg per cow per year. Average nitrogen input was 125,830 ± 134,330 kg, output was 45,010 ± 55,500 kg and surplus was 80,840 ± 85,980 kg. Large variation for nitrogen inputs, outputs and surplus was attributed to individual farms differences and especially whether they grew crops or not. Farms that did not grow crops had a higher nitrogen surplus because all feed was purchased and these farms had more than twice the imports as the farms that grew crops. Whole-farm nitrogen utilization efficiency, output over input, averaged 35.8% (64.2% of nitrogen remained on the farm).

Whole-farm simulation used by Rotz et al. (2002) found that eliminate purchased phosphorus (P) fertilizer resulted in a $5.50 increase in predicted annual farm net return per cow and improved whole-farm nutrient balance. A second strategy was to decrease ration dietary phosphorus, which resulted in a $22 increase in predicted annual farm net return per cow. Reducing dietary P is one of the easiest ways to reduce P accrual in the soil and as well as improving whole-farm P balance.

Grouping animals based on their dietary requirements is another strategy to decrease whole-farm nutrient balance (St-Pierre et al., 1999). Cows grouped based on milk production are fed closer to their requirements as compared to feeding one total mixed ration (TMR) to all lactating cows. The cluster method developed by McGilliard et al. (1983) enables more accurate feeding of the milking herd because cows are grouped based on similar crude protein and net energy of lactation requirements expressed as a percentage of ration dry matter. In addition to requirements for milk production, the cluster method considers ration intake and increased requirements for growth of younger cattle and cows producing milk with high fat percentage. The cluster method estimated that 15 to 25% of cows would have been misgrouped if only milk, fat corrected milk or dairy merit (fat corrected milk/body weight) were used to group cows.

Accuracy and precision monitor conformity and consistency. Accuracy is how far from the target value the measurement is and precision is the ability to repeat a series of measurements and get the same value each time (Merriam-Webster, 2011). The impact of precision feeding management on P balance and farm net return was studied by on two New York dairy farms (Ghebremichael et al., 2007) using an integrated farm system model (IFSM) (Rotz and Coiner, 2006) and the approach by Klausner et al. (1997). They observed that increased production of high-quality homegrown forages and reduced purchased feed and fertilizer improved whole-farm nutrient balance. Estimated phosphorus surplus using these methods were 9.6 and 9.5 kg/ha for one farm and 5.2 and 4.4 kg/ha for the second farm. The Klausner approach utilized actual farm data from previous years to predict whole-farm nutrient balance whereas IFSM predicted values used the average of a 25-year analysis. Using the Klausner approach, phosphorus balance was estimated to be lower than the IFSM estimation. Purchased mineral phosphorus supplementation decreased by adjusting ration dietary phosphorus to NRC (2001) requirements. When compared to the previous farm practices, reduced dietary P led to a 25% reduction in phosphorus feed intake. Predicted annual farm net-return increased by $12 to $20 per cow for both farms as a result of decreased mineral cost.

Effect of decreasing dietary phosphorus

A telephone survey of dairy nutritionists located in the United States conducted by Wu et al. (2000) showed that average dietary phosphorus on a dry matter basis was 0.48%. Delaware, Maryland, New York, Pennsylvania and Virginia dairy producers fed in excess of 126% of NRC requirements, averaging about 0.44% dietary phosphorus as a percent of diet dry matter (Dou et al., 2003).

The research provided by Wu et al. (2000) studied the impact of decreasing dietary phosphorus (ranging from 0.31% to 0.49%) on milk production, reproductive performance and fecal phosphorus excretion (Wu et al., 2000). Within the range of phosphorus studied, there was no impact on reproductive performance and milk production. Another study found no difference in milk production or reproductive performance in cows fed two different levels of dietary phosphorus over a two year period (Wu et al., 2000). The low phosphorus treatment consisted of 0.31% and 0.38% P while the high phosphorus treatment contained 0.44% and 0.48% during grazing and confinement periods. Results from these studies showed that feeding higher levels of dietary phosphorus was unnecessary. Similarly, no influence of dietary phosphorous on milk composition when cows were fed diets containing 0.37 or 0.57% phosphorus (Lopez et al., 2004).

However, cows that were fed 0.49% dietary phosphorus excreted significantly more fecal phosphorus than those fed 0.31% and 0.40% dietary phosphorus (Wu et al., 2000). Two studies (Herbein et al. 1996 and Morse et al.,1992) are in agreement that increased dietary phosphorus resulted in increased fecal phosphorus. Results from the Wu et al. (2000) study suggest that dietary phosphorus of 0.38-0.40% is sufficient for high producing dairy cows and 0.30% dietary phosphorus is sufficient for low to medium producing dairy cows.

Four dairy farms in New York were utilized to develop strategies to reduce phosphorus feed imports, fecal phosphorus and whole-farm phosphorus balance (Cerosaletti et al., 2004). Data to calculate whole-farm nutrient balance were collected for 28 months and dietary manipulation was implemented for three months. Dietary phosphorus was reduced from 153% to 111% of requirements, and fecal phosphorus decreased, by an average of 33%. These authors demonstrated timely forage sampling enabled formulation and implementation of rations that are lower in dietary phosphorus but met phosphorus requirements.

Variability in nutrient delivery

Knowledge of nutrient variability of feed ingredients is important to success in balancing rations according to animal nutrient requirements with greater precision. If a feed ingredient has high nutrient variability, nutritionists often incorporate a higher “safety” margin to ensure that the ration meets animal nutrient requirements. Nutritionists assume large variation in forage nutrient content and as a result feed evaluation on a frequent basis is common. However, dairy producers are less likely to test commodity-type feeds in spite of the large nutrient and dry matter content variation that is known to occur in these feedstuffs. The extent of variability of commodity type is illustrated in an evaluation of protein content of corn and soybean meal (Kertz, 1998). Protein content (as fed) of 10,195 corn samples averaged 8.5% and ranged from 7.0 to 10.0%. Soybean meal samples (26,357) averaged 47.5% protein and ranged from 42.25 to 50.0%. Average crude protein content of the previously mentioned feedstuffs was lower than NRC (1989) values.

As variation in TMR batch weight increases, the impact of uncertainty of CP and NDF in the TMR increases (Buckmaster and Muller, 1994). The authors suggested ingredient amounts need to be controlled within 1%, which resulted in less than 5% uncertainty in TMR nutrient concentrations. Variability between TMR batches can be reduced by monitoring ingredient amounts with high nutrient content that comprise a large proportion of the diet.

Sniffen et al. (1993) found that variation in by-product and forage sampling, the subsequent nutrient analysis of all ration components, accuracy of loading ingredients, thorough mixing of ingredients and delivery of the prescribed amounts of TMR to each group (Sniffen et al., 1993) were contributors to the delivery of desired nutrients to groups of dairy cattle on the farms. From a management perspective, accuracy and precision in loading of feeds into the mixer wagon can be improved by obtaining a more accurate representation of forage nutrient content. This is achieved by selecting one person to forage sample on the farm and one laboratory to analyze feed samples.

Basic concepts in quality and process control

Reviewing and improving the quality of products or services generated is an important aspect of any business. Automotive and food companies industries with high standards of quality control because the repercussions of poor quality have a very large economic impact. For example, in 2010, Toyota recalled 2.1 million cars for safety reasons; the accelerator pedal sticking due to improper carpet placement on the driver's side floor. This recall and vehicle accidents that occurred prior to the recall cost Toyota $2 billion dollars (Isidore, C., 2010). Other highly publicized recalls have included peanut butter, tomatoes, spinach, toys and strollers. These events are a result of improperly managed processes through which these products are created. The author of Total Quality Control, Armand Feigenbaum (1983), defined quality as "a customer determination which is based on the customer's actual experience with the product or service, measured against his or her requirement-stated or unstated, conscious or merely sensed, technically operational or entirely subjective-and always representing a moving target in a competitive market." This definition emphasizes the role of consumer perception and that quality is a moving target. Thus, companies should always strive to keep improving their product or service to meet the consumer's expectations for the product.

Quality control was defined as "the use of specifications and inspection of completed parts, subassemblies, and products to design, produce, review, sustain, and improve the quality of a product or service" (Summers, D. C., 2009). There are numerous facets of quality control and factors that contribute to the guidelines set. Customer service and satisfaction are two of the factors that influence the product or service offered. The concept of quality control applies to the dairy industry because the dairy cow relies on the dairy producer, nutritionist and feeder to provide the nutrients that she needs to meet her requirements. Variation in TMR mixing wagons, mixing times and delivery may all affect load deviation and subsequently milk production and animal health.

Statistical process control (SPC) is an important component of total quality management and one important tool in SPC is the control chart (Caulcutt, R., 1995). Walter Shewhart, the father of control charts, suggested that "measures of quality should be plotted as a time series graph" and includes "three horizontal lines to aid decision-making". Target values should be set based on either previously recorded data or may be related to specification limits set by the manufacturer or industry standards. Control lines, which are the upper and lower lines on a control chart, should be placed three standard deviations above and below the center line.

A process is said to be in control if data points (observations) are randomly scattered around the center line. When a process is in control, it is only influenced by common or random causes (Caulcutt, R., 1995 and Summers, D. C., 2009). If data points occur in a non-random pattern or one of the data points lies outside of the control limits, then an assignable cause is influencing the process. Sources of variation can be identified for an assignable cause.

Control charts are useful for process monitoring, problem solving and assessment of process stability. Changes in process variability are detected through a mean chart in conjunction with a conventional range chart. For problem solving and stability assessment, standard deviations can be obtained from the data points that are plotted. However, for process monitoring control charts, “the standard deviation must come from another source” (Caulcutt, R., 1995). In 1985, Montgomery stated that “the estimate of the process standard deviation used in constructing the control limits is calculated from the variability within each sample. Consequently, the estimate of standard deviations reflects within-sample variability only.”

The procedures for establishing control charts include grouping the data, statistical analyzing it, and evaluating it (Porter and Caulcutt, 1992). First data are obtained and placed into subgroups. For each subgroup, the mean and range are calculated and then for all of the data points, calculate the overall mean and mean range. Then, the process standard deviation is estimated using overall mean divided by a constant to adjust by sample size. Then, values for the control limits for mean and range charts are calculated using the previously calculated mean, range and standard deviation values. The group means (observation means) are plotted on the mean chart and the group ranges are plotted on the range chart.

If the mean and range charts indicate that the process is in control, then these charts can be utilized to monitor future progress. However, if these charts indicate that the process is not in control, then assignable causes need to be identified and corrected. Once the corrections are made in a process that is identified as out of control, then new control charts should be made to further monitor progress of the process.

Application of quality concepts on dairy farms

Control charts can be utilized within the dairy industry to aid in identifying and controlling the variation in dairy herd management. Using control charts in agricultural applications can improve efficiency, profitability and reduce environmental impact (de Vries and Reneau, 2010). Process control charts were utilized to estimate estrous detection efficiency (de Vries and Conlin, 2003). Observations used in the control charts were obtained using a dairy herd simulation model (de Vries, 2001). Cusum charts were more sensitive for detecting changes in estrus detection efficiency than Shewart charts (x-chart and p-chart). Cumulative sum control charts (CUSUM) that incorporate past observations. Shewart charts were created by Walter Shewart. The data points plotted on the x-chart are individual observations that follow a normal distribution while the data points plotted on the p-chart are proportions that follow a binomial distribution. Statistical process control (SPC) charts detected changes in estrus detection efficiency in a timely manner.

Pedometers were used to monitor activity (steps) for detecting metabolic diseases such as ketosis in dairy cows and control charts were created to view a period of time where ketosis occurred within the herd (Reneau and Lukas, 2006). Four Western Electric Rules (Western Electric Company, 1956) were created to detect unnatural observation patterns using four rules. The first rule is if any data point lies outside of the three sigma control limits, the second rule is if any two out of three consecutive data points lie outside of the two sigma control limits on one side of the centerline, the third rule is if any four out of five consecutive data points lie outside of the one sigma control limits on one side of the centerline and the fourth rule is if any nine consecutive data points are on one side of the centerline. Applying the Western Electric Rules to these control charts increased the sensitivity of detecting a process that is out of control. Ketosis was identified seven days sooner when applying rules 2 & 3. However, there were occasions when applying the Western Electric Rules led to more false alarms, especially when more of the rules were applied.

Control charts might also be used to monitor milk nitrogen urea (MUN) and somatic cell count (SCC) in the bulk tank. The use of control charts utilizing MUNs would allow the manager to detect diet problems that affect protein utilization, such as dietary crude protein or carbohydrate content. If the charts indicate that MUN or SCC data suggest a problem, the manager can take action to determine whether this was due to deviations in ingredient nutrient content or mixing errors. Similarly, control charts to track bulk tank SCC can help monitor farm management factors contributing to milk quality such as milking routine, bedding and dry cow management.

Utilizing control charts can also save the dairy producer money. A study by St-Pierre et al. (2007), where optimal sampling schedule for diet components was determined, showed that improved process control saved money. The authors used a computer simulation to demonstrate that use of one or more types of control charts to keep on farm feeding processes in control resulted in reduced costs. The longer the system was in control, the less feed cost per day. Use of multiple control charts was thought to add sensitivity to detecting abnormal observations. However, in their model, the use of multiple control charts was found to be unnecessary. Added benefits of utilizing multiple control charts probably needs to be determined based on type of application to dairy management.

Control charts could be used to monitor feed management and identify causes of variation, but this is not currently done. Large quantities of information are automatically recorded on dairy farms but are not utilized to its full potential for making management decisions. Consistent monitoring of feed management may result in reduced whole-farm nutrient surpluses, increase milk production and improve cow health.

Evaluating the current status of nitrogen and phosphorus susceptible to exiting dairy farms in the form of run-off is important to reduce agricultural sources of pollution entering the Chesapeake Bay. The objective of this study was to determine if feed management software had an impact on whole-farm nutrient balance on Virginia dairy farms.

Chapter 2: Whole-farm Nutrient Balance on Virginia Dairy Farms and the Influence of Feed Management Software on Accuracy and Precision in Feeding

Abstract

The impact of feed management software on whole-farm nutrient balance was studied on 18 dairy farms located in Virginia. Nine farms began using feed management software in 2006 and were compared to 9 control farms not using feed management software. Each of the treatment farms was visited on a monthly basis to collect dairy herd information, TMR and feed ingredient samples and feed management data. Annual inputs of nitrogen and phosphorus from purchased feed, fertilizer and animals were recorded from 2005 through 2010. Nitrogen and phosphorus exported from the farms as milk, animals, sold manure and feed were recorded. Herd sizes and crop hectares averaged 314 and 366 for treatment and 298 and 261 for control farms. Milk production averaged 3,226 and 2,650 tonnes per year respectively. Data were analyzed using PROC MIXED in SAS with repeated years, using 2005 data as a covariate. Measures of surplus (input-output) and ratio (input/output) for nitrogen and phosphorus were analyzed per farm and did not differ between treatment and control farms. Annual whole-farm nitrogen use efficiency averaged 3 for treatment and control farms. Annual whole-farm phosphorus use efficiency averaged 2 for treatment and control farms. Measures on a per farm, cow and hectare basis did not differ between treatment and control farms. On a per cow basis, annual nitrogen surplus averaged 126 ± 11 (SE) kg/yr and annual phosphorus surplus averaged 16 ± 3 kg/yr for treatment farms. Annual nitrogen surplus averaged 150 ± 16 (SE) kg/yr and annual phosphorus surplus averaged 16 ± 4 kg/yr for control farms on a per cow basis. Use of feed management software did not influence whole-farm nutrient balance. Multiple sources of variation contribute to errors in loading and delivery of rations were studied. Nutrient analysis of feed and forage samples showed differences from NRC (2001) values for dry matter, crude protein and phosphorus. Percent load deviation increased from 2007 to 2009 from 0.94 ± 0.53 to 2.37 ± 0.50 percent of the actual load weight indicating that farms did not improve with time of use of feed management software. Effects of month, day of the week and time of day on percent load deviation were not detected. The relationship between whole-farm nutrient balance and feed management data was compared for three years. Failure to observe benefits from use of feed

management software in this study indicates need for enhanced training of dairy managers, feeders and nutritionists to achieve improved farm nutrient balance.

(Key words: feed management, nitrogen, phosphorus, whole-farm nutrient balance)

Introduction

Agriculture is faced with increasing regulation as it has been identified as the source of 29% of the nitrogen (N) and 49% of the phosphorus (P) entering the Chesapeake Bay (Boesch et al., 2001). In October 2009, Chesapeake Bay Program leadership placed a cap on load allocations for N, at 91 million kg per year, and p, at 7 million kg per year entering the Chesapeake Bay. In order to achieve these goals, agriculture and in our example, dairy farms, need tools to reduce their impact on the environment.

Whole-farm nutrient balance (WFNB) is a tool to assess net balance of N and P on the farms. Nutrients enter the farms in the form of purchased feed, animals, fertilizer and manure. Nutrients leave the farms as sold feed, animals, milk and manure. Whole-farm nutrient balance is calculated by subtracting the exiting quantity of nutrients from the quantity of nutrients entering the farms. A surplus of nutrients on the farms represents potential environmental pollutants.

Spears et al. (2003a and 2003b) calculated WFNB on 41 dairy farms in Utah and Idaho. Twenty-three of these farms grew crops while 18 farms did not. One year of data was collected to estimate average P and N balance for all farms. Annual P surplus on a per farm basis was 14 ± 18 kg and annual N surplus on a per farm basis was 173 ± 185 kg.

Using four dairy farms in New York, Cerosaletti et al. (2004) estimated WFNB and developed strategies to reduce phosphorus feed imports and fecal phosphorus. Dietary manipulation was utilized to reduce annual N surplus per cow from 195 kg to 159 kg and P surplus per cow from 19 kg to 8 kg after dietary manipulation for one farm. The second farm was not successful in decreasing N surplus and P surplus decreased by 2%. At the beginning of the study, phosphorus intakes across all farms averaged 32% above requirements (NRC, 2001). Reductions in dietary P for one farm were achieved by manipulating the amount and types purchased feeds. Increased use of home grown forages, improved forage quality, careful management of feed mixing and delivery, and routine analysis of all feeds for N and P improves nutrient utilization efficiency (Cerosaletti et al., 2004).

Variation in nutrient content of feed ingredients is one source of error in feed management. Crude protein (CP) content of 10,195 corn samples analyzed by Kertz (1998) averaged 8.5% and ranged from 7.0 to 10.0% (air-dry basis). Soybean meal samples (26,357) averaged 47.5% CP and ranged from 42.25 to 50.0%. Protein content was highly variable and lower than averages reported in the NRC (2001).

Uncertainty of ingredient dry matter content, increased size of the TMR batch and variation in loading accuracy leads to increased uncertainty of CP and NDF content in the TMR (Buckmaster and Muller, 1994). Accurate measurement of dry matter of forages and wet by-products decreases the uncertainty in the TMR. Ingredients with the highest variability in dry matter content were alfalfa silage, followed by corn silage and wheat middlings. Shelled corn and soybean meal had the lowest variability in dry matter content. Uncertainty of CP content of the TMR was influenced the most by uncertainty in the amount of soybean meal since this ingredient had the highest CP content of all the feeds in the TMR. Therefore, variability between batches can be reduced by focusing on ingredient amounts with high nutrient content. More precise measurement of nutrient content is achieved by having one person obtain representative feed samples and by using one forage laboratory (Buckmaster and Muller, 1994).

Perceived limitations of previous WFNB studies are that they have been conducted over relatively short periods of time and failed to consider cow numbers relative to land area. Feed management software can be used to monitor accuracy and precision of loading and delivery. Sources of variation involved in successful management of feeding programs include nutrient variation of ingredients, and loading and delivery errors. The objectives of this study were to 1) evaluate the current WFNB status for dairy farms in Virginia 2) to evaluate the effect of use of feed management software on WFNB and 3) evaluate effect of implementation of feed management software on load deviation to investigate sources of variation.

Materials and Methods

This study consisted of eighteen dairy farms in Virginia chosen based on willingness to participate, proximity to the Chesapeake Bay Watershed, herd size and farm size. Nine farms installed feed management software (TMR Tracker, Ft. Atkinson, WI) in 2006 and were visited monthly by project personnel. Seven farms completed the study as one herd dispersed in 2007 and one in 2010. Ten additional farms with similar herd and farm size characteristics as treatment farms were selected as control farms. These farms did not install feed management software and were visited annually by project personnel. Control farm participation varied by year.

Whole-farm nutrient balance data were collected from 2005 through 2010. Data collected for the 2005 calendar year was used as a covariate. Data were collected for imported feed, manure or fertilizer, and animals and exported feed, manure, milk and animals. When nutrient analyses for feedstuffs were unavailable, values from the National Research Council (2001) were utilized. Milk production data were obtained from their milk marketing cooperative or milk receipts. Whole-farm nutrient balance was estimated (Koelsch, 2005).

Data were analyzed with PROC GLIMMIX (SAS, 2009). Variables in the model statement included the 2005 covariate, treatment, year and the treatment by year interaction with the Sattherwaite ddfm option (SAS, 2001). Year was the random measure with farm within treatment as the subject and a compound symmetry covariance structure. Slicediff by year option was utilized on the least squares means for the treatment by year interaction. Statistical significance was declared when $P < 0.10$. Since the number of participating control farms varied from year to year, a second analysis was performed using PROC GLIMMIX to compare only treatment and control farms that participated for all five years (seven treatment and two control farms). Statistical significance was declared when $P<0.10$.

A third analysis was performed on the WFNB data without the 2005 covariate year in the model, as 2005 may have not been a typical year. Analysis was performed using PROC GLIMMIX and statistical significance was declared when $P<0.10$.

Feed management (TMR Tracker, Ft. Akinson, WI) data were collected monthly from installation date (April and October 2006) to the end of 2009 (Table 2.1). Data from one month in each of the four seasons each year (January, April, July and October) were analyzed. Data points identified as program or operator errors (e.g. duplicated data for a load) were deleted from the data set. TMR loads with feed ingredients that had a negative or positive error of 100% were deleted.

Representative samples of feed and forage were obtained monthly from eight farms for nutrient analysis (Cumberland Valley Analytical Services, Hagerstown, MD). Feeds were grouped by feed type to obtain mean and standard deviation values for CP and P. Analytical values for CP and P of the major ingredients of the TMR from eight project farms were compared to NRC (2001) values for CP and P using the Student's t-test. Statistical significance was declared when $\alpha = 0.025$ for the two-tailed test.

Key measurements including percent load deviation, mean of percent load deviation and its standard deviation were calculated using Proc Means in SAS. The following equation expresses how the percent daily load deviation was calculated:

Percent daily load deviation = (recorded load weight – call weight)/ call weight

The call load weight was specified by the nutritionist. The absolute value of average percent daily load deviation was also used since this variable accounted for over and underfeeding in each load where as the previous measure would average over and underfeeding errors. Absolute value of average percent daily load deviation was calculated using the absolute value function in SAS, which sums the positive and negative deviations (over and under feeding) to represent true load deviation. Day, month, year and day of the week were created in SAS JMP. These data were merged with forage and feed ingredient analysis (Cumberland Valley Analytical Services, Hagerstown, MD). Nutrient values for mineral and concentrate ingredients were obtained from the dairy producer, nutritional consultant or feed companies. When nutrient analysis values were not available then nutrient values from National Research Council (2001) were used. Data were analyzed using PROC GLIMMIX and PROC MEANS (SAS, 2009).

During the analysis, variables in the model that were not found to be different were removed from the model. Only the final model is noted. The variables in the model statement included year, month and the year by month interaction with the Sattherwaite ddfm option (SAS, 2009). Variables in the random statement included farm, farm by year interaction and the farm by month interaction. Least square means for year, month and the year by month interaction were generated using the LSMeans statement. The slicediff option and tukey adjustment was utilized for year by month interaction least squares means.

Analysis focused on the variation in feed ingredient nutritional content, load deviation, operator deviation and ingredient deviation. Another analysis focused on the impact of load deviation on milk production using PROC GLIMMIX in SAS by farms. Variables in the model statement included percent load deviation, year and percent load deviation by year interaction with the solution option. Least squares means were generated using the LSMeans statement for year with a tukey adjustment. Statistical significance was declared when $P<0.10$.

The relationship between WFNB and yearly average percent load deviation was investigated. All combinations of N balance, P balance, yearly average percent daily load deviation and absolute value of average percent daily load deviation were analyzed.

Seven farms had three years worth of feed management data and one herd had two years of data. The combined dataset for WFNB and feed management data was analyzed in SAS JMP. The best line of fit was found using the Fit Y by X option where Y was N balance (kg) per farm or P balance (kg) per farm and X was yearly average percent daily load deviation or absolute value of average percent daily load deviation.

Results and Discussion

Treatment and control farms averaged 314 and 298 cows, respectively, with annual milk sales of 3,226 and 2,650 tonnes. Crop hectares averaged 366 and 261 respectively. Whole-farm nutrient balance, whether evaluated per farm, per hectare or per cow, was not affected by use of feed management software (Tables 2.2 and 2.3). This similarity between treatment and control farms was observed whether data were analyzed from all farms or just farms completing all five years of the study, and was observed whether 2005 data was used as a covariate or not.

Greater N and P surpluses per cow were observed in the Western dairy farms evaluated by Spears et al. (2003a, 2003b) than in this study. The farms included in our study were smaller than the farms evaluated by Spears et al. (2003a, 2003b), and all of our farms grew their own forages, which was not true of all of the Western farms. Farms in the Spears et al. (2003a, 2003b) study were located in Utah where ethanol based by-products are not locally available and would require greater transportation costs. Annual N and P surplus per cow found in our study were comparable to that found by Cerosaletti et al. (2004). More by-product feeds were incorporated into rations for the farms involved in our study as compared to the ration composition described by Cerosaletti et al. (2004).

No difference was found in the whole-farm nutrient use efficiency (ratio of inputs to outputs) using the 2005 covariate for both treatment and year. Annual whole-farm N use efficiency averaged 3:1 for treatment and control farms (Figure 2.3). Annual whole-farm P use efficiency averaged 2:1 for treatment and control farms (Figure 2.4). Annual whole-farm N and P use efficiencies were highly variable between farms and years but were comparable to the values reported by Koelsch (2005), Spears et al. (2003a, 2003b) and Cerosaletti et al. (2004).

Nitrogen and P balance were highly variable over time (Figures 2.1 and 2.2) because of changes in the amount of land relative to number of cows, land fertility, weather and markets. The amount of land relative to number of cows dictates the amount of homegrown forages to feed. Land fertility varies by location. Weather affects the quality and quantity of homegrown forages to feed cows. Low milk price relative to prices of corn and soybean meal led producers to seek less expensive sources of supplemental nutrients, such as by-product feeds higher in protein and P. The amount of crops sold and exported off the farm varied by year.

One source of variation that may influence WFNB is variation of feed ingredient nutrient content from values used in ration formulation. Corn silage and alfalfa haylage comprised over half of the TMR on a dry matter basis in our study. Average CP and P content of the corn silage samples in our study were lower than NRC (2001) values. Alfalfa haylage samples in our study had lower CP and P content than NRC (2001). These findings are in agreement with St-Pierre et al (2007).

Most by-product feeds were dry with little variation in dry matter content. Dried distillers grains varied between 19% and 41% CP. Average CP content for wet brewer's grains ranged from 22% to 37% CP. Variation in P was high for several feeds commonly found in dairy rations for treatment farms. Nutrient analysis for high moisture corn, wet brewer's grains and 48% soybean meal were different from NRC (2001) values. Comparisons of analytical values from samples obtained in this study with expected values from NRC (2001) (Tables 2.3 and 2.4) reinforce the need for frequent analysis noted by Kertz (1998) and Sniffen et al. (1993). Using NRC (2001) values in ration formulation instead of farm specific analytical values could result in provision of TMR's which would over or underfeed CP and P. Potential sources of deviation for values used in ration formulation from actual nutrient content include lag in time between sampling feed or forages, reformulation of the ration with new values and implementation of the ration by the dairy producer.

Percent load deviation increased as the project continued (Figure 2.5). This result was not expected and implies that as farm personnel did not become more familiar with the feed management software over time, or that increased familiarity did not improve precision of feed mixing. We observed that most feeders and nutritionists did not participate in evaluating feed management data. We did not observe the dedication of management time to feed management software that was expected, perhaps because educational support was lacking. Although project personnel routinely visited the farms to obtain feed samples and feed management data, time restrictions and other duties did not permit review of feed management software reports with the producers on each visit.

Interaction of farm and year affected measures of feeding accuracy and precision (Figure 2.6). Accuracy of mixing is best represented by mean percent load deviation, while precision can be assessed as the variation (standard error) of this measure over time. The mean percent load deviation for each year within farm was typically 1.5%, indicating that accuracy was good. However the standard error was larger than the mean on many farms, indicating imprecision, or large fluctuations in percent load deviation from day to day. Farms 3, 4 and 6 are examples of farms at the extremes on one or both of these measures. Farm 3 had a higher degree of accuracy and precision than other farms, and was the only farms where the mean percent load deviation decreased from 2008 to 2009. Even on this well managed farm, the standard error was larger than the mean for 2009. Farm 4 had low accuracy and precision due to a high turnover rate for feeders. Farm 6 was the most accurate in loading ingredients but loading was not precise because the standard errors were large.

Neither day of the week nor month of the year affected feeding accuracy (Percent load deviation; Figure 2.6). The lack of effect of day of the week was previously reported by Cox et al. (2007) and suggests no consistent effect of the regular feeder's day off on these farms. In contrast to the observation of Cox et al. (2007), daily load deviation was not correlated to milk production. The report of Cox et al. (2007) included many of these same herds at an earlier stage of the project. The negative relationship between milk yield and feeding accuracy observed in that earlier stage of the study was not observed when more data was included.

Analysis of average load deviation can be misleading, because incidences of overfeeding (positive deviation) offset incidences of underfeeding (negative deviation). Analysis instead of the absolute value of these deviations is more useful. A sample load from a farm on this study (Table 2.5) illustrates why consideration of absolute value is important. Ingredients in italics (corn silage, in this example) were underfed and those in bold (brewer's grains and alfalfa haylage) were overfed. On this day on this farm, corn silage was under-loaded by 329 kg but brewer's grains and alfalfa haylage were over-loaded by 320 and 190 kg respectively yielding total load weights and average deviations were close to what is desired. Total load weights and average deviations can be deceiving; knowledge of load weight and deviation for each ingredient is important to identify problem areas in loading ingredients.

Ingredients with highest total cost that represent the greater proportion of the load should be the focus of loading accuracy. High moisture corn and ground corn are expensive and had large average deviations and standard deviations of the average (Figure 2.8). Wet brewer's grains had both a large mean deviation (poor accuracy) and large standard deviation of the mean (poor precision) because it is hard to load, particles clump together and do not enter the mixer uniformly. Alfalfa hay and straw are the forages with the poorest accuracy and precision (largest mean and standard deviation of the mean) because the hay falls off in chunks from the hay bale. These ingredients were added in relatively small quantities in the farm presented as an example, however, so do not have as much of an impact on overall loading accuracy. In contrast, corn silage and alfalfa haylage were easier to a load than any other ingredient and therefore have a smaller average load deviation and standard deviation (Figure 2.9). However, their impact on TMR nutrient variation is significant.

Overfeeding feed ingredients that are nutrient dense increases nutrient content of the TMR thereby increasing nutrient excretion and feed costs. In contrast, underfeeding nutrients could decrease milk production and feed costs. However, income lost from decreased milk production is likely greater than feed cost reductions. As a result of over or underfeeding, errors in loading accuracy affects ingredient inventory and may increase WFNB if the amount of purchased feeds increases.

Conclusions

Use of feed management software had no impact on WFNB because of multiple factors related to the price of milk, feed, and the manager's ability to use feed management software. Feed prices for corn and soybean meal influence quantity of imported N and P since less expensive by-product feed ingredients tend to be high in P. Growing conditions also influence forage quality which has an impact on milk yield and purchase of supplemental feeds.

Feed management software provides information which enables the manager to monitor shrink and the ability of the feeder to load rations with a high degree of accuracy and precision. However, it was apparent that this information was not utilized to its full potential as accuracy decreased from 2007 to 2009. Neither season, day of the week or time of day that TMR loads were initiated influenced feeding accuracy (percent load deviation). There was no relationship between percent load deviation and milk production. Differences between nutrient content of feed samples collected during the study and NRC (2001) values reinforce the importance of timely and accurate nutrient analysis to enable the nutritionist to formulate rations more accurately.

Observations during farm visits showed that the feeders and management did not take initiative to monitor their progress and did not know what reports to view. Additional educational programs focused on what information is essential to improve feed management and economic consequences of poor feeding accuracy or precision may help improve adoption of feed management software.

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Table 2.1 Information contained within feed management software and used in analysis

	Description
Batch No.	Batch number corresponding to a load
Ingredient	Name of the ingredient, which was created by the producer
Recipe	Name of the recipe (ration, i.e. high cow, low cow, etc.), which was created by the producer
Date	Date that the batch was loaded and delivered
Time	Time that each ingredient in the batch was loaded into the mix wagon
Call Wt	The weight of each ingredient that was supposed to be added to the mix wagon
Actual Wt	The weight of each ingredient that was actually added to the mix wagon
Deviation	The difference between the call weight and actual weight, which can be a surplus or deficit

[1]TMR Tracker, Digi-Star, Fort Atkinson, WI, TMR Tracker II version

Table 2.2 Whole-farm nitrogen and phosphorus surplus kg per farm (SE) analyzed with all data, only data from farms participating throughout, and with or without a covariate year

	All farms model[1]	**Only farms participating for 5 years model**[2]	**No covariate model**[3]
Nitrogen surplus for treatment farms	41726 ± 4333	38979 ± 5329	45967 ± 9926
Nitrogen surplus for control farms	43626 ± 6237	53826 ± 10966	29368 ± 18569
Phosphorus surplus for treatment farms	5018 ± 1046	6032 ± 1161	6367 ± 1154
Phosphorus surplus for control farms	4508 ± 1478	3369 ± 2332	2195 ± 2159

[1] Model contains all of the participating farms for each year

[2]Model contains only farms that participated for all 5 years

[3]Covariate was removed from the model

Table 2.3 Whole-farm nitrogen and phosphorus surplus kg per cow and hectare (SE) analyzed with all data, only data from farms participating throughout, and with or without a covariate year

	All farms model[1]	**Only farms participating for 5 years model[2]**	**No covariate model[3]**
Nitrogen surplus per cow for treatment farms	126 ± 11	124 ± 11	131 ± 18
Nitrogen surplus per cow for control farms	150 ± 16	170 ± 21	147 ± 34
Phosphorus surplus per cow for treatment farms	16 ± 3	19 ± 4	20 ± 4
Phosphorus surplus per cow for control farms	16 ± 4	16 ± 7	13 ± 7
Nitrogen surplus per hectare for treatment farms	135 ± 15	135 ± 16	129 ± 26
Nitrogen surplus per hectare for control farms	156 ± 22	188 ± 30	210 ± 50
Phosphorus surplus per hectare for treatment farms	15 ± 4	18 ± 5	19 ± 4
Phosphorus surplus per hectare for control farms	15 ± 6	19 ± 9	18 ± 8

[1] Model contains all of the participating farms for each year

[2]Model contains only farms that participated for all 5 years

[3]Covariate was removed from the model

Figure 2.1 Nitrogen surplus per cow for treatment and control farms by year

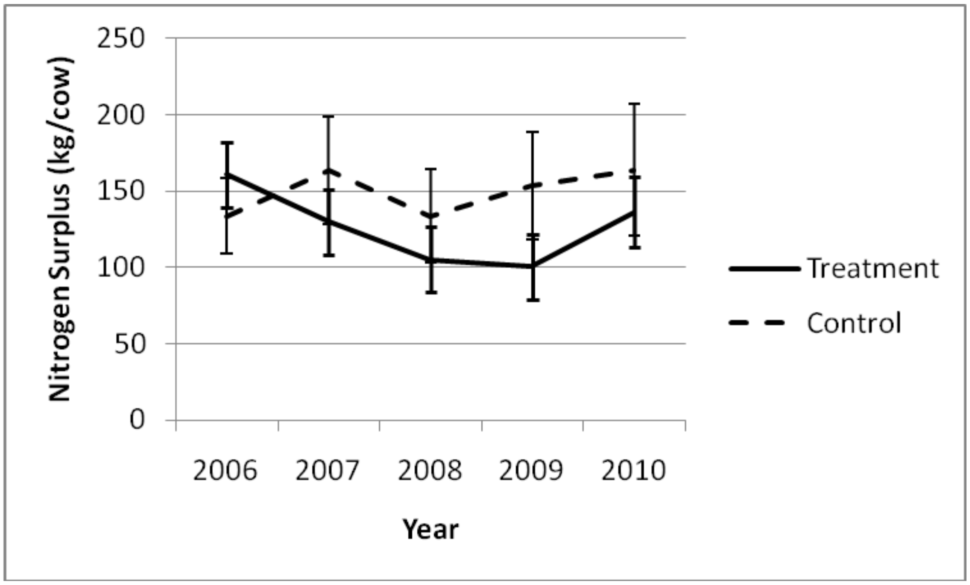


Figure 2.2 Phosphorus surplus per cow for treatment and control farms by year

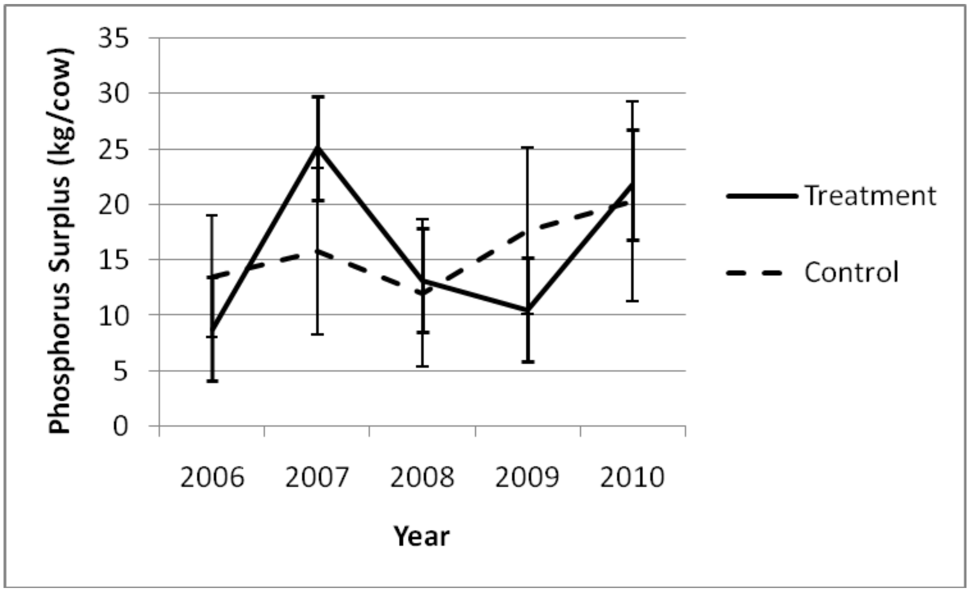


Figure 2.3 Whole-farm nitrogen use efficiency for treatment and control farms by year

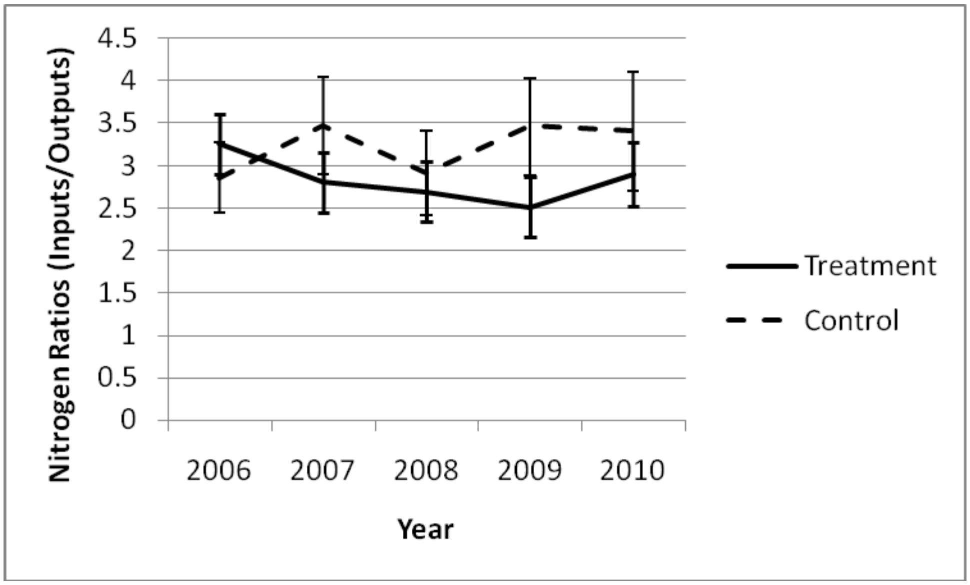


Figure 2.4 Whole-farm phosphorus use efficiency for treatment and control farms by year

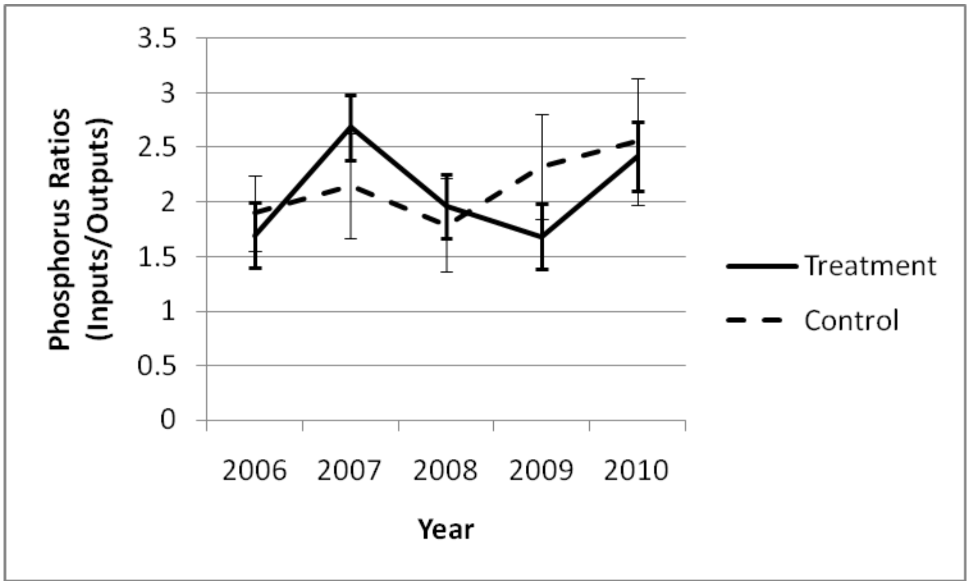


Table 2.4 Feed ingredient crude protein and phosphorus content and NRC (2001) values

Ingredient	Average Nutrient Analysis for Crude Protein	NRC (2001) Value for Crude Protein	Average Nutrient Analysis for Phosphorus	NRC (2001) Value for Phosphorus
Corn Silage	8.0	8.8	0.23	0.26
Alfalfa Haylage	18.9	21.9	0.32	0.35
Alfalfa Hay	19.3	20.8	0.29	0.30
High Moisture Corn	8.5	9.2	0.29	0.30
Hominy	10.0	11.9	0.50	0.65
Corn Gluten Feed	23.4	23.8	1.08	1.0
Wet Brewers Grains	33.6	28.4	0.62	0.59
Distillers Grains	29.6	29.7	0.75	0.83
48% Soybean Meal	52.7	53.8	0.74	0.70
Citrus Pulp	6.8	6.9	0.11	0.12
Whole Cottonseed	22.9	23.5	0.61	0.60
Soy Hulls	12.6	13.9	0.17	0.17

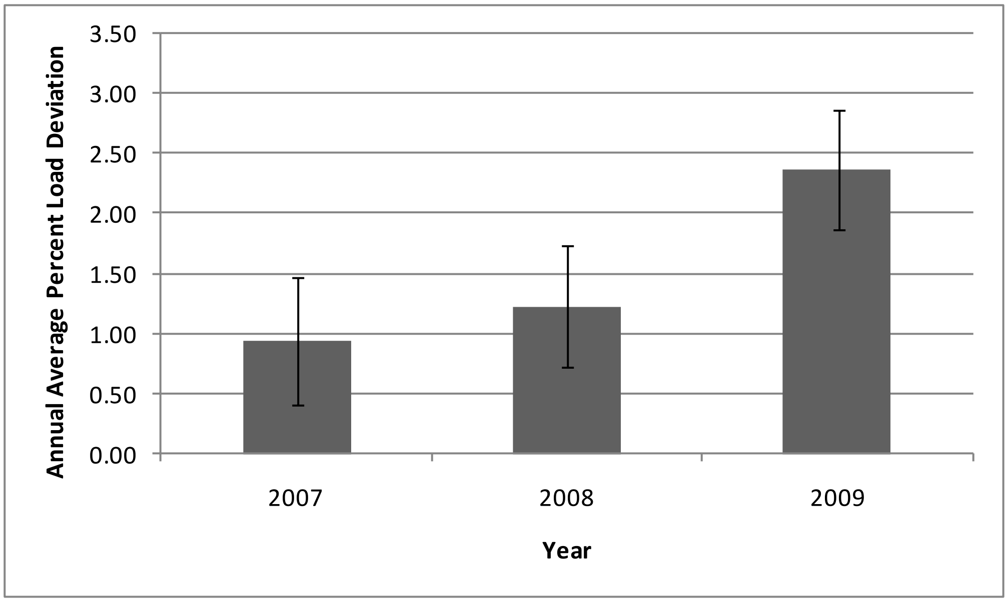
Table 2.5 Sample excerpt from report 150 (ingredient deviation by driver report) in feed management software[1] displaying one load

Batch No.	**Ingredient**	**Recipe**	**Date**	**Time**	**Call Wt**	**Actual Wt**	**Deviation**
4,009	*BCS*	*High99*	*02-01-09*	*12:13 pm*	*44*	*27*	*(16)*
4,009	*Grain*	*High99*	*02-01-09*	*12:14 pm*	*516*	*513*	*(3)*
4,009	*Gluten*	*High99*	*02-01-09*	*12:16 pm*	*108*	*104*	*(4)*
4,009	*Citrus*	*High99*	*02-01-09*	*12:18 pm*	*172*	*168*	*(5)*
4,009	**Distillers**	**High99**	**02-01-09**	**12:19 pm**	**151**	**200**	**49**
4,009	**Concentrate**	**High99**	**02-01-09**	**12:21 pm**	**311**	**345**	**34**
4,009	**Megalac**	**High99**	**02-01-09**	**12:23 pm**	**44**	**45**	**1**
4,009	**Hay**	**High99**	**02-01-09**	**12:29 pm**	**172**	**172**	**0**
4,009	**WBG**	**High99**	**02-01-09**	**12:19 pm**	**647**	**767**	**120**
4,009	**Haylage**	**High99**	**02-01-09**	**12:41 pm**	**444**	**753**	**309**
4,009	**Corn Silage**	**High99**	**02-01-09**	**12:47 pm**	**1,726**	**1,397**	**329**

[1]TMR Tracker, Digi-Star, Fort Atkinson, WI, TMR Tracker II version

[2]Underfed ingredients are in italics and overfed ingredients are in bold

Figure 2.5 Annual average percent load deviation[1] by year

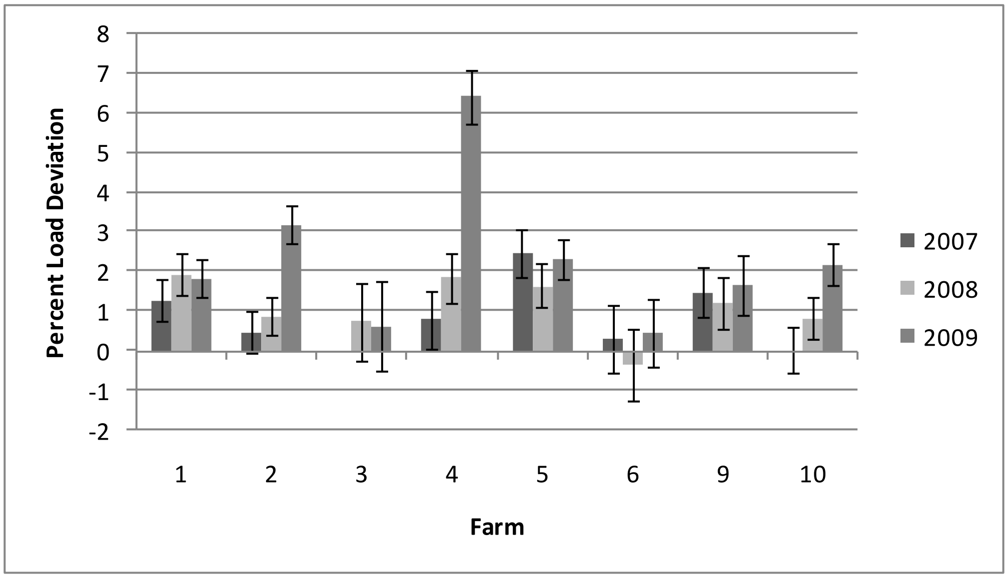


[1]Average percent load deviation = (actual weight – call weight)/call weight

[2] n=7 for 2007 and n=8 for 2008 and 2009

[3]Error bars represent standard error

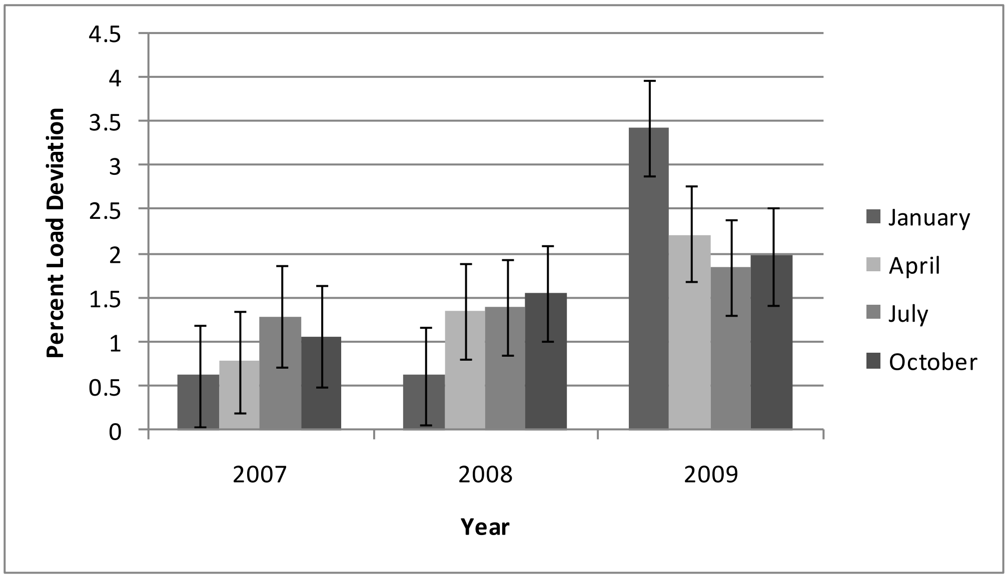
Figure 2.6 Percent load deviation[1] for farm by year



[1]Average percent load deviation = (actual weight – call weight)/call weight

[2]Error bars represent standard error

Figure 2.7 Monthly load deviation[1] by month by year



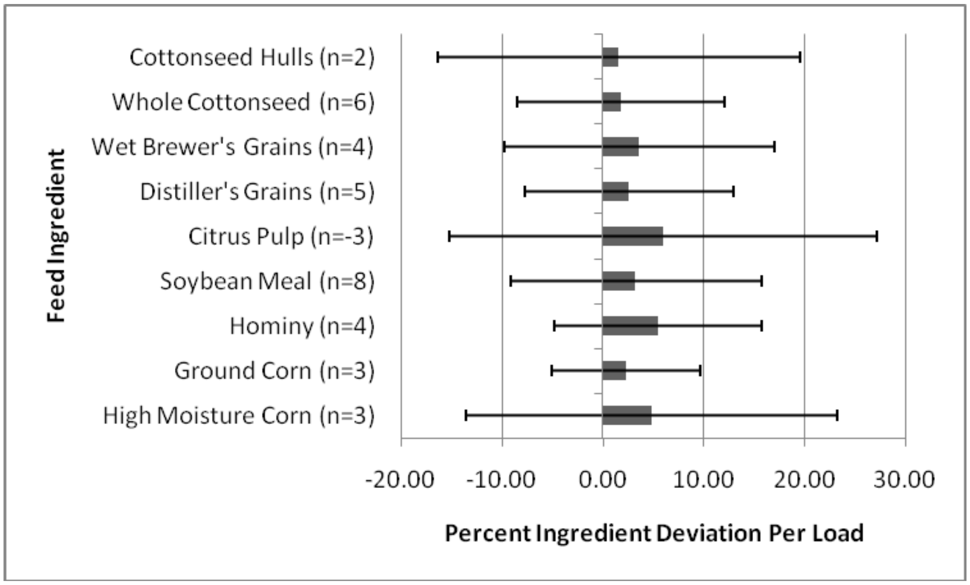
[1]Average percent load deviation = (actual weight – call weight)/call weight

[2]Error bars represent standard error

Table 2.6 Variation in loading accuracy for year, farm by year and monthly load deviation by month by year

Variation (SE)	**2007**	**2008**	**2009**
By year	0.53	0.50	0.50
By farm by year			
Farm 1	0.51	0.52	0.48
Farm 2	0.52	0.48	0.46
Farm 3	----	0.97	1.13
Farm 4	0.73	0.63	0.67
Farm 5	0.62	0.55	0.52
Farm 6	0.87	0.89	0.85
Farm 9	0.62	0.66	0.76
Farm 10	0.59	0.52	0.54
By month by year			
January	0.57	0.55	0.54
April	0.57	0.54	0.54
July	0.57	0.54	0.55
October	0.57	0.54	0.55

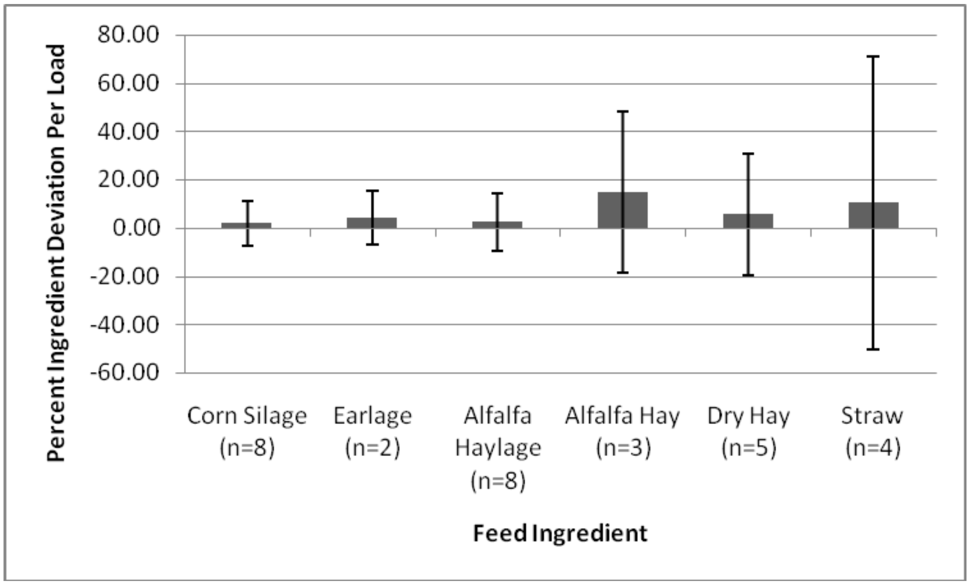
Figure 2.8 Percent deviation per load for by-product and commodity ingredients[1]



[1]n is the number of farms that utilized the feed ingredient

[2]Error bars represent standard deviation

Figure 2.9 Average percent load deviation per load for forages[1]



[1]n is the number of farms that utilized the feed ingredient

[2]Error bars represent standard deviation

Table 2.7 Variation in feed ingredient loading accuracy

Ingredient	Mean	SD
High Moisture Corn	4.87	18.42
Ground Corn	2.27	7.36
Hominy	5.46	10.24
Soybean Meal	3.26	12.44
Citrus Pulp	5.99	21.23
Distiller's Grains	2.61	10.35
Wet Brewer's Grains	3.62	13.43
Whole Cottonseed	1.83	10.28
Cottonseed Hulls	1.58	17.97
Corn Silage	1.87	9.22
Earlage	4.34	11.03
Alfalfa Haylage	2.57	12.05
Alfalfa Hay	14.85	33.38
Dry Hay	5.64	25.14
Straw	10.36	60.67

Chapter 3: An Example of Application of Control Charts to Feed Management

Abstract

Control charts are utilized daily in manufacturing facilities to monitor process control but have rarely been used in dairy herd management. Limited experimental applications of control charts have focused on estrus detection, urea metabolism and mastitis control. A study was conducted in which eight dairy farms utilized feed management software to monitor accuracy and precision of loading total mixed rations. Using data for loading corn silage from one farm, control charts were created to monitor process variation. When Shewart's basic rules of control charts were applied (define briefly that this means control limits set at one, two and three standard deviations above and below the mean with criteria for rejection defined), two data points for the individual ingredient X-bar chart were located outside of the control limits. Standard control limits may make little sense on dairy farms, however, because adding too much of an ingredient is far more common than adding too little. Uneven control limits were applied, including three standard deviations above the centerline and only one standard deviation below the centerline. With this test, seven additional data points fell outside of the control limits. Control charts with nontraditional control limits may be useful to monitor feed management and assist producers in making management decisions.

(key words: control chart, dairy, feed management)

Introduction

Control charts are tools used to monitor process control, identify assignable causes of variation and signal the need to take corrective action in a manufacturing process. These are used by many industries to ensure that products meet company, regulatory and customer standards. Statistical process control (SPC) charts have not been used routinely as a management tool within the dairy industry de Vries and Reneau, 2010. Research applications of control charts include estrus detection (de Vries and Conlin, 2003), pedometer activity for detection of metabolic disorders (Reneau and Lukas, 2006), milk urea nitrogen (MUN) for changes in protein nutrition and somatic cell count (SCC) for mastitis control (Reneau, 2010). Control chart principles can be applied to feed management on the dairy farm for loading accuracy and monitoring shrink. St-Pierre et al. (2007) used computer simulation to show that use of control charts improved farm feeding processes and reduced costs associated with forage sampling. Use of multiple control charts is thought to add sensitivity to detecting abnormal observations, but in their model St-Pierre et al. (2007) found that the use of multiple control charts was unnecessary. Data collection technology developed for dairy farms is highly automated and provides exceptional potential for application of SPC charts in feed management. The objective of this study was to provide an example of control chart application to feed management.

Materials and Methods

Control charts were created using feed management data to assess and evaluate process control. Data utilized to create the control charts were obtained from one farm's feed management software (TMR Tracker, Digi-Star, Ft. Atkinson, WI) for corn silage loading accuracy for one month. Feed management control charts were created with a centerline at zero instead of the average of data points (as is common in other industries) because the goal in animal production systems is to feed the call weight dictated by the nutritionist. According to business industry standards (Shewart, W. A., 1924), the upper and lower control limits were set at three standard deviations from the centerline. One SPC chart was created using industry standards and another was created using unconventional control limits, where the two and three standard deviations below the centerline were removed. Data points (corn silage loading accuracy by day) were plotted using mean and standard deviations of ingredient load calculated using PROC MEANS in SAS (2001).

Results and Discussion

The control chart utilizing the business industry standard of 3 standard deviations above and below the centerline revealed two data points that exceeded the upper control limits (Figure 3.1), signaling that the process was out of control (the feeder was loading more corn silage than acceptable) for those two loads. Control charts for individual ingredients are important to observe major ration ingredients such as corn silage, alfalfa haylage and hay since these ingredients constitute a large percentage of the total ration. Ingredients such as minerals are important to monitor because they affect cost and mineral content of the TMR.

When monitoring feed management, having three control limits on each side of the center line may not be relevant because dairy managers avoid underfeeding an ingredient to minimize risk of a decrease in milk production or health status. When corn silage feeding accuracy was evaluated with unbalanced control limits (only one standard below the centerline), seven more data points were outside the control limits (Figure 3.2). The use of uneven control limits in evaluating feed management increases sensitivity of detecting undesirable load deviations.

Control charts could also be used to monitor the accuracy and precision of total mixed ration load delivered to the herd. For example, if the data points in Figure 3.2 represented load deviations instead of individual ingredient deviations, total over and underfeeding would be displayed. The data point close to the third standard deviation above the centerline represents overfeeding and would result in increased daily feed cost and refusals. Data points around or below the third standard deviation below the centerline represents underfeeding and may result in decreased milk production and onset of metabolic diseases.

Conclusions

Application of control charts to feed management offers potential to allow dairy producers to easily monitor loading of individual ration ingredients and overall load deviations to identify problematic loads. Applying these to an overall load would indicate over and underfeeding of dry matter to a group of cows. Once these loads are identified, then managers can explore date, time of loading and feeder identity to identify possible areas for improved management. Using control charts offers great potential to improve feed management by improving accuracy of loading and precision and thereby decreased feed costs for animal production systems.

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Figure 3.1 X-bar chart for corn silage ingredient deviation (kg/load) for January 2009 for one farm

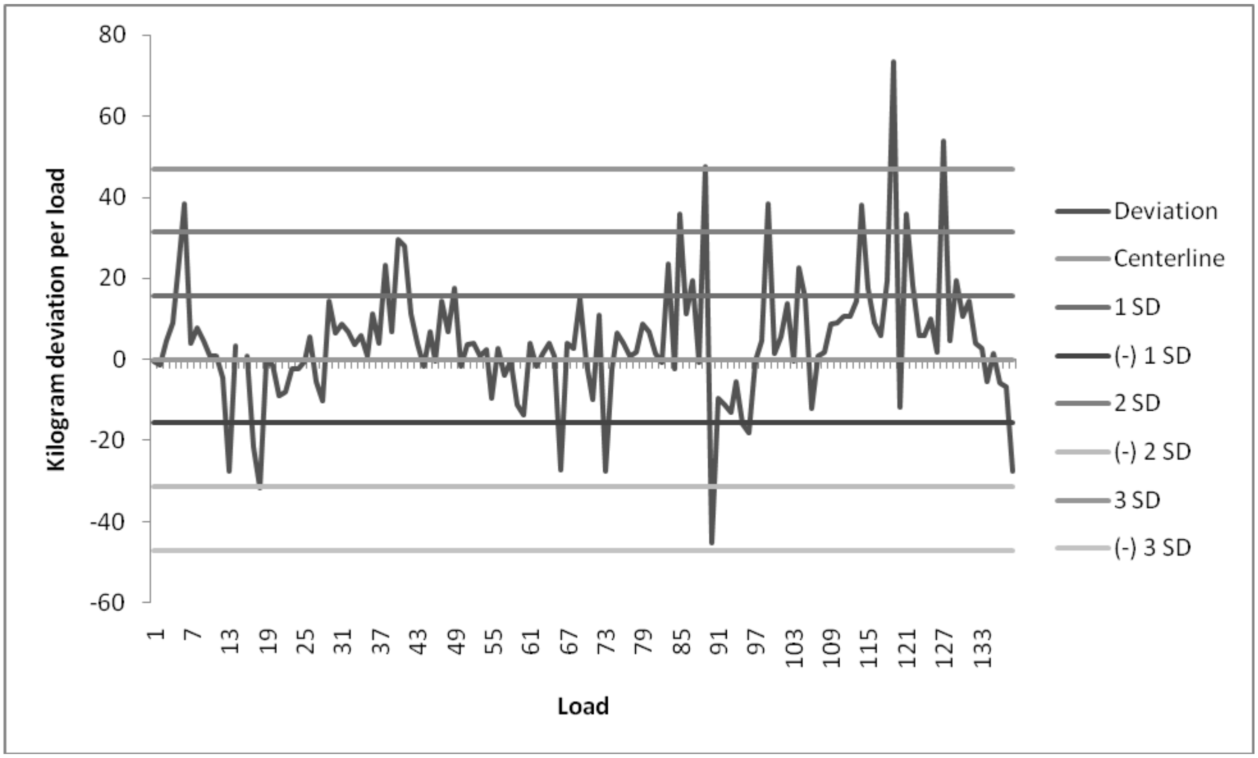
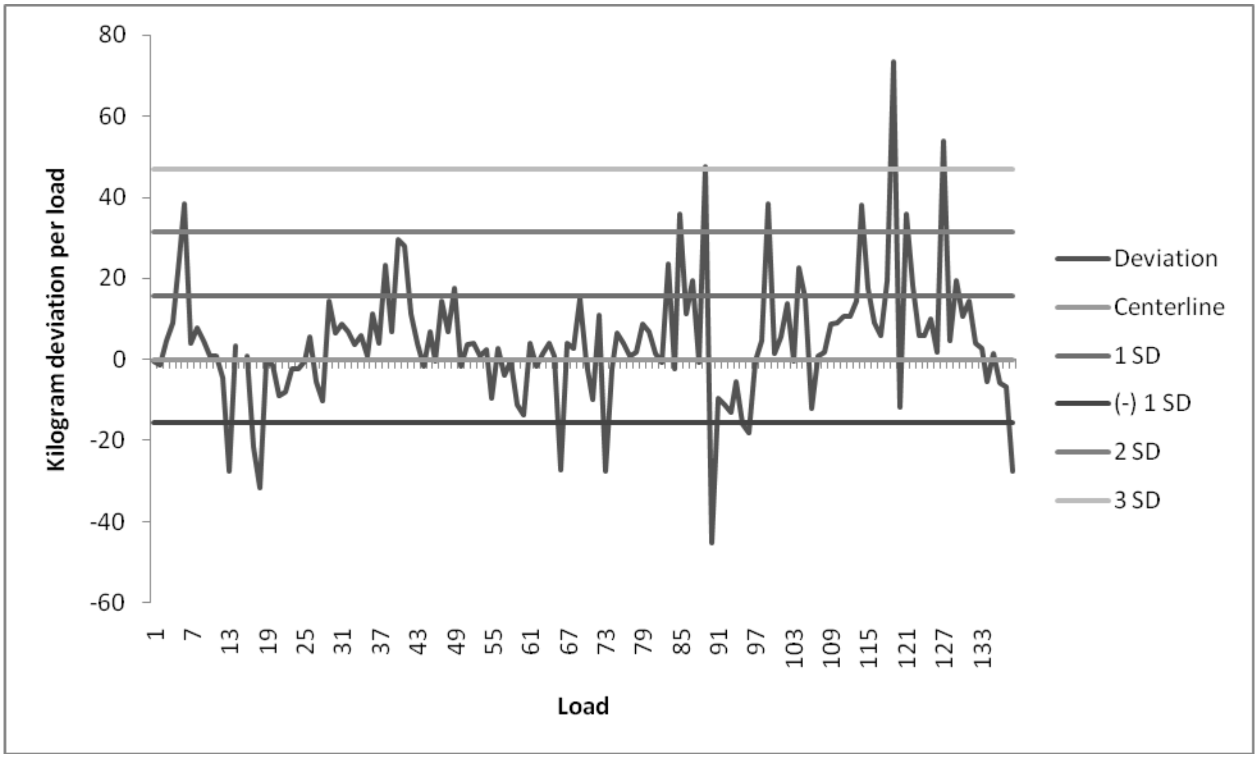


Figure 3.2 Proposed x-bar chart with unconventional control limits for corn silage ingredient deviation (kg/load) for January 2009 for one farm



Chapter 4: Cost of Reducing Protein and Phosphorus Content of Dairy Rations

Abstract

Reducing overfeeding of CP and P is an effective method to reduce excess nutrient excretion by dairy cows. However market conditions frequently dictate most economically desirable ingredients that are counterproductive to achieving this goal. Less expensive feeds such as by-products are frequently high in P (e.g. distiller's grains and corn gluten feed) or high in both CP and P. A linear program (Formulate2, Visalia, CA), was utilized to determine the impact of formulating rations for varying levels of CP and P on ration cost for a 658 kg dairy cow at 90 days in milk and producing 41 kg of milk. As dietary P decreased from 0.45 to 0.31 % DM, in increments of 0.02%, daily ration costs increased from $5.05 to $5.34. Ration cost increased because high P, less expensive by-product feeds were excluded from the ration to achieve lower dietary P. As CP increased from 16 to 18%, in increments of 0.5%, daily feed cost declined from $5.59 to $4.99. The greatest decline in daily ration cost occurred between 16 and 16.5% CP as requirements for metabolizable protein could be satisfied with less expensive feed ingredients. Rations with lower dietary P are more expensive than rations with higher levels of P.

(key words: crude protein, least cost ration, phosphorus)

Introduction

Reduced overfeeding of CP and P could effectively reduce N and P excretion by livestock. Decreased dietary P reduced fecal P and did not affect DMI, milk yield or reproduction (Morse et al., 1992; Wu et al., 2000; Lopez et al., 2004). Similarly, increasing dietary protein from 15.0 to 18.75% CP increased N excretion and decreased efficiency of utilization of N for milk production (Groff and Wu, 2005). Dietary CP concentrations recommended by the NRC (2001) range from 11.7 to 24% for all lactating cows and 14.5 to 17.5% for cows in mid-lactation. Protein contents as low as 13% are sufficient for cows in mid and late lactation producing 25 kg of milk with 3.5% fat (NRC, 2001).

Challenges arise trying to achieve nutritional accuracy at a reasonable cost per unit of production. Feed ingredients providing nutrients at the lowest cost per unit are by-products which are frequently high in P. Increased use of these ingredients results in rations not desirable from an environmental perspective.

The effect of changing nutrient concentration on feed cost depends on relative prices of alternative feeds (Howard et al., 1968). Rations re-formulated biweekly with current feed prices had lower dairy feed costs than those formulated with a previous year's feed prices, and rations that arbitrarily exclude feeds (e.g. urea) were more expensive (Howard et al., 1968). There was no difference in milk production, milk fat percent, body weight gain or occurrence of health disorders between treatments.

The work by Howard et al. (1968) created a foundation for the use of linear programs but least-cost rations have limitations. New software programs have been developed which enable formulation of diets to meet requirements of higher producing cows while minimizing nitrogen and P excretion (e.g. Cornell Net Carbohydrate and Protein System, 2008; CPM-Dairy 2003). These programs allow constraints to be placed on nutrients and ingredient inclusion. The objective of this study was to evaluate the effect of reducing dietary CP and P on feed costs utilizing commonly available feed ingredients in the eastern United States during 2011.

Materials and Methods

A ration formulation program (Formulate2, Visalia, CA) was utilized to formulate least cost rations containing differing amounts of CP and P for 658 kg dairy cow in her third lactation at 90 days in milk, producing 41 kg of milk with 25 kg/d DMI (Table 4.1). Dietary constraints on CP from 16-18% were imposed, increasing in increments of 0.5% while allowing dietary P to vary. In a second set of simulations, dietary P was constrained 0.31-0.45% in increments of 0.02% while allowing dietary CP to vary.

All rations met or were within 0.2% the metabolizable protein requirement for the animal. A feed library consisting of commonly available feed ingredients representing North America was developed. Ingredient prices represented the cost of delivered ingredients to a Virginia dairy farm in (Blue Seal Feed Mill, Feedstuffs, and USDA's National Weekly Feedstuff Wholesale Prices) in February 2011.

During initial runs, dietary P and CP were constrained simultaneously but no feasible solution was found. Constraints (minimum and maximums) were imposed for concentrate (% dry matter (DM)), ether extract (EE, % DM), neutral detergent fiber (NDF, % DM, nonfiber carbohydrates (NFC, % DM) and selenium (Se, ppm DM) (Table 4.2). Additional limitations were placed on corn distiller's grains with solubles, cottonseed hulls, whole cottonseed and molasses that reflect what a typical dairy ration in Virginia would contain.

Results and Discussion

Daily cost varied from $5.34 to $5.05 as dietary P increased from 0.31 to 0.45 %P (Figure 4.1). As dietary P was allowed to increase, inclusion of wheat middlings and corn silage increased and soybean hulls and cottonseed hulls decreased; the remainder of the ration composition varied only slightly (Table 4.3). The incorporation of rumen protected soybean meal was necessary in the lower P rations to meet metabolizable protein requirements and achieve adequate CP in the diet. When left uncontrolled, dietary CP increased in the higher P rations, 0.43% and 0.45% P, as corn distillers and wheat middlings became more economically attractive ingredients.

For dairy producers, it is important to meet the nutrient requirements at the lowest cost in order to optimize income over feed cost. However, from an environmental standpoint, the priority is to limit dietary P in order to reduce P excretion.

In the second set of simulations with dietary P unconstrained and dietary CP increased stepwise, little effect on feed cost was observed for rations with 16.5% to 18%.As CP increased, rations contained higher levels of grass/legume mixed silage, corn distillers and wheat middlings. Increased use of corn distillers and wheat middlings resulted in higher dietary P. Inclusion of rumen protected soybean meal, rolled barley and corn grain resulted in higher costs for the 16% CP rations. Rumen protected soybean meal was included in the lower CP rations to meet the metabolizable protein requirements of the animal. This ration included large quantities of wheat straw and little or no corn silage atypical of farms in this region of the country.

Conclusions

Given the economic conditions of February 2011, it was economically favorable to over feed P, but no economical penalty was associated to reducing dietary CP from 18% to 16.5%. For both sets of simulation, the content of the nutrient allowed to fluctuate increased as content of the controlled nutrient increased. Further research is needed to focus on feeding diets low in both CP and P to evaluate long-term net costs considering impacts on milk production, reproduction, nutrient management and feed costs.

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Table 4.1 Animal and production inputs for ration solution

Category	**Input Value**
Average age in months	53.0
Average lactation	3.0
Average age at first calving	24.0
Calving interval	13.0
Average body weight (kg)	658
Average days carrying calf	30
Average body condition score	3.0
Average days in milk	90
Milk weight (kg)	41
Milk fat percentage	3.50
Milk protein percentage (true)	3.20
Lactose percentage	4.85

Table 4.2 User specified nutrient constraints for least cost ration solutions

Nutrient	**User Minimum**	**User Maximum**
Concentrate (% DM)	40.00	55.00
Ether Extract (% DM)	2.00	8.00
NDF (% DM)	28.00	
CP (% DM)	Variable	Variable
NFC (% DM)	30.00	39.00
P (% DM)	Variable	Variable
Se (ppm DM)		0.30

[1]User specified minimum and maximum for crude protein, ranged from 15 to 18%, and phosphorus, ranged from 0.31 to 0.45

Table 4.3 User specified maximums and minimums on an as-fed basis for ingredient inclusion within the ration solution

Ingredient	**Minimum (kg)**	**Maximum (kg)**
Corn distillers grains with soluble		4.00
Cottonseed, hulls		2.00
Cottonseed, whole with lint		3.00
Molasses, sugarcane		0.50
Sodium chloride, NaCl	0.05	0.05
Sodium Bicarbonate	0.14	0.14
Magnesium Oxide	0.04	0.04

Figure 4.1 Changes in ration costs as a result of increasing dietary phosphorus

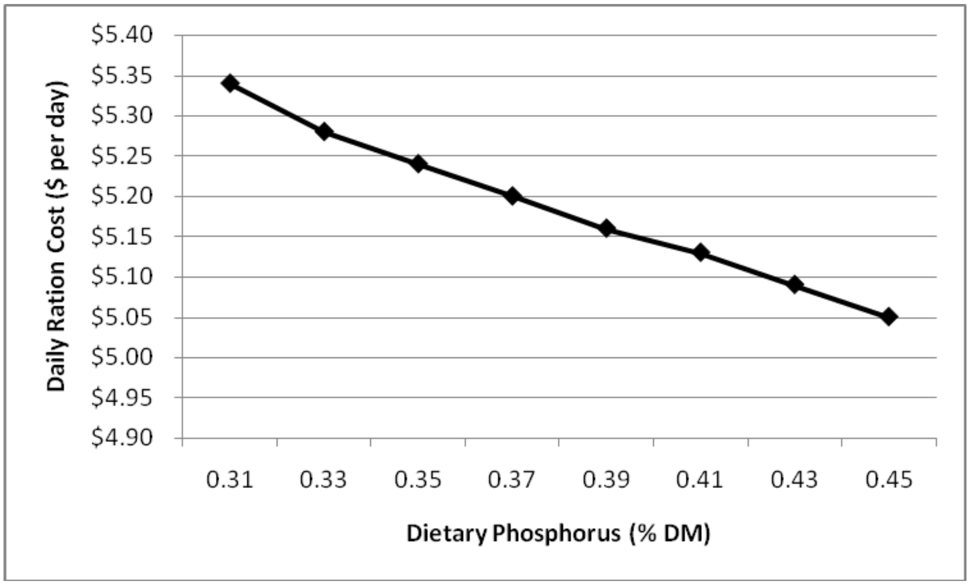

Table 4.4 Ration costs with varying levels of dietary phosphorus

P (% DM)	**0.31**	**0.33**	**0.35**	**0.37**	**0.39**	**0.41**	**0.43**	**0.45**
Cost	$5.34	$5.28	$5.24	$5.20	$5.16	$5.13	$5.09	$5.05
CP (% DM)	16.24	16.27	16.20	16.42	16.38	16.36	16.36	16.31
MP Supplied (g)	2842.21	2842.21	2842.21	2849.03	2844.53	2844.88	2848.00	2843.38
MP Required (g)	2846.46	2846.46	2846.46	2844.75	2844.53	2844.88	2848.00	2843.38
NFC (% DM)	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00

Table 4.5 Ration composition in kg (as-fed) for varying levels of phosphorus

Ingredients in Ration	$/tonne	0.31	0.33	0.35	0.37	0.39	0.41	0.43	0.45
Corn, silage normal	$54	15.25	14.13	18.52	24.05	30.03	34.99	39.23	35.10
Grass/legume mix silage, immature	$73	12.70	12.08	9.48	9.21	6.54	3.82	2.13	2.03
Wheat, Straw	$114	3.09	3.88	3.75	1.82	1.14	0.87	0.26	1.88
Soybean meal, solvent 48% CP	$475	0.75	0.73	0.73	0.61	0.59	0.58	0.51	0.49
Corn distillers grains with solubles	$259	0.49	1.71	1.27	4.00	4.00	4.00	4.00	4.00
Wheat, middlings	$182	---	---	0.02	0.12	0.09	---	0.23	1.38
Cottonseed, meal solvent 41% CP	$320	---	---	1.36	0.12	1.24	2.43	3.00	2.83
Cottonseed Hulls	$149	1.95	2.00	2.00	2.00	2.00	1.81	1.73	0.70
Soybean Hulls	$226	1.66	0.24	---	0.01	0.01	---	0.05	0.03
Molasses, sugarcane	$198	0.05	0.05	0.05	0.05	0.05	0.05	---	0.03
Vitamin E (60,000)	$5,512	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Selenium Premix, 0.06%	$265	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Limestone	$55	1.09	1.12	1.16	1.16	1.20	1.24	1.27	1.27
Barley, rolled	$243	2.17	2.56	2.36	0.96	0.41	0.04	---	---
Soybean meal, nonenzymatically browned	$535	2.31	2.05	1.50	1.44	0.87	0.29	---	---
Vitamin ADE	$5,200	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Premix	

[1]All rations include 0.05 kg sodium chloride, 0.14 kg sodium bicarbonate and 0.04 kg magnesium oxide

Figure 4.2 Changes in ration costs as a result of increasing crude protein

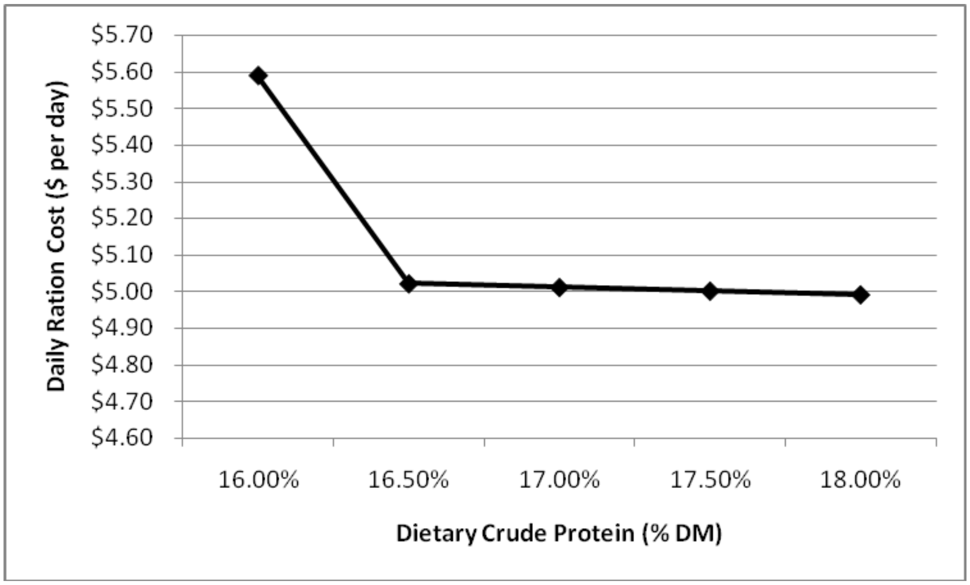

Table 4.6 Ration costs for varying levels of crude protein

Crude Protein (% DM)	16.0%	16.5%	17.0%	17.5%	18.0%
Cost	$5.59	$5.02	$5.01	$5.00	$4.99
Phosphorus (% DM)	0.37	0.47	0.48	0.49	0.50
MP Supplied (g)	2849.88	2843.38	2843.38	2843.38	2843.34
MP Required (g)	2853.88	2843.38	2843.38	2843.38	2843.34
NFC (%DM)	30.00	30.02	30.01	30.00	30.03

Table 4.7 Ration composition in kg (as-fed) for varying levels of crude protein

Ingredients in Ration	$/tonne	16.00	16.50	17.00	17.50	18.00
Corn, silage normal	$54	---	32.93	31.44	29.88	28.59
Grass/legume mix silage, immature	$73	6.21	2.28	4.10	5.95	7.71
Wheat, Straw	$114	8.59	2.55	2.04	1.54	0.99
Soybean meal, solvent 48% CP	$475	1.05	0.43	0.40	0.36	0.33
Corn distillers grains with solubles	$259	---	3.99	4.00	4.00	4.00
Wheat, middlings	$182	0.89	2.33	2.38	2.44	2.48
Cottonseed, meal solvent 41% CP	$320	3.08	2.77	2.77	2.75	2.79
Cottonseed Hulls	$149	1.66	---	---	---	---
Molasses, sugarcane	$198	0.50	---	---	---	---
Vitamin E (60,000)	$5,512	0.01	0.01	0.01	0.01	0.01
Selenium, 0.06%	$265	0.01	0.01	0.01	0.01	0.01
Limestone, ground	$55	1.23	1.27	1.24	1.22	1.19
Corn grain dry, ground	$290	1.84	---	---	---	---
Barley, rolled	$243	4.08	---	---	---	---
Soybean meal, nonenzymatically browned	$535	0.78	---	---	0.01	---
Vitamin ADE Premix	$5,200	0.01	0.01	0.01	0.01	0.01

[1]All rations include 0.05 kg sodium chloride, 0.14 kg sodium bicarbonate and 0.05 kg magnesium oxide

Conclusions

Implementation of feed management software had no effect on WFNB, and no consistent effect of year was observed. Feed price relationships likely influenced the effect of feed management software on WFNB; lower prices of high P by-product feed ingredients as compared to corn and soybean meal generally increased P imports..

Percent load deviation increased over time from 2007 to 2009, indicating reduced feeding accuracy. This suggests poor utilization of feed management software. Feeding accuracy was not consistently affected by month, day of the week and time of day, and there was no relationship between feeding accuracy and milk production. Differences were found between nutrient content of feed samples collected during the study and NRC (2001) values.

To increase utilization of feed management software, graphical representation of the data rather than numerical presentation would be easier and quicker for producers to assess. Educational programming for managers and feeders is needed, focused on how to interpret and use software outputs. Use of control charts may allow dairy producers to easily monitor loading and feeding accuracy to identify problematic loads. Once these loads are identified, then the producers can find more specific information about the load such as date, time and feeder id by looking into one of the reports.

Given the economic conditions of February 2011, it was economically favorable to over feed P, but no economical penalty was associated to reducing dietary CP from 18% to 16.5%. For both sets of simulation, the content of the nutrient allowed to fluctuate increased as content of the controlled nutrient increased. Further research is needed to focus on feeding diets low in both CP and P to evaluate long-term net costs considering impacts on milk production, reproduction, nutrient management and feed costs.

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Appendix A

Farms Summaries

The eight treatment farms had an average herd size of 315 cows, 3,225,527 kg for annual milk production and 366 crop hectares. Farms 1 to 6 and 9 to 10 are treatment farms. The control farms have an average herd size of 298 cows, 2,650,017 kg for annual milk production and 261 crop hectares. Farms 7 and 11 through 15 are control farms.

Farm 1

Farm 1 had an average herd size of 315 cows, 3,758,600 kg annual milk production and 261 crop hectares. The lactating cows consisted of four groups. Three groups of cows were housed in free stall barns that are bedded with sand. The fourth group of cows was housed in a bedded pack with straw and sawdust. Rations were adjusted for moisture three times a month. Refusals were not recorded. The nutritionist adjusted the ration on a monthly basis as needed. Two rations were fed to the cows, with three groups fed the high cow ration and one group fed the low cow ration. The ration was fed twice a day with a three to five minute mixing time. Perceived feeding accuracy for loading was good and delivery is excellent. There are three feeders, one primarily feeding in the morning, the second primarily feeding in the afternoon and the third feeding as needed. This farm used a Harsh mixer.

Farm 2

Farm 2 had an average herd size of 492 cows, 5,814,935 kg annual milk production and 611 crop hectares. The lactating cows consist of five groups with an additional group for treated cows. All cows are housed in free stalls bedded with sand. The cows have access to a salt block within their feed bunks. This farm does use a standard operating procedure when training new employees. Adjustments of the ration for moisture occur daily. Feed refusals are recorded. The ration was delivered to the cows three times a day. Four of the lactating groups receive the high cow ration and the fifth group receives the low cow ration. There was one main feeder on this farms and has been employed for ten years. This farms utilized two Kuhn Knight 3070 Reel mixer that received maintenance as needed.

Farm 3

Farm 3 had an average herd size of 138 cows, 1,340,552 kg annual milk production and 163 crop hectares. The lactating cows consist of one group that are housed in free stalls bedded with sawdust and hydrated lime. The cows are provided with free choice salt. Employees are provided with hand-on training and have access to standard operating procedures. Adjustments for moisture occur based on perceived differences or if there is a large increase in feed refusal amounts. Two nutritionists adjust the ration once or twice a month. The cows are fed twice daily. Perceived feeding accuracy was within five percent and delivery was feeding everything that is in the mix wagon. There are two operators, the manager who has been employed for 14 years and a farms hand who has been employed for one year. This farm has a 20 year old Knight Reel Auggie that receives grease once or twice a month.

Farm 4

Farm 4 had an average herd size of 446 cows, 4,293,487 kg annual milk production and 644 crop hectares. The lactating cows are organized into four milking groups, with the middle group being housed at another farm. Three groups are housed in free stalls bedded with sawdust and the fourth group is housed in free stalls bedded with sand. The ratio is adjusted daily based on moisture and the nutritionist formulates new rations monthly. Feed refusals are not recorded. The cows are fed twice daily. Operators have changed on a yearly basis and there are normally two per year. This farm has a 3 year old Knight 3060 that receives weekly maintenance.

Farm 5

Farm 5 had an average herd size of 298 cows, 1,733,055 kg annual milk production and 543 crop hectares. The lactating cows are organized into three milking groups. Two groups are housed in free stalls bedded with newspaper. The third group is housed in a bedded pack bedded with wood shavings. The ration was adjusted based on moisture as needed and the nutritionist formulates new rations as needed. The cows are fed twice daily. The main operator has been employed for over 40 years. This farm purchased an Oswalt 4 auger in 1988, has been refurbished four times and is maintained weekly.

Farm 6

Farm 6 had an average herd size of 159 cows, 1,622,472 kg annual milk production and 135 crop hectares. The lactating cows are organized into two groups. The cows are housed in free stalls and a pack barn bedded with straw and sawdust respectively. Along with the TMR, the cows are provided with a free choice mineral. The ration was adjusted weekly for moisture. This farm has two mixers, a Harsh and a Mon Mix.

Farm 7

Farm 7 had an average herd size of 281 cows, 3,145,679 kg annual milk production and 192 crop hectares. Two groups of lactating cows are housed in free stalls bedded with mattresses with sawdust. The ration was adjusted for moisture based on clean-up and weather changes. Feed refusals are not recorded. The nutritionist formulates a new ration once a year. The cows are fed twice a day with 40 minutes mixing time and 10 minute feed out time. The owner estimates perceived loading accuracy to be between one and two percent. This farm employees three operators and one of the operators is the owner. This farm utilizes a three year old Keenan mixer wagon that receives grease every two weeks.

Farm 9

Farm 9 had an average herd size of 224 cows, 2,802,457 kg annual milk production and 151 crop hectares. The lactating cows are housed in free stalls bedded with sawdust and a pack barn for 40 cows bedded with sawdust. The cows located in the pack barn are provided with free choice hay. Employees are usually trained for one week and the farm does have a standard operating procedure. The ration is adjusted for moisture when it rains. The nutritionist formulated a new ration once monthly or more frequently if there are any feed changes. The ration was fed three times a day with a five to eight minute mixing time depending if the ration contains hay. There are four operators consisting of three main and one relief feeder. The feeder that has the first feeding shift has been employed for 7 years, the second feeder has been employed for one year and the third feeder has been employed for 22 years. The relief feeder has been employed for 28 years. This farm has a three year old NDE mixer that receives maintenance monthly.

Farm 10

Farm 10 had an average herd size of 412 cows, 4,171,484 kg annual milk production and 382 crop hectares. The lactating cows are organized into four groups and are housed in free stall barns bedded with sawdust. The cows are offered a free choice mineral. The ration is adjusted weekly for moisture. The nutritionist formulates rations weekly. There are two feeders. This farm has a 16 year old Reel Auggie mixer that receives maintenance monthly.

Farm 11

Farm 11 had an average herd size of 181 cows, 2,008,813 kg annual milk production and 346 crop hectares. Further information was not acquired.

Farm 12

Farm 12 had an average herd size of 1230 cows, 8,435,543 kg annual milk production and 944 crop hectares. Further information was not acquired.

Farm 13

Farm 13 had an average herd size of 266 cows, 2,457,605 kg annual milk production and 205 crop hectares. Further information was not acquired.

Farm 14

Farm 14 had an average herd size of 300 cows, 2,932,985 kg annual milk production and 192 crop hectares. The lactating cows are organized into two groups and are housed in two poll barns bedded with wood shavings. The ration is adjusted weekly for moisture and feed refusals are not recorded. The nutritionist formulated a new ration monthly, with changes of feeds or when a change in intake occurs. Perceived feeding accuracy for loading is 90%. There are two managers on the farms. This farm has a 6 year old Reel Auggie mixer that is maintained weekly.

Farm 15

Farm 15 had an average herd size of 105 cows, 903,864 kg annual milk production and 82 crop hectares. The lactating cows are organized into two groups, a fresh cow and a late lactation group. All lactating cows are housed in free stalls bedded with mattresses and sawdust. All feeds are loaded and mixed by the owner, so there is no standard operating procedure. The ration is adjusted for moisture as needed. Feed refusals are recorded daily and remixed as part of the dry cow and heifer rations. New rations are formulated as needed with forage changes. The cows are fed twice daily. The perceived feeding accuracy is 95% for loading and 95% for delivery. This farm has a 13 year old 127 John Deere Reel type mixer that receives maintenance as needed.

Appendix B

Table 5.1 shows the whole-farm nitrogen balance (kg/yr) on a per farm basis for all farms for all five years of the study (2005-2010). The data collected from 2005 was used as a covariate in the analysis. Large variation occurred between years, which depended on the amounts of nitrogen inputs and outputs. Similar observations are made for whole-farm phosphorus balance (kg/yr) on a per farm basis for all farms for all five years of the study (Table 5.2).

Some of the variation observed between years within farm can be explained by varying herd sizes. Therefore, the best way to analyze nutrient surplus was on a per cow basis. Tables 5.3 and 5.4 show the whole-farm nitrogen and phosphorus balance (kg/yr) for all farms for all five years of the study. Variations across years within farm is observed. Farm 9 was the only farms where nitrogen surplus (kg/yr) per cow decreased over time. Decreasing nitrogen surplus was achievable with dietary manipulation. The nutritionist for farm 9 was conscious of the need for decreasing dietary crude protein and was proactive in working to achieve this goal. Phosphorus surplus (kg/yr) per cow did not decrease over time for any of the farms. It was more difficult to decrease phosphorus surplus because most feeds purchased are less expensive by-products that are high in phosphorus.

Overall average daily percent load deviation and the absolute value for percent load deviation were 1.42 ± 4.72 and 2.23 ± 4.90. Figure 5.1 shows the average daily percent load deviation and the absolute value for percent load deviation by farms from 2007 to 2009. Farm 3 was both accurate and precise in both average and absolute value of daily percent load deviation. Both deviations are close to zero and have a small standard deviation. Farm 2 had a small mean percent load deviation but the largest standard deviation. This observation was unexpected since all three feeders have been working on this farms throughout the duration of this study. Large load deviations may be a result of the feed center layout, which is not conducive to accurate and precise loading of feed ingredients.

Farm 1, 3 and 4 had differences between feeders overall. Differences were found for the feeder by year interaction for all farms (Figures 5.2-5.9). Large variation in load deviation is noted between feeders and years, especially in the standard error. The number of feeders varied for each farms and year since most farms changed their feeders annually. This constant change in feeders on the farms probably did contribute to the large variation in load deviation. The lack of consistency and training were also possible contributing factors. Farm 3, 4 and 6 had some negative load deviations, which indicate underfeeding. This observation is interesting since there is a tendency to over feed not under feed. This result may be due to equipment or ingredient loading problems. Farm 2 had some of the largest standard errors while farm 4 had some of the largest average percent load deviations when compared to other farms. The largest standard error seen on farm 2 is for feeder 6, which was added in 2009. This feeder may be a weekend only feeder because the largest standard error but this speculation has not been confirmed. Feeder 1 on farm 4 in 2009 had the largest mean percent load deviation when compared to other farms and feeders. Previously, the feeder had a small percent load deviation in 2007 and 2008, so it is unknown why this drastic change occurred. Overall, feeders need to be responsible for improving their percent load deviation by viewing the feed management data and discussing their progress with the owner.

Table 5.1 Whole-farm nitrogen balance (kg/yr) on a per farm basis for 2005 to 2010

Farm	2005	2006	2007	2008	2009	2010
1	55,882	58,349	36,748	45,071	44,643	57,685
2	59,978	70,145	94,011	97,004	115,255	47,304
3	14,918	20,096	5,665	-15,168	-789	28,224
4	32,104	26,620	46,471	14,502	12,321	24,024
5	63,499	57,137	51,586	41,440	14,193	77,214
6	15,685	21,565	10,629	18,161	26,546	----------
7	9,253	14,273	-----------	-----------	-----------	----------
9	45,301	41,882	32,900	32,825	29,231	25,635
10	66,984	68,474	106,867	101,958	48,927	50,393
11	30,545	27,194	25,366	31,461	26,095	----------
12	297,796	275,881	-----------	-----------	-----------	----------
13	25,744	20,774	-----------	9,985	-----------	----------
14	30,799	30,697	53,613	42,743	49,783	35,993
15	17,112	14,976	15,980	14,181	15,815	19,900

Table 5.2 Whole-farm phosphorus balance (kg/yr) on a per farm basis for 2005 to 2010

Farm	2005	2006	2007	2008	2009	2010
1	5,367	7,651	3,923	5,195	4,155	4,998
2	14,139	1,274	3,065	5,325	4,926	7,153
3	4,127	2,457	5,981	-1,056	-791	4,538
4	4,824	20	20,064	8,369	9,251	7,835
5	14,827	6,422	22,441	13,540	8,269	10,266
6	-1,504	-966	-778	-971	-181	----------
7	2,139	-906	-----------	-----------	-----------	----------
9	4,130	2,000	5,063	4,478	3,868	15,012
10	2,488	2,533	9,611	8,618	5,096	1,299
11	3,565	4,183	3,474	4,115	5,068	----------
12	21,399	19,106	-----------	-----------	-----------	----------
13	307	-52	-----------	-1,324	-----------	----------
14	1,025	2,250	3,305	1,835	2,311	3,077
15	2,343	1,826	1,629	1,154	1,926	2,637

Table 5.3 Whole-farm nitrogen balance (kg/yr) on a per cow basis for 2005 to 2010

Farm	2005	2006	2007	2008	2009	2010
1	189	188	116	143	140	175
2	168	175	215	176	197	76
3	112	149	36	-108	-6	217
4	90	59	103	32	25	50
5	219	204	156	126	51	276
6	95	154	63	106	178	-------
7	33	50	-------	-------	-------	-------
9	218	190	151	146	130	103
10	188	190	223	245	115	116
11	174	155	141	175	134	-------
12	248	219	-------	-------	-------	-------
13	117	74	-------	34	-------	-------
14	104	104	175	146	163	118
15	165	136	161	135	151	184

Table 5.4 Whole-farm phosphorus balance (kg/yr) on a per cow basis for 2005 to 2010

Farm	2005	2006	2007	2008	2009	2010
1	18	25	12	16	13	15
2	39	3	7	10	8	11
3	31	18	38	-8	-6	35
4	14	-----	45	19	19	16
5	51	23	68	41	30	37
6	-9	-7	-5	-6	-1	------
7	8	-3	------	------	------	------
9	20	9	23	20	17	60
10	7	7	20	21	12	3
11	20	24	19	23	26	------
12	18	15	------	------	------	------
13	1	-----	------	-4	------	------
14	3	8	11	6	8	10
15	23	17	16	11	18	24

Figure 5.1 Average daily percent load deviation and the absolute value for percent load deviation by farm

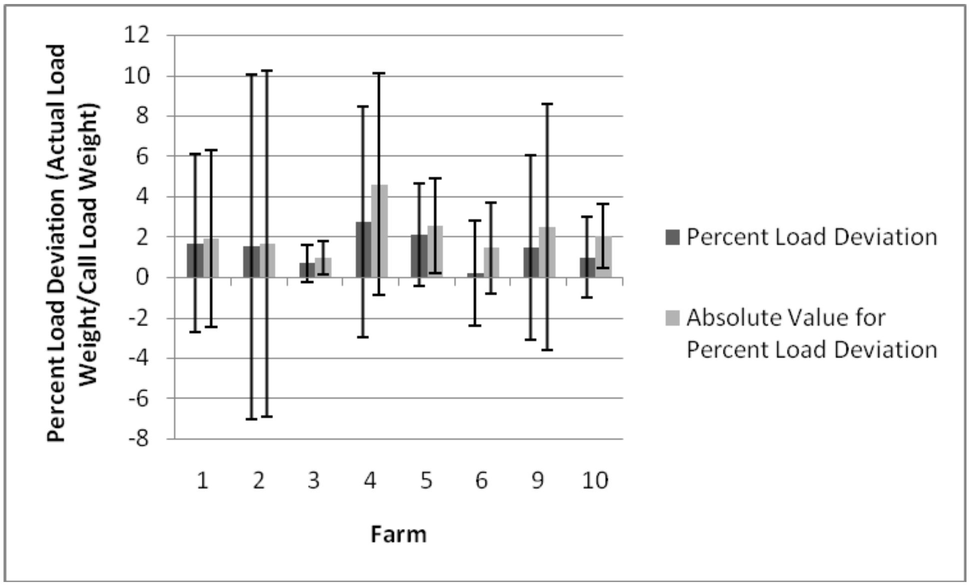

Figure 5.2 Percent load deviation for feeders on Farm 1

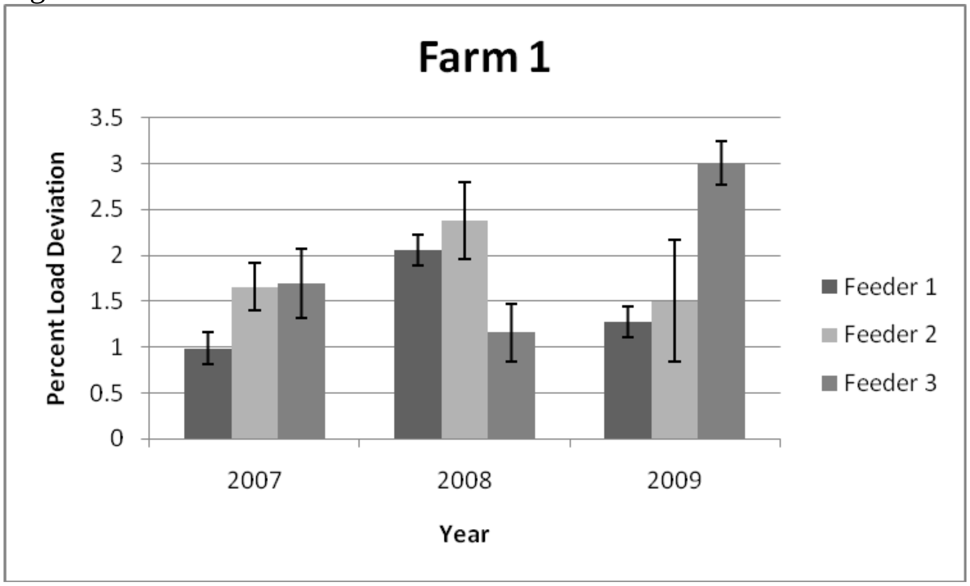

Figure 5.3 Percent load deviation for feeders on Farm 2

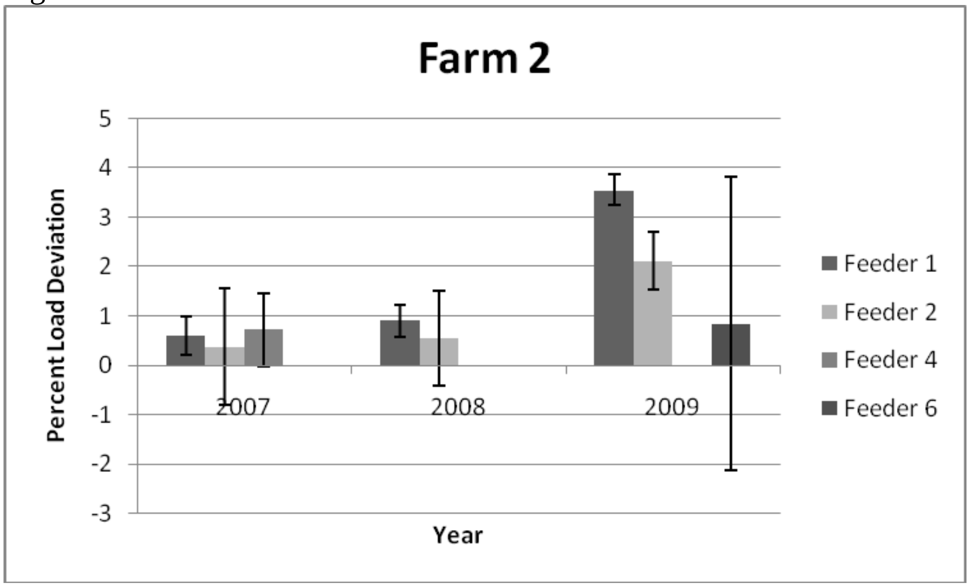

Figure 5.4 Percent load deviation for feeders on Farm 3

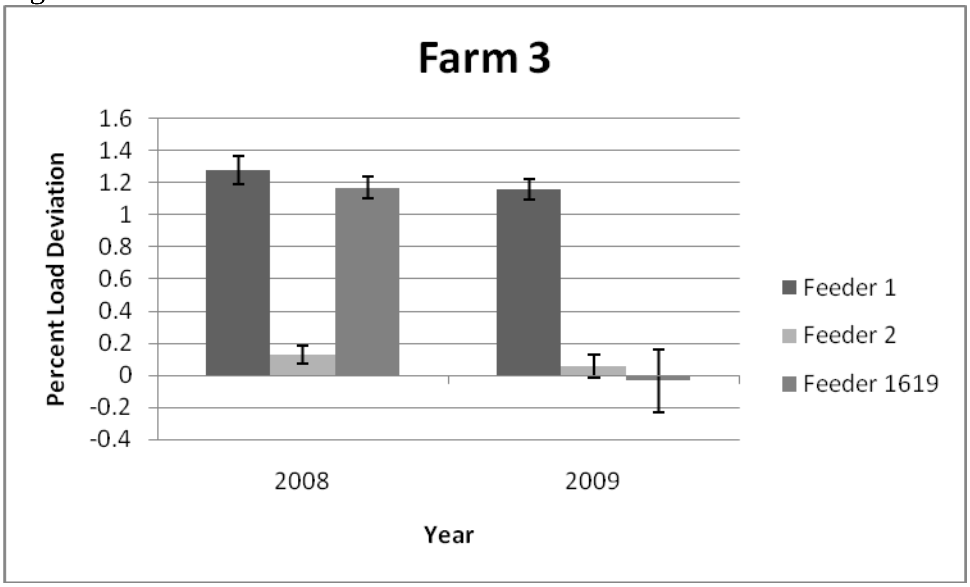

Figure 5.5 Percent load deviation for feeders on Farm 4

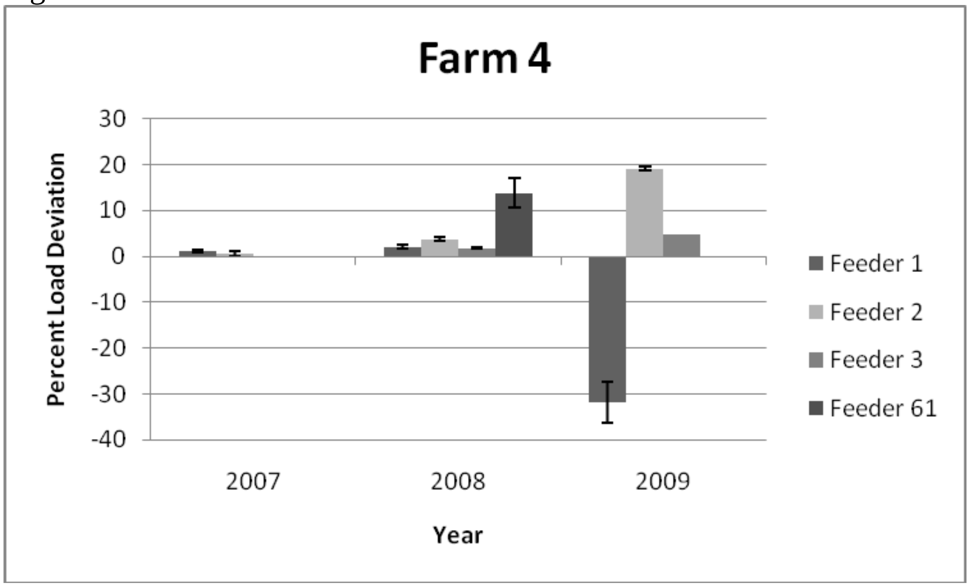

Figure 5.6 Percent load deviation for feeders on Farm 5

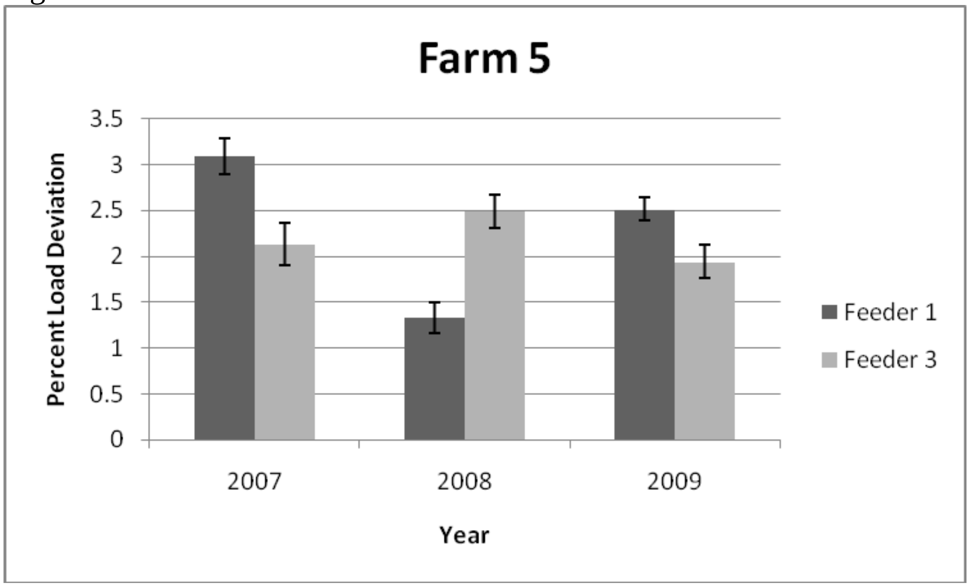

Figure 5.7 Percent load deviation for feeders on Farm 6

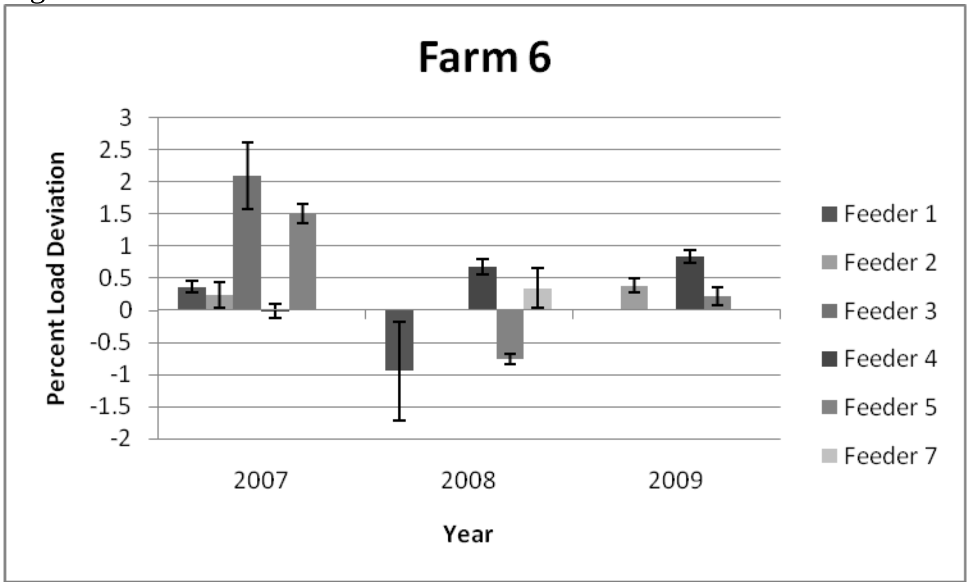

Figure 5.8 Percent load deviation for feeders on Farm 9

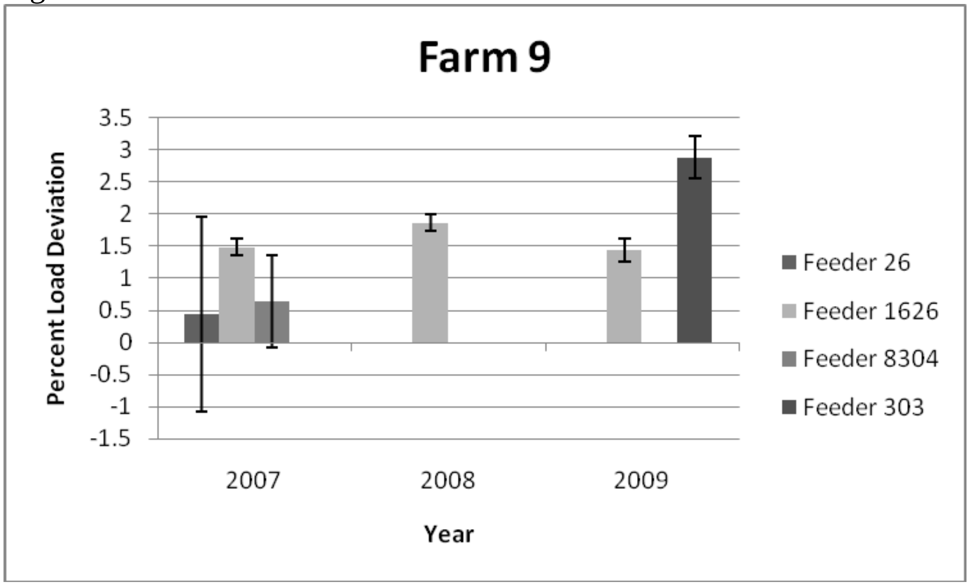

Figure 5.9 Percent load deviation for feeders on Farm 10