Assessment of Feeding Management in the National Dairy FARM Program

Jessica A. Pempek[1]
Department of Veterinary Preventive Medicine
The Ohio State University

Abstract

A number of animal welfare assurance programs have been developed in recent years to encourage the adoption of welfare standards across food animal industries and to assure the public that these standards are being followed. In contrast to the European Union, the United States has relied less on legislative action and has instead focused on the creation of retailer- and industry-driven audits and assessment programs to meet public expectations about animal welfare. An animal welfare assessment program used in the dairy industry is The National Dairy FARM Animal Care Program: Farmers Assuring Responsible Management. The mission of this Program is to provide assurance to consumers and members of the public that the dairy industry is committed to the use of best management practices to promote the highest level of animal care (www.nationaldairyfarm). The FARM Program provides evidence-based standards for various aspects of animal care and highlights the importance of proper feeding management practices to promote continuous improvement of the welfare of dairy animals. Feeding management of all animal groups is assessed using both animal-based measures (e.g., measurements taken directly from the animal, such as body condition score) and resource-based measures (e.g., measurements taken from the environment or management of the animal, such as milk quantity for pre-weaned heifers, feed bunk space allowance for growing and adult animals, etc.). The purpose of this paper is to: 1) provide an overview of the FARM Program; 2) discuss the Program's evaluation of feeding management practices; and 3) review the supporting scientific literature.

Introduction

Animal welfare is a key social concern that must be addressed to safeguard the future viability of the dairy industry (von Keyserlingk et al., 2013). Compared to the European Union, the United States has minimal federal regulations for animal welfare; instead, food retailers and industry leaders have created animal welfare audits and assessment programs to assure consumers that animals raised for food have a good quality of life (Mench, 2003). To be sustainable, such audits and assessment programs must be evidence-based and reflect the shared values of relevant stakeholders.

The National Dairy FARM Animal Care Program

An animal welfare assessment program used by the U.S. dairy industry is The National Dairy FARM Animal Care Program: Farmers Assuring Responsible Management. The FARM Program was created in 2009 by the National Milk Producers Federation with the support of Dairy Management Incorporated™ to bolster

[1]Contact at: A100E Sisson Hall, 1920 Coffey Road, Columbus, OH 43210, (740) 312-9311, Email: pempek.4@osu.edu.

consumer confidence and demonstrate the dairy industry's commitment to animal care. The Program is an animal welfare assurance program that promotes a continuous improvement process to encourage the participation of dairy producers nationwide. According to the FARM Program, their basic standards and guidelines are evidence-based and incorporate the views of various stakeholder groups, as the Program's Technical Writing Group is comprised of animal welfare scientists, veterinarians, cooperative members, and dairy producers (NMPF, 2015). Further, the Program incorporates the use of third-party verification (e.g., external evaluations conducted by trained individuals who do not have a conflict of interest with the operation or the outcome of the program) to promote social confidence and document the integrity of the Program's animal care standards and their on-going evaluation.

FARM Assessment of Feeding Management

The criteria for assessing animal welfare are generally divided into those that describe the physical environment and resources available to the animal (resource-based measures) and those that describe the state of the animal (animal-based measures; Mench, 2003). The FARM Program includes animal- and resource-based measures of welfare throughout their animal care standards and guidelines, as they pertain to: 1) nutrition, 2) animal health, 3) environment and facilities, 4) animal handling, movement, and transportation, and 5) special needs animals. This paper will focus on the nutritional component of the FARM Program for newborn and milk-fed dairy calves, growing heifers, and cows.

Evaluation procedure

After a dairy producer (e.g., individual producer, cooperative member) has shown interest in the FARM Program, the evaluator will contact the producer and schedule a date to conduct the on-farm evaluation. On the day of the evaluation, evaluators will first conduct a short 'entrance interview' with the producer to communicate the goals of the Program and provide an overview of the evaluation procedure. Evaluators will then use the Management Checklists provided in the Animal Care Reference Manual to conduct the site evaluation and complete animal observations (NMPF, 2013). After the evaluation is complete, evaluators review their findings, calculate observation numbers, and meet with the producer for a 'closing meeting' to discuss strengths of the operation and review areas of improvement, if necessary.

Animal-Based Measures of Nutrition

Body condition score

A direct method for assessing feeding management practices on-farm is to evaluate the condition of animals. A body condition score (**BCS**) is an assessment of the proportion of body fat an animal possesses and has been recognized by animal scientists and dairy producers as a means to assess feeding management practices (Roche et al., 2009). The FARM Program assigns BCS (1 = thin to 5 = fat; whole point increments) based on visual appraisal of the animal. Extreme BCS (either too thin or too fat) reflects an increased risk of compromised animal welfare (e.g., Roche et al., 2009). Emaciation increases the animal's risk of mild or severe lameness (Randall et al., 2015), and lower calving BCS is associated with reduced production (Waltner et al., 1993) and reproduction (e.g., Heuer et al., 1999). The FARM Program requires dairy producers to take corrective action for animals that receive a BCS score of 1. The Program goal for BCS in a herd is that 99% or more of all classes of animals score 2 or more.

Overconditioning predisposes cows to increased risk of periparturient metabolic disorders (ketosis: Gillund et al., 2001; milk fever: Roche and Berry, 2006; displaced abomasum: Dyk, 1995) and impaired reproduction (Roche et al., 2007). Further, BCS is negatively associated with DMI, particularly during the transition period (Roche et al., 2008). Although overconditioning is not directly assessed per the FARM Program, evaluators should consider the nutritional consequences of both BCS extremes. If necessary, high BCS can be scored separately from low BCS and discussed with the dairy producer during the closing meeting.

Resource-based Measures of Nutrition

Newborn and milk-fed dairy calves

The FARM Program considers a number of resource-based measures of feeding management practices on-farm. To provide clarity, the Program's assessment questions will first be provided, followed by a brief review of the supporting scientific literature.

Do "*all calves receive colostrum or colostrum replacer soon after birth, even if transported off the farm*" (NMPF, 2013, p. 15)? Colostrum management directly influences calf health and survival (Godden, 2008). During the on-farm data collection portion of the assessment, FARM Program evaluators are trained to look for evidence of proper colostrum management (e.g., written standard operating procedures, colostrometer, Brix refractometer, etc.). Components of a successful colostrum management program include: 1) calves should ingest their first meal of colostrum within 6 hr of birth; 2) colostrum should be of high quality (IgG concentration greater than 50 g/L); and 3) calves should receive 4 qt (or 10 % body weight (**BW**), whichever is greater) of high quality colostrum within 12 hr of birth (Davis and Drackley, 1998). Dairy producers are also encouraged to work with their veterinarian to measure prevalence of failure of passive transfer (**FPT**) to assess colostrum management practices; calves are defined as having FPT if serum IgG concentration is <10 g/L when sampled between 24 and 48 hr of birth (Quigley, 2004).

Do "*calves receive a volume and quality of milk or milk replacer to maintain health, growth, and vigor until weaned or marketed*" (NMPF, 2013, p. 15)? The FARM Program emphasizes the benefits of increased milk allowance for calves during the pre-weaning period. Per the Program's Animal Care Reference Manual (2013, p. 15), "Feeding only four quarts per day of milk or milk replacer equivalent does not allow the calf to meet its nutritional requirements for maintenance, growth and development." Holstein calves ingest 10.6 qt or more of whole milk per day when offered ad libitum (Jasper and Weary, 2002; von Keyserlingk et al., 2004), approximately twice the conventional milk allowance of 10% BW (Drackley, 2008). As a result of higher milk intake, ad libitum-fed calves have higher pre-weaning (0 to 36 d of age) average daily gain (**ADG**) compared to calves fed 5.3 qt/day (1.72 versus 1.06 ± 0.11 lb/day, respectively; Jasper and Weary, 2002). Similar weight gains have also been reported in calves fed milk ad libitum versus 10% BW (Appleby et al., 2001) and calves fed 20 versus 10% BW (Khan et al., 2007). Further, increased growth rates early in life have been associated with long-term benefits, such as reduced calving age (Raeth-Knight et al., 2009) and higher first-lactation milk yield (Soberon et al., 2012).

Providing calves more milk may reduce calf-starter grain intake during the pre-weaning period (Jasper and Weary, 2002). Fortunately, research continues to investigate methods of stimulating solid food intake pre-weaning to

reduce potential growth post-weaning (Khan et al., 2007; de Passillé et al., 2011; Khan et al., 2011). For instance, a feeding program where calves were initially offered a high milk allowance (20% BW) during the first 25 days of life gradually diluted milk with water (10% of volume/feeding) until a milk-feeding rate of 10% BW was achieved (day 26 to 30), thus calves were a low milk allowance (10% BW) in the weeks before weaning. This step-down milk-feeding program increased starter grain and hay intake and allowed calves to be weaned without experiencing a growth lag (Khan et al., 2007). Other approaches to increasing starter intake pre-weaning include group housing with calves of similar age (De Paula Vieira et al., 2010) or with older animals (De Paula Vieira et al., 2012).

Are "*calves offered fresh, palatable starter feed"? Do "calves have access to palatable, clean, fresh water as necessary to maintain proper hydration*" (NMPF, 2013, p. 15)? Although starter and water consumption are not directly assessed per the FARM Program, it is important for evaluators to ensure farms are offering ad libitum starter grain from the first week of life (Drackley, 2008). Evaluators should also examine feeding management protocols and confirm that farms are in compliance with standard operating procedures (**SOP**); for instance, if an SOP states that calves receive starter grain from 3 days of age, evaluators should verify that all calves 3 days of age or older have access to starter grain.

Growing heifers and cows

Do "*rations provide the required nutrients for maintenance, growth, health, and lactation for the appropriate physiological life stage*" (NMPF, 2013, p. 18)? Proper feeding management is necessary to ensure the health and welfare of all dairy animals, and promoting dry matter intake (**DMI**) to support milk production is the cornerstone of successful dairying (NRC, 2001). The FARM Program encourages consultation with a qualified nutritionist to assist with ration formulation. Evaluators for the Program are encouraged to ask producers if they have an existing relationship with a nutritional consultant, how often they meet, etc. to provide evidence for the answer to this question during the evaluation.

Is "*sufficient feed bunk space provided that allows all animals to feed at the same time"? Are "sufficient quantities of feed available for all animals during a 24 hr period*" (NMPF, 2013, p. 18)? A majority of the literature investigates how changes in nutrient composition impacts DMI; yet, accessibility of feed (e.g., stocking density, feed distribution, etc.,) may be more important than actual amounts of nutrients provided (Grant and Albright, 1995; Grant and Albright, 2001). Thus, the FARM Program guidelines focus on the animal's ability to gain access to the feed bunk. Current industry-recommended best practices with regard to feed bunk space allowance for growing heifers 6-to-12, 12-to-18, and over 18 mo of age is 18, 20, and 24 in of linear feeding space/heifer, respectively (Dairy Calf & Heifer Association, 2010). For lactating cows housed in a freestall barn, at least 24 in of linear feeding space/cow (e.g., 1 headlock/cow) should be provided (Grant and Albright, 2001), and 30 in/cow is currently recommended for dry cows (Nordlund et al., 2006).

Although such recommendations have traditionally been considered adequate, total daily feeding time increases as feed bunk space allowance increases, especially during peak feeding times (e.g., from 25 to 36 in/cow; DeVries and von Keyserlingk, 2005). Cows are highly motivated to access freshly delivered feed (DeVries and von Keyserlingk, 2005). When feeding space is reduced, some cows

may be unable to eat when fresh total mixed ration (**TMR**) is delivered, which consequently shifts feeding time. Cows frequently sort TMR, which reduces feed quality throughout the day (DeVries et al., 2005). Therefore, cows forced to delay feeding due to overstocking may consume a poorer quality diet and be unable to meet their nutritional demands for milk production.

Reduced access to feed increases aggressive interactions and competitive displacements (i.e., an instigated displacement resulting in the complete withdrawal of another animal from the feed bunk) (DeVries and von Keyserlingk, 2006; Huzzey et al., 2006; Proudfoot et al., 2009), which has physiological consequences (Huzzey et al., 2012a, Huzzey et al., 2012b). Overstocking (dry cows: 1 freestall/2 cows and 13.6 in feed bunk space/ cow) increases plasma nonesterified fatty acid (**NEFA**) concentrations and tends to increase fecal cortisol metabolite concentrations (Huzzey et al., 2012b). Cattle with lower displacement indices (e.g., cows that are frequently displaced but have difficulty displacing others) also have the highest (fastest) feeding rates (Proudfoot et al., 2009) and greatest physiological response to the stressor (Huzzey et al., 2012a). Thus, providing increased feeding space improves access to feed and reduces competition at the feed bunk, particularly for subordinate animals (e.g., often heifers).

Action Plan

After the completion of the animal care evaluation, a written Action Plan is developed if improvement is necessary. Action Plans: 1) identify opportunities for improving animal care; 2) facilitate the specific actions needed to implement improvement; and 3) provide a schedule and date for completion. For example, if only 95% of the animals scored 2 or more for BCS in a specific herd, the producer would need to implement an Action Plan to improve individual- and herd-level BCS. The FARM Program recommends that the development of Action Plans should be a collaborative effort between the dairy producer, the evaluator, and the herd veterinarian. It is the responsibility of the FARM Program evaluator to determine whether a follow-up evaluation is necessary to assess improvement.

Conclusions

The mission of The National Dairy FARM Animal Care Program is to provide assurance to consumers that the dairy industry is committed to the highest level of animal care. The Program assesses feeding management of all animal groups through the evaluation of animal- (e.g., BCS) and resource-based measures (e.g., colostrum quality and quantity, feed bunk space allowance, etc). Action Plans are created to improve specific aspects of animal care and continuously improve the welfare of dairy animals in the U.S.

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Fetal Programming in Dairy Cattle

A.E. Relling[1,2], A. Chiarle[3], and M.J. Giuliodori[3]
Department of Animal Sciences, The Ohio State University[2]
Veterinary College, La Plata National University, Argentina[3]

Abstract

It has been widely known that maternal nutrition may play a role in the development of the fetus in mammalians. Many studies have been conducted on the study of fetal programing in sheep and beef cows, but there is not much research on the area in dairy cows. In 2013 at the Tristate Dairy Conference, Dr. Schoonmaker presented a review on the same topic showing a lot of possible areas of research for fetal programing in dairy cows. Our idea is not to cover again his perspectives but to show some results and future research on the area. On this review, we will show some data on the effect of increasing number of parity, days in milk, milk yield, and milk energy output at the time of conception and their effect on the offspring performance and longevity. At this time, there is not much information on the role of different nutrients impact on fetal programing. However, there are some physiological aspects of the fetal and placenta development that may be considered important for future research on the impact of different nutrients during gestation. The current data on dairy cows suggest that cow health may be more important than milk yield or milk energy output. The main reason of this may be due to the possible, but unknown, increase in requirements on subacute inflammatory states.

Introduction

The study of fetal programing in animal production became relevant after the study of Godfrey and Baker (2001). This study shows the effect of adult undernutrition and its impact on the health of their offspring. Since then, there are thousands of publications in many species that look on how nutritional or endocrine changes during gestation impact offspring health or performance. Considering large farm animals, sheep is used as a model for human health (Vuguin, 2007). For this reason, there are many studies looking into fetal programing in sheep. In beef cows, the type of production system and the outcome makes the study of fetal programming a very important tool to improve productivity. The reason for this is during the last third of gestation in US cow-calf operation systems, the cows receive some type of supplementation, most of the times as hay or they were grazing poor quality forage. The strategic supplementation during this period of time improves performance in the cow and in the offspring (Larson et al., 2009; Funston et al., 2012). In dairy cows, diet composition is more controlled than in cow-calf operation systems and generally diets are formulated to meet or exceed the known nutrient requirements. Also, the main objectives in lactating dairy cow diets are to cover lactation requirements at the different physiological stages. In our opinion, the main reason why there are more studies

[1]Contact at: 1680 Madison Ave, 114 Gerlaugh Hall, Wooster, OH 44691, (330) 263-3900, FAX: (330) 263-3949, Email:relling.1@osu.edu.

conducted on fetal programing in sheep and beef cows than in dairy cows is because the different production systems and the expected outcomes on the production in each system. However, we know that lactating dairy cows' metabolism changes a lot during lactation, somewhat similiar to milk production. Because of that, we thought it would be logical to expect an imprinting effect of milk production and physiological stage on fetal development.

Description of the Model

Lactating dairy cows are unique models in which conception may coincide with the higher maternal nutrient and energy requirements. In early lactation, the cow enters a negative energy balance that leads to mobilization of body energy reserves. During the last part of this negative energy balance is when we want the cow to conceive. However, we need to consider that nutrients must be partitioned between the mammary gland and the placenta. Therefore, our starting hypothesis was that milk production will play a role in fetal development.

Fetal Program Effect

As mentioned earlier in the manuscript, there is not much research on fetal programing in dairy cows. However, there are some research that looks into it. One of the first studies that looked into the role of maternal performance on their offspring performance was conducted by Pryce et al. (2002). They use two genetic lines as maternal treatments and evaluate the effect that the genetic line has on reproductive performance. In this study they did not find difference on maternal genetic line and reproductive performance, neither in milk yield, body condition score, nor dry matter intake on the first 180 days of lactation (Pryce et al., 2002). However, the study did not have a large number of animals and there were various management systems. This may result in not enough experimental units to test their proposed objective.

Another interesting study on fetal programming was carried out by Berry et al. (2008). In this study, they evaluated maternal milk production in their offspring. They used a large data base of more than 20,000 cows. Despite the objective to evaluate the effect of milk production, they separated the dams only by milk yield, without talking in consideration other variables, such as days in milk. From this study, they observed that milk yield at the time of conception had a negative impact on milk yield of the offspring and survival of the offspring to the second lactation. Also, increased dam milk yield increases somatic cell counts on the offspring (Berry et al., 2008).

However, it is known that milk yield changes depending on the days in milk of each cow. For that reason, we used a large data base (more than 150,000 dams and 200,000 offspring) and added into the model the effect of milk yield at the time of conception, number of parity, days in milk at conception, and their interaction (Chiarle et al., 2015). We did not observe an effect of the interactions of the explanatory variables. Considering milk yield at the time of conception, there was no effect of milk yield or energy yield on the dam at the time of conception or the offspring's milk yield in the first lactation. This is different from the results of Berry et al. (2008), but it is possible that the difference is due to the inclusion of days in milk in our model. When we evaluated days in milk (**DIM**), we observed a quadratic effect of DIM at conception on the offspring's milk yield (Figure 1). The offspring conceived from cows in early lactation produced less than offspring conceived at later DIM, and it plateaued at day 150. When we evaluated the effect of number of parity on the offspring's milk yield, we observed

a decrease in the offspring's milk yield when the dam had increased number of lactations (1st, 2nd, 3rd or subsequent, Figure 2). This model does not take in consideration the bull or the genetic improvement on each parturition; therefore, the response may be bigger if we add those variables in the model. Within in each cow, milk yield and DIM are confounded, and for that reason, it may be possible why our results in milk yield differ from those presented by Berry et al. (2008).

Another study was conducted by Gonzalez-Recio et al. (2012). This study supported the effect of dam parity on the offspring's milk yield. Also, it revealed that dam parity or number of lactations has an impact on the offspring's longevity and milk composition. If the offspring is born in the first parturition, it has a longer lifespan and a greater fat/protein ratio. Gonzalez-Recio et al. (2012) also looked at the effect of dam subclinical mastitis and the effect on offspring milk yield and longevity. Despite there not being a significant difference, dam subclinical mastitis trended to decrease milk yield and lifespan on the offspring.

So far, there are no studies that can explain the physiology mechanism of these results; however, we suggest that the uterine environment may play a big role on the fetal development. It is possible that in cows with more parities or in early stages of production, the uterus is healing form injuries produced by calving and aging. This may lead to changes in expression of genes, endocrine responses, or even an increase in immune response.

A study presented by Valour et al. (2014) showed on 18 day embryos, difference in genes occurred that are involved in energy and lipid metabolism, depending the physiological stage of the cow. They compared 2 different physiological stages (heifers, early lactation, and late lactation). These group of dams presented different endocrine and metabolite plasma profiles, such as changes in plasma insulin, non-esterified fatty acids (**NEFA**), glucose, and insulin-like growth factor-1 (**IGF-1**) concentrations. In their conclusion, they stated that energy nutrient availability in the dam may have an effect on endometrium physiology.

Conclusions and Future Research

Despite there not being much research on fetal programing in dairy cows, there is evidence that physiological stage of the dam has an impact on the productivity of the offspring. Because of the genetic selection for milk yield and the effects on mammary development, dam milk production does not seem to be the most important factor regulating fetal programing.

There are some things that we have to consider for future research in this area. Some of those are the association of embryonic and fetal development and the association with placenta physiology. This will help us to understand at what particular time a particular nutrient is required. Also to evaluate if we can nutritionally, through endocrine changes, manipulate the placenta physiology to improve the availability of nutrients to the fetus, in particular periods of development.

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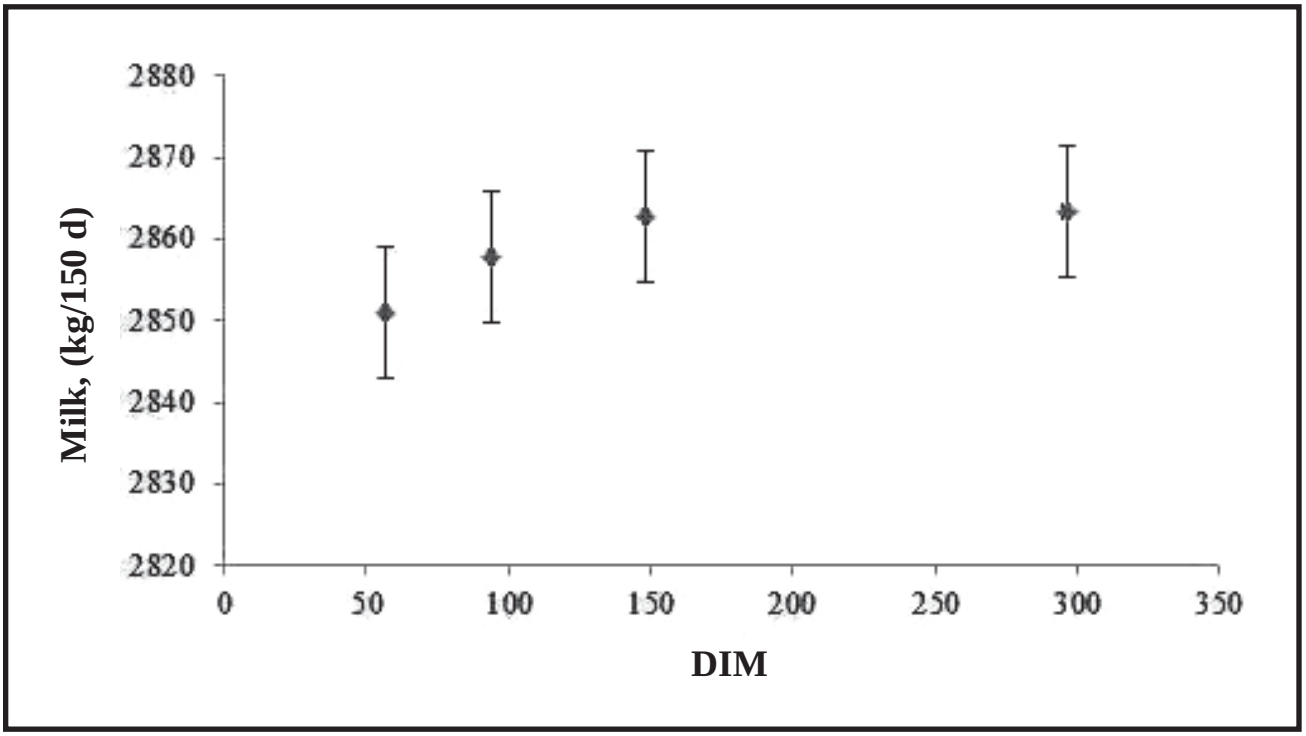

Figure 1. Effect of dam days in milk (DIM) on their offspring's accumulated milk yield in the first 150 days of lactation of the first lactation (P value for linear effect < 0.01, quadratic < 0.01, cubic > 0.10).

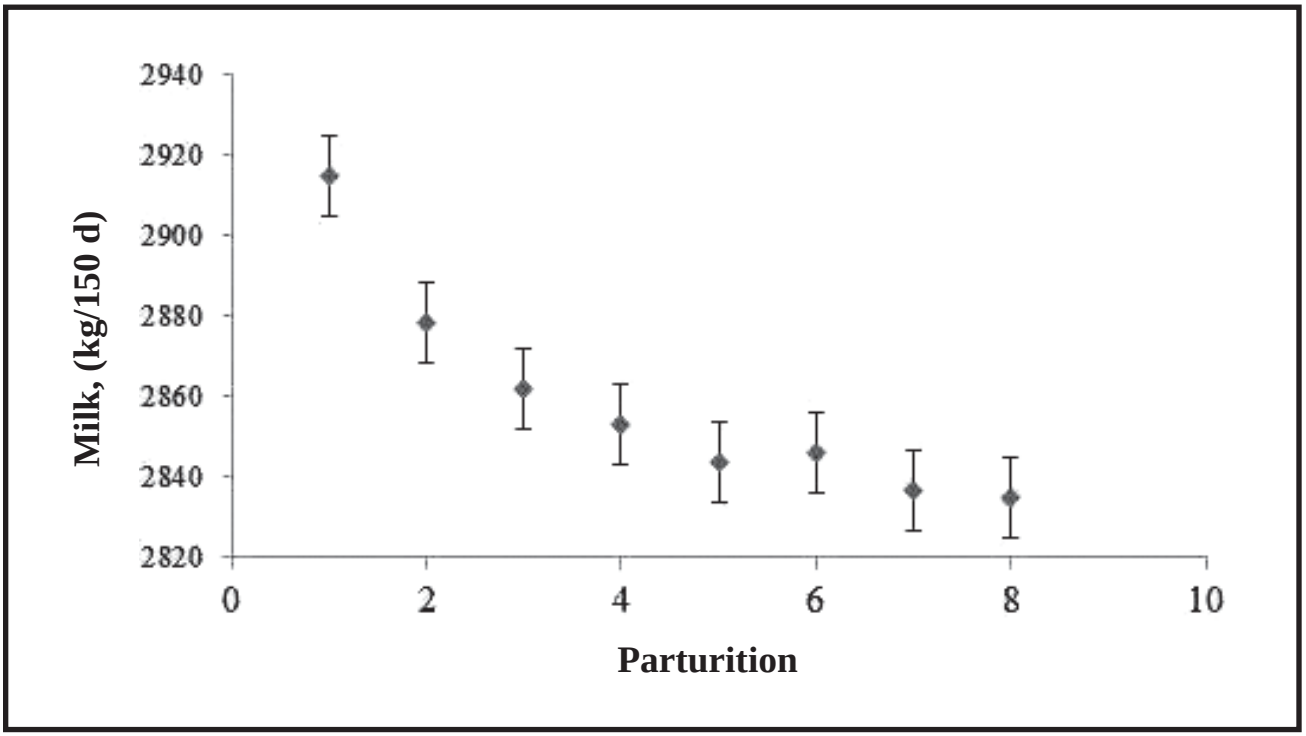

Figure 2. Effect of dam number of partuirtions on their offspring's accumulated milk yield in the first 150 days of lactation of the first lactation (P value for linear effect < 0.01, quadratic = 0.05, cubic > 0.10.

TMR Sampling: Valuable Exercise or a Random Number Generator?

Bill Weiss[1,2], Peihua Zhang[2], John Goeser[3], and Normand St-Pierre[2]
[2]Department of Animal Sciences, The Ohio State University
[3]Rock River Laboratory, Inc. and
Department of Dairy Science, University of Wisconsin

Summary

Sampling and analyzing the total mixed ration (**TMR**) has several potential uses. It can be used to identify nutritional deficiencies or surpluses in the diet that was actually fed to the cows. It can be used to estimate manure excretion of nutrients via mass balance calculations. The consistency of ration delivery can be evaluated by sampling the TMR, and it can be used to determine whether the ration that is delivered to the cows is the same as the diet that was formulated. However, for any of these uses to be valid, the TMR sample must accurately reflect the diet that was actually fed. Previously, we found that sampling variation was substantial for TMR samples. This was investigated further by sampling three different TMR (one had silages and concentrate; one had silages, concentrate and hay, and one had silages, hay, whole cottonseed, and concentrate) using two different sampling protocols. One protocol was simple and consisted of taking several handfuls of TMR across the feed bunk. The other protocol consisted of putting trays in the feedbunk prior to feed delivery and then removing the trays filled with TMR, mixing, and sampling from the trays. Sampling protocol had very little effect on sampling variation or on the accuracy of the sample. Samples of TMR did not accurately estimate the true mineral concentrations (sodium, phosphorus, and copper) of the TMR. A single sample of TMR (using either protocol), however, generally gave an accurate estimate of the true concentration for dry matter (**DM**) and crude protein (**CP**) in the TMR. For neutral detergent fiber (**NDF**), a single sample had a high risk of being wrong (i.e., inaccurate), but taking duplicate samples and averaging the analytical results were generally accurate. TMR sampling can be accurate for macronutrients but care must be taken when sampling and often duplicate samples will be required.

Introduction

Proper sampling of ration ingredients and submitting those samples for nutrient analysis to a good lab are essential components of diet formulation. The relative importance of sampling, analytical, and real variation on overall variation in nutrient composition data of ingredients has been discussed at previous conferences (Weiss et al., 2012; Weiss et al., 2014). Sampling variation was an equal or greater source of variation than was real month-to-month variation for corn silage over a 12-month period. Although real variation over a 12-month period was the greatest source of variation for hay crop silage, sampling variation was still an important source of variation. The overall conclusion from all those data is that averages of duplicate samples should be used for ration formulation. Using means rather than individual sample data will increase the likelihood that the nutrient composition of the

[1]Contact at 1680 Madison Ave., Wooster OH 44676, (330) 263-3622, E-mail: Weiss.6@osu.edu.

actual diet is reasonably close to formulation specifications.

Ingredients are sampled and analyzed mainly to provide data for diet formulation. TMR are sampled and analyzed for other reasons, including monitoring consistency both within a feedbunk and day-to-day, evaluating the feeder and TMR mixer, and determining whether the nutrient composition of ingredients within the TMR may have changed. Because of the different use of TMR composition data compared with ingredient composition data, sampling protocols and schedules developed for ingredients may not fit TMR sampling.

Why Sample a TMR ?

1. *Assessing within bunk variation in nutrient delivery*. Ideally, the nutritional composition and physical form of a TMR is consistent within a pen (the portion of the TMR that was delivered first should be very similar that which was delivered last). Numerous factors affect consistency of TMR delivery, and these were discussed at a previous conference (Oelberg, 2015) and will not be discussed here. When evaluating consistency of delivery, samples are taken at various locations across the bunk, analyzed for something and then the variation is calculated. This measure of variation is compared to a benchmark to determine whether the TMR is consistent across the pen. A basic premise of this approach is that the variation between samples is caused by location and not sampling. Sampling variation refers to the difference between two samples taken in the same location within a feed bunk. If that variation was similar to the variation between samples taken at different locations within the feed bunk, you would not know whether diet delivery was inconsistent (i.e., location in the bunk really affects composition) or if the sampler was not very good at taking representative samples. Therefore, if your objective is to evaluate consistency, multiple samples at multiple locations within the feed bunk should be taken so variation caused by sampling and location can be partitioned.

2. *Assessing day-to-day consistency of TMR delivery*. It is unclear at this time whether day-to-day variation in nutrient composition of TMR is important. In a survey-type experiment (Sova et al., 2014), herd average milk production was negatively correlated with day-to-day variation in NE_L concentration (i.e., high variation was associated with lower herd average production). However in controlled experiments, substantial day-to-day variation in NDF, forage to concentration ratio, and fatty acids had no major effects on cow productivity (McBeth et al., 2013; Weiss et al., 2013; Yoder et al., 2013). Nonetheless, if your objective is to evaluate day-to-day variation in nutrient delivery, sampling variation must be separated from variation caused by day. To do this, multiple samples must be taken each day over multiple days. This will allow you to determine whether day is the source of variation or if the observed variation is simply an artifact of sampling (or more likely both sources are probably important).

3. *Determining whether the delivered ration matches the formulated one*. The nutrient composition of commonly fed forages and many concentrates exhibit substantial within farm variation (Weiss et al., 2012; St-Pierre and Weiss, 2015). Sampling and monitoring TMR composition could be used to suggest when the nutrient composition of a feed or feeds have changed, indicating it is time to re-sample ingredients and re-formulate the

diet. In addition to the nutrient composition of the individual ingredients in a TMR, the nutrient composition of a TMR also reflects the recipe that was actually delivered to the pen on that day. Sampling TMR can be used to troubleshoot diets and feed delivery. If a diet is formulated to precisely meet the nutrient requirements for a pen of cows and if the requirement model used is accurate, milk production should decrease if the actual delivered diet provides less nutrients over a period of days than anticipated. Because of feeder errors and scale errors, the delivered diet may differ markedly from the formulated diet even, when the nutrient composition of the individual ingredients has not changed. Sampling a TMR, if the results accurately reflect the delivered diet, could help a nutritionist identify nutrient deficiencies or feed delivery problems. To make valid conclusions regarding the nutrient composition of the delivered diet, the sample results must accurately reflect the composition of the TMR delivered to the pen. If sampling error is high, a nutritionist may conclude that the delivered TMR is not what was formulated and spend time trying to identify the reason why that occurred, when in reality the TMR was correct; it was the sample that was bad. Conversely, a bad sample could suggest that the TMR is matching specifications when really it does not.

4. *Monitoring nutrient management plans*. On some dairy operations, the amount of P and N excreted in manure must be monitored to ensure compliance with environmental regulations. Accurate sampling of manure is extremely difficult and calculated nutrient balance offers an alternative approach (Castillo et al., 2013). Intake of P or N can be calculated by multiplying feed delivery to the herd times its concentration of P and N and sampling milk and analyzing that for P and N and then subtracting milk secretion from intake. The remainder is an estimate of the amount of N and P excreted in manure. Measuring the P and N (i.e., CP) in a TMR sample can be used to estimate intake of those nutrients. However, if the sample does not accurately reflect the TMR, the actual nutrient application to soil may exceed a farm's nutrient management plan.

Using TMR composition data to evaluate diets and troubleshoot nutritional problems has great potential; however, for TMR data to be useful, the nutrient composition of the sample must accurately reflect what was delivered to the pen (i.e., the sample results must be accurate). The recurring theme for all the possible uses of TMR sampling data is that sampling error must be known for you to reach valid conclusions regarding the data.

Is Sampling Error a Concern for TMR?

Sampling error (or sampling variation) simply means that if you take multiple samples from the same population, you obtain different values (ignoring analytical variation). A population could be a truck load of distiller grains, a pile of silage that will be fed to a group of cows today, or a TMR that was delivered to a pen of cows. With respect to feeds and TMR, sampling error occurs because different particles (which are what are actually sampled) have widely different nutrient composition. A TMR is comprised of particles that vary in density, size, shape, and nutrient composition. A stem of hay is light, long, and is generally high in fiber, whereas a grain of salt is heavy, small, and has no fiber. Because of this, sampling error is a major issue for TMR. From a field study of about 50 dairy farms across the U.S., sampling and analytical variation (because of the design of the experiment, these 2 sources of variation

could not be separated) accounted for 36 to 70% of the total within farm variation in TMR composition (the range represents different nutrients) over a 12-month period (St-Pierre and Weiss, 2015). Sampling error was great enough to have a substantial impact on interpretation of results (Table 1). For example, based on Table 1, you have a 10% chance that a single sample of TMR could have a CP concentration <16% when the true concentration was 17.1%. These large sampling errors reflect the heterogeneous nature of TMR and the ease at which poor samples can be taken.

Improper sampling techniques could result in a sample having fewer small particles than the actual TMR. Small particles are often rich in starch, minerals, or protein, which means that in this case, the sample might have lower concentrations of those nutrients than the actual TMR. Because of the wide disparity between particles with respect to size and density, particle gradients can develop within a pile of TMR in the feed bunk. With mechanical movements, large light particles (such as pieces of hay) tend to rise to the top of a stack and dense small particles tend to sink. This means that a handful of TMR taken from the top of the pile may have higher NDF concentrations, and a handful of TMR taken from the bottom of the pile may be enriched in starch or protein.

TMR Sampling Project

To determine whether sampling method affected the accuracy (i.e., how close the nutrient composition of a TMR sample came to the true composition of the TMR) and precision (how much variation was observed among samples) of TMR sampling and to determine the overall accuracy of TMR sampling, a study was conducted at the Krauss Dairy Center at OARDC in Wooster. Three different pens with TMR that differed greatly in ingredient components (Table 2) were sampled for 3 consecutive days and then sampled again for 3 consecutive days the following week. Each TMR was sampled using 2 different sampling methods (discussed below) and a duplicate sample was taken each day from each method. Each sample was then assayed in duplicate for DM, NDF, and CP using standard wet chemistry methods at the OARDC Dairy Nutrition Lab. Dry ground samples were sent to Rock River Laboratory (Watertown, WI) and analyzed in duplicate for major and trace minerals using standard wet chemistry methods. This protocol allowed us to determine sampling error for 3 different types of TMR and whether sampling method could affect accuracy and precision. Not all the statistical analyses have been completed, so this paper will discuss mostly accuracy rather than precision.

Sampling protocols

Both protocols were performed immediately after the TMR was delivered to the pen. The simple protocol consisted of taking 1 handful of TMR every approximately 10 feet of the feed bunk, yielding about 6 handfuls per pen. The top, middle, and bottom third of the TMR was sampled alternatively as the sampler walked the feed bunk. The handfuls were placed into a large plastic bag. The handfuls were collected with the palm facing upward to reduce loss of small particles. That process was immediately repeated to yield a duplicate sample. The complex sampling protocol consisted of placing 4 trays (2 ft wide x 3 ft long x 8 inches tall in the manger just before TMR delivery. The trays were equally spaced across the bunk (Tray 1 was at the south end, then 2, 3, and 4). Immediately after feed was delivered, the 4 trays filled with TMR were pulled to the center aisle. At this point, the simple sampling protocol was conducted. After that was completed, the contents of Tray 1was emptied onto a clean sheet of plastic and mixed using a scoop. The contents

was sectioned and 2 approximately 1/8 sections was removed with a scoop and placed into an empty, clean tray. That process was repeated with Tray 3. The subsample from Trays 1 and 3 were combined, thoroughly mixed, and a section was removed with a scoop and placed into a bag. The duplicate sample was obtained by repeating this process using the contents of Tray 2 and 4. The 4 samples per pen (2 sampling methods in duplicate) were brought to the lab and analyzed.

Determining accuracy

Each day the TMR were sampled, all TMR ingredients (silages, hays, concentrate mixes, and cottonseed) were sampled in duplicate and analyzed in duplicate using standard wet chemistry methods. Ingredient inclusion amounts were recorded electronically using commercially available TMR software. Multiplying inclusion rate by assayed composition (mean of the duplicate samples and duplicate assays) yielded what we considered the actual or true composition of the TMR.

Effect of Sampling Protocol

The effect of sampling protocol (simple vs. complex) on sampling variation was not consistent across the different TMR or across nutrients. For the majority of TMR and nutrients, protocol had no effect on sampling variation. The complex protocol had greater sampling variation than the simple method for DM concentration in TMR-1 (contained hay and cottonseed), for NDF concentrations for TMR-2 (contained hay), and TMR-3 (contained only silage and concentrate). Conversely, the complex protocol had statistically lower sampling variation for NDF concentration of TMR-1, for CP and Na in TMR-2, and Na in TMR-3. We hypothesized that for the most variable matrix (TMR-1 that contained silage concentrate, hay, and cottonseed), the complex sampling method would be more consistent, and for the simplest matrix (TMR-3 with just silages and concentrate), sampling protocol would not have any effect on sampling variation. With respect to sampling variation, the simple protocol was generally just as good (and much easier and faster) than the complex method.

We also statistically tested whether sampling protocol affected nutrient concentrations. This does not evaluate accuracy (e.g., the protocols could give similar numbers but both could be wrong). For most nutrients and TMR types, sampling protocol did not affect analytical results. The only meaningful difference between sampling protocols was for NDF concentration of TMR-3 (silage and concentrate only). The simple method yielded a mean of 46.1%, whereas the complex method had a mean of 43.2% (Table 3). If this was a consistent finding across TMR types (i.e., the simple method had higher NDF concentrations) ,it would likely mean that the protocol resulted in loss of small particles, but since this was only found with one TMR type, it may be just a spurious finding.

Accuracy has a flexible definition depending on how good is good enough. If you were constructing a nuclear submarine, tolerances might be expressed in nanometers, but if you are digging a hole for a fence pole, tolerances may be several inches. For TMR accuracy, we decided that if a sample result was within 5% of the real value, the sample was accurate. Accuracy was evaluated for major nutrients (DM, NDF, and CP), phosphorus (because it can be used in nutrient management plans and because it is mostly in basal ingredients, not mineral supplements), sodium (because most sodium is from salt), and copper (as an example trace mineral). To evaluate accuracy, we calculated the deviation of the real value from each sample result and

we also calculated the mean of the duplicate samples (within each protocol) and calculated the deviation of the real value from that mean.

Minerals

About half the copper in the 3 TMR were from mineral supplements within the concentrate mix and about half was from basal ingredients. Taking a single sample using either protocol from any of the 3 types of TMR had absolutely no value in estimating the true concentration of copper. Of the 72 individual TMR samples (3 types of TMR x 6 days x 2 protocols x 2 duplicate samples = 72), only 8 (11%) of the samples were within 5% of the true value and 39 samples (54%) were more than 20% different from the true value. Across sampling protocols and TMR types, samples usually had lower concentrations of Cu than the actual TMR. The samples for TMR-3 (silage and concentrate) were slightly less inaccurate compared with the other two types of TMR. The average deviation for TMR-1 and TMR-2 was about 25% (averaged across sampling protocol) and about 18% for TMR-3. Taking duplicate samples and averaging slightly improved the accuracy of TMR samples for copper, but the results were generally so inaccurate as to be useless. Only 1 (3%) of the duplicate means was within 5% of the true mean, and 17 of the means (47%) were more than 20% different from the mean.

The vast majority of sodium in these TMR was from added salt contained in the concentrate mix; therefore, sodium can be used as a marker of concentrate inclusion accuracy and the uniformity of the mix. On average, sample concentrations of sodium were higher than true concentrations for TMR-1 (hay and cottonseed) and TMR-3 (silage) but lower for TMR-3 (hay). Both sampling protocols had the same pattern. No difference in accuracy of single samples was found between the 2 sampling protocols, and results for sodium were similar to those for copper. For sodium, individual samples from TMR-2 (included hay) were more accurate than for the other 2 types of TMR (average deviation for TMR-2 was about 10% compared with about 22% for the other 2 TMR). We do not have a reason why that type of TMR yielded more accurate sampling results. Overall, single samples for sodium were not accurate; only 12 of the samples (17%) were within 5% of the actual concentration and 29 samples (40%) were more than 20% different from actual concentrations. Taking duplicate samples and averaging did not improve the accuracy greatly. Only 6 duplicate means (17%) were within 5% of the actual value.

Unlike sodium and copper, essentially all the phosphorus in the 3 TMR was from basal ingredients not mineral supplements. Across sampling protocols and TMR types, concentrations of P in samples was less than the actual concentration. Sampling method or TMR type had no effect on accuracy; accuracy was poor for everything. Only 2 samples (3%) had P concentrations within 5% of the true concentrations and 23 samples (31%) differed from the true values by more than 20%. Averaging duplicate samples did not improve accuracy. These data bring into question the use of TMR sample data to calculate P balance on farm as part of a nutrient management plan. The overall conclusion of these data is that a single TMR sample has little value in assessing the accuracy of mineral delivery and averaging duplicate samples probably will not help very much. Indeed averaging all the samples within a protocol was still not accurate for minerals (Table 3).

Macronutrients

Sampling a TMR was accurate for estimating its true DM concentration. This was true for both sampling protocols and all 3 types

of TMR. The average deviation was <3% and 96% of the samples were within 5% of the true values. Sampling TMR using either method accurately reflected the CP concentration of the TMR. Differences in accuracy between sampling protocols were minor. For TMR-2 and TMR-3, a single sample was within 5% of the true concentration of CP 80% of the time and only 1 sample (TMR-2) was >10% different from the true value. Single samples were less reliable for the TMR with hay and cottonseed (54% of the samples were within 5% of the true value and 8% of the samples were more than 10% different from the mean). Averaging duplicate samples eliminated the extreme error (no mean was more than 8% different from the true value and most means were within 6% of the mean).

As with all other nutrients, sampling protocol had no effect on accuracy for NDF concentrations and accuracy did not differ greatly between the TMR types. A single sample to assess the NDF concentration of a TMR was less reliable than for CP. Only 50% of the single samples were within 5% of the true concentration for NDF and almost 20% of the samples differed by more than 10% (Figure 1; Table 3). Using means of duplicates increased the chance of being within 5% of the mean (60% of the means were within 5% of the true values), but more importantly, means greatly reduced the chances to obtain extreme deviations (10% of the means were more than 10% different from the true value).

Conclusions

Using a simple, yet good sampling technique for obtaining TMR samples was generally accurate for macronutrients (DM, NDF, and CP); however, using results from a single sample had a high risk of being very wrong (>10% different) with respect to NDF. Taking duplicate samples and averaging reduced the risk of being wrong but did not greatly increase overall accuracy. Sampling TMR did not accurately assess mineral delivery.

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Table 1. Sampling variation in TMR samples taken from 49 farms (one pen per farm) over a 12-month period (St-Pierre and Weiss, 2015).

Nutrient	Mean	Sampling +analytical variation	
		SD	80% range[1]
DM, %	48.3	2.91	44.6 – 52.0
NDF, % of DM	32.9	1.81	30.6 – 35.2
CP, % of DM	17.1	0.89	16.0 – 18.2
P, % of DM	0.41	0.030	0.37 – 0.45
Na, % of DM	0.42	0.091	0.30 – 0.54
Cu, ppm	23	5.1	16.5 – 29.5

[1]Assuming a normal distribution, 80% of the samples should fall within this range. 10% of the samples would be higher than the highest value and 10% would be lower than the lowest value.

Table 2. Ingredient composition of three types of TMR (% of DM).

	TMR-1	TMR-2	TMR-3
Corn silage	43	19	22
Alfalfa silage	8	32	0
Mixed silage	0	21	58
High quality grass hay	8	0	0
Low quality grass hay	0	9	0
Whole cottonseed	10	0	0
Concentrate[1]	31	19	20

[1]A different concentrate mix was fed in each TMR but the primary ingredients were ground corn, soybean meal, and minerals. The concentrate was fed as a meal.

Table 3. The true nutrient concentrations of three TMR (measured over a 6-day period) and concentrations obtained from sampling the TMR using a simple or complex protocol. All values are on a DM basis[1].

	True Concentration[2]		Simple Protocol[3]		Complex Protocol[3]	
	Mean	Range	Mean	Range	Mean	Range
DM, %						
TMR-1	55.5	55.4 – 57.5	55.1	53.9 – 56.5	54.6	48.6 – 56.9
TMR-2	52.1	50.8 – 54.2	51.3	49.8 – 53.5	51.7	50.0 – 53.1
TMR-3	49.7	48.5 – 50.7	48.7	46.7 – 50.9	49.5	48.1 – 51.2
NDF, %						
TMR-1	32.4	31.2 – 34.2	31.5	28.4 – 35.0	32.2	29.7 – 35.3
TMR-2	41.8	41.2 – 43.0	43.7	41.1 – 48.6	42.4	39.2 – 46.4
TMR-3	45.8	44.8 – 47.4	46.1	42.5 – 50.3	43.2	39.7 – 47.2
CP, %						
TMR-1	16.4	15.8 – 16.8	15.7	14.5 – 16.6	15.3	15.8 – 16.8
TMR-2	13.1	13.0 – 13.2	12.9	11.6 – 13.5	13.0	12.3 – 13.4
TMR-3	12.5	12.2 – 13.0	12.4	11.9 – 13.1	12.8	12.1 – 13.2
P, %						
TMR-1	0.38	0.35 – 0.40	0.32	0.28 – 0.34	0.32	0.28 – 0.35
TMR-2	0.29	0.28 – 0.30	0.23	0.21 – 0.26	0.23	0.20 – 0.25
TMR-3	0.27	0.25 – 0.29	0.24	0.21 – 0.26	0.23	0.19 – 0.27
Na, %						
TMR-1	0.12	0.10 – 0.13	0.14	0.11 – 0.18	0.14	0.12 – 0.17
TMR-2	0.07	0.06 – 0.08	0.06	0.06 – 0.08	0.06	0.06 – 0.08
TMR-3	0.12	0.09 – 0.14	0.13	0.11 – 0.15	0.13	0.11 – 0.15
Cu, ppm						
TMR-1	14.6	13 – 17	11.6	8 - 16	12.6	7 – 16
TMR-2	19.2	18 – 20	14.5	9 - 19	13.8	8 – 17

[1]TMR-1 contained silages, hay, whole cottonseed, and concentrate; TMR-2 contained silages, hay, and concentrate; TMR-3 contained silages and concentrates.

[2]True concentrations were determined using composition data of the TMR ingredients and actual inclusion rates. The range represents concentrations over a 6-day period.

[3]The simple protocol consisted of taking handfuls of TMR across the feed bunk. The complex protocol consisted of putting trays in the feed bunk prior to feed delivery and sampling from the trays. The mean was calculated across 6 days and duplicate samples each day (within sampling protocol). Range represents the lowest and highest value for a sample.

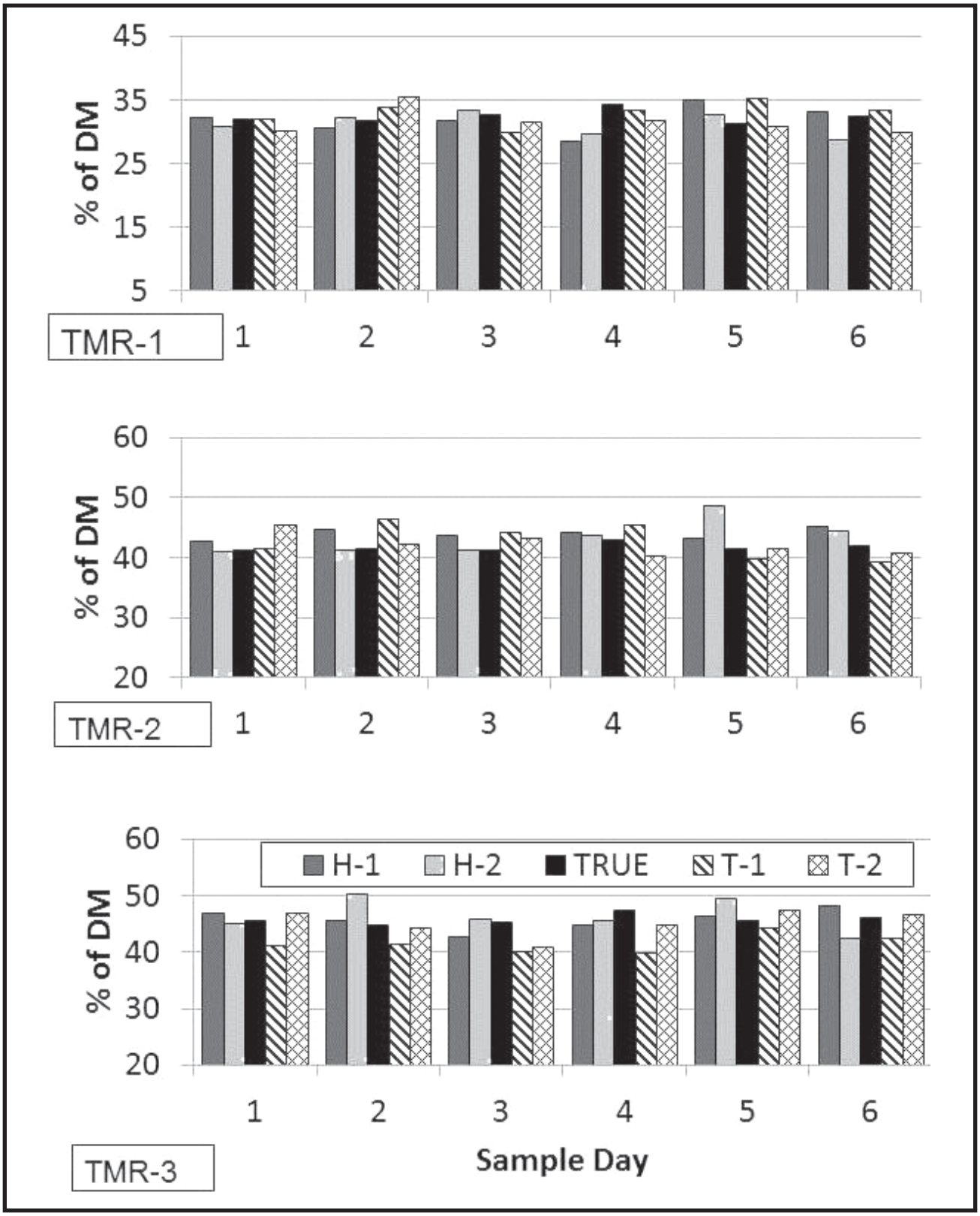

Figure 1. True NDF concentration of 3 different TMR and concentrations in individual samples collected over 6 days. H-1 and H-2 are for duplicate samples collected by taking handfuls of TMR across the bunk and T-1 and T-2 are from duplicate samples collected in a tray while feed was delivered.

Future Direction for Managing N and P on Dairy Farms

Chanhee Lee[1]
Department of Animal Sciences
The Ohio State University

Abstract

Dairy manure contains macro and micronutrients which are valuable nutrients for crop growth when applied to land. However, manure nutrients, especially nitrogen (**N**) and phosphorus (**P**), can become potential pollutants contaminating the environment such as air, soil, and ground and surface water if manure is not properly managed in farms and properly applied to land. Due to growing environmental concerns, efforts to lower N and P excretions from cows and N and P losses during manure storage and after manure application need to be made in dairy operations. Nitrogen and P excretion from dairy cows can be reduced through diet manipulation. Formulating diets meeting or being slightly lower than the N and P requirements for lactating cows (i.e., avoiding excessive dietary N and P) is the most effective strategy. However, N and P-deficient diets must be fed with caution because dairy production can be impaired depending on the degree of N and P deficiency. Substantial N losses occur during manure storage through ammonia volatilization, which causes odor and air pollution. Moreover, N losses during manure storage decrease manure quality as fertilizer (relatively low N and high P), causing potential over-application of P to the field when manure application rate is N-based. Covering lagoons and treating manure with acid (acidification) are effective in suppressing ammonia volatilization from manure. Extracting P from manure by adding chemicals and/or centrifuging can avoid over-application of manure P to land. After manure application, N and P are also lost through volatilization, leaching, and runoff, causing surface water pollution. Selecting proper manure application techniques, crop rotation, and application timing can help not only minimize N and P losses from manured soil but also improve crop production. In conclusions, there are a number of strategies that are effective in lowering N and P losses in dairy operations. When those strategies are applied in combination, the effectiveness in lowering N and P losses would be greater. In addition to these strategies, producers need to monitor their feed, manure, and soil for N and P concentrations, which can identify the opportunities to minimize N and P losses and then environmental impacts in individual farms because dairy farms have various feeding and manure management systems.

Introduction

The amount of fresh manure, excluding bedding and added water, produced by dairy operations is approximately 23 million kg a day in Ohio, making dairy farms the largest manure producers among livestock and poultry operations in Ohio (Figure 1). Dairy manure contains a number of macro and micronutrients, which can be valuable nutrients for crops when manure is used as fertilizer. However, the

[1]Contact at: 313 Gerlaugh Hall, 1680 Madison Ave., Wooster, OH, (330) 263-3794, lee.7502@osu.edu.

nutrients, especially N and P, are also potential environmental pollutants if manure is not properly managed.

Nitrogen is one of the nutrients excreted in great amounts by dairy cows. A dairy cow producing 40 kg of milk a day excretes about 450 g of N in manure (136,000 kg N daily in Ohio). A considerable amount of N in manure is lost through ammonia volatilization, and the loss occurs on barn floors, during manure storage, and after field application. Depending on various factors (e.g., environmental conditions), the loss of N through ammonia volatilization can be 20 to 80% of total N in fresh manure (OSU Extension, 2006). Livestock animals, including dairy cows, may contribute up to 50% of total anthropogenic ammonia emitted in the US (NRC, 2003). The ammonia emitted from manure contributes to farm odor and affects air quality (US EPA, 2004). Although ammonia emitted to the atmosphere has a short life from hours to days depending on atmospheric conditions, ammonia reacts with combustion sources, such as nitric and sulfuric acids, to form fine particulate matter with a diameter ≤ 2.5 μm (PM2.5; ammonium nitrate and ammonium sulfate; Hristov, 2011), which impairs air visibility and directly affects human health (respiratory diseases; WHO, 2005). Livestock animals in the North Central region may contribute up to 20% of total PM2.5 in cool weather (Hristov, 2011). Nitrogen excreted in manure also directly contributes to surface and ground water pollution through N runoff and nitrate leaching after field application of manure as fertilizer. Nitrogen is also lost through nitrous oxide ($\mathbf{N_2O}$) emissions during the process of fecal and soil microbial nitrification and denitrification (more N_2O is emitted from manure-amended soil due to soil nitrifiers and denitrifiers). Nitrous oxide is a powerful greenhouse gas and is 298 times stronger in global warming potential than carbon dioxide. Dairy manure may contribute 33% of total N_2O emitted from animal manure in the US (US EPA, 2015). Moreover, the N losses reduce manure quality as a fertilizer due to the relatively low N concentration, which can negatively affect crop yields when dairy manure is used as a sole fertilizer.

Phosphorus has received attention as a pollutant produced from agriculture since P was identified as the primary nutrient polluting surface water. A dairy cow producing 40 kg of milk excretes about 50 g of P in manure which is about 15,000 kg of P excretion daily from dairy operations in Ohio.The Ohio EPA (2010) estimated that 89% of total P loading into the west basin of Lake Erie is from non-point sources (mostly agriculture), among which animal manure contributed 27% and commercial fertilizers contributed 66% (biosolids contribute 7%). For Grand Lake St. Mary's (OH), livestock animal operations, including dairy farms are responsible for most P loading (Tetra Tech, 2010). Unlike N, manure P is not lost during manure storage at farms but is lost after field application through runoff (Ohio EPA, 2010). Over-applied manure (or manure P) on fields may be the primary source of P in field runoff. High P loading into surface water, primarily originating from agriculture, was identified as the major factor causing eutrophication and harmful algae blooms in lakes (Ohio EPA, 2010).

Therefore, nutrient management, especially of N and P, from dairy feed to manure application is needed to decrease N and P excretion from cows and to lower N and P losses during manure storage and after manure application to fields to minimize environmental impacts.

Dietary Manipulation to Lower N and P Excretion

Nitrogen and P are required nutrients for dairy production and must be provided through diets to meet the requirements for maintenance and lactation. The intake and milk yield of dairy cows can be impaired if dietary N and P supplies are deficient (Lee et al., 2012a; Puggaard et al., 2014). However, if provided in excess, excretion of N and P increases because N and P provided above the requirements are not utilized for maintenance and production in dairy cows but are excreted in urine and feces, i.e., manure (Olmos Colmenero and Broderick, 2006; Alvarez-Fuentes et al., 2016). Once N and P are excreted, these nutrients become potential environmental pollutants that can contaminate air, soil, and water if manure is not properly managed and properly applied to the field (Ohio EPA, 2010; Hristov et al., 2011). One approach for dairy operations is to use dietary manipulation to lower environmental impacts.

A number of strategies have been investigated to improve dietary N utilization, i.e., efficient N utilization to improve production and lower N excretion, such as different types of carbohydrate supplementation, synchronization of ruminal energy and protein, supplementation with ionophores, feeding secondary plant metabolites, and rumen defaunation (Sinclair et al., 2000; Ipharraguerre and Clark, 2003; Makkar, 2003; Hristov et al., 2005). However, these strategies have had minimal effects, or the results have been inconsistent. More recently, supplementary nitrate has been investigated as a feed additive, primarily to lower enteric methane emissions. Encapsulated nitrate (a slow release form of nitrate) fed to beef cattle increased dietary N utilization and decreased urinary N losses compared with supplementary urea. In non-lactating cows, Guyader et al. (2015) observed up to a 12% decrease in urinary N excretion and numerically increased N retention (N utilization efficiency) in cows fed nitrate compared with urea. However, no effects of nitrate vs. urea on dietary N utilization and excretion in dairy cows were also reported (van Zijderveld et al., 2011).

The most powerful and consistently effective strategy among studies on improving dietary N utilization and lowering N excretion is to reduce dietary protein concentrations. Olmos Colmenero and Broderick (2006) compared diets with different dietary crude protein (**CP**) levels (13.5 to 19.4% on a DM basis) in dairy cows. In this study, production was not affected, but urinary N was significantly lowered from 257 to 113 g/day by lowering dietary CP levels. A number of studies have shown that reducing dietary protein concentrations has consistently decreased urinary N excretion (Recktenwald et al., 2014; Lee et al., 2015), and the decreases in urinary N excretion have significantly lowered ammonia emissions from manure during storage (a 2%-unit decrease in dietary CP decreased ammonia emissions up to 40% compared with the control; Lee et al., 2012b). Protein deficiency in diets, however, often impairs milk yield and milk protein yield of dairy cows with depressed dry matter intake (**DMI**). A series of long-term studies indicated that deficient metabolizable protein (**MP**) supplies at about 8 to 13% below the MP requirement (NRC, 2001) decreased DMI, milk yield, and fiber digestibility (Lee et al., 2012b; Giallongo et al., 2015). In these studies, dietary CP concentrations for the low protein diets were about 14% (DM basis), and the control diets were about 16% CP (corn and alfalfa silages-, corn-, and soybean meal-based diets), which met the MP requirement. However, because NRC (2001) under-predicts milk yields when cows are fed a deficient protein diet (Lee et al., 2012b; Figure 2), a slight decrease in dietary protein level below the current requirement (i.e., 15.5 to 16.0% CP) is expected to lower urinary N

excretion and ammonia emissions from manure without altering lactating performance.

Phosphorus is also an essential nutrient for lactating dairy cows. If dietary P supply does not meet the requirement for maintenance and lactation, then milk yield can decrease and health problems can occur (Puggaard et al., 2013; Grünberg, 2014). Conversely, if dietary P supply is in excess, then dietary P provided above the requirement is excreted primarily in feces (Alvarez-Fuentes et al., 2016; Figure 3). Therefore, studies have been conducted to find effective strategies to lower P excretion by manipulating diets and rumen environments. However, most strategies have not been effective or had minimal effects. For example, Jarrett et al. (2014) fed a diet with phytase to dairy cows to improve dietary phyate-P availability in the digestive tract. In the study, fecal phytate-P decreased by about 25% with feeding of phytase, but total P excretion increased with phytase supplementation (57.4 vs. 52.6 g/day; $P = 0.02$). Additionally, feeding forage in different sizes was investigated to reduce fecal P excretion. The hypothesis of a study by Puggaard et al. (2013) was that feeding short sizes of forage vs. long forage to cows can lower amounts of saliva P entering the rumen by reducing rumination, which might decrease fecal P excretion because saliva P is the major P source entering the rumen. The hypothesis of another study (Jarrett et al., 2014) was that feeding longer forage can decrease rumen passage rates compared with short forage, which can decrease P excretion in feces. In both studies, short forage significantly increased fecal P excretion by 15 and 6%, respectively, compared with long forage, indicating feeding long forage might be effective in reducing fecal P excretion in dairy cows by lowering rumen passage rates.

Overall, lowering dietary P concentration is the most powerful strategy to reduce fecal P excretion (Figure 3). The next question becomes 'how much can dietary P concentration be reduced?' The requirement model for lactating cows (NRC, 2001) estimates the P requirement to be 0.32 to 0.42% in diets (DM basis; generally 0.40%). However, several studies have shown that slightly lower P concentrations in diets below the requirement did not impair lactating performance and health in long-term feeding studies (Wu et al., 2001; Ekelund et al., 2006; Puggaard et al., 2013). Among those studies, the lowest P concentration in the diets that did not affect production was 0.28% on a DM basis (corn silage-, grass silage-, sugar beet pulp-, and soybean meal-based diet; Puggaard et al., 2013). However, in the same study, a dietary P concentration at 0.26% (DM basis) severely decreased feed intake and milk yield, and feeding at the low level could not be continued in the study. Although this study concluded that 0.28% P in dietary DM was adequate for lactating cows, the study must be repeated to confirm the results with various dietary conditions (a European diet was used in this study). A dietary P concentration of about 0.30 to 0.35% (DM basis) was investigated repeatedly and no detrimental effects on DMI and lactating performance were reported (North American diets were used in those studies; Wu et al., 2001; Knowlton and Herbein, 2002; Odongo et al., 2007).

Therefore, providing dietary N and P in diets that are slightly below or that meet the requirement for lactating cows is the most effective and practical strategy (without extra costs) for producers to decrease N and P excretions from dairy cows.

Strategies to Lower N Losses from Manure During Storage

Manure is stored at dairy farms for days to months with various management systems until field application. The types of manure

can be categorized by moisture content, e.g., liquid, slurry, semi solid, and solid, and manure is handled differently depending on types of manure (OSU Extension, 2006). The widely-used manure storage system in large dairy farms is a lagoon and pond to hold liquid manure because the manure is mixed with considerable amounts of water to maintain cleanliness in the milking operation. During manure storage, changes in P concentration are negligible. However, large amounts of N are lost through ammonia volatilization during manure storage. Lee et al. (2011) reported that about 50% of total N in manure was lost through ammonia volatilization within 3 days after feces and urine were mixed in a laboratory incubation system. There are several critical reasons for reducing ammonia emissions from manure during storage: 1) to lower environmental pollutions directly caused by ammonia emitted from manure, 2) to improve manure quality as fertilizer at the time of manure application, and 3) to lower environmental impacts after field application of manure. The potential environmental pollutants resulting in odor, air quality issues, and PM2.5 formation caused by ammonia emitted from manure were addressed earlier (reason 1). The ratio of N and P required for crop growth is quite close to the ratio of N and P in fresh manure (i.e., manure balanced with N and P). Therefore, fresh dairy manure can be a good fertilizer for crops. However, considerable ammonia volatilization during manure storage can create an imbalance between N and P in manure. For example, the ratio of N and P is 7:1 in fresh manure, which changes to 2 to 4:1 at the time of manure application after storage (i.e., manure imbalanced with N and P). Because of the imbalance, dairy manure is not a good sole fertilizer at the time of field application (reason 2). With the imbalanced manure, if manure application is P-based, N provided to crops is less than the requirement, which may affect crop yields. If manure application is N-based, excessive P will be applied to the field, which increases the risk of surface water pollution through P runoff (e.g., eutrophication, harmful algae blooms; reason 3). Therefore, lowering ammonia emissions from manure during storage in dairy operations is critical.

Various strategies have been investigated for decades, and the strategies that have been most effective at mitigating ammonia emissions during manure storage are discussed here. Covering lagoons with impermeable or permeable materials can lower ammonia volatilization up to 20 to 100% compared with manure in uncovered lagoons (Ndegwa et al., 2008). As a result, manure from covered lagoons is expected to be 3 to 4 times greater in N concentration at the time of application compared with manure from lagoons without covering. Another effective strategy is manure acidification. Ammonia volatilization is highly dependent on manure pH, i.e., ammonia formation (NH_3 from $NH4^+$); volatilization is inhibited at low pH (Hristov et al., 2011). In a series of studies, acidification of cattle manure with sulfuric acids considerably lowered ammonia emissions up to 90% during manure storage and up to 67% after field application (Sorensen and Eriksen, 2009; Petersen et al., 2012). The reduction in ammonia emissions during storage resulted in increased manure quality (i.e., readily available N in manure was increased up to 75% with manure acidification; Kai et al., 2008). Moreover, acidified manure may produce up to 70% less methane compared with untreated manure (Petersen et al., 2012). Currently, manure acidification systems in animal operations are commercially available to producers in Denmark. However, potential work hazards with handling strong acids for manure acidification must be addressed.

Extracting P from manure during storage is another potential strategy to decrease

environmental impacts. Although this strategy may not affect ammonia volatilization during manure storage (yet to be studied), it could help lower environmental impacts when manure is applied to the field. As described earlier, imbalanced manure is created after manure storage due to considerable ammonia volatilization. Therefore, extracting P from manure will help keep it more balanced in N and P. Phosphorus in manure can be removed through physical, chemical, or thermochemical processes. Because most P is excreted in feces, a physical separation of solid from liquid can extract P from manure. The liquid-solid separation, however, requires specific separation equipment (e.g., screening, centrifuging) for effective particle separation from liquid (Azuara et al., 2013): just gravitational separation was not successful to separate tiny particles from liquid, e.g., 95% of the manure P remains in manure effluent (Powers et al., 1995). Phosphorus-binding chemicals to crystallize and precipitate manure P have been widely investigated, with reports that ferric, calcium, magnesium, and aluminum compounds are effective as P-crystallizing agents (Barrow et al., 1997; Sherman et al., 2000; Cabeza et al., 2011; Antonini et al., 2012). More recently, Azuara et al. (2013) used a pyrolysis process to extract P from manure solid (250 to 600 μm in diameter) after liquid-solid separation. As a result, 90% of total manure P was recovered mostly as a form of ortho-phosphate, and the study reported that the pyrolysis process was cost-effective for swine manure. The P compounds extracted from manure also have been tested as a P fertilizer. In one study, the P extract was as effective as commercial P fertilizers for crop production (Achat et al., 2014). Recently, a large centrifuge was installed at one dairy farm in Ohio to test P removal from manure (Figure 4). The centrifuge precipitated particles and formed a P-rich solid, where the P extraction efficiency after centrifugation was 57% of total P in the manure. The advantage of the centrifuge system is that manure liquid after centrifugation is well balanced with N and P, and the P-rich solid can be transported greater distances at a lower cost. The owner's goal is to remove more than 80% of the P in manure with centrifugation and by adding various P-binding polymers.

Generally, the strategies to lower environmental impacts during manure storage have been pretty effective as demonstrated above. However, the strategies that can decrease ammonia emissions during manure storage may have potential risks of greater ammonia volatilization from the manure after field application, which has not been well investigated. In addition, these strategies usually require extra costs to implement and maintain the systems. Therefore, changing management systems may not be a preferable strategy, especially for medium and small dairy farms.

N and P Losses After Field Application of Manure

The major purpose of fertilization is to increase crop dry matter production and the yield of the harvested parts of crops. Nutrient supply from manure and commercial fertilizers affects not only the size (quantity) but also the nutrient composition (quality) of crops (Heeb et al., 2006). Although crops require various macro and micro nutrients for growth, N and P (with potassium) are usually the most limiting factors in crop production. As indicated previously, however, nutrient supply applied in excess to land potentially increases the risks for environmental pollution. Therefore, fertilization with manure requires careful consideration from both economic and environmental viewpoints.

The sources of N and P required for crop growth are primarily provided from soil organic matter and fertilizer (manure and/or

commercial fertilizer). The application rates of nutrients for various crops have been established (MSU Extension, 1995). Therefore, knowing nutrient concentrations in soil and manure is key to appropriate nutrient application to land for maximizing crop yields and minimizing nutrient losses. Producers who do not know the nutrient concentrations in their manure and soil may refer to a guideline available that helps estimate their nutrient concentrations in manure at the time of application (e.g., OSU Extension, 2006). However, the estimated nutrient concentrations (especially N) in guidelines are quite variable. For example, N losses from holding ponds and lagoons were estimated to be 20 to 40% and 70 to 85%, respectively, of total manure N (OSU Extension, 2006). Nitrogen losses from manure are variable depending on factors like surface area, storage length, temperature, and wind (Hristov et al., 2011). Because individual dairy farms are affected by different factors, more studies are needed to examine N losses under various practical conditions to more accurately estimating manure N and P at the time of application. The most efficient strategy is probably to establish a nutrient management plan for individual dairy farms according to their own manure management systems and environmental factors.

Although producers may know the nutrient concentrations in their soil and manure at the time of manure application by lab tests, dairy manure is usually not an ideal sole fertilizer for crops because of its imbalance of nutrients. As described earlier, the imbalance in manure primarily occurs by considerable N losses through ammonia volatilization during manure storage. Therefore, if manure is not managed to decrease ammonia volatilization during storage, such as with acidification and covering lagoons (which is not the case for most farms in the US), addition of a commercial N fertilizer with dairy manure is required at the time of application. Otherwise, dairy manure may limit crop yields when application is P-based (N deficiency) or may increase environmental impacts when application is N-based (over-application of P). However, because adding a commercial N fertilizer to manure requires extra costs to producers, it may not be a favorable strategy in practice. Moreover, manure and soil tests must be conducted to determine the amount of a commercial N fertilizer to be added to the manure.

There are various strategies that can lower N and P losses after manure application to the field. Manure application techniques, rotational cropping, and application timing can significantly affect N and P losses from the field. For example, manure injection into soil significantly lowered ammonia and nitrous oxide emissions from manure compared with surface application (Montes et al., 2013) and N and P losses from runoff (Daverede et al., 2004; Laboski et al., 2013). Crop rotation, e.g., corn and soybean, requires less N addition than consecutive corn cropping because of atmospheric N fixation by legumes, which can be a good strategy for efficient use of an imbalanced manure (relatively low N and high P), such as dairy manure (OSU Extension, 2006). Moreover, manure surface application in winter on frozen ground or snow always needs to be avoided due to considerable losses of N and P through runoff via rainfall and snow melting (Srinivasan et al., 2006). These strategies are not new but are still effective in practice at reducing N and P losses after field application. Therefore, adopting these strategies in combination can significantly lower ammonia volatilization and P losses through runoff from manure-amended soil.

Conclusions

Individual dairy farms have different nutrient feeding and manure management

systems depending on size of farm (e.g., herd size) and land for crops. Because herd size is usually maintained at each dairy farm, the amount of manure produced and stored at individual farms does not vary. If feed composition in herd diets is consistent, the amounts of N and P excreted by cows and the N and P concentrations in manure at the time of field application will not vastly vary at individual farms. In addition, nutrient build-up on land is also easily monitored by a soil test before manure application (e.g., once a year). Therefore, it is not difficult for producers to monitor nutrient production, losses, and utilization in their dairy operation systems. Knowing nutrient flows (from feeds to manure as fertilizer) in individual farms will help identify opportunities to improve dairy and crop production and to lower environmental impacts. Formulating dietary protein (i.e., N) and P in dairy diets to meet or be slightly below the requirements is the most important and effective strategy to lower environmental impacts by reducing N and P excretion. After lowering N and P excretion from cows, the key strategy to lowering environmental impacts and maintaining manure quality as a fertilizer is to minimize ammonia volatilization during manure storage. Because individual farms are under different factors affecting N losses during manure storage, a common nutrient management plan across all dairy farms is not ideal. Therefore, establishing a nutrient monitoring plan for individual farms (e.g., N and P excretion, N losses during manure storage, and N and P concentrations at the time of application) is important for appropriate nutrient management.

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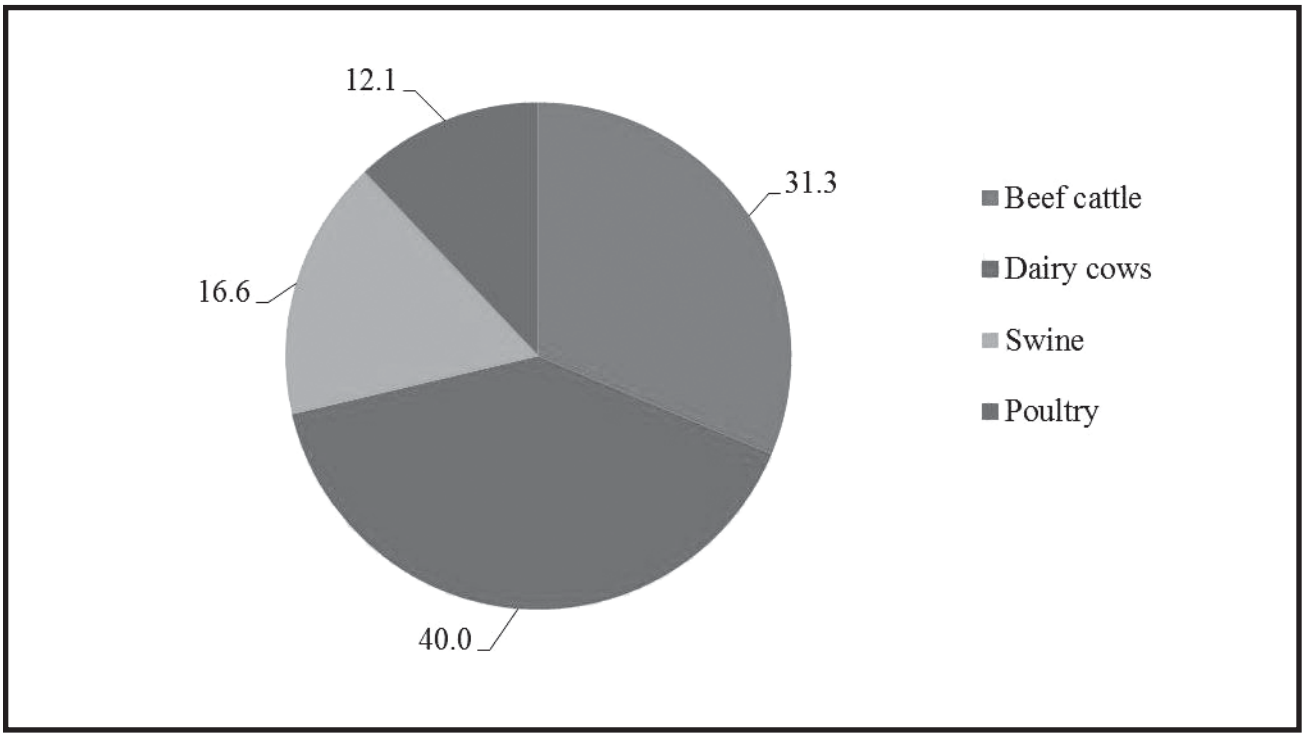

Figure 1. Proportions (%) of daily manure production by livestock in Ohio (calculated based on Ohio livestock populations on January 2014 with typical livestock manure production; ODA, 2015; OSU Bulletin-604, 2006).

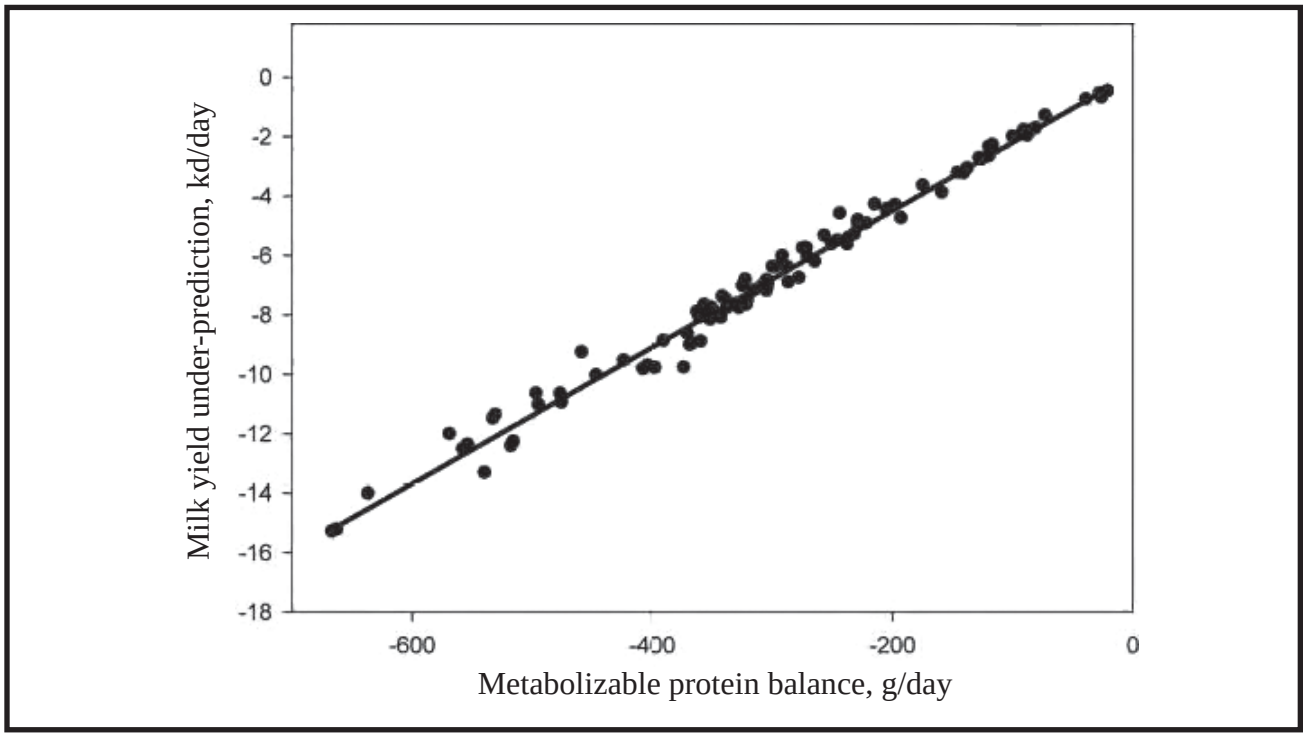

Figure 2. Relationship of metabolizable protein balance (NRC, 2001) and under-prediction of milk yield in dairy cows (Lee et al., 2012b).

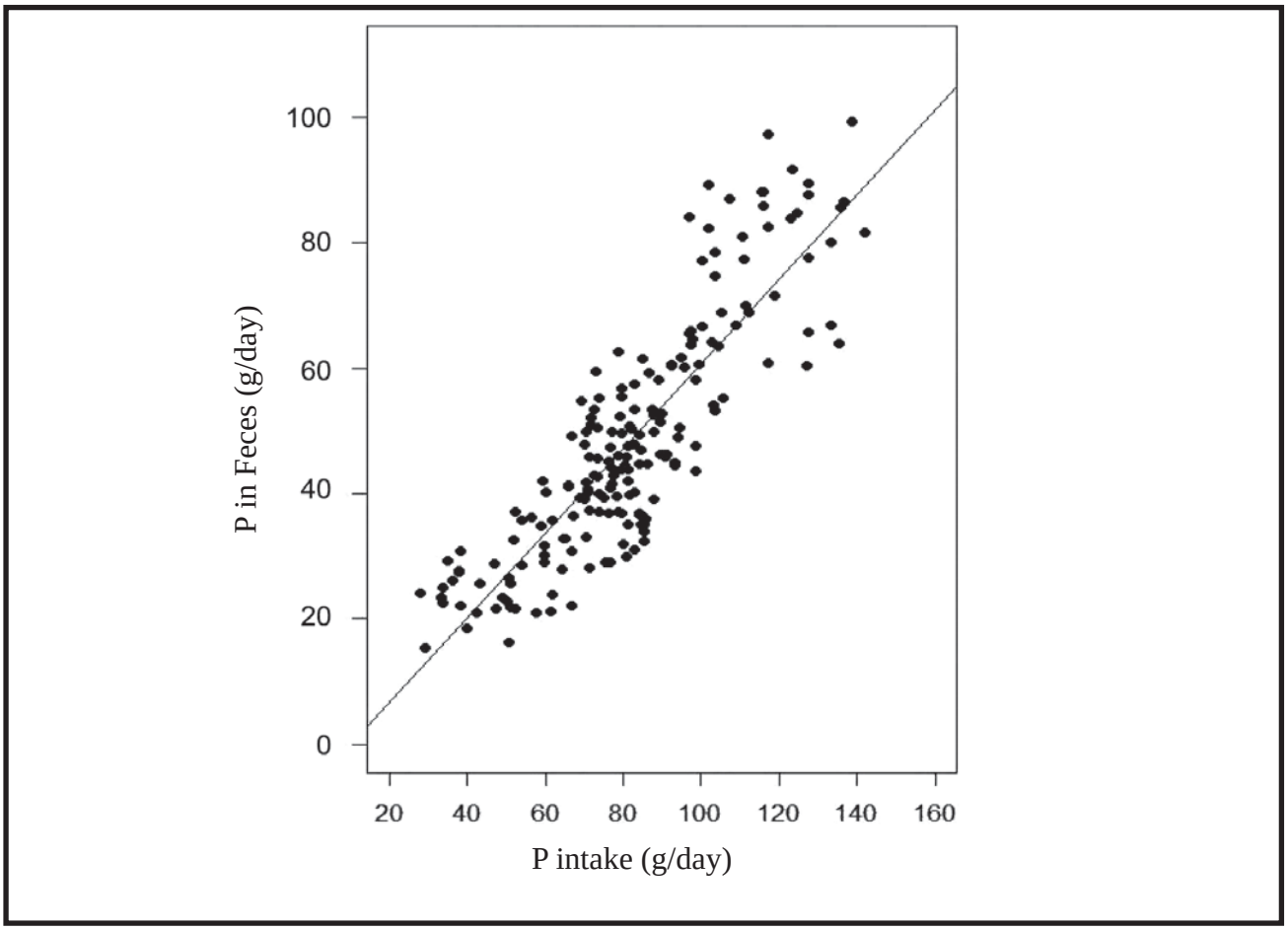

Figure 3. Relationship between P intake and fecal P output (Alvarez-Fuentes et al., 2016).

Figure 4. A centrifuge to precipitate manure solid rich in P (left) and manure solid after centrifuging (right); pictures used with permission.

Effects of the New Veterinary Feed Directive on Dairy Feeding Programs

Dan Grooms DVM, PhD[1]
Department of Large Animal Clinical Sciences
College of Veterinary Medicine
Michigan State University

The use of pharmaceutical products in food animals is under close scrutiny by the general public and regulatory agencies around the world. The scrutiny is especially intense with respect to antimicrobial use (antibiotic and antimicrobial are the same thing). Increasing bacterial resistance to antimicrobials and fear of antimicrobial residues in food drives this scrutiny. Either of these situations have potentially life-threatening implications for anyone who might come in contact with a resistant bacteria or chemical residue, so the scrutiny is justifiable (Note the issue of antimicrobial resistance is not just a human issue but an animal one as well as, evidence of the increasing development of antibiotic resistance in pathogens of animal importance). More importantly, they put the entire food animal industry at risk for increased scrutiny, increased regulations, and ultimately loss of public confidence. Confusion about use of antimicrobials in food animals adds to the scrutiny. Reasons for this confusion that have been postulated include: 1) the fact that antimicrobial use in food animals is not a black-and-white issue; it is a complex issue that is frequently over simplified by both critics and proponents, 2) failure to understand that a concern is not equivalent to risk, 3) disconnect between consumers and agriculture, with most consumers being at least three generations removed from the farm, and 4) activist messaging - the media and the internet are often inaccurate and misleading regarding antimicrobial use, and in particular, antimicrobial resistance and its relationship to use in food-animal production (NIAA, 2011).

We can have a healthy debate about the source of antimicrobial resistance and if residues exist; however, the reality is that if we use antimicrobials in food animals, we contribute to the potential risk of antimicrobial resistance developing and antimicrobial residues showing up in human food. It is IMPERATIVE that we do everything we can to reduce these risks, while at the same time making sure we properly care for the health of our animals.

Antimicrobial stewardship is the responsibility of everyone involved in the care of food animals. This includes livestock owners, employees, allied industry personnel (e.g. nutritionists), and veterinarians, among others. This message needs to be heard and applied by all of us to take measures towards doing what's right when it comes to responsible use of antimicrobials. No areas of the livestock industry are exempt from the need to use antimicrobials responsibly, as the majority of livestock eventually end up in the human food chain. Whether you run a dairy operation, a heifer raising operation, a feedlot, a cow-calf operation, or raise 4-H steers, how you care for those animals has potential human health impacts. Part of how you care for your animals includes the responsible use of antimicrobials.

[1]Contact at: 736 Wilson R, East Lansing, MI 48824, (517) 355-9593, FAX: (517) 432-1042, Email: grooms@cvm.msu.edu.

By the way, although this discussion revolves around prudent antimicrobial use, the same arguments pertain to any pharmaceutical product used in food producing animals. Anthelmintics, non-steroidal anti-inflammatories, etc. Misuse of any of these drugs has animal health and public health consequences.

Antimicrobial use in food animals is regulated by the U.S. Food and Drug Administration Center for Veterinary Medicine (**FDA CVM**). However, there are many other agencies involved in the oversight of drug use in cattle besides the FDA. These include the Environmental Protection Agency (**EPA** - approves pesticide labels), the US Department of Agriculture Food Safety and Inspection Service (**FSIS** - inspects cattle harvest ante- and postmortem and tests for drug residues), United States Department of Agriculture Center for Veterinary Biologics (**CVB** - vaccine approval), the Drug Enforcement Agency (**DEA** - defines and enforces regulations related to the distribution and use of controlled substances), individual state veterinary medical boards (define and enforce veterinary practice act), and individual state pharmacy boards (define and enforce pharmacy and drug distribution law) (Fajt, 2013). For dairy operations, there is also the National Conference on Interstate Milk Shipments (**NCIMS**), which oversees the Pasteurized Milk Ordinance (**PMO**). The PMO defines procedures for milk sanitation and prevention of milk borne disease. Regulatory oversight provides assurance in the development of safe products and that no harmful residues enter the food supply.

Efforts have been made to promote the judicious use of antimicrobials in animals (AVMA/AABP, 2016; National Dairy Farm Program, 2016). These have been largely educational efforts to increase awareness and best practices with respect to prudent drug use in food animals. In 2012, the FDA finalized Guidance for Industry #209 (FDA GFI #209, 2012) which provides a framework for the voluntary adoption of practices to ensure the appropriate or judicious use of medically important antimicrobial drugs in food-producing animals. This framework includes the principles of phasing in such measures as: 1) limiting medically important antimicrobial drugs to uses in food-producing animals that are considered necessary for assuring animal health and 2) limiting such drugs to uses in food-producing animals that include veterinary oversight or consultation. It is apparent that FDA will be introducing policies over time with this framework in mind. Let's examine each of these more carefully.

Principle 1: The use of medically important antimicrobial drugs in food-producing animals should be limited to those uses that are considered necessary for assuring animal health. FDA believes the use of medically important antimicrobials in food-producing animals for production purposes (e.g., to promote growth or improve feed efficiency) represents an injudicious use of these important drugs. FDA believes that use of medically important antimicrobials for treatment, control, or prevention of specific diseases (disease prevention is defined as administration of an antimicrobial drug to animals, none of which are exhibiting clinical signs of disease, in a situation where disease is likely to occur if the drug is not administered – see further discussion later), including administration through feed or water, to be a judicious use that is necessary for assuring the health of food-producing animals. The term "medically important antimicrobials" generally refers to antimicrobials that are important for therapeutic use in humans. A list of "medically important antimicrobials" can be found in Appendix A of the FDA Guidance for Industry #152 (FDA GFI #152, 2003)

Principle 2: The use of medically important antimicrobial drugs in food-producing animals should be limited to those uses that include veterinary oversight or consultation. In addition to instituting voluntary measures that would limit use of medically important antimicrobial drugs in food-producing animals to uses that are considered necessary to assure the animals' health (Principle #1), FDA also believes it is important to phase-in the practice of including veterinary oversight or consultation in the use of these drugs. Essentially what this means is that all antimicrobials considered medically important will eventually fall under the oversight of veterinarians. There are three classes of animal drugs: Over-the-Counter (**OTC**), Prescription (**RX**), and Veterinary Feed Directive (**VFD**). OTC drugs can be sold by any person or establishment without the prescription of a veterinarian. Prescription drugs can only be sold to farmers by a veterinarian or pharmacist, and only with the prescription of a veterinarian. VFD covers drugs intended for use in or on feed, which is limited by an approved application to use under the professional supervision of a licensed veterinarian. Eventually, it is likely that all antimicrobials that are considered medically important will no longer be available OTC. Examples of this would include injectable penicillin or oxytetracyline, or feed additive antimicrobials such as AS-700.

In 2013, FDA finalized Guidance for Industry #213 (FDA GFI #213, 2013). This document essentially implemented the two principles of GFI #209 for feed and water antimicrobials. This document does two things: 1) it eliminated the use of medically important antimicrobials for production uses (e.g. growth promotion), and 2) it requires that feed and water antimicrobials must be used under the guidance of licensed veterinarians. Complete implementation of these rules are to occur by January 1, 2017.

The veterinary feed directive, or VFD, is the mechanism that has been devised to give veterinarians the tools to control and deliver medically important antimicrobials to food animals. Although logistically different, a VFD is essentially a prescription; the difference is that a prescription can only be filled by a licensed pharmacy whereas a VFD can be filled by an approved feed distributor. A VFD can be written only by a veterinarian licensed in the state where the targeted animals are to be fed. The veterinarian must have a Veterinary Client Patient Relationship (**VCPR**) with that client as defined by the state where the animals are fed. Logistically, the veterinarian will write a VFD and send a copy to the client and the feed distributor. At this time, the VFD must be written or it can be sent electronically. No "over-the-phone" or verbal contingencies for issuing a VFD are in place. More information can be found about the VFD at the FDA VFD resource page accessible at: http://www.fda.gov/AnimalVeterinary/DevelopmentApprovalProcess/ucm071807.htm

So, as professionals interested and responsible for the safe use of antimicrobials, what can we do to ensure responsible use of antimicrobials and compliance to the new rules with respect to antimicrobial use in feed and water? Here are 5 things WE can do TODAY to improve antimicrobial stewardship:

1. Encourage proper VCPR. This relationship is necessary to obtain most antimicrobials and likely will become more important in the future. The American Association of Bovine Practitioners (AABP) has established guidelines for a VCPR; "Establishing and Maintaining the Veterinarian-Client-Patient Relationship in Bovine Practice" (AABP VCPR, 2013). Key components of a VCPR include: 1) an agreement by both a veterinarian and producer that a VCPR exists, 2) a veterinarian of record with

oversight of herd veterinary treatments, 3) clarity of relationships with consultants and other veterinarians, 4) written treatment protocols for all drugs to be used on the farm, 5) written or electronic treatment records, and 6) provision of drugs for only specific time frames and for specific protocols. Outside of future regulatory requirements, this relationship is really important in helping to ensure the health of your animals and the safety of the food they produce. Note: Every state has defined a VCPR. State VCPR regulations can be accessed at: http://www.fda.gov/AnimalVeterinary/DevelopmentApprovalProcess/ucm460406.htm

2. Keep good records. Records provide many GOOD things in terms of managing the health, safety, and productivity of our animals. Unfortunately, records are often one of the most neglected management tools. Whether it is to ensure that we follow proper withdrawal times or monitoring our treatment success, records are critical for managing the safe use of antimicrobials, as well as the health of our herds. In fact, one of the best ways to keep yourself out of trouble with regulatory agencies (should you ever have a drug residue issue) is to have good records.

3. Develop appropriate treatment protocols for common health problems. Protocols help to avoid the "shotgun" approach to treating problems. Protocols should be developed for the most common health problems you face with the assistance of your veterinarian. They should be written down, easily accessible, and reviewed regularly (at least once a year). Protocols should not depend on routine extra-label use where there are alternatives that can be used. For example, talk with your veterinarian about alternatives to Procaine Penicillin that will be effective at the labeled dosage.

4. Learn about the VFD and work closely as a team with all those involved with developing and delivering diets to animals. This would include farm management, veterinarians, nutritionists, and employees. A suggestion would be to make one person the "go to" person for learning about, educating others, and implementing the VFD in your organization.

5. Be GREAT stewards of antibiotic use. It is important that we all make every attempt to use antibiotics in a prudent manner in order to maintain their effectiveness for both humans and animals.

Let's be clear, the livestock industry as a whole has a great track record of providing safe food. However, times keep changing and the demands of not only consumers but of the public as a whole, make it essential that the livestock industry be above reproach in regard to antimicrobial use. That means that what we did yesterday may not be good enough today. Let's all step forward and take a role in ensuring careful use of antimicrobials. It is in the best interest of the animals we care for and the public who buy our products. *It is the right thing to do!*

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On-Farm Assessment of Forage Quality

Dan Undersander[1]
Department of Agronomy
University of Wisconsin

Abstract

High forage quality is key to good levels of milk production. Frequent forage analysis is an absolute must; however, several on-farm assessments of forage quality and/or forage quality change can be made to suggest that forages should be retested and rations rebalanced. This paper suggests several new technologies that can be matched with forage testing to better provide consistent, high quality feed to the milking dairy cow. Starting at mowing, forage quality only declines from cutting to feeding, so it is important to cut when the alfalfa or grass is at high quality, as estimated by plant height. Forage quality can be estimated by attachments to choppers and balers. Silage moisture changes content of silage on the face of a tube or bunker changes daily and must be adjusted for. We should recognize heating as an energy loss and take steps to reduce it in future harvests. Similarly, mold should be monitored and attempts made to reduce it in future forage storage.

Introduction

Dr. David Mertens (2012), USDA-DFRC, proposed that the five most important nutritional measurements for hay crops are: dry matter (**DM**), ash, amylase-treated neutral detergent fiber (**aNDF**), some measure of digestibility or energy value, and crude protein (**CP**). More and more, these parameters can be estimated on-farm, or at least one can receive a flag as to when a parameter has changed.

As Figure 1 shows, when forage quality declines, additional concentrate can offset part of the lost milk reduction but not all. Thus, it is important to harvest forage when quality is high and to minimize losses of the quality through harvesting, storage, and feedout.

Several sources have indicated that forage analysis should be more frequent as herd size increases (St-Pierre and Weiss, 2007; Weiss and St-Pierre, 2009; Hoffman et al., 2010). The purpose of this paper is to give some tools to use to improve consistency of forage quality fed to animals in between the forage samplings.

Harvesting

Forage quality of alfalfa changes on a daily basis in the spring (Table 1). Every day results in a gain of 0.4 unit NDF and loss of 0.4 unit of fiber digestibility. Grasses show similar response on first cutting when they are heading. At the same time, alfalfa adds about 160 lbs DM per acre dry matter per day. Harvesting early unduly stresses the alfalfa plant and can reduce later cutting yields and winter survival. So we want to harvest at the quality we need but not too early because each day early reduces yield and increases cost per ton of forage.

[1]Contact at: 1575 Linden Drive, Madison, WI 53706, (608) 263-5070, Email: djunders@wisc.edu.

Figure 2 shows that the rate of forage quality change is at a constant rate around harvest, but the lines have different intercepts. So that, for example, if one wanted to harvest at 180 relative feed value (**RFV**), there was almost a two week difference reaching this quality among years. Thus, calendar date is not a good indicator of when to start first cutting. Maturity stage is not a good indicator on first cutting since plants often do not flower normally. Similarly, some have recommended a Growing Degree Day model for determining when to harvest, while this may work at some sites, it is no better than calendar date over the wide range of conditions in the Midwest.

A method that has proven to have great utility is to measure plant height and harvest accordingly (Sulc et al., 1997).This makes biological sense given that the percentage stem increases as plants get taller and stems are lower in quality than leaves. The recommendation would be to harvest alfalfa at 28 inches or bud stage, whichever comes first, for dairy cattle or 32 inches or early flower for growing animals and beef cattle. Second and later harvests can be at 28 to 30 days for dairy cattle, which is normally about bud stage. Note that these recommendations are assuming that there will be a 10% quality loss from the standing to harvested forage.

Near infrared reflectance (**NIR**) equipment is available on some choppers for measuring forage quality. The moisture measurement is strongest and can indicate whether or not the forage is in the appropriate moisture range for harvesting. Protein and fiber measurements need to be validated by post-harvest sampling but can be an indication of quality change and possibly be used for inventorying heifer/dry cow vs lactating cow feed. Some systems are also moving towards yield estimates which would allow stand determinations and site-specific applications of fertilizer, etc.

Attachments for balers are also getting much more sophisticated. Units are available that will monitor the moisture content of the forage going into the bale. Some units will adjust preservative application accordingly, since the amount of preservative needed is directly related to the moisture content of the hay being baled. This kind of attachment can be particularly valuable if fields are disuniform so that moisture content varies across the field. One company makes an attachment that will mark wet bales with spray so that they can be readily sorted and handled separately from dryer bales. Several companies have attachments that are estimating forage quality of hay in the bale and printing an RFID tag with quality information so that high quality bales can be separated from lower quality bales when removing them from the field.

Leafiness

We all know that leafier forage is higher quality. However, few realize the extent to which this is true. Figure 3 is from a study done in MN, PA and WI in 2015. About 71% of the change in forage quality was due to changes in leaf content. This huge quality effect suggests two things:

1. Any movement of forage during the harvesting process results in leaf loss, which is both a dry matter, and especially, a forage quality loss. Therefore, move the forage as little as possible between mowing and harvesting.

2. Any change in leafiness during feedout should be a red flag that the quality of the forage has changed. The forage should be sampled, analyzed, and the ration rebalanced.

Also, beware of leaf drop prior to mowing. This can be significant in cool and wet conditions that are conducive to growth of fungi on the leaf that can cause leaf drop. If you are seeing high amounts of leaves on the ground when mowing, consider applying a fungicide 3 weeks prior to harvest to reduce the leaf diseases.

Monitor Moisture

Figure 4 shows the variation in DM content of alfalfa haylage in a bunker at the USDA Prairie du Sac Research Station over time. Five samples were taken in an 'X' pattern across the face each day and averaged. The pattern of DM obviously reflects the rainfall pattern. Generally, a front comes through every 3 to 4 days, usually with rain, but not always. Haylage generally dried after rains the first of August and again after Sept 8, during which dry periods occurred. The important thing to notice is that DM could vary from 30 to 45% over a two week period. If the amount added to the TMR did not reflect the moisture change, then cattle were likely receiving less DM (or more) than expected.

Moisture can be determined quickly by taking a sample and microwave drying it. The sample must be dried 3 min., stirred, dried 3 min. again, stirred, and then dried at 1 min. intervals and weighed until no weight loss occurs. This is reasonably quick, but will generally take about half an hour time.

Another method is the Koster Moisture Tester, where the sample is put into a pan and heat from an infrared light blown through it. This system has the advantage of the operator being able to start the drying and do some other work while the sample is drying. Figure 5 shows an inexpensive DM tester than can be made on the farm: Simply take a piece of PVC pipe, cut a hole in to insert a hair dryer and then set the sample on top in a colander or pan with screened bottom.

Instrumentation is being developed that will mount the NIR scanner on a loader and moisture can be read as the forage is dumped into the TMR mixer. Some TMR mixers are also made with moisture sensors.

Heating/Mold Losses

Heating should be recognized as a loss of energy for animals being fed since it represents plant enzymes or microbes breaking down starch and sugars and releasing heat and CO_2. Heating can be monitored in a bunker or tube by feel. Heating will occur because of several (mis)management practices. The most common causes of heating are:

1. Less than desired packing density. We recommend a packing density of 45 lbs silage per ft^3. At this density, there is still 40% pore space; lesser density means air will move in faster and farther to initiate mold grow.

2. Feeding too little off the face. At 45 lbs silage per ft^3, we would expect air to move in 30 inches from the face. Thus, the recommendation is to remove 1 ft/day from the face so silage is only exposed to air 2.5 days before being fed.

If excessive heating occurs in bunkers or tubes, it might be worthwhile to consider management changes for the next harvest period. It might also be worthwhile to consider adding *Lactobacillus buchneri* or some other acetic acid producing bacteria as an inoculant when the forage is ensiled as acetic acid reduces microbial growth and heating.

Heating can also occur in wet hay. If harvesting hay above 16% moisture in large square or round bales, consider using a preservative to minimize the heating loss. Other considerations are to make smaller bales of the wet hay (to increase surface area to volume and allow more heat exchange) and leave bales separate for two weeks. Another option is to wrap the bales in plastic. Wrapping in at least 6 layers of plastic within 24 hours of baling wet hay will reduce heating.

Conclusions

Forage should be sampled frequently on a farm for analysis. However, more and more of the needed parameters can be estimated on-farm, or at least one can receive a flag as to when a parameter has changed. In addition, analyzing on farm can help develop good management for high quality forage. Harvesting forage when quality is high and minimizing leaf loss during harvest is the first step to high quality forage in the tube or bunker. In addition, monitoring moisture at feedout can assure that cows are getting the DM that they need. Heating is an energy loss to the cattle we are feeding and should be studied to determine how to minimize now and prevent in the future.

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Table 1. Rate of alfalfa forage quality change per day.[1,2]

Component	Mean
Crude protein, % of DM	-0.25
Acid detergent fiber, % of DM	0.36
Neutral detergent fiber, % of DM	0.43
Neutral detergent fiber digestibility, % of NDF	-0.43
RFV, points	-2.9
RFQ, points	-3.6

[1]Undersander, 2009 unpublished.
[2]RFV = relative feed value and RFQ = relative forage quality.

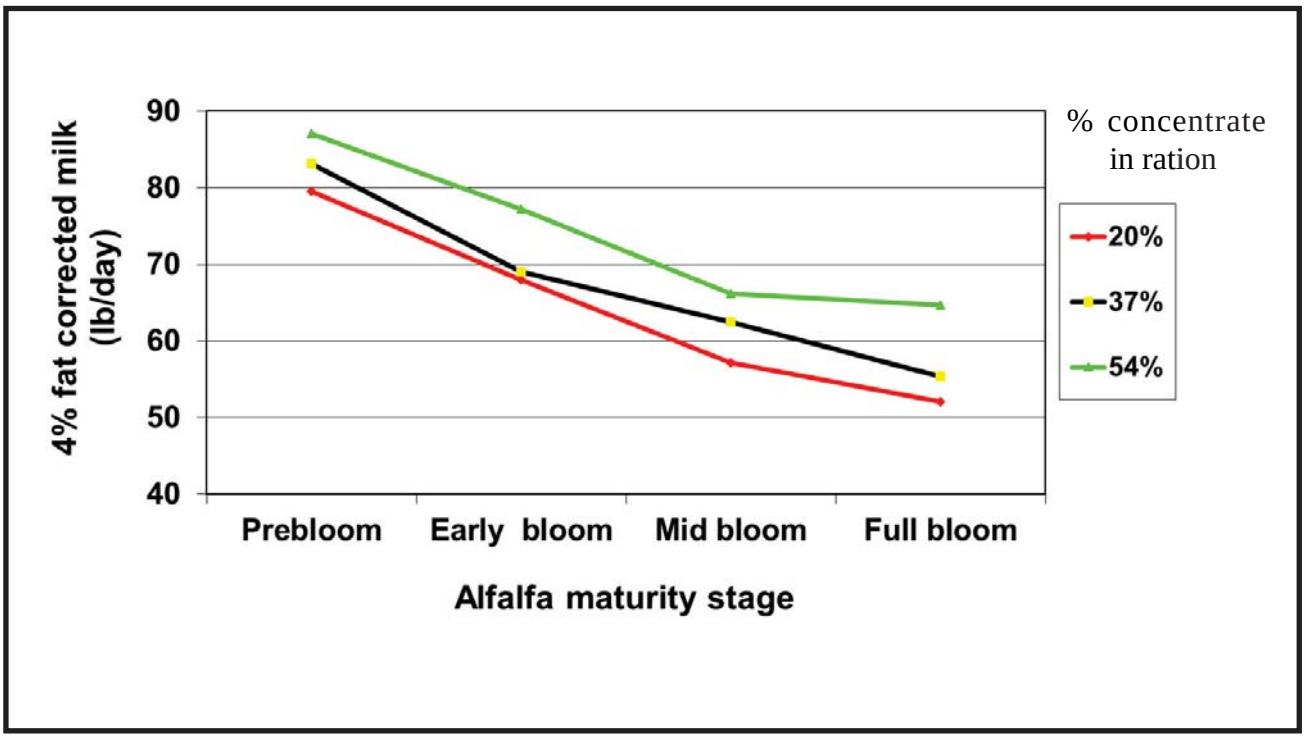

Figure 1. Effect of forage quality on 4% fat-corrected milk production at three concentrate levels.

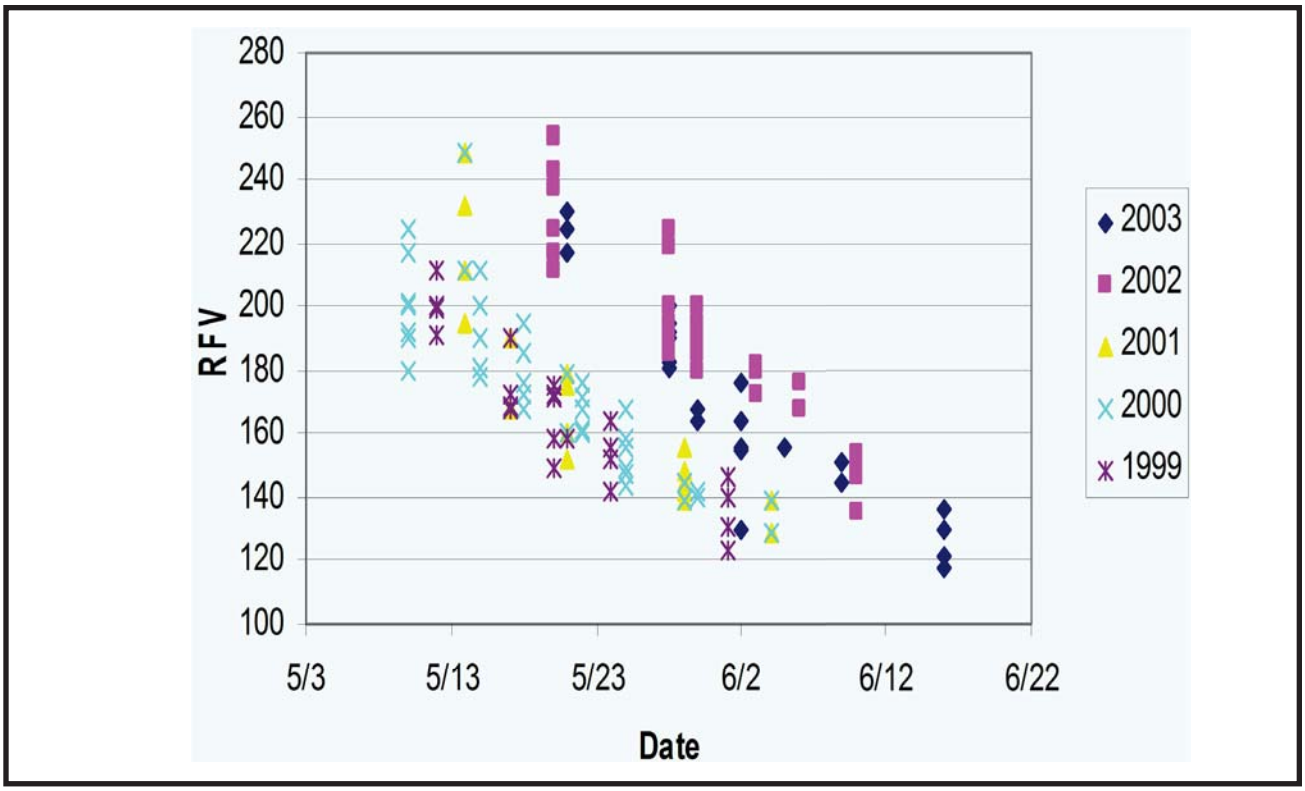

Figure 2. Rate of forage quality (RFV = Relative Feed Value) change per day in Wisconsin.

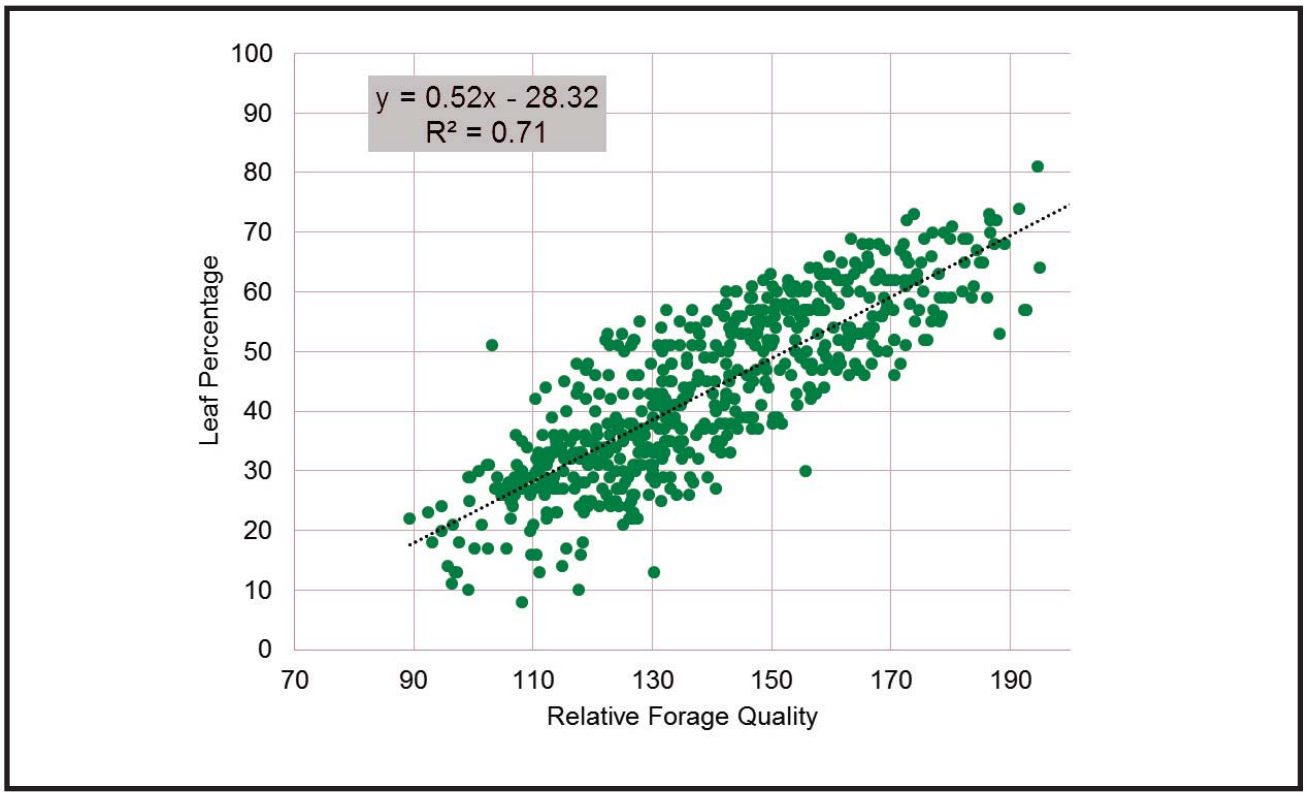

Figure 3. Effect of leaf percentage on forage quality.

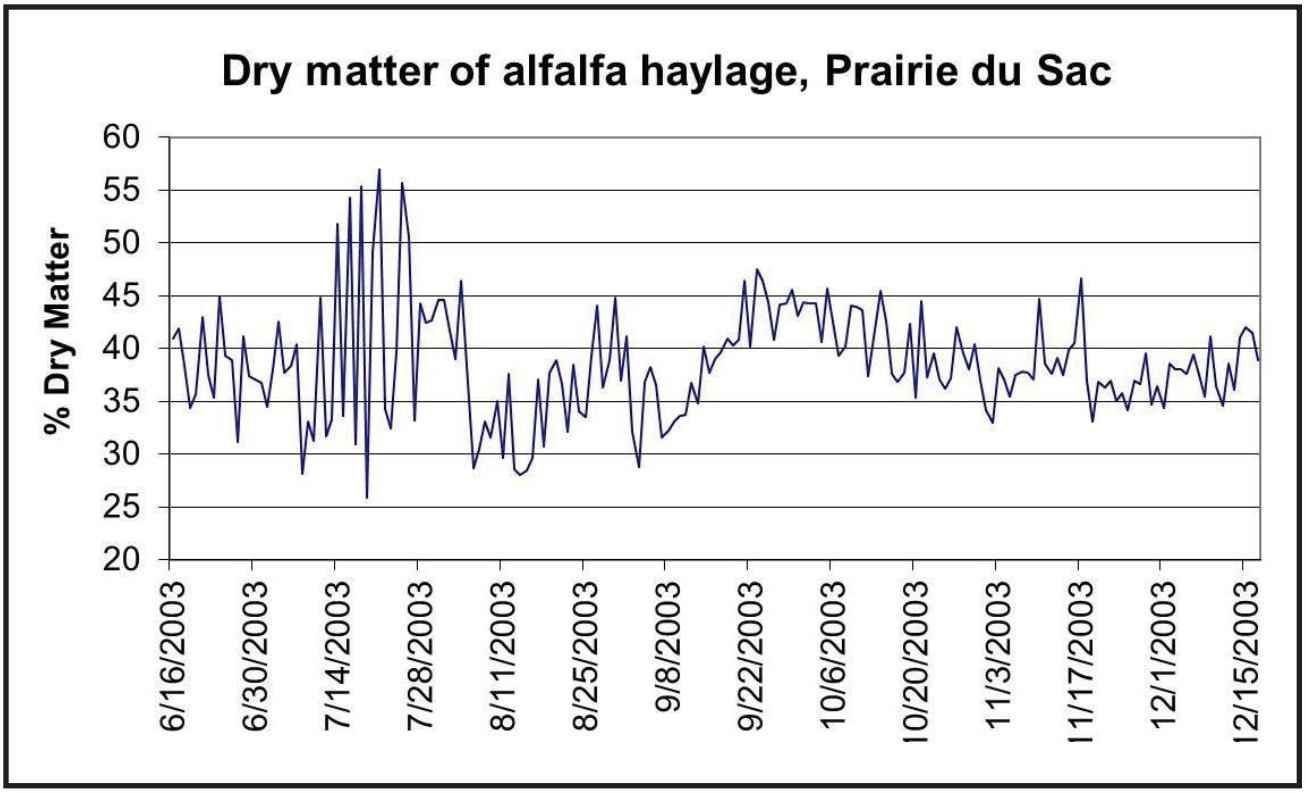

Figure 4. Variation in alfalfa haylage dry matter in a bunker.

Figure 5. Cheap moisture tester.

Prediction of Blood Non-Esterified Fatty Acid and Fatty Acid Analysis of Individual Cow Milk Samples

D.M. Barbano[1]‡, M.E. Woolpert*†, H.M. Dann†, K.W. Cotanch†, C. Melilli‡, L.E. Chase§, and R.J. Grant†

**Department of Animal and Veterinary Science, University of Vermont, Burlington 05405*
†William H. Miner Agricultural Research Institute, Chazy, NY 12921
‡Department of Food Science, Cornell University, Ithaca, NY 14853
§Department of Animal Science, Cornell University, Ithaca, NY 14853

Abstract

The overall objective of our research program on mid-infrared (**IR**) milk analysis is to develop a suite of milk analysis measurements that can be used as precision farm management tools. Currently, we have developed and tested rapid milk fatty acid analysis tools that can be used to determine the outcome of feeding and farm management changes by measuring de novo, mixed origin, and preformed milk fatty acids. These measures have been applied to a large number of dairy herds over a 4 year period, and a positive relationship between milk de novo fatty acid content and bulk tank milk fat and protein concentration were observed. Two 40 farm field studies in 2 different years (2014 and 2015) were conducted and farm management and feeding practices were identified that were related to higher milk de novo fatty acid content and higher bulk tank fat and protein tests. In both years, the high de novo farms had higher fat and protein tests. The high de novo farms tended to have more feed bunk space per cow, lower free stall stocking density, and had lower fat content in the ration. In 2014, at 25 kg/cow/day of milk, the average high de novo (**HDN**) farm earned a gross of $5.50 and $7.72/cow for fat and protein, respectively. The average low de novo (**LDN**) farm at 25 kg/cow/day milk earned a gross of $5.26 and $7.29/cow for fat and protein, respectively. These differences for fat and protein between HDN and LDN herds at 25 kg of milk per 100 cows per year would result in a gross income difference of $8,544 for fat and $15,695 for protein. In 2015, at 30 kg/cow/day of milk, the average HDN farm earned a gross of $5.00 and $5.49/cow for fat and protein, respectively. The average LDN farm at 30 kg/cow/day milk earned a gross of $4.01 and $5.30/cow for fat and protein, respectively. These differences for fat and protein between HDN and LDN herds at 30 kg of milk would result in a gross income difference of $9,125 for fat and $6,935 for protein per 100 milking cows per year. When the fatty acid analysis method and the newly developed blood nonesterified fatty acid test based on an mid-Fourier transform infrared (**FTIR**) analysis of milk are applied to milks from individual cows on a weekly basis, the metabolic status with respect to fat mobilization, ketosis, and displaced abomasum in transition cows can be rapidly determined. Work is on-going to determine how to best use mid-FTIR milk testing for real-time farm management decision making.

Introduction

Mid-IR transmittance milk analysis has been used routinely for about 40 years to measure fat, protein, and lactose contents of milk for both payment of dairy farmers and analysis of individual cow milk for dairy herd improvement record keeping. The sample preparation technology is simple (i.e., does not

[1]Contact at: Department of Food Science, 289 Stocking Hall, Ithaca, NY 14853, (607) 255 4122, Email: barbano1@aol.com.

use any chemical reagents), the milk is only warmed to about 40oC, mixed, and pumped directly into the instrument. The instruments can be purchased in various configurations that will test between 50 and 600 samples per hour for all measured components. The basis of the measurement of fat, protein, and lactose is the vibration of specific chemical bonds that are characteristic in the structure of fat, protein, and lactose in milk. The first generation of mid-IR milk analyzers used individual optical filters in pairs, that selected 2 bands (sample and reference) of wavelengths to measure each milk component (Kaylegian et al., 2009). Each filter was mounted in a filter wheel within the instrument and each filter was rotated into the light path, and an absorbance reading at each band of wavelengths was recorded. In the late 1990's, with the routine use of lasers and affordable computing power, there was a significant change in the internal optical system of IR milk analyzers from a physical optical filter system to an interferometer based Fourier transform (**FT**) optical system. With this change, a complete mid-FTIR spectra of every sample was produced within the instrument. At that time, neither the equipment manufacturers nor the users of the instruments knew what to do with the additional information at other wavelengths within the full spectra. Therefore, the first versions of FTIR instrument software reduced the spectra to a copy of what the optical filters would have produced (i.e., created virtual filters within the software) and then used information to predict fat, protein, and lactose contents of milk by the traditional filter approach (Kaylegian et al., 2009). There were 2 immediate advantages of the change in hardware: 1) the analysis speed could be increased and 2) consistency of virtual filters from one instrument to another was much better and would enable achievement of better agreement of results among instruments.

With time, both researchers within the instrument manufacturing companies and other groups of researchers started to explore the rest of the mid-IR spectra to determine if there was other information that could be used to predict other characteristics of milk. Partial least square (**PLS**) regression analysis was used to analyze the absorbance data from the full spectra. One of the first new parameters to be measured by this approach was milk urea nitrogen (**MUN**), with the goal of using the new information as a dairy herd management tool to evaluate how effectively dairy cows were using protein in the dairy ration. The MUN is closely related to blood urea nitrogen and thus the milk analysis becomes a proxy for collecting and analyzing a blood sample for urea. Over the years, this measurement has become routine in dairy herd improvement (**DHI**) milk testing and has also been included in most bulk milk testing for herd management informational purposes, along with the milk payment testing for milk fat, protein, and solids. With time, researchers developed other measures of milk characteristics based on information in the mid-FTIR spectra of milk. The beauty of this approach is that it only takes computer analysis of the spectra to do this. The analysis time and procedure for milk analysis by the instrument remains the same. So additional value is derived from the same milk spectra, while the per sample operational cost is virtually the same. The cost of adding new measures is the cost of development of the new PLS models.

As a result, PLS models have been developed to measure milk beta-hydroxyl butyrate (**BHB**) and milk acetone (Duffield et al., 1997; de Roos et al., 2006; Rutten et al., 2009; van Knegsel et al., 2010). Soyeurt et al. (2006) developed PLS models to measure the fatty acid composition of the milk fat portion of milk directly from the milk spectra. These new PLS prediction models were targeted mainly for producing data to be used for genetic selection of

cows, but more recently, their value as potential herd management tools has been evolving. The PLS approach continues to be applied to develop of metrics that may be useful in the dairy industry.

Milk Fatty Acid Composition

Bulk tank milk

Soyeurt, et al. (2006) quantified milk fatty acids by mid-FTIR, but they also measured some groups of fatty acids (e.g., saturated, monounsaturated, and polyunsaturated). The information on groups of fatty acids was of primary interest to dairy product manufacturers because these groups of fatty acids need to be listed on the nutritional label of dairy foods, but can also be applied to milk from individual cows. It was thought that if a rapid measurement of these groups of fatty acids was available, then it might be feasible to use genetic selection or feeding approaches to produce less saturated fat and more unsaturated fat. Some progress can be made in this area of modification of milk fatty acid composition with bypass fat feeding. However, in practice, it is very difficult to make large enough changes in milk fatty acid composition for the Food and Drug Administration to allow a food label claim.

Another potential application of mid-IR fatty acid measurement would be to obtain milk fatty acid data in a form that would be useful for more tactical feeding and farm management decision making. To address this application, Barbano et al. (2014a,b) were the first to develop PLS fatty acid prediction models to measure groups of fatty acids as they relate to the biosynthetic origin of the milk fatty acids (i.e., de novo – C4 thru C14, mixed origin – C16, and preformed > C18) from mid-FTIR spectra of milk. Once these fatty acid prediction models were developed and operational in the software of a commercial infrared milk analyzer (Delta Instruments, Model FTA, Drachten, The Netherlands), a survey of bulk tank milk fatty composition was initiated with the St Albans Cooperative Creamery (St Albans, VT). Because the fatty acid results are derived from the same sample and spectra used to obtain the milk payment test for fat and protein, we were able to start collecting data on milk fatty acid composition of bulk tank milk from 430 farms in the cooperative at a frequency of 3 to 20 times per month. At the present time, we have 4 years of data for these farms. Barbano et al. (2014a,b) reported a positive relationship between increasing levels of de novo fatty acids as a percentage of milk total fatty acids, grams of de novo fatty acids per 100 grams of milk, and the fat and protein concentration in bulk tank milk. In general, as de novo fatty acids increased, fat (Figures 1a,b) and protein (Figure 2a,b) concentration in the bulk tank increased for both Holstein and Jersey farms. Given this relationship that we observed in data from the 430 farms, we selected a subpopulation of 40 farms (20 low de novo and 20 high de novo) in 2014 and then another 40 farms again in 2015 to determine differences in feeding and management practices between high and low de novo herds, the relationship to bulk tank milk composition, and differences in milk payment.

The 2014 field study identified management practices (Woolpert et al., 2015), such as higher stall stocking density and lower feeding frequency that were related to lower de novo fatty acid (**FA**) content in bulk tank milk. Farms with lower de novo FA, on average, produced less milk fat and protein per cow per day. Milk yield tended to be higher for HDN farms (P = 0.06). Milk fat yield, protein yield, and protein content were higher (P = 0.01) on HDN farms, while milk fat content tended to be higher (P = 0.10). The higher milk fat and protein yields per cow per day for HDN farms

would indicate that gross milk income per cow was higher on HDN farms during the period of the study. The difference in income per cow would depend on the actual milk price at any point in time. However, the average fat and protein prices for the Federal Milk Order No. 1 for March and April 2014 was $4.62 and $10.17 per kg, respectively. Therefore, at 25 kg/cow/day of milk, the average HDN farm earned a gross of $5.50 and $7.72/cow for fat and protein, respectively. The average LDN farm at 25 kg/cow/day milk earned a gross of $5.26 and $7.29/cow for fat and protein, respectively. These differences for fat and protein between HDN and LDN herds at 25 kg of milk per 100 cows per year would result in a gross income difference of $8,544 for fat and $15,695 for protein.

In the 2015 study (Woolpert, 2016), cow comfort indicators and dietary physically effective neutral detergent fiber (**peNDF**) were related to de novo FA concentration in bulk tank milk on high-producing, Holstein dairy farms. Again, both management (i.e., frequent feed delivery and increased feed bunk space per cow) and dietary factors (i.e., adequate peNDF and lower ether extract) that differed between HDN and LDN farms have been shown to affect rumen function; therefore, de novo FA concentration may be an important tool to monitor cows' rumen function on commercial dairy farms. However, the average fat and protein price for the Federal Milk Order No. 1 for February through April, 2015 was $4.19 and $5.74 per kg, respectively. Therefore, at 30 kg of milk/cow/day, the average HDN farm earned a gross of $5.00 and $5.49/cow for fat and protein, respectively. The average LDN farm at 30 kg/cow/day milk earned a gross of $4.01 and $5.30/cow for fat and protein, respectively. These differences for fat and protein between HDN and LDN herds at 30 kg of milk would result in a gross income difference of $9,125 for fat and $6,935 for protein per 100 milking cows per year.

Individual cow milk

Recently, we have applied the mid-IR milk fatty acid analysis models to individual cow milks. Lynch et al. (1992) reported that milk fatty acid composition (based on gas chromatography analysis) for individual cows changed systematically with days in milk, particularly during the transition period. Generally, the relative percentage of total fatty acids that are de novo fatty acids increases with days in milk and becomes relatively stable for the remainder of lactation after cows have reached positive energy balance. We have begun monitoring individual cow milks from the dairy herd at Miner Institute using a mid-FTIR (Delta Instruments, Model FTA, Drachten, The Netherlands) at the farm at 3 consecutive milkings, one day per week, and we have observed the same milk fatty composition behavior as was reported by Lynch et al., 1992. However, there is considerable cow-to-cow variation in level and the temporal patterns of change in the relative proportions of the de novo, mixed, and preformed milk fatty acids that seem to reflect real-time cow-to-cow differences in energy balance and metabolic health status of individual cows. Generally, healthy cows at day 7 in lactation that do not have excessively high blood NEFA will have a relatively high percentage of total fatty acids that are de novo fatty acids (20% or higher), and with increasing days in milk, the de novo value as a proportion of total fatty acids should be in the range of 27 to 30% of total fatty acids when the cow reaches positive energy balance. Generally, the mixed origin fatty acids as a percentage of total fatty acids will increase with days in milk and preformed fatty acids will decrease.

Blood NEFA

The concentration of nonesterfied fatty acids (**NEFA**) in the blood of lactating dairy

cows is used as an index of how much fat is being mobilized by a dairy cow from adipose tissue at the beginning of lactation. When blood NEFA and blood BHB are too high, cows are susceptible to a range of metabolic health issues, such as displaced abomasum, ketosis, retained placenta, and others (Ospina et al., 2010; McArt et al., 2012). Barbano et al. (2015) were the first to report and validate a blood NEFA prediction model based on the analysis of milk samples from individual cows. Milk and blood samples were collected from 60 lactating Holstein cows once per week for the first 3 weeks of lactation. Cows were milked 3 times per day. Within + or – one milking of the time of blood collection, a milk sample was analyzed using a mid-IR milk analyzer (Delta Instruments, model FTA, Drachten, The Netherlands). A Wako NEFA HR test kit (WAKO Chemicals USA, Inc., Richmond, VA) was used as an *in vitro* enzymatic colorimetric method for the quantitation of NEFA in blood serum, and these values were used as reference values for development of a PLS regression model to predict blood NEFA from the mid-IR milk spectra. There are no NEFA in milk, so a model to predict blood NEFA from a milk sample uses differences in the milk spectra from sample-to-sample that are correlated with changes in blood NEFA. The final PLS model had 9 factors, used wavelengths in the following ranges (3000 to 2800, 1800 to 1700, 1585 to 1000 cm-1) with a standard error of cross validation of 172 uEq/L. Validation milk and blood sample pairs (n = 53) were collected from Holstein cows from a different herd. The mean value for the blood reference test was 713 uEq/L of serum and the mean value for the milk based blood NEFA prediction was 703 uEq/L of serum with a standard deviation of the difference (**SDD**) of 218 uEq/L for the 53 validation samples. Blood NEFA measured on blood is a snapshot of the NEFA concentration at an instant in time, while blood NEFA predicted from milk analysis represents a time average for the total time between milkings. The FTIR milk analysis to estimate blood NEFA is rapid (about 10 seconds), done simultaneously with all other milk component measures, and uses no reagents. This approach could be useful for rapid evaluation of risk for ketosis, displaced abomasum, and possibly reproductive disorders. In the same test on the same milk, the fatty acid composition of the milk fat is also determined. We have observed that there is a relationship between the milk estimated blood NEFA concentration and the change in de novo fatty acids as a percentage of total fatty acids. The combination of many measured parameters in milk as a group and their inter-relationships may have predictive power to provide an advanced warning that a cow is going to have a displaced abomasum.

Conclusions

The application of mid-IR analysis of both bulk tank and individual cow milk samples for parameters that may be useful in support of farm management decision making has potential to enable farm managers to improve the economic performance and sustainability of milk production by improving feed efficiency. Farm management and feeding practices that increase de novo fatty acids as a percentage of total milk fatty acids is correlated with achievement of higher fat and protein tests in the bulk tank. In studies on individual farms where data on milk produced per cow was collected, the production per cow was the same or higher for high de novo fatty herds, so there was higher output per day of fat and protein when de novo fatty acid was higher. More individual cow diagnostic tests using mid-FTIR milk analysis are being developed. In larger herds, the possibility of an economically feasible approach to on-farm, real-time milk analysis by mid-FTIR should be explored as a management tool.

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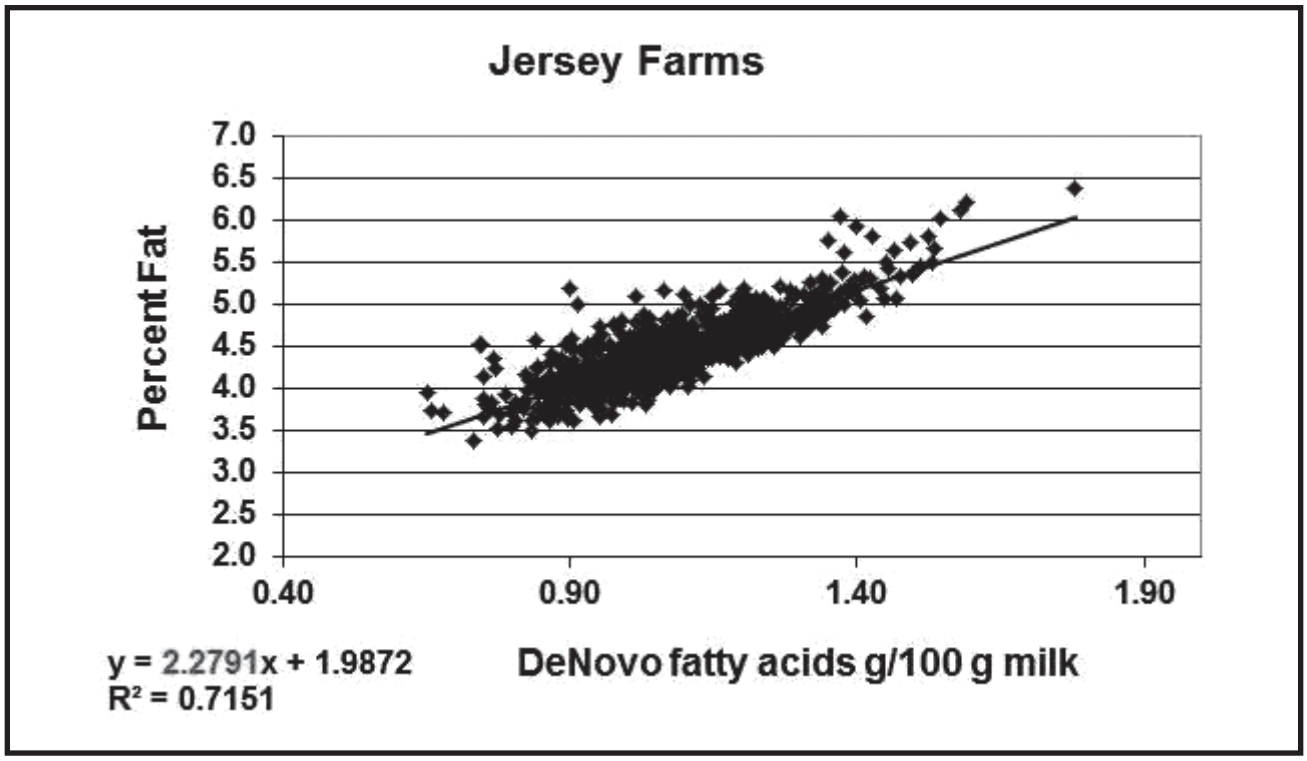

Figure 1a. Percent fat in the bulk tank milk plotted as a function of de novo fatty acids (grams per 100 grams of milk) for Jersey farms.

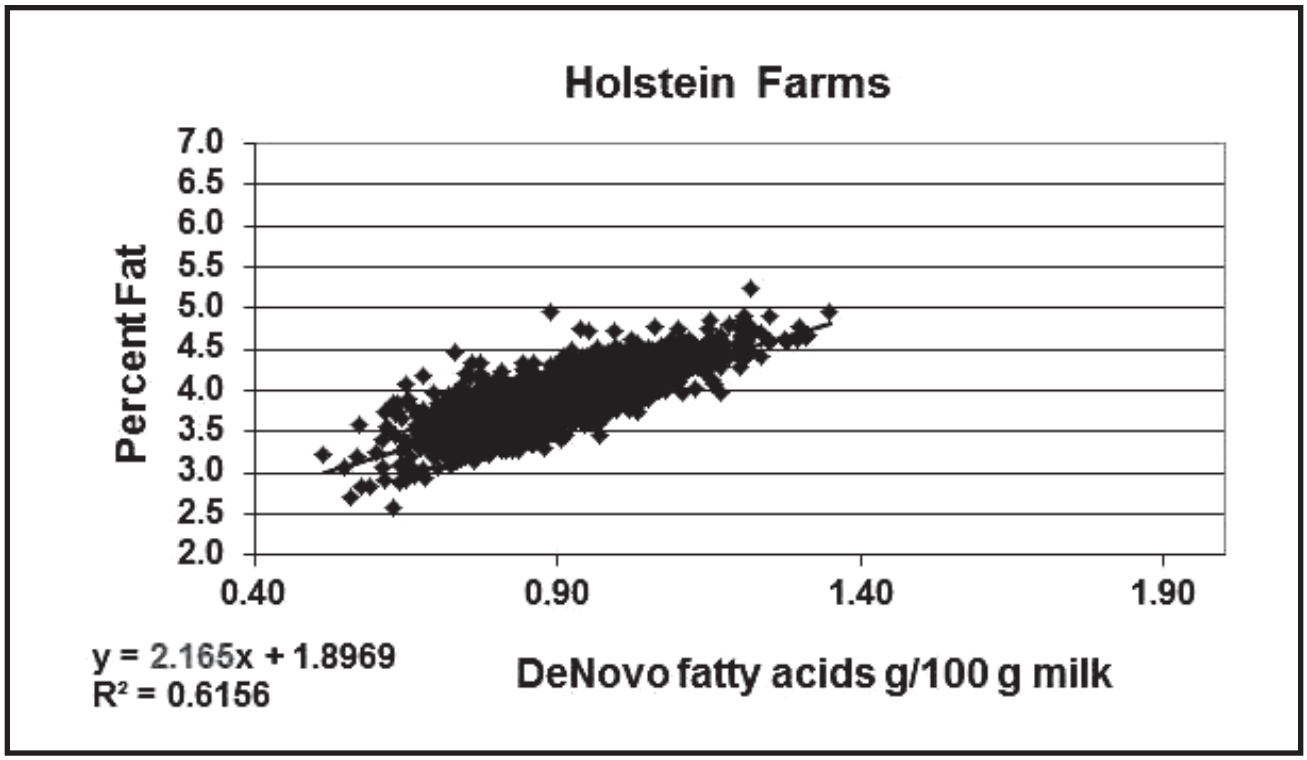

Figure 1b. Percent fat in the bulk tank milk plotted as a function of de novo fatty acids (grams per 100 grams of milk) for Holstein farms.

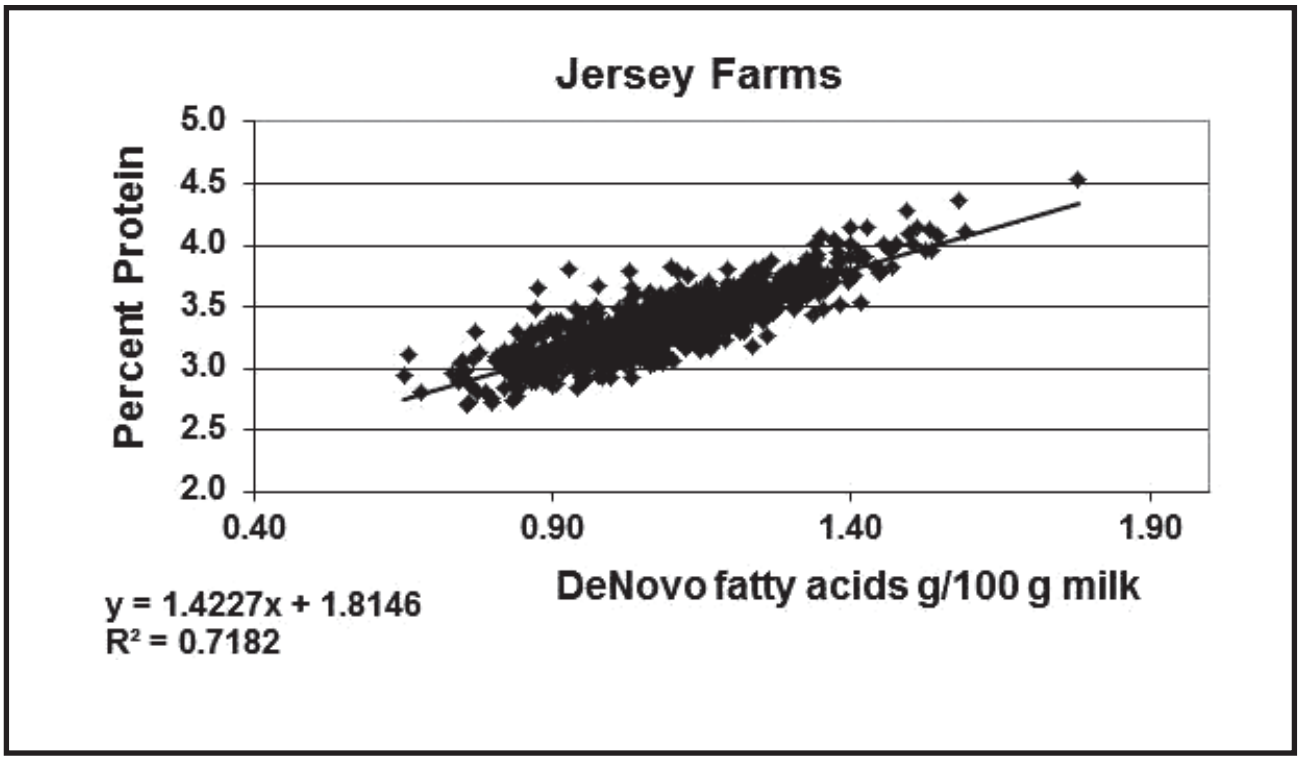

Figure 2a. Percent true protein in the bulk tank milk plotted as a function of de novo fatty acids (grams per 100 grams of milk) for Jersey farms.

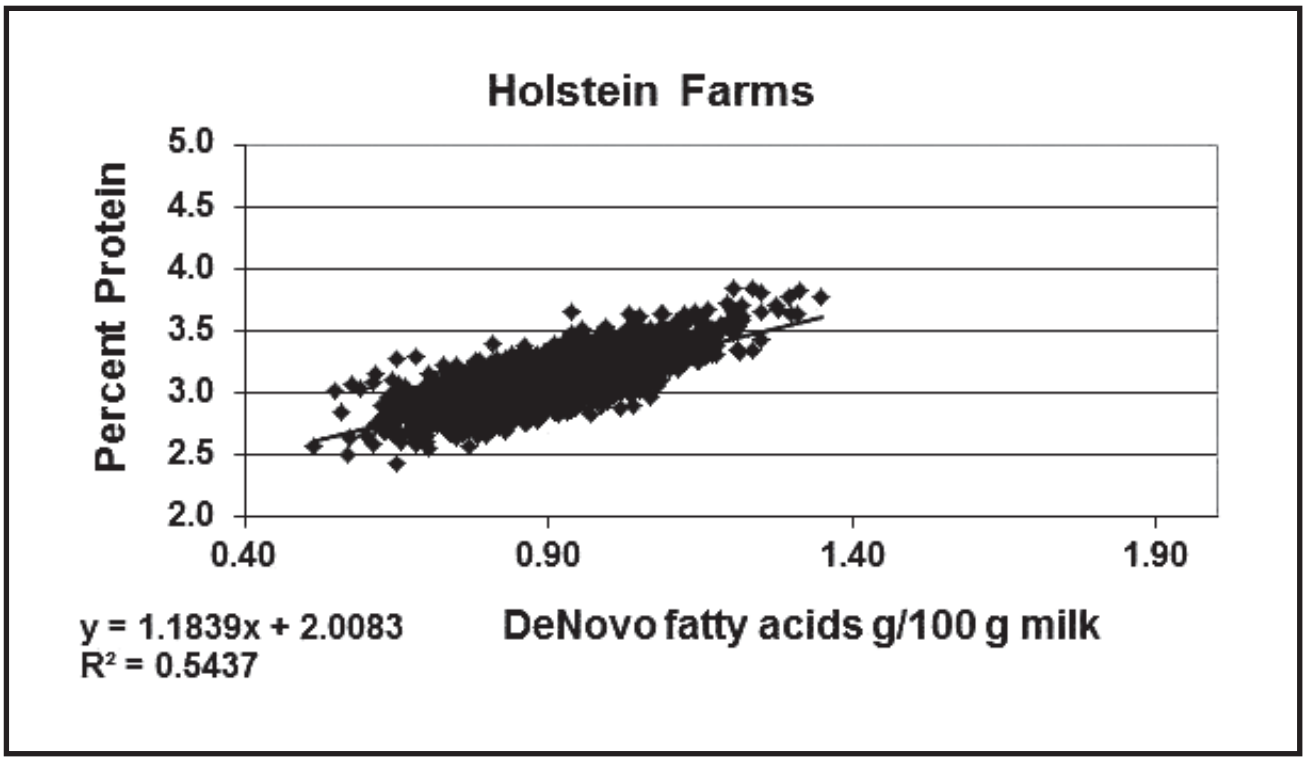

Figure 2b. Percent true protein in the bulk tank milk plotted as a function of de novo fatty acids (grams per 100 grams of milk) for Holstein farms.

Influence of Microbial Ecology in the Rumen and Lower Gut on Production Efficiency of Dairy Cows

Gregory B. Penner[1]
Department of Animal and Poultry Science
University of Saskatchewan

Introduction

From a classical nutrition perspective, the ruminal microbes have been recognized as a critical component for the success of feeding programs for dairy cows. Generally, the relationship between dairy cattle and the microbial community inhabiting their gastrointestinal tract (**GIT**) has been referred to as a symbiotic relationship where both the cow and microbial community provide benefits for each other. The cow provides a regular supply of fermentable material, maintains an anaerobic environment, regulates osmolality and ruminal pH, and removes end products of fermentation that could be inhibitory to microbes, such as volatile fatty acids (**VFA**). In return, the microbes digest feed that would otherwise be indigestible, provide a source of energy as VFA, provide a source of vitamins, convert non-protein nitrogen into protein, and are the primary source of metabolizable protein. Despite the known importance of the microbiome, modeling their activity and outcomes on production remains a challenge.

Perhaps part of the challenge with modeling the activity of the microbial community is related to its complexity. It is currently estimated that over 5000 species inhabit the GIT (Henderson et al., 2015). In addition, the relationship between the cow and microbes is much more complex than described above. In fact, recent research has demonstrated that the host animal and its microbial inhabitants communicate with each other (Thomas and Versalovic, 2010) and that specific microbes might be critical for the development of the host immune system (Chung et al., 2012). A challenge in the field of dairy nutrition and physiology is that past research has largely focused on the ruminal microbiome, thereby ignoring more distal regions. Obviously, this presents a challenge when trying to extrapolate results from monogastric species to applicable approaches for dairy cattle. Reasons to focus on the ruminal microbiome are numerous and include, among other things, the importance of the ruminal microbial community for fermentation of feed, large capacity and high diversity of the ruminal microbial community, and ease of access for sampling. However, as demonstrated for monogastric species, the microbial community structure of the intestinal tract may have critical roles in the health and productivity of cattle.

An Overview of Microbial Colonization of the GIT

While a detailed description of the microbial community structure across the GIT of cattle is out of scope for this paper, it is important to understand some of the characteristic changes that occur among regions and how the microbial communities are established. Firstly, our

[1]Contact at: AGRIC 6D18, 51 Campus Drive, Saskatoon, Saskatchewan, Canada, S7N 5A8, (306) 966-4219, Email: greg.penner@usask.ca.

knowledge of the microbial community structure has increased dramatically with the advancement of culture-independent methods. Culture-independent methods allow researchers to use highly conserved regions of the bacterial genetic information (DNA and RNA) to evaluate what species are present, and with in-depth techniques, researchers can also get an understanding of the activity that those species may have. To identify species, researchers cluster the genetic sequence and assume that sequences with more than 97% similarity represent the same species. Rather than stating the number of species (as errors can occur), the term 'operational taxonomic unit' (**OTU**) is used (Khafipour et al., 2016). In a recent study (Henderson et al., 2015) comparing the ruminal microbial inhabitants from a broad group of ruminant and camelids with samples coming world-wide, they identified that Prevotella, Butyrivibrio, Ruminococcus, Lachnospiraceae, Ruminococcaceae, Bacteroidales, and Clostridiales were the dominant genus. Interestingly, only 35% of the OTU were named species or species awaiting a name, and most of these groups have not been cultured. The low proportion of identified species, let alone a lack of characterization of their activity, highlights the need for more research in this area.

Establishment of the GIT microflora begins with the onset of calving. While there is no clear consensus on the dominant species inhabiting the GIT of calves, it is evident that age-dependent changes occur along with differences in the dominant genera among regions of the GIT (Malmuthuge et al., 2014, 2015). Differences in dominant species among studies may be due to the environment, milk and solid feed composition, and genetics. In general, the abundant genera in the rumen were Streptococcus, Bacteroidetes, and Prevotella within 12 h of birth, with the abundance of Firmicutes and Bacteroidetes increasing while Proteobacteria decreases with advancing age. Interestingly, in the small intestine, Lactobacillus, Bifidobacterium, E. coli, and Streptococcus were dominant, while the large intestine followed patterns reported for the rumen. The similarity for the major inhabitants of the forestomach and hind-gut regions of the GIT are perhaps not surprising given that microbes in both regions have extensive fermentation activity. Moreover, as this research was conducted initially with suckling calves, differences in the microbial community structure due to changes in nutrient supply are likely causative. Regardless of the individual species, all studies support the notion that the ruminal community adapts in a sequential approach to become more similar to a mature ruminant, but that the exact composition may affect on many factors (Li et al., 2012; Rey et al., 2014; Malmuthuge et al., 2015). In addition to the changes in composition, there is a reduction in the microbial density from the reticulo-rumen to the small intestine, with density increasing again in the large intestine (Mao et al., 2015). The change in the microbial community towards that found in mature ruminants questions whether accelerating this microbial colonization pattern would have beneficial effects on the host and provide the means necessary to ensure colonization with a stable and diverse microbial community structure is achieved.

In addition to age-related responses, dietary change induces alterations of the microbial community structure. Mohammed et al. (2012) evaluated changes in the microbial community structure as primiparous heifers transitioned from the far-off dry period into the close-up dry period, and finally into lactation. They noted that there was marked variability for the changes in the microbial community among cows where the microbial community structure was resistant for some cows and variable for others. They found that variability

in the microbial community structure was not associated with ruminal acidosis post-partum. The variability in the resilience of the microbial community to tolerate dietary changes is puzzling and poses a challenge when designing strategies to manipulate the microbial community structure.

Although not dairy focused, Petri et al. (2013a) evaluated how the microbial community structure as beef heifers were transitioned to a high-grain finishing diet. That study demonstrated a reduction in Butyrivibrio and an increase in Prevotella. Interestingly, there was a core group of microbes that were present, including the Bacteroidetes, Firmicutes, and Proteobacteria (Petri et al., 2013b). This core microbiome fits with that found in a much larger study by Henderson et al. (2015). The identification of a core microbiome common within an animal even with diets that differ in the forage-to-concentrate ratio (initial was 95% forage, final was 9% forage) suggests that part of the microbial community may be essential or perhaps are robust enough to adapt to differing dietary scenarios and can resist change.

Stability of the Microbiome: A Case for Host-Microbe Regulation

There is no doubt that diet can influence the microbial community structure within the gastrointestinal tract (Petri et al., 2013ab; Mohammed et al., 2012; Khafipour et al., 2016). However, there are a number of studies suggesting that the microbial community, at least the core community, is relatively stable within individual cattle. Initial evidence for a stable microbial community has been provided by Weimer et al. (2010). In that study, dairy cows fed the same diet were selected based on differences in the microbial community structure using automated ribosomal intergenic spacer analysis (**ARISA**). The ARISA allows for a general identification of the microbial community structure. To test whether the microbial community structure was specific for each cow, ruminal digesta were manually evacuated from each cow and the digesta were swapped (i.e. digesta from 1 cow was placed in the rumen of another and vice versa). The microbial community structure was then evaluated over time to determine if change in the composition occurred within a 65-day period. The results of this study were interesting. Firstly, cows with differing microbial community structures also had differing ruminal conditions (pH and VFA concentration), even when fed the same diet. Following the introduction of ruminal digesta from the other cow, the microbial community and ruminal conditions were similar to the donor. However, after a period of 65-days, the microbial community profile and ruminal fermentation conditions again resembled that which occurred prior to the ruminal digesta swap. Other studies have also suggested that the microbial community structure is more similar for an individual cow measured over time and when fed diets that differed than between cows when fed the same diet (Li et al., 2010; Petri et al., 2013a,b). Collectively, these studies suggest that the rumen microbial community structure appears to be specific for each cow, although modest changes relative to the original community structure can occur when major perturbations are imposed. The data also provided some initial evidence in dairy cattle that there may be some form of communication between the cow and their resident microbes.

The existence of communication mechanisms between the host and the microbes is not a new concept; however, its application for production animals is novel. Mechanisms for communication are not fully elucidated but include luminal nutrient sensing and the direct impacts that byproducts of microbial fermentation have on the host. A good example of

this are free fatty acid receptors that detect VFA. Moreover, VFA (particularly butyrate) promotes proliferation of the ruminal epithelium and other GIT tissues, with changes in hormones likely mediating the response (Penner et al., 2011). In addition to luminal nutrient sensing, the GIT has receptors that can detect bacteria or fragments of bacteria, protozoa, and fungi (Ishii et al., 2008). When these receptors are stimulated, an immune response can be initiated. The intestinal regions of the GIT also secretes antimicrobial proteins and mucus that help to control the microbial community structure. It is not clear whether antimicrobial proteins are released from the rumen, although a recent report has suggested that there may be the release of immune-related compounds, such as tumor-necrosis factor alpha, interferon gamma, and leukocytes (Trevisi et al., 2014). Sensing and control of the microbial community is essential to limit the transfer of pathogenic organisms across the GIT, create tolerance for commensal microflora thereby reducing the risk for chronic inflammation, and helping to activate an immune response when needed. In addition, it is likely that a combination of luminal sensing and the secretion of antimicrobial proteins helps to explain why cows have differences and resilience to change for the microbial community structure.

Modifying the Microbial Community: Applicability to Dairy Production and Efficiency

Is there a need to manipulate the microbial community structure? The necessity or motivation to manipulate the microbial community structure assumes that there may be an ideal microbial community or at least part of a community that would be beneficial for the health or production efficiency. To date, there is no work that conclusively proves there is a beneficial microbial community structure; however, there are associations between desirable production parameters and the microbial community structure. Jami et al. (2014) evaluated the microbial community profile in 15 primiparous heifers at the same physiological state. As with other studies, they demonstrated that although cows were fed similar diets, there was substantial variability in the microbial community structure among heifers. Then they compared indicators of the microbial community structure with production characteristics. The first variable they examined was the Firmicutes:Bacteriodetes ratio, and they reported a positive association with milk fat yield (R^2 = 0.51). Abundance of the phyla Actinobacteria was positively related to milk, fat, and lactose yields, and Bacteroidetes was negatively associated with residual feed intake and milk fat yield. While they were able to detect positive and negative associations with some genera, many of the correlations were weak. Regardless, this is the first study to report that the microbial community profile may be associated with production outcomes in dairy cattle. Research is needed to verify whether similar relationships can be detected in a broader population and whether attempts to manipulate the ruminal microbial community structure can improve production outcomes.

Altering early microbial community establishment

As mentioned above, once established it appears that, at least part, of the microbiome is stable (Weimer et al., 2010; Petri et al., 2013a,b). This presents a challenge when it may be desirable to manipulate the microbial community structure. Given that the microbial community structure in calves is being established, early postnatal exposure may be a practical time point when the microbial community of the GIT could be modified. It may be important to consider inoculation strategies that promote diversity of the microbial community as

diversity is considered an essential component and that diversity increases with advancing age (Oikonomou et al., 2013; Jami et al., 2014; Malmuthuge et al., 2015). Calves with less microbial diversity assessed in fecal samples were also associated with greater incidence rates for diarrhea and pneumonia (Oikonomou et al., 2013). These findings are possible as establishment of the GIT microflora also stimulates development of the immune system (Ishii et al., 2008) and may help calves face immune challenges beyond that localized to the GIT.

Development of strategies to manipulate the microbial community structure should include a range of microbes considered to be beneficial in mature dairy cattle, especially when this approach is used to promote GIT development, an issue of importance for calves. Species specificity may be a critical factor in the selection of microbes to promote or support GIT function. One study conducted using sterile mice evaluated the effect of inoculating the mice with microbes from mice, microbes from humans, or microbes from rats (Chung et al., 2012). They found that the effect of donor source (mice vs. human vs. rat) had a major effect on development of the gastrointestinal tract in terms of immune system development and establishment of the microflora. Only mice inoculated with microbes from mice had an immune system that was considered to develop normally, while those inoculated with microbes from human or rat microflora had immature GIT development. While species dependency has not been confirmed in cattle, these data may suggest that strategies to promote GIT development by improving the microbial community structure should consider a diverse microbial profile and incorporate microbial species that are components of the core microbiome. Unfortunately, this area has received very little research attention to date.

Finally, there is a consensus that diversity of the microbial community structure is an important feature of a healthy microbial community (Heiman and Greenway, 2016). Antimicrobial treatment, to treat infection, has been shown to modify the microbial community structure, providing a situation post-treatment which may further challenge the host (Oh et al., 2016). This may be a particular challenge with in-feed antimicrobial use but still may be relevant with injectable administration routes (Zhang et al., 2013). While providing in-feed antimicrobials is not an approved practice for lactating dairy cattle, there are times when calves could consume antibiotics if they are consuming waste milk. Antibiotic feeding reduces the microbial diversity (Oh et al., 2016) in the GIT and may result in the establishment of an undesirable microbial community. Under such a scenario, it may be beneficial to develop strategies to facilitate establishment of a stable microbial community structure.

Conclusions

The microbial community helps to support feed digestion and provides essential nutrients for dairy cattle. The role of the microbial community structure needs to be expanded to consider its role to support GIT development and immune system tolerance and development. It is clear that individual cows have a distinct microbial community and that similarities in the microbial community can be detected within cows across diets and among cows. These key groups are considered to be the core microbiome, and there appears to be an association between the abundance of key genera and important production outcomes, such as the yields of milk and fat. While it may be beneficial to manipulate the microbial community composition, communication between the microbes and host may provide a resistance to such manipulation. However,

the post-natal period for calves or following antimicrobial therapy may be two key time points for when the composition of the microflora could be manipulated. Manipulations should include a broad spectrum of microbial genera specific to the production setting. Future research is needed to confirm whether strategies to manipulate the microbial community structure result in positive benefits to the health, development, and productivity of dairy cattle.

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Assessment of Feeding Management in the National Dairy FARM Program

Jessica A. Pempek[1]
Department of Veterinary Preventive Medicine
The Ohio State University

Abstract

A number of animal welfare assurance programs have been developed in recent years to encourage the adoption of welfare standards across food animal industries and to assure the public that these standards are being followed. In contrast to the European Union, the United States has relied less on legislative action and has instead focused on the creation of retailer- and industry-driven audits and assessment programs to meet public expectations about animal welfare. An animal welfare assessment program used in the dairy industry is The National Dairy FARM Animal Care Program: Farmers Assuring Responsible Management. The mission of this Program is to provide assurance to consumers and members of the public that the dairy industry is committed to the use of best management practices to promote the highest level of animal care (www.nationaldairyfarm). The FARM Program provides evidence-based standards for various aspects of animal care and highlights the importance of proper feeding management practices to promote continuous improvement of the welfare of dairy animals. Feeding management of all animal groups is assessed using both animal-based measures (e.g., measurements taken directly from the animal, such as body condition score) and resource-based measures (e.g., measurements taken from the environment or management of the animal, such as milk quantity for pre-weaned heifers, feed bunk space allowance for growing and adult animals, etc.). The purpose of this paper is to: 1) provide an overview of the FARM Program; 2) discuss the Program's evaluation of feeding management practices; and 3) review the supporting scientific literature.

Introduction

Animal welfare is a key social concern that must be addressed to safeguard the future viability of the dairy industry (von Keyserlingk et al., 2013). Compared to the European Union, the United States has minimal federal regulations for animal welfare; instead, food retailers and industry leaders have created animal welfare audits and assessment programs to assure consumers that animals raised for food have a good quality of life (Mench, 2003). To be sustainable, such audits and assessment programs must be evidence-based and reflect the shared values of relevant stakeholders.

The National Dairy FARM Animal Care Program

An animal welfare assessment program used by the U.S. dairy industry is The National Dairy FARM Animal Care Program: Farmers Assuring Responsible Management. The FARM Program was created in 2009 by the National Milk Producers Federation with the support of Dairy Management Incorporated™ to bolster

[1]Contact at: A100E Sisson Hall, 1920 Coffey Road, Columbus, OH 43210, (740) 312-9311, Email: pempek.4@osu.edu.

consumer confidence and demonstrate the dairy industry's commitment to animal care. The Program is an animal welfare assurance program that promotes a continuous improvement process to encourage the participation of dairy producers nationwide. According to the FARM Program, their basic standards and guidelines are evidence-based and incorporate the views of various stakeholder groups, as the Program's Technical Writing Group is comprised of animal welfare scientists, veterinarians, cooperative members, and dairy producers (NMPF, 2015). Further, the Program incorporates the use of third-party verification (e.g., external evaluations conducted by trained individuals who do not have a conflict of interest with the operation or the outcome of the program) to promote social confidence and document the integrity of the Program's animal care standards and their on-going evaluation.

FARM Assessment of Feeding Management

The criteria for assessing animal welfare are generally divided into those that describe the physical environment and resources available to the animal (resource-based measures) and those that describe the state of the animal (animal-based measures; Mench, 2003). The FARM Program includes animal- and resource-based measures of welfare throughout their animal care standards and guidelines, as they pertain to: 1) nutrition, 2) animal health, 3) environment and facilities, 4) animal handling, movement, and transportation, and 5) special needs animals. This paper will focus on the nutritional component of the FARM Program for newborn and milk-fed dairy calves, growing heifers, and cows.

Evaluation procedure

After a dairy producer (e.g., individual producer, cooperative member) has shown interest in the FARM Program, the evaluator will contact the producer and schedule a date to conduct the on-farm evaluation. On the day of the evaluation, evaluators will first conduct a short 'entrance interview' with the producer to communicate the goals of the Program and provide an overview of the evaluation procedure. Evaluators will then use the Management Checklists provided in the Animal Care Reference Manual to conduct the site evaluation and complete animal observations (NMPF, 2013). After the evaluation is complete, evaluators review their findings, calculate observation numbers, and meet with the producer for a 'closing meeting' to discuss strengths of the operation and review areas of improvement, if necessary.

Animal-Based Measures of Nutrition

Body condition score

A direct method for assessing feeding management practices on-farm is to evaluate the condition of animals. A body condition score (**BCS**) is an assessment of the proportion of body fat an animal possesses and has been recognized by animal scientists and dairy producers as a means to assess feeding management practices (Roche et al., 2009). The FARM Program assigns BCS (1 = thin to 5 = fat; whole point increments) based on visual appraisal of the animal. Extreme BCS (either too thin or too fat) reflects an increased risk of compromised animal welfare (e.g., Roche et al., 2009). Emaciation increases the animal's risk of mild or severe lameness (Randall et al., 2015), and lower calving BCS is associated with reduced production (Waltner et al., 1993) and reproduction (e.g., Heuer et al., 1999). The FARM Program requires dairy producers to take corrective action for animals that receive a BCS score of 1. The Program goal for BCS in a herd is that 99% or more of all classes of animals score 2 or more.

Overconditioning predisposes cows to increased risk of periparturient metabolic disorders (ketosis: Gillund et al., 2001; milk fever: Roche and Berry, 2006; displaced abomasum: Dyk, 1995) and impaired reproduction (Roche et al., 2007). Further, BCS is negatively associated with DMI, particularly during the transition period (Roche et al., 2008). Although overconditioning is not directly assessed per the FARM Program, evaluators should consider the nutritional consequences of both BCS extremes. If necessary, high BCS can be scored separately from low BCS and discussed with the dairy producer during the closing meeting.

Resource-based Measures of Nutrition

Newborn and milk-fed dairy calves

The FARM Program considers a number of resource-based measures of feeding management practices on-farm. To provide clarity, the Program's assessment questions will first be provided, followed by a brief review of the supporting scientific literature.

Do "*all calves receive colostrum or colostrum replacer soon after birth, even if transported off the farm*" (NMPF, 2013, p. 15)? Colostrum management directly influences calf health and survival (Godden, 2008). During the on-farm data collection portion of the assessment, FARM Program evaluators are trained to look for evidence of proper colostrum management (e.g., written standard operating procedures, colostrometer, Brix refractometer, etc.). Components of a successful colostrum management program include: 1) calves should ingest their first meal of colostrum within 6 hr of birth; 2) colostrum should be of high quality (IgG concentration greater than 50 g/L); and 3) calves should receive 4 qt (or 10 % body weight (**BW**), whichever is greater) of high quality colostrum within 12 hr of birth (Davis and Drackley, 1998). Dairy producers are also encouraged to work with their veterinarian to measure prevalence of failure of passive transfer (**FPT**) to assess colostrum management practices; calves are defined as having FPT if serum IgG concentration is <10 g/L when sampled between 24 and 48 hr of birth (Quigley, 2004).

Do "*calves receive a volume and quality of milk or milk replacer to maintain health, growth, and vigor until weaned or marketed*" (NMPF, 2013, p. 15)? The FARM Program emphasizes the benefits of increased milk allowance for calves during the pre-weaning period. Per the Program's Animal Care Reference Manual (2013, p. 15), "Feeding only four quarts per day of milk or milk replacer equivalent does not allow the calf to meet its nutritional requirements for maintenance, growth and development." Holstein calves ingest 10.6 qt or more of whole milk per day when offered ad libitum (Jasper and Weary, 2002; von Keyserlingk et al., 2004), approximately twice the conventional milk allowance of 10% BW (Drackley, 2008). As a result of higher milk intake, ad libitum-fed calves have higher pre-weaning (0 to 36 d of age) average daily gain (**ADG**) compared to calves fed 5.3 qt/day (1.72 versus 1.06 ± 0.11 lb/day, respectively; Jasper and Weary, 2002). Similar weight gains have also been reported in calves fed milk ad libitum versus 10% BW (Appleby et al., 2001) and calves fed 20 versus 10% BW (Khan et al., 2007). Further, increased growth rates early in life have been associated with long-term benefits, such as reduced calving age (Raeth-Knight et al., 2009) and higher first-lactation milk yield (Soberon et al., 2012).

Providing calves more milk may reduce calf-starter grain intake during the pre-weaning period (Jasper and Weary, 2002). Fortunately, research continues to investigate methods of stimulating solid food intake pre-weaning to

reduce potential growth post-weaning (Khan et al., 2007; de Passillé et al., 2011; Khan et al., 2011). For instance, a feeding program where calves were initially offered a high milk allowance (20% BW) during the first 25 days of life gradually diluted milk with water (10% of volume/feeding) until a milk-feeding rate of 10% BW was achieved (day 26 to 30), thus calves were a low milk allowance (10% BW) in the weeks before weaning. This step-down milk-feeding program increased starter grain and hay intake and allowed calves to be weaned without experiencing a growth lag (Khan et al., 2007). Other approaches to increasing starter intake pre-weaning include group housing with calves of similar age (De Paula Vieira et al., 2010) or with older animals (De Paula Vieira et al., 2012).

Are "*calves offered fresh, palatable starter feed"? Do "calves have access to palatable, clean, fresh water as necessary to maintain proper hydration*" (NMPF, 2013, p. 15)? Although starter and water consumption are not directly assessed per the FARM Program, it is important for evaluators to ensure farms are offering ad libitum starter grain from the first week of life (Drackley, 2008). Evaluators should also examine feeding management protocols and confirm that farms are in compliance with standard operating procedures (**SOP**); for instance, if an SOP states that calves receive starter grain from 3 days of age, evaluators should verify that all calves 3 days of age or older have access to starter grain.

Growing heifers and cows

Do "*rations provide the required nutrients for maintenance, growth, health, and lactation for the appropriate physiological life stage*" (NMPF, 2013, p. 18)? Proper feeding management is necessary to ensure the health and welfare of all dairy animals, and promoting dry matter intake (**DMI**) to support milk production is the cornerstone of successful dairying (NRC, 2001). The FARM Program encourages consultation with a qualified nutritionist to assist with ration formulation. Evaluators for the Program are encouraged to ask producers if they have an existing relationship with a nutritional consultant, how often they meet, etc. to provide evidence for the answer to this question during the evaluation.

Is "*sufficient feed bunk space provided that allows all animals to feed at the same time"? Are "sufficient quantities of feed available for all animals during a 24 hr period*" (NMPF, 2013, p. 18)? A majority of the literature investigates how changes in nutrient composition impacts DMI; yet, accessibility of feed (e.g., stocking density, feed distribution, etc.,) may be more important than actual amounts of nutrients provided (Grant and Albright, 1995; Grant and Albright, 2001). Thus, the FARM Program guidelines focus on the animal's ability to gain access to the feed bunk. Current industry-recommended best practices with regard to feed bunk space allowance for growing heifers 6-to-12, 12-to-18, and over 18 mo of age is 18, 20, and 24 in of linear feeding space/heifer, respectively (Dairy Calf & Heifer Association, 2010). For lactating cows housed in a freestall barn, at least 24 in of linear feeding space/cow (e.g., 1 headlock/cow) should be provided (Grant and Albright, 2001), and 30 in/cow is currently recommended for dry cows (Nordlund et al., 2006).

Although such recommendations have traditionally been considered adequate, total daily feeding time increases as feed bunk space allowance increases, especially during peak feeding times (e.g., from 25 to 36 in/cow; DeVries and von Keyserlingk, 2005). Cows are highly motivated to access freshly delivered feed (DeVries and von Keyserlingk, 2005). When feeding space is reduced, some cows

may be unable to eat when fresh total mixed ration (**TMR**) is delivered, which consequently shifts feeding time. Cows frequently sort TMR, which reduces feed quality throughout the day (DeVries et al., 2005). Therefore, cows forced to delay feeding due to overstocking may consume a poorer quality diet and be unable to meet their nutritional demands for milk production.

Reduced access to feed increases aggressive interactions and competitive displacements (i.e., an instigated displacement resulting in the complete withdrawal of another animal from the feed bunk) (DeVries and von Keyserlingk, 2006; Huzzey et al., 2006; Proudfoot et al., 2009), which has physiological consequences (Huzzey et al., 2012a, Huzzey et al., 2012b). Overstocking (dry cows: 1 freestall/2 cows and 13.6 in feed bunk space/ cow) increases plasma nonesterified fatty acid (**NEFA**) concentrations and tends to increase fecal cortisol metabolite concentrations (Huzzey et al., 2012b). Cattle with lower displacement indices (e.g., cows that are frequently displaced but have difficulty displacing others) also have the highest (fastest) feeding rates (Proudfoot et al., 2009) and greatest physiological response to the stressor (Huzzey et al., 2012a). Thus, providing increased feeding space improves access to feed and reduces competition at the feed bunk, particularly for subordinate animals (e.g., often heifers).

Action Plan

After the completion of the animal care evaluation, a written Action Plan is developed if improvement is necessary. Action Plans: 1) identify opportunities for improving animal care; 2) facilitate the specific actions needed to implement improvement; and 3) provide a schedule and date for completion. For example, if only 95% of the animals scored 2 or more for BCS in a specific herd, the producer would need to implement an Action Plan to improve individual- and herd-level BCS. The FARM Program recommends that the development of Action Plans should be a collaborative effort between the dairy producer, the evaluator, and the herd veterinarian. It is the responsibility of the FARM Program evaluator to determine whether a follow-up evaluation is necessary to assess improvement.

Conclusions

The mission of The National Dairy FARM Animal Care Program is to provide assurance to consumers that the dairy industry is committed to the highest level of animal care. The Program assesses feeding management of all animal groups through the evaluation of animal- (e.g., BCS) and resource-based measures (e.g., colostrum quality and quantity, feed bunk space allowance, etc). Action Plans are created to improve specific aspects of animal care and continuously improve the welfare of dairy animals in the U.S.

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Role of Dairy Cattle in Converting Feed to Food

Juan M. Tricarico[1]
Innovation Center for U.S. Dairy[1]

Abstract

The net contributions dairy cows make to the food system in the United States are not necessarily well understood by consumers. Estimates of nutrient conversion efficiency are sometimes used to describe these contributions but are often poorly documented or based on dubious assumptions. The main objectives of the first study were to: 1) define coefficients to calculate human-edible fractions of major dairy feed ingredients used in the United States, and 2) estimate the share of the dairy ration that is human-edible on a national level using these coefficients. The analysis was performed on a national average dairy ration computed from 350 farm surveys used in the carbon footprint life cycle assessment for fluid milk. The national average ration includes weighed rations for calves, open heifers, bred heifers, first-calf heifers, springers, lactating cows, and dry cows, and accounts for forage grazed during the year. The national average ration includes 33 ingredients and contains 53% forage and 47% concentrate (DM basis). Food, fuel, and fiber industry by-products (14 ingredients) account for 19% of dairy feed DM. Eight major crops account for 80% of dairy feed DM (corn 42%, alfalfa 22%, wheat 3.1%, soybean 3.0%, canola 1.8%, sorghum 1.7%, barley 1.4%, and cottonseed 1.4%). Two coefficients were calculated to estimate human-edible fractions of each ingredient. The composition coefficient was calculated as 1 minus NDF content (except for cottonseed where oil content was used). The non-NDF fraction was considered human-edible if it does not contain toxic compounds, and ingredients containing more than 30% NDF were excluded. The demand coefficient was calculated by multiplying the first coefficient by the proportion of total ingredient production currently demanded by the U.S. food industry. This coefficient incorporates current consumer demand, preferences, and eating habits.The amount of human-edible dairy feed is either 20 or 2.2% of ration DM when using composition and demand coefficients, respectively. Dairy cows make a net positive contribution to food supply in the United States by converting significant amounts of otherwise unusable plant matter in feed into food.

Introduction

The net contributions dairy cows make to the food system in the United States are not necessarily well understood by consumers. The belief that dairy cattle compete directly with humans for food is based on the misperception that dairy feed and human food are interchangeable. In addition, estimates of nutrient conversion efficiency are sometimes used to describe dairy cattle as inefficient. However, these estimates often rely on dubious assumptions, poorly documented coefficients, and ignore the ability of dairy cattle to convert human-inedible plant matter into nutritious dairy products.

[1]Contact at: 10255 W. Higgins Road, Suite 900, Rosemont, IL 60018-5616, (847) 627-3721, Email: Juan.Tricarico@dairy.org.

Descriptive Analysis of How Dairy Cows Convert Feed into Food in the United States

This study evaluated the feed ingredients consumed by dairy cattle in the United States with the goal of determining the portion of dairy feed that could be potentially consumed directly by humans. To provide a better understanding of the extent dairy contributes to or detracts from the current food supply in the United States, this study focused on the following objectives:

1. Define composition and demand coefficients to calculate human-edible fractions of major dairy feed ingredients used in the United States, and
2. Estimate the share of the dairy ration that is human-edible on a national level using these coefficients and supply and demand analysis of the crops from which these ingredients originate.

Definition of composition and demand coefficients

The descriptive analysis was performed on a national average dairy ration computed from 350 farm surveys conducted for the life cycle assessment study on greenhouse gas emissions from production of fluid milk in the U.S. (Thoma et al., 2013). The national average ration includes weighed rations for calves, open heifers, bred heifers, first-calf heifers, springers, lactating cows, and dry cows, and accounts for forage grazed during the year.

It became clear early in the analysis that although some dairy feed ingredients can be used directly in human food products, their current demand by U.S. consumers can be very small or they are not economically viable substitutes for current foodstuffs. Therefore, 2 distinct coefficients were developed to describe the human-edible fractions of dairy feed ingredients based either on their chemical composition or U.S. food industry demand.

The *Composition Coefficient* was calculated to define human-edible fractions based on chemical composition as: ***1-NDF content*** (with one exception; see cottonseed below). The composition coefficient excludes NDF because humans cannot digest and extract nutrients from fiber – the non-NDF fraction was considered human-edible if it does not contain toxic compounds. The oil content was used to calculate the composition coefficient for cottonseed instead of 1-NDF content because cottonseed contains the toxic compound gossypol but its oil is human-edible. The composition coefficients for ingredients containing more than 30% NDF which were set to zero because they were considered unsuitable for human consumption.

The *Demand Coefficient* was calculated to define human-edible fractions based on the United States food industry demand for that ingredient as: ***composition coefficient x percent food use of total domestic use***. Percent food use of total domestic use for corn grain and barley were calculated by dividing the food use by the total domestic use from USDA supply and disappearance balance sheets averaged over the 5-year period from 2009 to 2014. Percent food use of total domestic use for cottonseed was obtained from the National Cottonseed Products Association. The demand coefficient adjusts the composition coefficient by current demand for that ingredient by the United States food industry and reflects the food industry's response to current consumer preferences and eating habits.

Composition and demand coefficients were not calculated for protein mix, supplement, grain mix, partial mix ration, and miscellaneous because they represent mixes with variable

and uncertain composition (these 5 ingredients account for 14% of diet DM). Composition and demand coefficients were not calculated for soy hulls, molasses, whole roasted soybeans, hominy, beet pulp, sorghum grain, and whey because their inclusion rates are less than 1% and would have only a negligible impact on the human-edible portion of the national average dairy ration (these 7 ingredients account for 3% of diet DM).

Composition of the national average dairy diet

The national average dairy diet includes 33 ingredients. Ten ingredients are forages that account for 53% of diet DM, and 23 ingredients are concentrates that account for 47% of diet DM (Figure 1). The national average dairy diet also includes 14 by-products from the food, fuel, and fiber industries that account for 19% of diet DM (Figure 1). Only 1 by-product (wheat straw) is considered a forage while the other 13 by-products are considered concentrates, even though they may contain considerable amounts of NDF (Figure 1).

Eight major crops account for the 80% of the national average dairy diet DM (Figure 2). Supply and demand analysis indicates that dairy feed primarily demands corn and alfalfa (Figure 2), while the human food industry primarily demands wheat, oilseeds, and barley (Figure 3).

Human-edible fraction of the national average dairy diet by composition

Composition coefficients were defined as zero for 13 ingredients representing 56% of diet DM because they contain more than 30% NDF and are unsuitable for consumption as food by humans (corn silage, alfalfa silage, wheat silage, sorghum silage, oat silage, alfalfa hay, oat hay, grass hay, wheat straw, pasture, citrus pulp, almond hulls, and cotton gin trash).

No forage crops (i.e., silage, hay, straw, and pasture) were considered suitable for human consumption. This is due to the difference between the human digestive system and the ruminant digestive systems of cattle, sheep, and goats. A large portion of the energy in forage crops is in the forms of cellulose or hemicellulose, which "are inefficiently digested by monogastrics and are not digestible by man" (CAST, 2013). Silage crops include corn silage, alfalfa silage, wheat silage, sorghum silage, and oat silage. Altogether, these feed ingredients account for 36.8% of the DM in the national average dairy diet. Corn silage represents 22.4% of dietary DM and is by far the largest single contributor to the national average dairy diet. Wilkinson (2011) specifically addressed the use of corn silage for human consumption, stating "the maize hybrids grown for silage are different to those grown for sweet corn [hybrids demanded by the food industry] and no part of the plant is considered suitable for human consumption." Citrus pulp, almond hulls, and cotton gin trash are by-products of the citrus, almond, and cotton processing industries, respectively. None of these ingredients are fit for human consumption, but ruminants are able to eat, digest, and turn them into animal-derived food products suitable for human consumption. Dairy cattle therefore offer a way to turn plants and plant by-products unsuitable for human direct consumption into nutritious dairy and meat products.

Composition coefficients were calculated for 8 dairy feed ingredients that originate from 5 crops and represent 26.3% of the national average dairy diet DM (Table 1). These ingredients include grain corn, high moisture corn grain, distiller's grains, corn gluten feed, cottonseed, soybean meal, canola meal, and barley. *Twenty percent of dairy feed is human-edible by composition* according to this analysis (Table 1).

Human-edible fraction of the national average dairy diet by U.S. food industry demand

Demand coefficients were defined as zero for distiller's grains, high moisture corn grain, corn gluten free, soybean meal, and canola meal (Table 1). Distiller's grains are primarily produced from corn in the U.S. and is a by-product of the ethanol industry. Distiller's grains contain fiber and protein that remains after the starch has been converted to ethanol. Although distiller's grains can be blended with wheat flour and used in baked goods, the U.S. food industry does not demand any distiller's grains, except for minute quantities used in novelty and research baked goods to show proof of concept. High moisture corn kernels are harvested at 24% or greater moisture before fermenting and storing in a silo to use as livestock feed. The high moisture content makes transporting, keeping it insect and mold free, and ultimately drying high moisture corn prohibitively expensive. Therefore, it is unlikely that the U.S. food industry would ever demand high moisture corn grain for processing into food products fit for human consumption. Corn gluten feed is a by-product of industrial corn milling operations and contains protein and fiber. Corn gluten feed is not demanded by the U.S. food industry due to its fiber content and strong fermented taste. In addition to animal feed, corn gluten meal is used as a soil amendment and pesticide. Soybean and canola meals are co-products of the oilseed crushing industry. After crushing, the oil is primarily used in the food sector as a component of vegetable oil and the meal is used as a source of protein in livestock feed. Soybean and canola meals are not included in human food products and therefore are not demanded by the U.S. food industry.

Demand coefficients were calculated for corn grain, cottonseed, and barley (Table 1) by multiplying percent food use of total domestic use by the corresponding composition coefficient. Corn grain can be used in human food products after milling and conversion to high-fructose corn syrup, glucose and dextrose (sweeteners), starch, beverage alcohol, and cereals. Food use for corn grain was calculated by summing domestic use values for those food products (Table 2). Starch and alcohol for beverages and manufacturing were included in the sum although both have non-food uses (e.g. drywall for building construction for starch) because non-food use data were not available and the amounts are likely negligible for the purposes of our calculations given the large value for total domestic use (demand coefficient for corn grain: 0.91 x 0.12 = 10.9%).

Barley is commonly used in both human food and animal feed. Food for barley use was calculated by dividing food, alcohol, and industrial use by total domestic use (Table 3). Although food, alcohol, and industrial use of barley includes non-food uses, their amounts are likely negligible for the purposes of our calculations given the relatively large value for total domestic use (79 x 0.72 = 57%).

Cottonseeds contain gossypol, a compound that is toxic to humans. Cottonseed is used by the oilseed crushing industry to extract oil that can be included in vegetable oil products for human consumption. The oil content of cottonseed is 16% of DM according to the National Cottonseed Products Association (NCPA, 2016), and 90% of cottonseed oil produced is used for human consumption, predominantly in salad or cooking oil and to a lesser extent in the production of baking and frying fats (demand coefficient for cottonseed: 16 x 0.90 = 14%).

Using the demand coefficients described above suggests that *2.2% of dairy feed is in demand by the food industry in the United States,* primarily in the form of corn grain and barley (Table 1).

Conclusion

Dairy feed is not primarily composed of human-edible cereal grains and oilseeds. Dairy cows convert feed into food by recycling nutrients in human-inedible agricultural and industrial by-products into nutritious milk and dairy products. The competition between dairy feed and human food is negligible and dairy cows make a net positive contribution to the food supply in the United States.

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Table 1. Composition and demand coefficients for human-edible dairy feed ingredients.

Ingredient[1]	Composition coefficent[2]	Demand coefficient[3]	Edible by composition[4]	Edible by demand[5]
Corn grain	0.91	0.109	8.8%	1.05%
Distiller's grains	0.61		2.5%	
High moisture corn grain	0.90		2.5%	
Corn gluten feed	0.65		1.7%	
Cottonseed	0.16	0.144	0.4%	0.32%
Soybean meal	0.88		1.7%	
Canola meal	0.70		1.3%	
Barley	0.79	0.570	1.1%	0.80%

[1]Percent DM in the national average dairy diet: corn grain (9.7%), distiller's grains (4.1%), high moisture corn grain (2.8%), corn gluten feed (2.6%), cottonseed (2.0%), soybean meal (1.9%), canola meal (1.8%), and barley (1.4%). These 8 ingredients represent 26.3% of the total national average dairy diet DM.

[2]Composition coefficients were calculated as 1-NDF using NDF values (on DM basis) from Dairy NRC (2001) (corn grain = 9.5%, distiller's grains = 38.8%, high moisture corn = 10.3%, corn gluten feed = 5.5%, soybean meal = 12.3%, canola meal = 29.8%, and barley = 20.8%), except for cottonseed were oil content was used (16% on DM basis).

[3]Demand coefficient was calculated by multiplying the composition coefficient by the percent food use of total domestic use (corn grain = 12%, cottonseed = 90%, and barley =72%).

[4]Edible by composition was calculated by multiplying each ingredient's composition coefficient by its corresponding amount in the national average dairy diet on a DM basis.

[5]Edible by demand was calculated by multiplying each ingredient's demand coefficient by its corresponding amount in the national average dairy diet on a DM basis.

Table 2. U.S. corn domestic and food use for marketing years (Sep-Aug) 2009 to 2014.

	09/10	10/11	11/12	12/13	13/14
High-fructose corn syrup (HFCS)	512	521	512	491	478
Glucose and dextrose	257	272	294	292	308
Starch	250	258	254	249	219
Alcohol for fuel	4,591	5,019	5,000	4,641	5,124
Alcohol for beverages and manufacturing	134	135	137	140	142
Cereals and other products	194	197	203	199	201
Seed	22	23	25	25	23
Total food, seed, and industrial use	5,961	6,426	6,424	6,038	6,493
Food use[1]	1,348	1,384	1,400	1,372	1,347
Total domestic use	11,062	11,202	10,943	10,353	11,534
Percent food use of total domestic use	12%	12%	13%	13%	12%

[1]Food use was calculated by summing high-fructose corn syrup (HFCS), glucose and dextrose (sweeteners), starch, alcohol for beverages and manufacturing, and cereals and other products. Starch includes non-food uses such as drywall for building construction and alcohol for beverages and manufacturing also includes some non-food uses.

Table 3. U.S. barley domestic and food use for marketing years (Jun-May) 2009 to 2014.

	09/10	10/11	11/12	12/13	13/14
Food, alcohol, and industrial use	158.7	153.7	149.0	141.0	148.3
Seed use	5.0	4.8	6.0	5.8	4.9
Feed and residual use	47.0	49.8	36.6	66.2	66.1
Total domestic use	211	208	192	213	219
Percent food use of total domestic use[1]	75%	74%	78%	66%	68%

[1]Percent food use was calculated by dividing food, alcohol, and industrial use by total domestic use.

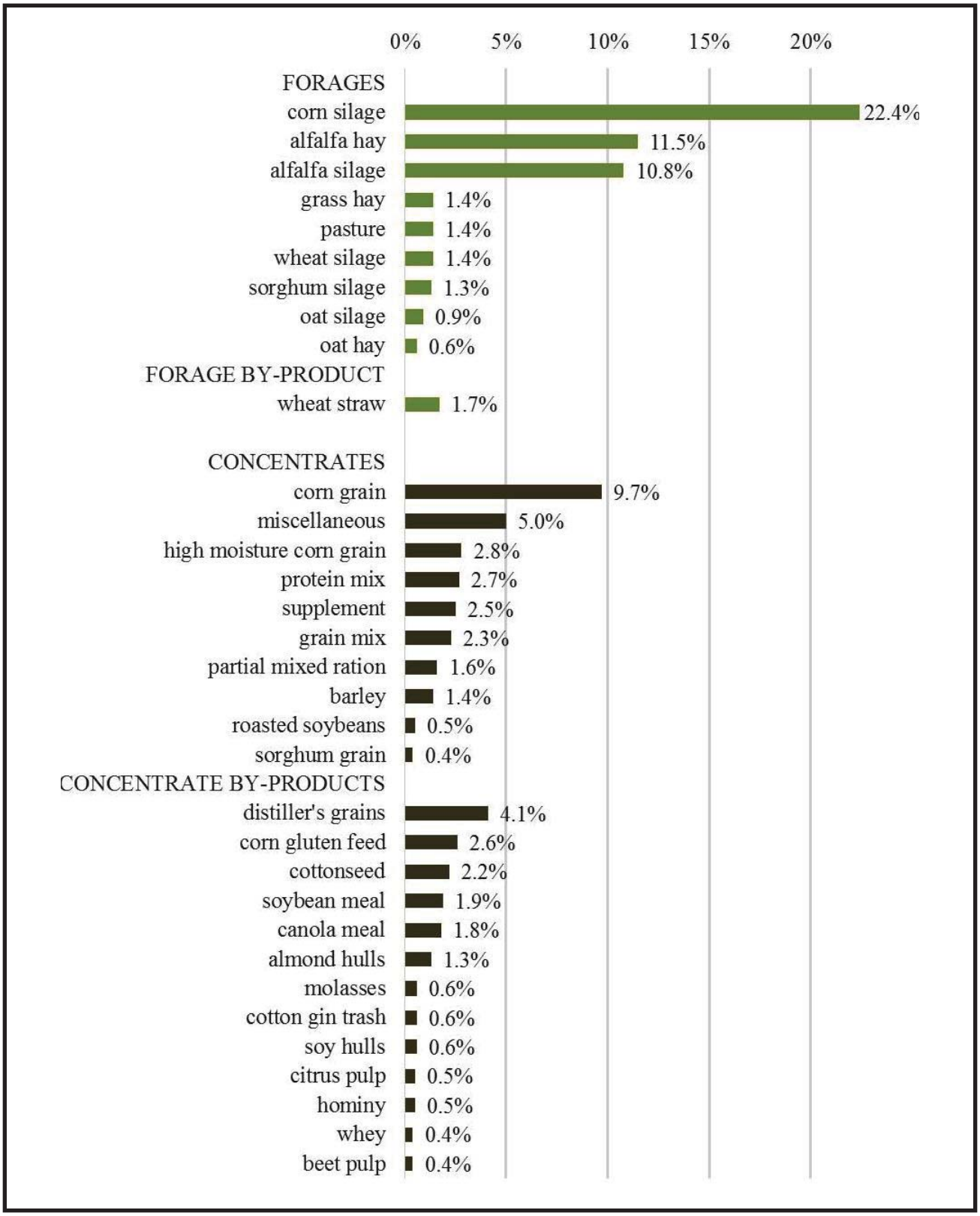

Figure 1. Composition of the national average dairy diet on a percent DM basis.

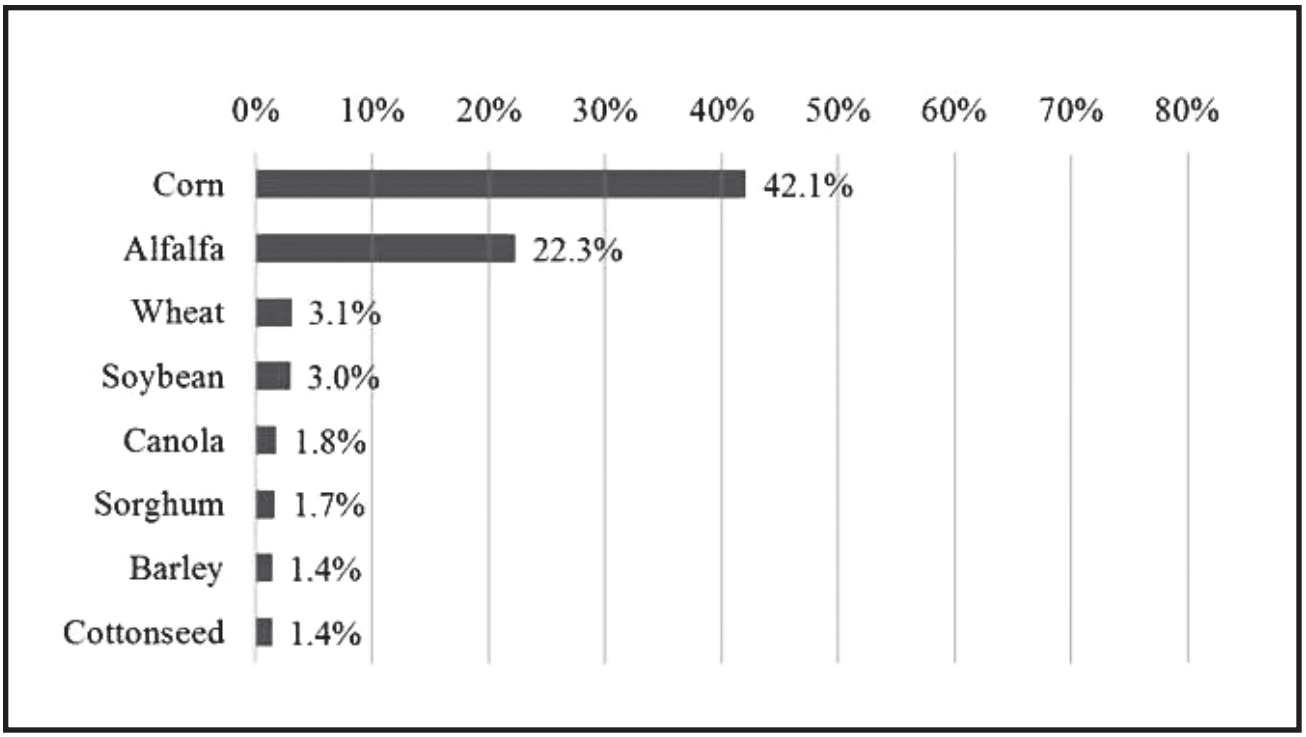

Figure 2. Contribution (DM basis) by the eight major crops supplying 80% of the DM in the national average dairy diet.

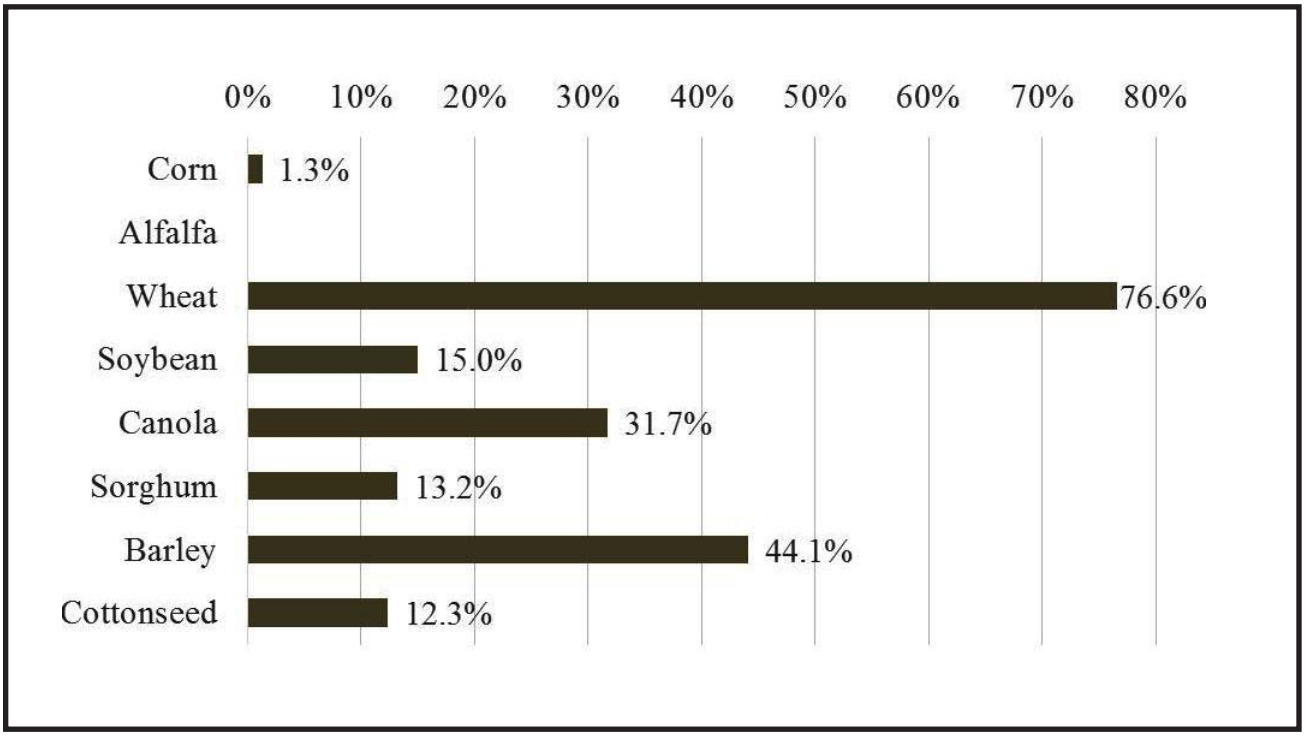

Figure 3. Percent food use of total domestic use for the 8 major crops in teh national average dairy diet.

Changing Demand for Dairy Products and How This May Affect Dairy Production in the U.S.

Mark W. Stephenson[1]
Director of Dairy Policy Analysis
University of Wisconsin-Madison

Introduction

Milk equivalent per capita disappearance of all dairy products has been increasing since the mid 1970s, but not all dairy products have enjoyed increased sales. Over that more than 40 year time period, cheese has been a bright star for the dairy industry and more recently, products like yogurt have seen dramatic increases. But, during that same time period, products such as cottage cheese, nonfat dry milk, and ice cream have been in decline. During much of this time, per capita fluid milk sales have been in decline, but even within that segment, category shifting has occurred. Initially, there was a significant move away from whole milk toward lower fat products, but in 2015, that trend was reversed. Changing patterns of consumption will always mean that the dairy industry must be prepared to meet the customer at the point of sale.

Basic Concepts and Calculations for Domestic Dairy Product Consumption

Words such as sales, demand, disappearance, and availability are all used in discussions of domestic dairy consumption and each can be relevant in certain instances. Consumption usually refers to the amount of a product used by individuals or businesses (food processors, restaurants, etc.) during a particular period of time, such as a month, quarter, or year. For fluid milk products, actual sales data are reported and these provide a reasonably accurate indication of how much product was consumed. *Demand* is often used as a general descriptor about market conditions (such as "demand is up"), but economists use that term more specifically to describe the *relationship* between a quantity demanded (sales) and various factors including price, incomes, population, etc. *Disappearance* describes how calculations of "consumption" are typically done, using information on production, stocks, imports, exports and other factors to arrive at an estimated quantity of product that is not otherwise accounted for—which is often defined as domestic *Availability*.

The most comprehensive data for a discussion of longer-term trends in domestic dairy product consumption are published by the Economic Research Service (**ERS**) of USDA. For fluid milk, the data are from actual commercial sales figures, compiled based on data from regulatory agencies, such as the Dairy Division of the Agricultural Marketing Service of USDA or the California Department of Food and Agriculture. Consumption calculations for other products are typically made using the concept of "disappearance," which estimates what was consumed based on accounting for the sources and uses (supply and utilization) of products. For total milk "disappearance," this calculation would include the elements shown in Table 1. Milk fed to calves is subtracted to calculate the

[1]Contact at: 427 Lorch Street, 202 Taylor Hall, Madison, WI 53707, (608) 890-3755, Email: mwstephenson@wisc.edu.

milk available for human consumption. To this are added the milk equivalents in imports and beginning stocks to arrive at a total supply. The "milk equivalent" concept is used to convert pounds of product to pounds of milk (for example, one lb of cheese equals 10 lb of milk) for the purposes of an aggregated calculation such as this one. The use of milk equivalents often represents a gross approximation because most dairy products contain dairy components (fat, protein, and lactose) in proportions different than the original milk, and this sometimes results in the use of milk equivalent calculations based on butterfat and(or) solids-not-fat.

The calculation then subtracts the uses of milk (equivalents) other than by consumers (broadly defined as households and businesses), including exports, shipments to US territories (technically, not part of exports), and ending stocks of products. This calculation results in "commercial disappearance." Once the commercial disappearance is calculated, it is often of interest to examine this as an amount per person (per capita) using data on the total US population. This calculation is the basis for much of the information about aggregate consumption of dairy products in the US and is frequently used in analysis of factors influencing per capita demands using time-series data. These data are available through 2013 and serve as the basis for much of the subsequent analysis and discussion. It is worth noting that calculating consumption as a residual is conceptually different than the way in which economists conceive of demand for the product arising from personal preference or business decisions.

Although these calculations provide an overall indication of the growth (or lack of it) in different dairy product categories, they have some important limitations for the purposes of predicting future consumption. First, because they adjust consumption for imports and exports, any rapid change in trade can have an effect on domestic consumption. A rapid increase in exports, for example (without a correspondingly rapid increase in domestic production), would reduce commercial disappearance in the US, but this would not be an indication of a reduction in demand for the product—rather quite the opposite. This effect typically has been short-term in the past, but it may have increasing importance in the next decade. Second, the data do not allow determination of the marketing channels through which different products are sold and how those are changing over time. Fluid milk sales are primarily retail, but cheese is sold through both retail and foodservice, and many dry dairy products are sold primarily to other dairy product[2] or food manufacturers. These different marketing channels and their development can be of importance to determining future consumption trends. Finally, despite the numerous categories that are reported, the level of disaggregation may obscure the different performance of individual products (perhaps down to the level of Stock Keeping Units (**SKU**) at the retail level). Although yogurt consumption has grown at a rapid rate during the past decade, recent evidence suggests that the "Greek yogurt" category has grown even more rapidly. Organic fluid milk sales (for which sales information is available) have grown more rapidly than for the "conventional" fluid milk categories. In addition, in 2015, whole milk sales increased while low fat and skim milk sales declined.

Review of US Dairy Consumption Patterns, 2004 to 2013

Per capita domestic consumption of dairy products has been growing steadily since reaching a low point in 1974 (Figure 1), although it remains considerably lower than during the first half of the 20th century. Expressed in milk equivalents per capita (based on butterfat in this case), overall dairy product consumption has

[2]An empirically important example is the use of non-fat dry milk in cheese production because it increases cheese yields.

increased 72 lb/person since the mid-1970s, a compound annual growth rate (**CAGR**) of 0.4% per year. However, this modest overall growth obscures the much more dramatic shifts in the composition of dairy consumption that have occurred since 2000.

Fluid milk products have the largest per capita consumption amounts (Figure 2); fluid and related products accounted for one-third of total milk equivalent consumption in 2013. However, both the amounts and the growth rates during the past decade differ by product category. For beverage milk, the four most important categories (in order of decreasing per capita consumption) are reduced fat milk, whole milk, skim milk, and lowfat milk. The reduced fat and lowfat milk categories have seen relatively small increases in per capita consumption during the past decade, whereas skim milk and whole milk have experienced decreases (with the noted exception of whole milk in 2015). Yogurt consumption has grown substantially during the past decade, and flavored lowfat milk, cream, and sour cream have experienced growth in per capita consumption.

Dairy products other than fluid and related account for about two-thirds of domestic per capita consumption on a milk-equivalent basis and have also experienced varying growth patterns. Frozen dairy products and cheese have higher per capita consumption (Figure 3). Both American and other types of cheese have experienced growth in per capita consumption since 2004, whereas per capita consumption of frozen dairy products and many of its component products have decreased by a relatively large amount. Many other manufactured dairy products have experienced growth in per capita consumption, with the exception of dry whey. Yogurt is included in this figure to indicate its importance relative to non-fluid products, and it is clear that growth in per capita yogurt consumption is large compared to other products.

The changes in per capita consumption can also be compared based on CAGR during the period from 2004 to 2013 (Figures 4 and 5). The per capita consumption of fluid milk and related products overall has experienced modest negative growth (-0.5% per year) during the past decade. Within the category, however, are products like yogurt that have experienced rapid growth. The traditional beverage milk categories have modest per capita growth at best, and both skim and whole milk have experienced negative growth rates during the decade of 2004 to 2013. There is a clear substitution of lowfat flavored milks for flavored whole milk, and cream and specialty products like eggnog have seen growth rates of greater than 2% per year. The fastest growth rates for products other than fluid are for yogurt (more than 7% CAGR) and dry or condensed products (Figure 5). Both cheese categories reported (American and other) and butter have experienced growth faster than the average for all dairy (again, expressed as milk equivalents). Fluid milk products, frozen dairy products, whole milk powder (**WMP**), and dry whey have experienced significant reductions in per capita consumption during the past decade.

Changes in per capita consumption are relevant, but it is also important to consider the effects of population growth, which for the US averaged about 0.9% per year during 2004 to 2013. The CAGR for total domestic consumption indicate some patterns similar to those for per capita consumption (Figures 6 and 7). The CAGR for total domestic consumption of yogurt was more than 8% per year, and flavored lowfat milks, cream products, and eggnog grew at rates around 4% per year during 2004 to 2013. Lowfat and reduced fat milk consumption grew somewhat faster than the population. A number of fluid milk products (especially whole milk) experienced decreases in total consumption because the decrease in their per capita consumption was larger than

the increase in population. For products other than fluid, the largest increases in total domestic consumption occurred for NDM (and for dry milk products more generally), but evaporated and condensed skim milk, cheese products, and butter also experienced growth rates of around 2% per year. Lowfat cottage cheese and ice cream experienced growth of less than 1% per year. Frozen desserts, WMP, and dry whey experienced decreased total consumption during the past decade.

Organic fluid milk products are not explicitly identified in the availability calculations from ERS, but other sources report monthly sales data for organic whole and reduced fat milk since January 2006. Organic milk consumption more than doubled from 2006 to mid-2013; the CAGR was 13.6% per year (hence higher than the other product categories reported in Figure 6). Despite the rapid growth, organic milk sales accounted for less than 5% of total fluid milk sales in 2013.

The reduction in domestic dry whey consumption (Figure 7) merits additional discussion. Production of dry whey has not declined at nearly the rate suggested by the CAGR of less than -6% per year (Figure 8). Production of dry whey was about 9% lower in 2013 than in 2004, with a CGAR of -1.0% per year. Domestic consumption has fallen by more because a larger proportion of the dry whey produced is exported (therefore subtracted from domestic availability) and domestic production of whey protein concentrates and lactose has grown rapidly (Figure 8), but these are not included in the categories reported by ERS. Thus, the dry whey number is not a particularly good indication of the growth in domestic or total consumption for the whey product category.

It is also relevant to consider the extent to which growth in consumption for each of the products has contributed to increased demand for milk components. Although ERS provides an overall milk equivalent consumption value, it does not indicate which conversion factors were used for individual product categories. Thus, it is challenging to arrive at a detailed accounting. It is commonly noted that much of the increase in the demand for farm milk over the past decade arises from growth in cheese consumption due to its relatively rapid growth and its large share of milk use throughout the period. As noted above, cheese consumption grew at a CAGR of 2% during the past decade and total cheese consumption increased by about 1.7 billion lb - a 15% increase over 2000. A rough estimate of the proportion of the increase in total milk production this represents is to multiply the 1.7 billion lb of cheese by the approximate conversion factor of 10 lb of milk per lb of cheese. The 17 billion lb of milk equivalent resulting from increased domestic cheese consumption is more than 75% of the increase in US milk production from 2004 to 2013, 21 billion lb per year. Thus, although there has been rapid growth in domestic consumption of many products—some much faster than cheese—the growth of domestic cheese consumption has been a major factor in the expansion of the industry.

Review of Factors Influencing US Dairy Consumption Patterns

A variety of factors affect the domestic consumption of dairy products. These include *economic factors* (prices of products and their variation, household incomes, consumer confidence), *demographic factors* (population growth, ethnic mix, household size and composition), *health and nutrition information* (research on the health impacts of dairy products, dietary trends or fads), *consumer tastes and preferences* (interest in new flavors and different foods, proportion of food consumed

away from home) and *business strategies* (research and development, new product introductions, promotion, generic or branded advertising). Many of these factors have been analyzed with formal (for example, econometric modeling) or informal (for example, implied correlation between trends in consumption and a specific factor) approaches. However, many of the more recent formal studies of factors affecting consumption use cross-sectional data from a sample of households[3] (rather than "commercial disappearance" data over time) and do not systematically examine the impact that these factors have had on consumption trends. Moreover, the limited data on many of the factors above make it challenging to determine with accuracy the role that each of the factors plays in determining longer-term trends. Detailed household level data only apply to categories of dairy products consumed at home (and typically purchased through retail outlets) and therefore do not provide insights on consumption through food service or by other food manufacturers. Moreover, even the results of formal studies often differ in their findings based on the time period, the number of product categories analyzed, the methods used, and other differences in their approach. As a result, it is challenging to assess the contribution of each of these factors to longer-term trends, and I adopt a rather selective approach to discussion of them.

Most studies of household-level demand have used econometric models to determine the impact of prices (of the product itself on other products) and demographic characteristics on dairy product consumption (Chouinard et al., 2010; Davis et al., 2010). In general, these studies find that dairy product consumption is sensitive to prices, household income or expenditures, and selected demographic factors. Studies using household level data (and shorter time intervals) tend to find greater responsiveness to prices than those using time-series data or more aggregated time intervals. Fluid products tend to have less responsiveness[4] to prices than other products analyzed. Consumption of most products increases with increased household income or expenditures; although Davis et al. (2010) found that for 12 dairy product categories, consumption increased roughly proportional to total household expenditures (that is, the expenditure elasticity is close to 1.0).

Although the studies reporting the responsiveness of consumption to prices and incomes do not usually allow us to draw conclusions on aggregate consumption over time, they provide a basis for claims that increasing real incomes and decreasing real dairy product prices are among the primary drivers of changes in demand. Real income per capita and dairy product consumption have both increased since the 1970s (Figure 9), but the relationship is by no means a perfect one. Moreover, prior to 1974, there was an inverse relationship between the income and per capita consumption of dairy products (Figure 1). There has also been a decline during the past decade in the average ratio of the Consumer Price Index (**CPI**) for all dairy products and the overall CPI (Figure 10), although the trend is small and has been punctuated with periods in which dairy prices had increased faster than consumer prices overall.

Other studies have argued that demographics and changes in food-spending patterns have more influence than prices and income on consumption trends. Kaiser (2005) found that for 1995 to 2004, changes in the proportion of the population with children under

[3]One motivation for the use of cross-sectional data is that statistical methods consistent with economic theory are reasonably well developed (e.g., Davis et al., 2010) and commonly used. Another motivation is the availability of detailed data from vendors such as IRI and Nielsen.

[4]Typically, this discussion is framed in terms of whether demand is "elastic" or "inelastic", which are defined as the percentage change in quantity consumed divided by the percentage change in price being greater than 1 (bigger percentage change in quantity than price) or less than 1 (smaller percentage change in quantity than price), respectively. Often, this has more important implications for pricing policy, either by individual firms or governments, than on longer-term trends.

5 years old were more important than changes in real retail prices to explain the decline in per capita fluid milk consumption. The same study also found that the growing Hispanic population and increases in per capita food consumed away from home had a much larger impact than household income on per capita demand for cheese. Demographic characteristics of the household have frequently been found to have influence on dairy product consumption. The recent study by Davis et al. (2010) found that household size, age of the principal shopper (defined in that study as "the household head"), household composition (for example, single person household, presence of children in selected age categories), education, ethnicity, region of the country, and income category (different from expenditures) had statistically significant impacts on purchases of some dairy products. Per capita expenditures on food away from home have grown to represent nearly half of total food expenditures in recent years and are certainly highly correlated with per capita dairy product consumption (Figure 11). However, it is neither entirely clear what the direct impact on increased eating away from home is on dairy product consumption nor is the future pattern of food consumption clear in the current economic environment. After a long period of increases, expenditures in per capita on food away from home have changed little since 2008.

Another factor cited by many analysts as affecting trends in dairy product consumption is increased consumer awareness of the health impacts of diet. There have been a number of trends in dieting and nutrition during the past decade, including low-fat, low-carb, and "functional foods" (e.g., Sharma, 2005). The US dairy industry has provided significant funding to research potential health claims, especially the role of calcium in osteoporosis and how low-fat dairy products can support weight loss. The shift towards lower average fat consumption in beverage milk consumption seems to support this trend. However, it is not entirely clear how additional information of this type has affected long-term trends. Williams (2005) discussed the use of health claims on foods by consumers, stating that "consumers do not clearly distinguish between nutrient content, structure-function, and health claims." Although he notes "there is some evidence that the use of health claims improves the quality of dietary choices and knowledge of diet-disease relationships," the overall effects are not clear. In the US, per capita consumption of butterfat has continued to rise[5], despite the emphasis during much of the past decade on consuming low-fat dairy products. Even with the beverage milk category, the *reduction* in amount of per capita butterfat from decreased whole milk consumption (until 2015) is essentially equal to the *increased* butterfat from increased consumption of cream products.

Price volatility is a factor that has been mentioned more frequently in recent years as likely to influence future growth in dairy product demand. The argument is made that retail consumers dislike price changes and the food manufacturing and food service industries want to avoid large changes in their input costs (or costs associated with changing their ingredient mix). Various segments of the dairy industry have expressed concern that the recent increase in price variation will create permanent losses in sales (compared to a situation with less price variation) as retail and food industry buyers seek alternatives to dairy that exhibit less price variation. This argument has not been empirically evaluated, although one study (Maynard, 2000) provides some initial insights. Maynard (2000) examined whether retail sales of fluid milk were affected by four alternative measures of retail price variation. He found that the retail price changes themselves did not have an influence on sales, but that deviations from

[5]The ERS food availability per capita uses milk equivalents expressed in terms of butterfat, so an increase in per capita availability also implies an increase in butterfat consumption.

the prices expected by consumers (under two different assumptions about how consumers would form those expectations) did have an impact on sales. However, because the effects of unexpected increases and decreases were roughly equal in size, he concluded that there is not likely to be a persistent negative effect on sales due to volatility as long as both types of deviations occur with equal frequency. Because this study addressed only retail sales of fluid milk and used data from a period in which price variation was less than it has been in recent year, it is not a definitive answer to the question about how price variation will influence future trends in dairy product consumption.

Another factor that is often cited when referring to growth in US domestic consumption is dairy policy. Much of this discussion involves implicit or explicit criticisms of the Dairy Product Price Support Program (**DPPSP**) and Federal Milk Marketing Orders (**FMMO**). The DPPSP is argued to have reduced innovation (particularly for dry dairy products) because it provides a guaranteed market outlet for only a limited number of standardized products. Risk-averse dairy processing companies (especially cooperatives), it is argued, therefore have fewer incentives to develop new products and invest in new processing facilities. The impact of this effect on overall dairy product consumption has not been systematically examined. The minimum price regulation under FMMO is frequently indicated to have the effect of increasing prices for fluid milk and decreasing prices for manufactured products (e.g., Stephenson, 2003) and higher prices sometimes are argued to be an important factor in the declines in fluid milk consumption. However, there are three main issues with this argument. First, most of these comparisons about price and consumption impacts are made assuming a perfectly competitive milk market in the absence of minimum price regulation, but it is not clear that this assumption is justified (Paggi and Nicholson, 2011). Second, some analyses have indicated that factors other than price are more powerful explanations for the decline in fluid milk sales—consistent with different patterns of per capita consumption for different fluid milk products. Finally, if milk pricing under FMMO decreases manufactured product prices (such as cheese) this would have a positive effect on consumptions of milk equivalents that could offset the negative effect of higher fluid prices[6]. Thus, the effect of policy on consumption during the previous decade is not well understood, despite its potential importance. Future policy developments (discussed below) may have a larger impact on domestic consumption and trade during the next 10 years.

An important conclusion from the foregoing is that many factors affect trends in per capita and total consumption of dairy products. Although some of these factors have been explored through formal economic analysis, the results from these studies are not always consistent. Other factors have been hypothesized and receive a good deal of discussion but have not (yet) been formally analyzed in a single consistent framework. In addition, the factors that may drive trends in dairy demand in the future may vary from those in the past. One implication is that accurate longer-term predictions of changes in dairy production consumption are difficult.

Projected Growth Rates of US Dairy Product Consumption through 2020

A number of studies have projected future US dairy product consumption or growth rates. Some of these studies are derived from the annual outlook (and forecast) cycle and are undertaken by USDA and the Food and

[6]The reduction in fluid sales would need to be more than 10 times the increase in cheese consumption to result in a reduction in per capita milk equivalent consumption.

Agricultural Policy Research Institute (**FAPRI**)[7]. The methods used to develop these forecasts often are neither described in detail nor are the product categories defined in the same manner for each forecast. The USDA outlook, for example, forecasts total milk equivalent consumption based on fat or nonfat-solids calculations (Table 2). FAPRI (2010) forecasts future US consumption for 12 dairy product categories, and FAPRI-ISU forecasts four major product categories. There are notable differences among the forecasts from the different organizations and with the observed growth rates during 2004 to 2013 (Table 2). USDA (2011) projects continued overall growth in dairy products at 1.3%, but as noted previously, the growth rates for different products vary a great deal. FAPRI (2010) and FAPRI-ISU (2011) differ in both the signs and magnitudes for three of the four product categories for which there is overlap (butter, NDM, cheese, and fluid), and most differ a good deal from the rate of growth observed during the past decade. The inconsistencies in these projections and the limited information about how the forecasts were developed makes it challenging to use these estimates to develop assumed growth rates (necessary for subsequent analyses).

Schmit and Kaiser (2006) provide a more detailed discussion of the development of projected growth rates for fluid milk and cheese. They used information from previous studies of the impacts of demographic shifts and other factors to project consumption of fluid milk and cheese through 2015. A major motivation was to examine the extent to which projections of population and consumer food-spending patterns would extend or alter previously observed consumption trends. They developed a partial equilibrium model of the US domestic dairy sector that segmented the industry into retail, wholesale, and farm markets. Fluid milk and cheese were explicitly modeled, but other manufactured dairy products (e.g., butter and frozen products) were considered exogenous. The model simulations projected a growth rate for per capita fluid product consumption of -0.43% per year, which when combined with population growth would result in modest growth in fluid sales. The authors note that this is a slower rate of decline that that observed in the decade prior to their work but is roughly consistent with the growth for 2004 to 2013 (Figure 4). Cheese consumption per capita was projected to grow at 0.82% per year, or somewhat more slowly than the observed growth for 2004 to 2013 (Figure 5).

Conclusion

On a milk equivalent basis, per capita domestic disappearance for all dairy products has been increasing for more than 40 years. During that time, the dairy industry has seen significant category shifts among products that are in favor (for instance, cheese and yogurt) and those that suffered a loss of demand (examples include ice cream, cottage cheese, and higher fat dairy products). However, the growth in domestic demand (including population growth and per capita increases) has not been enough to offset the increase in productivity of milk production.

Milk production per cow has been a remarkable linear growth of just about 284 lb/cow/yr of milk. This growth outpaces domestic demand and implies either the need to continually reduce the U.S. cow herd or to seek new markets for dairy products. The U.S. dairy market has pursued exports as the opportunity for new growth and with it comes a somewhat different product mix that is demanded for our domestic markets. There continues to be new opportunities for dairy product sales, but the

[7]FAPRI is a collaboration between the University of Missouri and Iowa State University. The FAPRI 2010 projections are from the University of Missouri, and the FAPRI-ISU projections are from Iowa State. Different researchers at the two institutions develop these projections.

industry must be nimble to take advantage of them.

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Table 1. Calculation of commercial milk disappearance in the US, 2014.

Element of Calculation	Amount, million lb per year
Supply	
Milk production (+)	206,046
Fed to calves (-)	869
Milk for human use (=)	205,177
Imports (+)	4,315
Beginning Stocks (+)	11,173
Total supply (=)	220,665
Utilization	
Exports (-)	12,444
Shipments to US territories (-)	943
Ending stocks (-)	11,223
Commercial disappearance (=)	196,055
Per capita Calculation	
US Population, millions	318.9
Per capita disappearance (lb)	614

Table 2. Projected compound annual growth rate (CAGR) per year for US consumption of selected dairy products, previous studies.

Product or Category	Observed CAGR	Schmit and Kaiser (2006)	FABRI (2010)[a]	FAPRI-ISU (2011)[a]	USDA Outlook (2011)[a]
Period for which rate applies	2000 to 2009	2005 to 2015	2009 to 2019	2010 to 2020	2010 to 2020
Butter	1.1%		-0.4%	1.7%	
NDM	4.8%		-2.8%	2.0%	
Total Cheese	1.1%	0.8%	0.5%	2.4%	
American	0.6%		0.7%		
Other	1.4%		0.5%		
Total Fluid	-0.4%	-0.4%	-0.3%	0.3%	
Whole	-3.2%		-2.2%		
2% fat	0.3%		0.9%		
Lowfat	0.1%		-0.4%		
Other	-1.2%		0.5%		
Ice Cream	-2.4%		-0.4%		
Evaporated & Condensed	2.3%		2.1%		
Butterfat					1.3%
Solids Not Fat					1.3%

[a]Calculated based on consumption projections expressed as quantities.

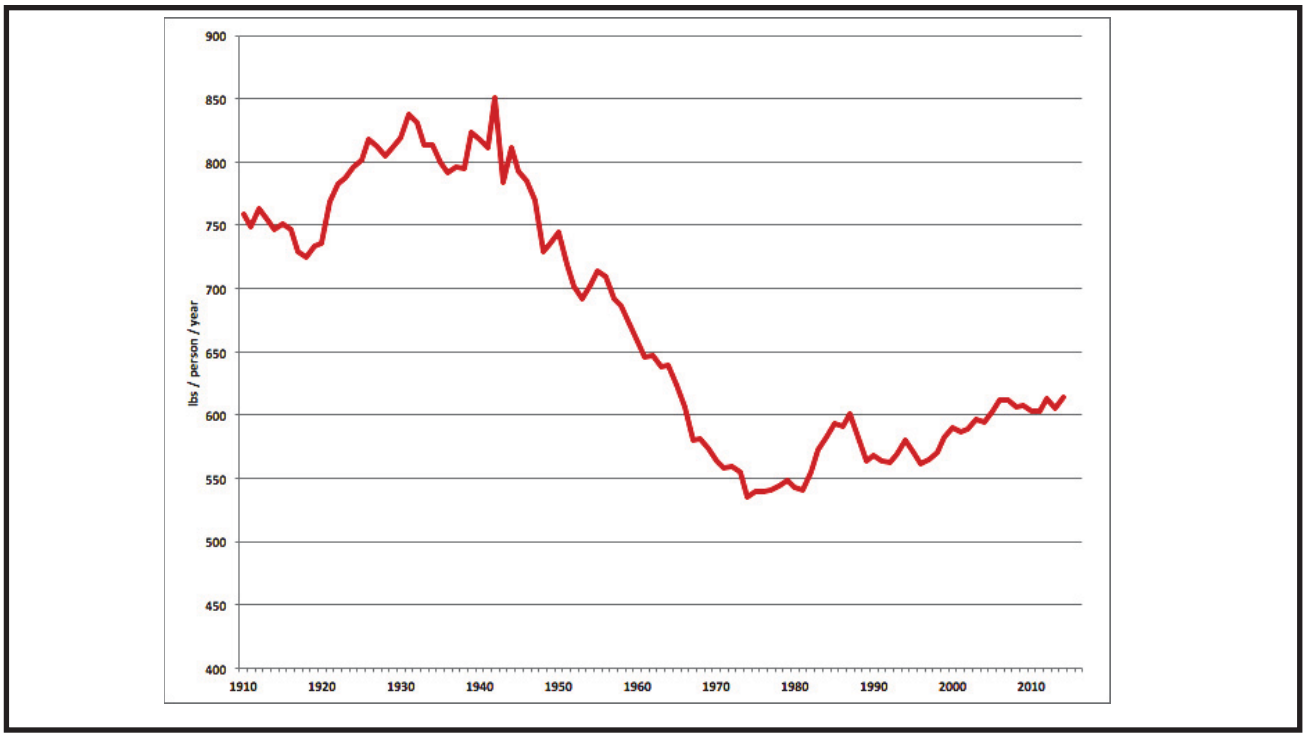

Figure 1. Per capita domestic availability of milk equivalents from 1910 to 2014.

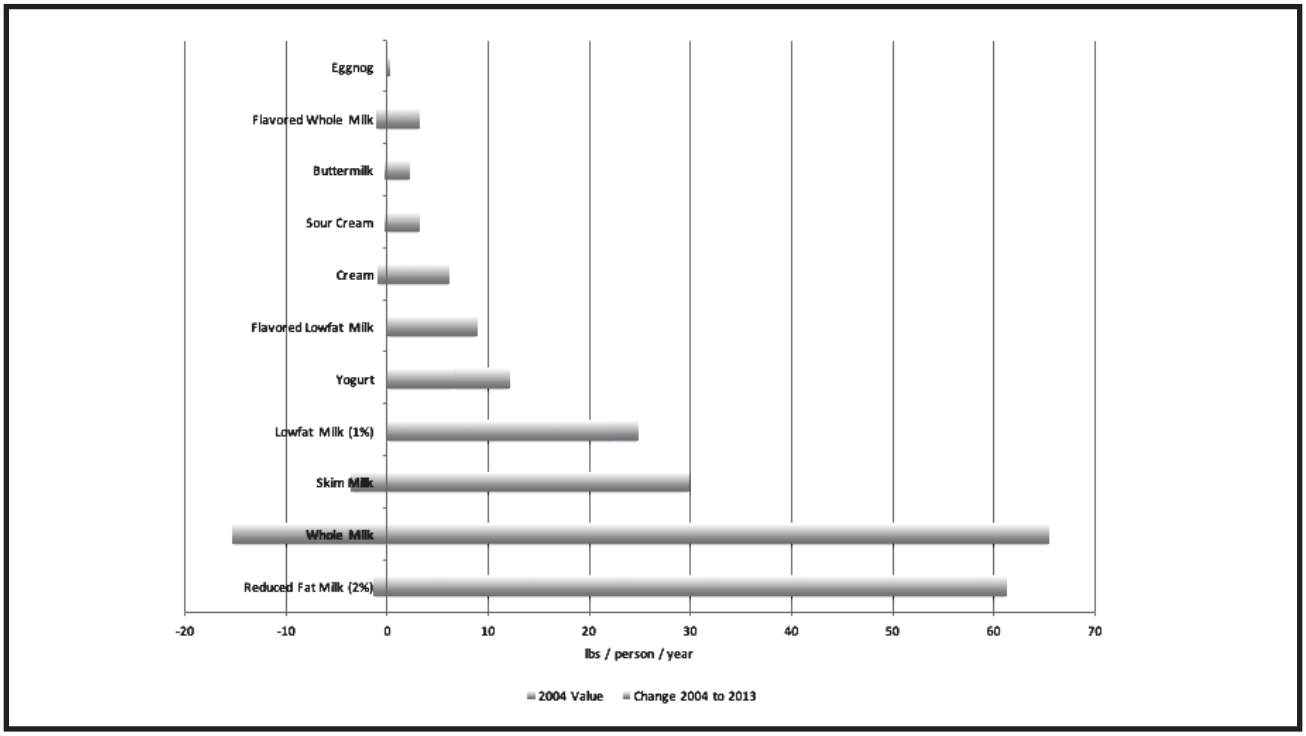

Figure 2. Per capita domestic availability of fluid and associated products in 2004 and changes from 2004 to 2013.

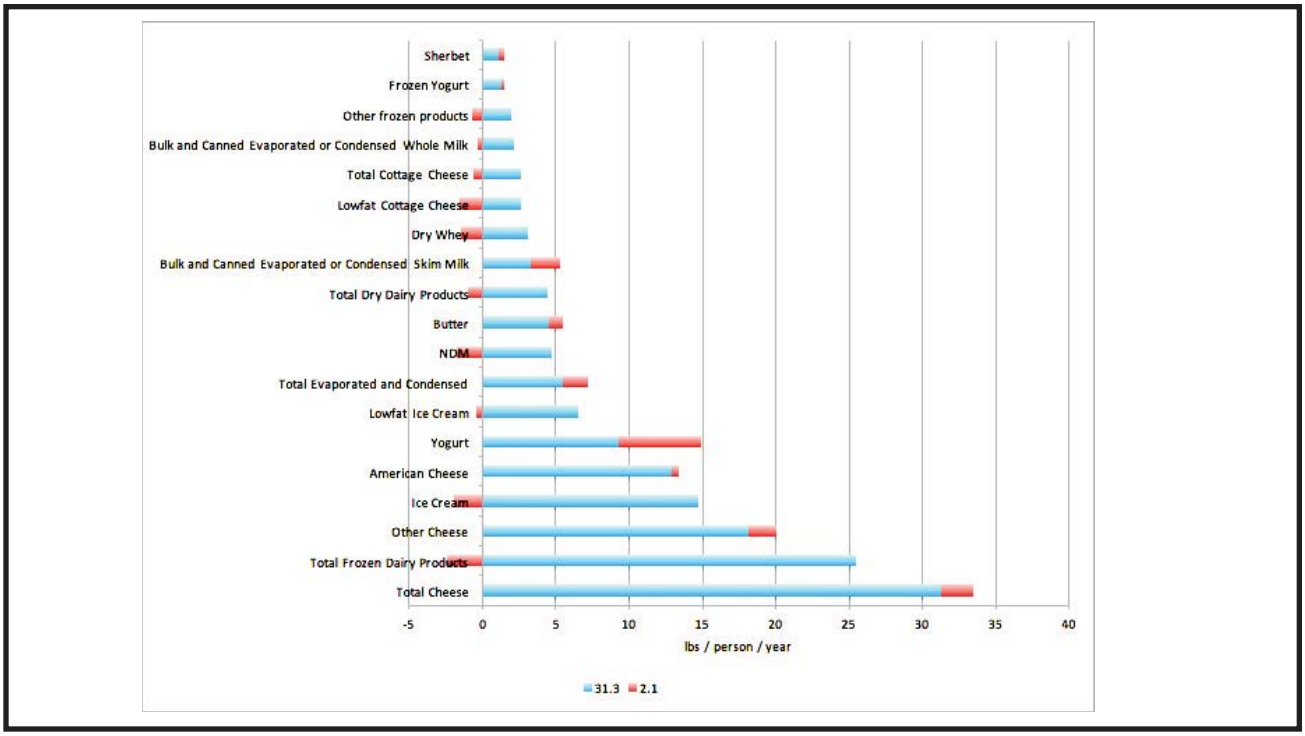

Figure 3. Per capita domestic availability in 2004 of selected products and changes from 2004 to 2013.

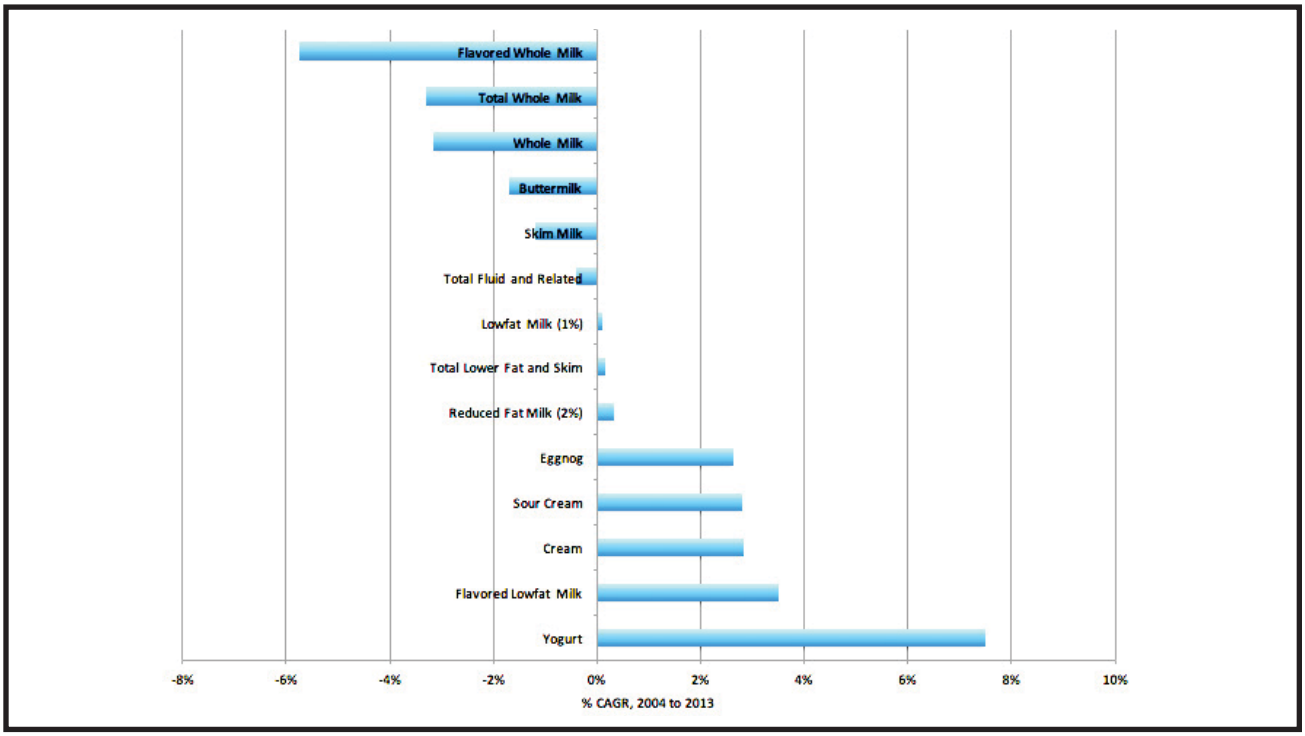

Figure 4. Compound annual growth rate (CAGR) for per capita domestic availability of fluid milk and related products from 2004 to 2013.

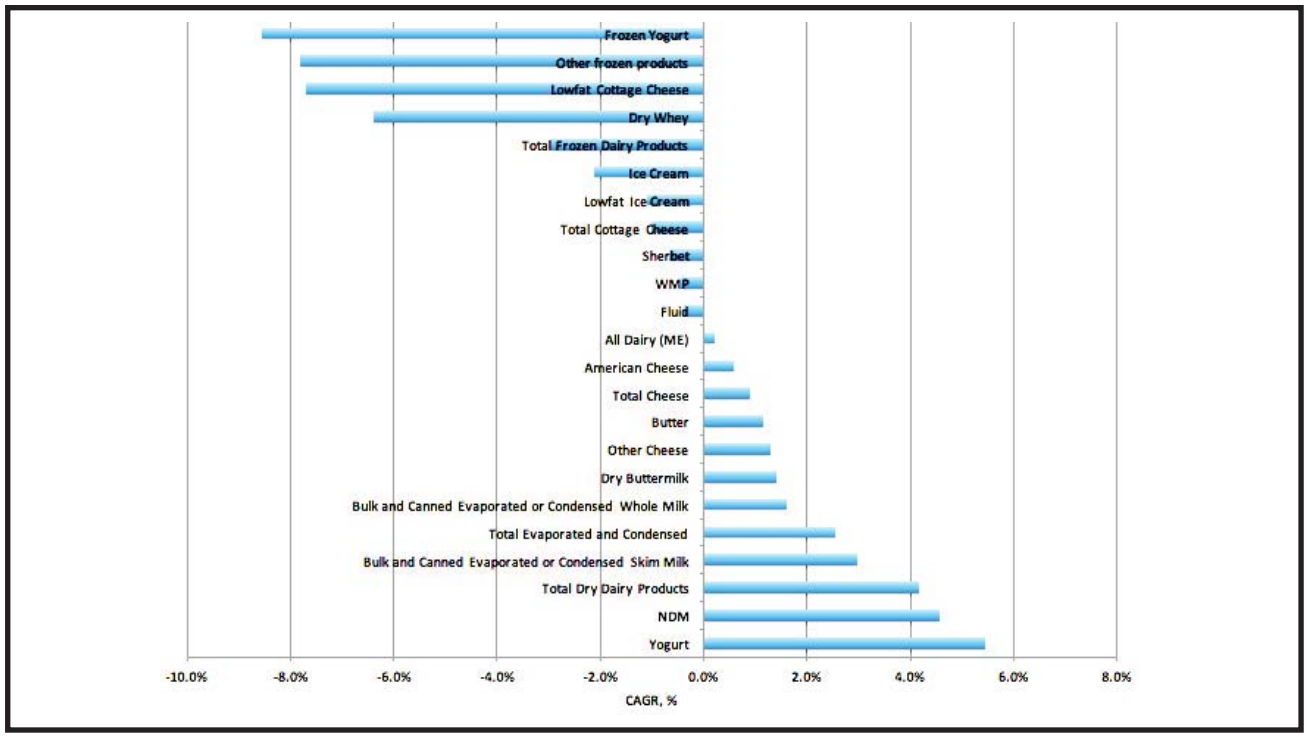

Figure 5. Compound annual growth rate (CAGR) for per capita domestic availability of selected dairy Products from 2004 to 2013.

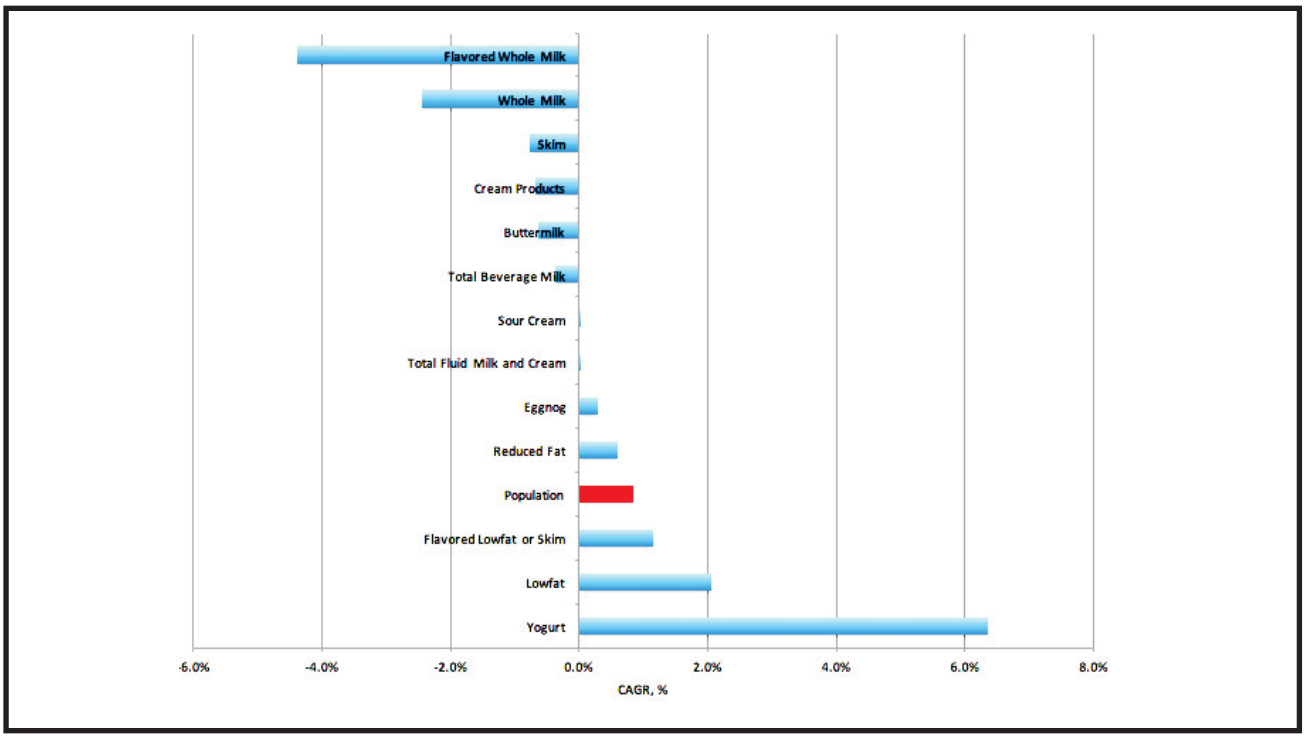

Figure 6. Compound annual growth rate (CAGR) for total domestic availability of fluid milk and related products from 2004 to 2013.

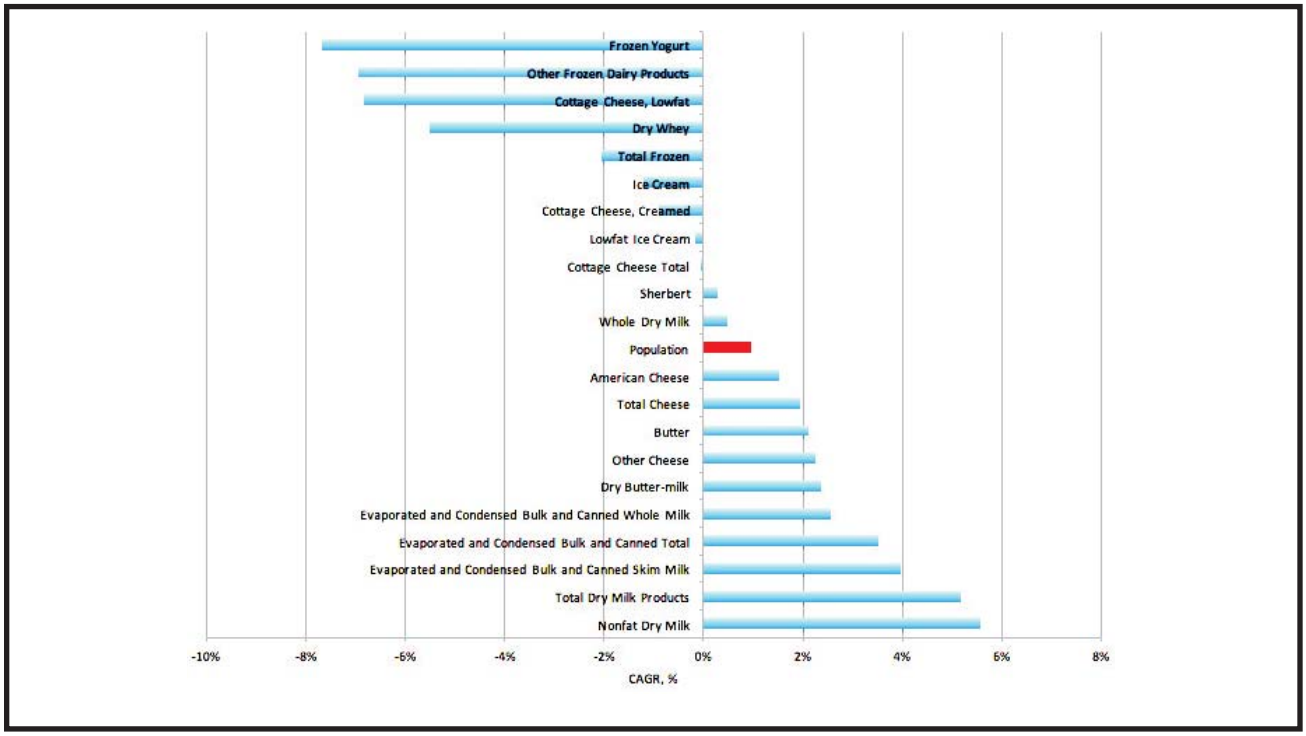

Figure 7. Compound annual growth rate (CAGR) for total domestic availability of selected dairy products from 2004 to 2013.

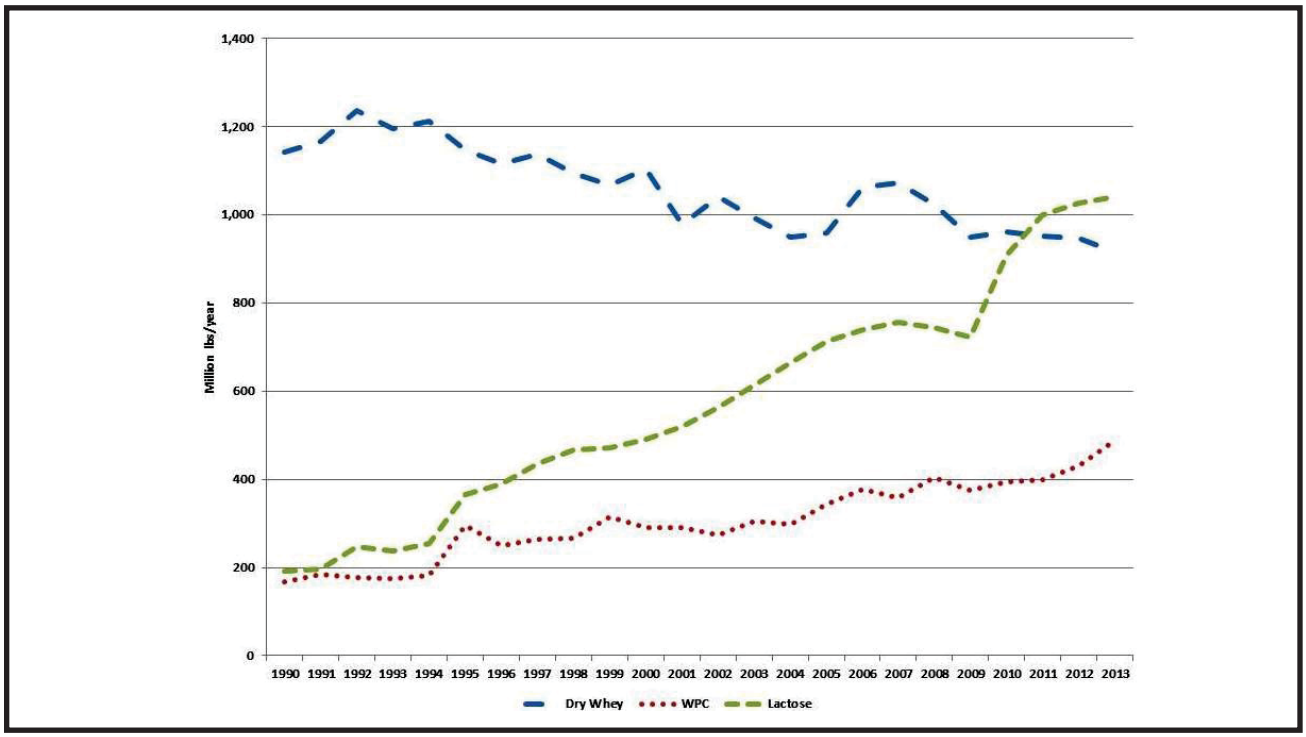

Figure 8. Domestic whey product production from 1990 to 2013 (WPC = whey protein concentrate).

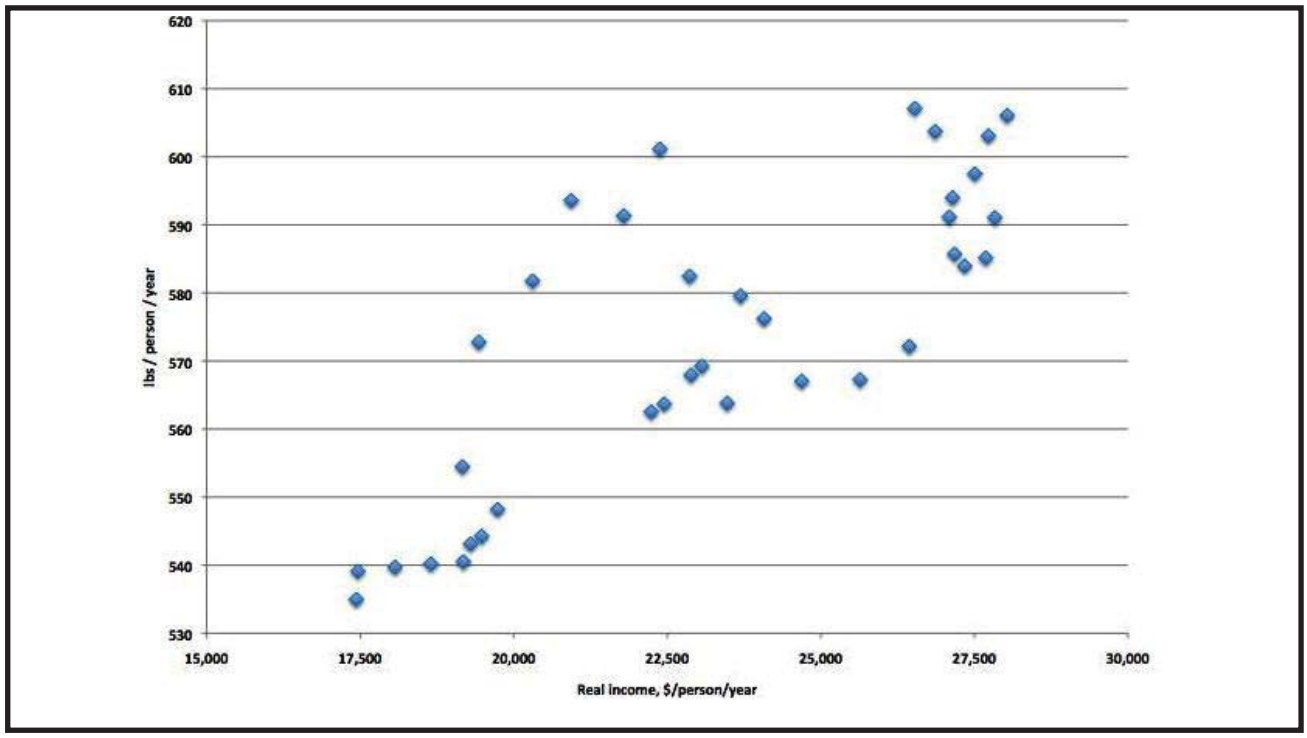

Figure 9. Per capita dairy consumption (milk equivalent) and real income per capita, annual data from 1974 to 2013.

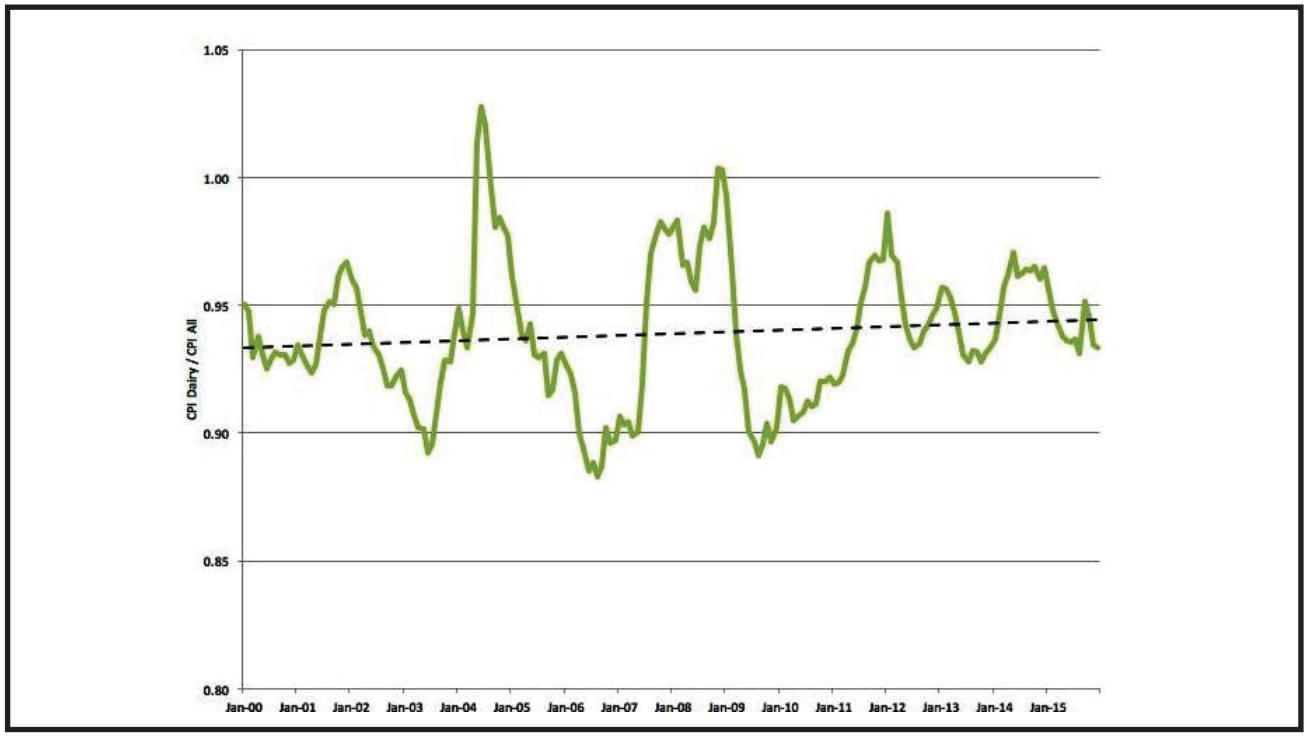

Figure 10. Ratio of dairy consumer price index (CPI) to overall CPI, Monthly January 2000 to July 2015.

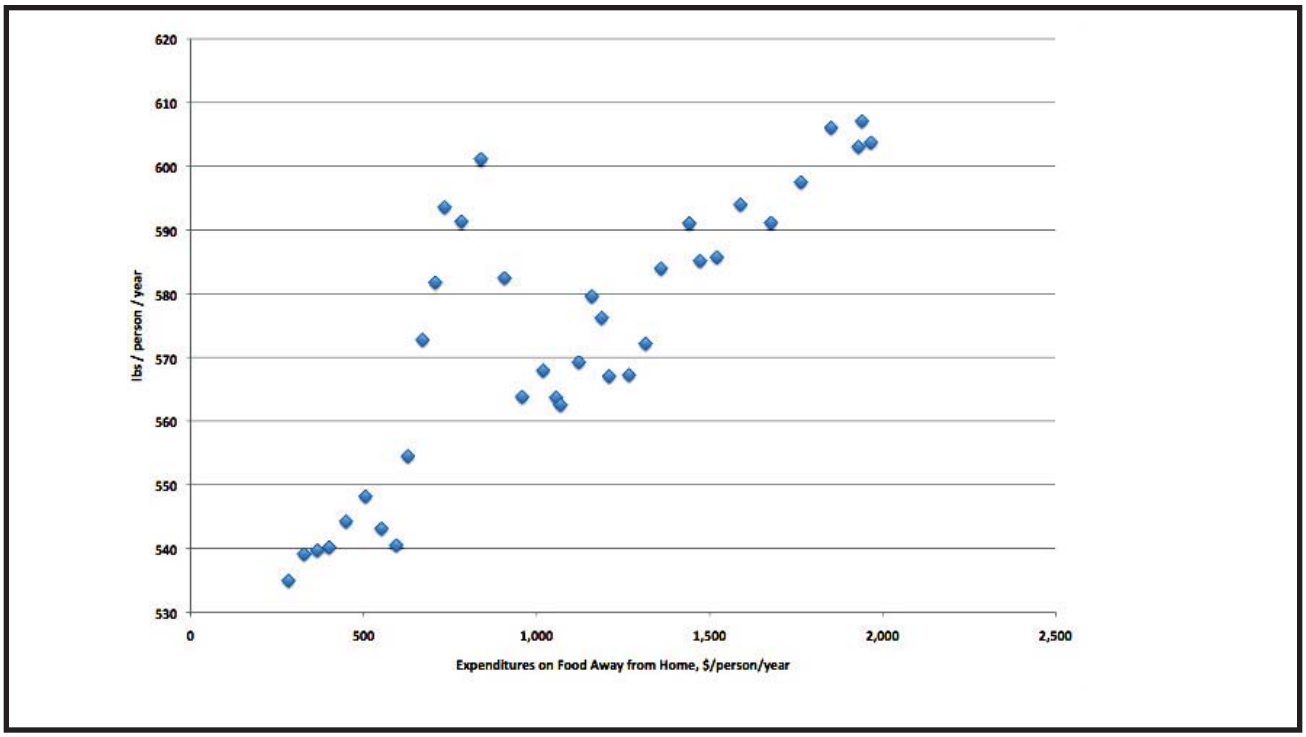

Figure 11. Expenditures on food away from home and per capita consumption of dairy products, annual data from 1974 to 2013.

Designing Feeding Facilities to Maintain Feed Quality

Micheal J. Brouk[1] and Joseph P. Harner, III
Animal Sciences and Industry
Kansas State University

Introduction

Feeding facilities associated with commercial dairy farms should provide an efficient and economical method to produce high quality total mixed rations (**TMR**) for the dairy herd. It is important that feed quality be preserved and shrink minimized from delivery of the feedstuff to the farm until it is placed in the bunk for consumption by the herd. Feed quality can be defined in many different ways. Many times, feed quality is associated with nutrient composition. While extremely important to dairy nutrition, nutrient composition is only the start of defining feed quality. Feed quality factors also include consistency, particle length, anti-quality factors, texture, odor, taste, and temperature. Of the feedstuffs on the dairy, wet products are generally the greatest source of variation and have the greatest potential to reduce the quality of the TMR. Feeding facilities should be designed in a manner to maximize the quality of the TMR by effectively minimizing factors that would reduce TMR quality. One of the major issues with reduced feed quality is associated with shrink of wet feedstuffs. As wet feedstuffs shrink, feed quality is often reduced due to the impact of bacteria, yeast, molds, and moisture loss. Nutrient loss and the increase in anti-quality factors associated with shrink often result in significant losses of production in addition to the economic losses often associated with physical loss of dry matter (Brouk, 2009).

Economic Impact of Shrink

The loss of feedstuffs during storage can be a significant economic issue for dairy farms. Currently, equipment and software are available to dairy farms to effectively track and determine feedstuff shrink. Systems allow producers to accurately record on a daily basis the entrance of feedstuffs onto the farm and the utilization of feedstuffs in TMR mixes. This combined with simply monthly feedstuff inventory adjustments can provide an operation with an efficient way to track feedstuff utilization and the shrink associated with various types of feedstuffs stored in various structures on the farm. These data are very valuable in determining areas of concern, as well as providing economic data necessary to guide future capital investment decisions. Table 1 demonstrates the increase in feedstuff cost as it enters the TMR mixer due to shrink occurring during storage on a dairy farm. For example, if soybean meal is purchased for $300/ton and there is a 5% loss of material during storage, then the cost of soybean meal in the ration increases by $15/ton. If the farm is feeding 5 lb/head/day of soybean meal to 250 cows, then the total annual loss associated with soybean meal would be $3,422 or a 3.75 cent increase in daily per cow feed cost. It is also important to consider that cheaper feedstuffs like corn silage at $50/ton are often fed in greater daily amounts. If corn silage is valued at $50/ton and has a total shrink of 16%, the annual loss associated

[1]Contact at: 134 Call Hall, 1530 Mid Campus Drive, Manhattan, KS 66506, (785) 532-1207, FAX: (785) 532-5681, Email: mbrouk@ksu.edu.

with feeding a 250-cow herd 30 lb/cow day would be $21,900. This would amount to a daily loss per cow of 24 cents. If one considers all the feedstuff shrink on an operation, it is not unusual to find a daily per cow savings of more than 50 cents. With the decrease in margins on dairy operations, determining how to minimize these losses becomes an important management decision.

Storage Structures

Decisions concerning the type of storage structure needed are first dependent on the type of material and then the amount of minimal shrink. Wet feeds and silages obviously require a different structure than dry feeds. The bulk density or physical form of dry feeds may also determine the type of storage structure required. Feedstuffs like whole cottonseed must be stored in flat storage rather than bins. After considering moisture and physical form, the next factor considered is the acceptable amount of shrink associated with different types of feedstuff storage. Data contained in Table 2 demonstrates the amounts of shrink associated with different types of feed and feed storage facilities. For many feedstuffs, enclosed bins result in the least amount of feed shrink. However, filling and unloading this structures requires augers or additional feed handling equipment. Depending on the equipment, the rate of delivery may increase feed mixing time or reduce the access to the feed mixing area while bins are refilled. If bins are utilized, it is possible to design the feed delivery on one side of the bins and the refilling area on the opposite side of the facility. This would allow feed mixing to continue while bins are refilled. Utilization of appropriately sized bin unloading equipment can also reduce the time to deliver ingredients into the TMR mixer.

In some cases, producers may choose to utilize enclosed bins for complete grain mixes that are delivered to the farm. This reduces the number of feedstuffs that need to be inventoried on the farm and can reduce errors associated with loading individual feedstuffs into the TMR wagon. Purchasing individual feedstuffs to be delivered and mixed at the farm is not always the most economical when one considers the cost of shrink, inventory, and additional on-farm mixing time required to blend feedstuffs into the TMR. Some producers have discovered considerable savings and have chosen to buy grain mixes that are delivered directly from the feed supplier ready to be directly incorporated into the TMR.

Once feedstuffs are placed into a 3-sided commodity shed, it is often assumed that the feed is well protected. However, moisture can enter the open front of the bay. As shown in Table 3, significant amounts of moisture can enter the facility. It shows the amount of rain entering every linear foot of a commodity shed assuming 1 inch of moisture blows into a bay for different side wall heights. For example, for a commodity shed, with a 24 foot high sidewall, 15 gallons of water per linear foot will enter a bay. If a curtain is dropped to reduce the opening to 8 feet (skid steer height), then 10 gallons of moisture are prevented from entering the bay, or a 67% reduction. A 50% reduction occurs if a curtain is dropped leaving a 12 foot (pay loader height) opening. Lowering a curtain or flexible door at night or upon completion of feeding may prevent significant ingredient losses due to rainfall and subsequent spoilage. Frequency of rainfall events would determine curtain management and frequency of lowering. Curtains also minimize the impacts of wind and potential movement of ingredients between bays without solid dividers. Buildings for storing commodities delivered in live bottom trailers may be able to reduce the sidewall height to a 14 foot opening using permanent materials.

Storage structures which leave feed exposed to the elements will result in increased losses. The length of storage will also impact shrink. Feedstuffs utilized in a few days compared to those stored for several weeks will generally have reduced storage losses. Increased feed moisture will also increase feed loss due to increased storage time. Enclosed storage should be considered for feedstuffs held more than a couple of weeks.

Figure 1 provides an illustration of a windbreak around a feed center. The windbreak should be located at least 4 times the height of the windbreak away from the feed center. This space will serve as a snow dump area. If snow is not an issue, the windbreak may be located closer to the feed center. "L" shaped commodity sheds provide protection from the wind from multiple directions. Feed center protection is increased if the building is oriented such that the prevailing wind is perpendicular to the intersection of the two building sides (corner of "L") than along one side. A single row of commodity bays may be modified along one side to include a 2nd building to provide additional wind protection. Many dairy farms also need a place to store additional commodities, ground hay, or daily silage needs prior to feeding.

Figure 2 provides an illustration of a totally enclosed commodity building. The advantage to this building is that weather related shrinkage losses are minimized. The overall building width is typically 60 to 80 feet wider than a 3-sided commodity building. This is necessary to provide room inside the building to maneuver semi-trucks delivering ingredients. The authors recommend consulting with trucking firms to make sure there is adequate room. Significant reductions in open space may increase feed loading time since feed loading equipment may not have free space to maneuver rapidly.

Figure 3 illustrates a feed center with a stationery mixer. There is room around the mixer to use micro ingredient tanks, as well as liquid tanks. Stationery mixers enable more hopper bottom tanks with automated handling equipment to be utilized for low inclusion rate ingredients and liquids. Commodity bays are in close proximity of the stationery mixer, allowing adequate time to secure individual ingredients. Another advantage is minimum losses due to weather shrinkage.

Stationary mixers provide an added advantage in limiting the number of people loading the TMR mixer on larger operations. Reducing the amount of TMR variation associated with errors in adding feed to the TMR may be reduced if only one to two people are preforming this task. Stationary mixers also may increase the efficiency of feed delivery equipment and reduce the variation associated with mixing. Often, mixing time is associated with total delivery time. There can be 10 to 15 minutes difference in drive time from the feed mixing area to different pens. This can result in over or under mixing of the TMR. With stationary mixers, the TMR is not mixed on the way to the pen.

When designing feedstuff storage, it is important to consider the rotation of feedstuff inventory. Even vertical bins need to be completely emptied on a regular basis prior to refilling with feed. Therefore, it is important to design with extra bin capacity to accommodate this activity. In flat storage, bay width is often increased to 24 to 30 ft to allow newly delivered feed to be placed next to the existing feed. This eliminates the need to remove existing feed to allow newly delivered feed to be placed behind existing feed in narrow bays.

Correctly formulated TMR is dependent on the accuracy of the weighing equipment

utilized in the process. With digital readouts, it is often assumed that the numbers visible on the readout are the exact amount of feed in the mixer. All scales have a range of accuracy. Often, even when correctly calibrated, a scale has an allowable variation of 1% of the weight. Thus, an actual variation of 10 lb on a 1,000 lb reading would be within the range of performance of the scale. Regular maintenance and calibration of weighing equipment should be part of the standard protocols for any dairy. Servicing scales on a regular basis can improve the accuracy of the feed weighing process and improve the consistency of the TMR.

In addition to the maintenance of the scale, it is important to maintain the TMR mixer. Knives and wear points within the mixer need to be changed on a regular basis. Too often these items are forgotten and the result is poorly processed forages and inadequately mixed TMR. Often, when this is discovered, repairs and adjustments are made. However, usually mix times have been increased to account for the worn equipment. These times are not reduced when the new knives are installed. The result is overmixed rations and too much forage particle size reduction. Regular maintenance of the mixing equipment is important in producing high quality TMR.

Technology continues to advance in the area of feed mixing equipment. Today, there are options that allow individual feedstuffs to be weighed, loaded into a TMR mixer, mixed, and then delivered to the feedbunk by automated equipment. Commercial feed mills have utilized this type of equipment for decades. When correctly calibrated, these systems are capable of weighing feedstuffs with much greater accuracy than the conventional loader and TMR wagon. Systems also reduce the amount of time required to mix and deliver feed. If feeds are weighed into a hopper while one load of feed is being delivered to the pens, then the batched feed is simply dumped into the TMR wagon in a matter of a couple of minutes as compared to 12 to 15 minutes of time spent loading individual ingredients. When considering automated systems for larger dairy farms, handling large volumes of forages and other feedstuffs is a challenge. However, future advances in technology and systems will overcome these issues.

Silage Storage and Management

Mold, yeast, and heat are major issues with silage quality. Mistakes during harvest and storage are often compounded by issues during feeding. Often, silages harvested with too little moisture are spoiled prior to incorporation into the TMR. Once incorporated into the TMR, the spoilage continues and quality of the whole TMR is reduced. Whitlock et al. (2000) demonstrated that feeding even low levels of spoiled silage to steers reduced animal performance, intake, and digestibility. The heat produced by secondary fermentation is the transformation of feed energy and nutrients into wasted heat energy. Losses associated with heating of the silage face are determined by the density of the face, moisture of the silage, fermentation of the silage, and the rate of removal. Today, producers are encouraged to remove a minimum of 8 to 12 inches of material from the face of the silo each day to minimize the effects of secondary heating. Correctly designing silage storage, piles or bunkers, to match the daily feeding rate of the herd is often not adequately considered. As a result, silages faces are exposed for a greater number of days, and animals may be fed spoiled feed.

Silages need to be delivered to the feed mixing area daily. Using a loader for this operation will likely result in forage being spilled from the silage storage to the feed center.

Losses are minimized if the silages are loaded and hauled to the feed center. During this operation, it is advised to premix the silage by using a silage de-facer to remove the amount of packed forage needed for the day. Silage de-facers are important in maintaining silage face density and keeping the face vertical as compared with using a loader bucket.

Key Performance Indicators

Feed represents approximately 50% of the total cost of a dairy operation. Feed quality is directly related to milk production. Yet, on most dairy farms, there are a few key performance indicators (**KPI**) that are associated with feed. A list of goals for the feed center might include:

- Minimize feed loss,
- Minimize TMR variation,
- Minimize labor and energy,
- Uniformly mix TMR,
- Uniformly process forage,
- Monitor mixing and delivery accuracy,
- Track feedstuff inventory, and
- Monitor nutrient content and feedstuff quality.

On other aspects of the dairy operations, KPI are often utilized to track the progress of the dairy in relationship to stated goals. When considering the importance of the feeding operation, very little time and effort is expended in developing KPI to evaluate this area. Utilizing feed management software, TMR audits, and feedstuff nutrient analyses can be easily utilized to develop KPI to address the goals stated above.

Conclusions

Feed center design should focus on delivering high quality TMR to the dairy herd. Correctly designed facilities should minimize feed loss while providing adequate space for efficient feed mixing. Dairy farms should utilize available software and technology to accurately track the movement of feedstuffs on the farm and to assess the losses associated with current facilities and management. Data obtained from tracking feed shrink could be utilized to justify capital expenditures for additional equipment or changes to the feed center and associated feed storage. When considering changes to existing feed centers or the design of new feed centers, it is important to consider recent advancements in technology and automation. These advancements may help reduce shrink and increase the accuracy of TMR mixing.

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Table 1. Impact of shrink percentage on the cost of feedstuffs and the estimated annual loss of a 250-cow herd feeding 5 lb of an ingredient.

Price, $/ton	$50		$100		$150		$200	
Shrink, %	Increased Cost $/Ton	Annual Loss*	Increased Cost $/Ton	Annual Loss*	Increased Cost $/Ton	Annual Loss*	Increased Cost $/Ton	Annual Loss*
1	$0.50	$114	$1.00	$228	$1.50	$342	$2.00	$456
3	$1.50	$342	$3.00	$684	$4.50	$1,027	$6.00	$1,369
5	$2.50	$570	$5.00	$1,141	$7.50	$1,711	$10.00	$2,281
8	$4.00	$913	$8.00	$1,825	$12.00	$2,738	$16.00	$3,650
12	$6.00	$1,369	$12.00	$2,738	$18.00	$4,106	$24.00	$5,475
16	$8.00	$1,825	$16.00	$3,650	$24.00	$5,475	$32.00	$7,300
20	$10.00	$2,281	$20.00	$4,563	$30.00	$6,844	$40.00	$9,125

Price, $/ton	$250		$300		$400		$800	
Shrink, %	Increased Cost $/Ton	Annual Loss*	Increased Cost $/Ton	Annual Loss*	Increased Cost $/Ton	Annual Loss*	Increased Cost $/Ton	Annual Loss*
1	$2.50	$570	$3.00	$684	$4.00	$913	$8.00	$1,825
3	$7.50	$1,711	$9.00	$2,053	$12.00	$2,738	$24.00	$5,475
5	$12.50	$2,852	$15.00	$3,422	$20.00	$4,563	$40.00	$9,125
8	$20.00	$4,563	$24.00	$5,475	$32.00	$7,300	$64.00	$14,600
12	$30.00	$6,844	$36.00	$8,213	$48.00	$10,950	$96.00	$21,900
16	$40.00	$9,125	$48.00	$10,950	$64.00	$14,600	$128.00	$29,200
20	$50.00	$11,406	$60.00	$13,688	$80.00	$18,250	$160.00	$36,500

*Annual loss associated with shrink percentage when feeding 5 lb of the ingredient daily to 250 dairy cows.

Table 2. Percent loss of different ingredients based on type of storage facility (Kertz, 1998).

Ingredient	Uncovered Open Piles	Covered 3-sided Bay	Closed Bin
Whole Cottonseed	10 – 20 %	5 -15 %	-------
Dry Meal	5 – 10 %	3 – 8 %	2 – 4 %
Soybean Hulls	12 – 20 %	5 – 10 %	2 – 5 %
Dry Distillers	15 -22 %	7 – 10 %	3 – 5 %
Wet Distillers	15 – 40 %	15 – 40 %	-------

Table 3. Amount of water entering a commodity shed per linear foot due to 1 inch rainfall blowing into the open bays.

		Impact of Reducing Opening to 8 feet		Impact of Reducing Opening to 12 feet	
Height of Open Side (feet)	Gallons moisture entering the commodity shed at full opening	Reduction in gallons of moisture entering commodity bays	Reduction as compared to fully open side wall	Reduction in gallons of moisture entering commodity bays	Reduction as compared to fully open side wall
8	5.0	NA[1]	NA	NA	NA
12	7.5	2.5	33%	NA	NA
16	10.0	5.0	50%	2.5	25%
20	12.5	7.5	60%	5.0	40%
24	15.0	10.0	67%	7.5	50%
28	17.5	12.5	71%	10.0	57%
32	19.9	15.0	75%	12.5	63%

[1]NA = Not applicable.

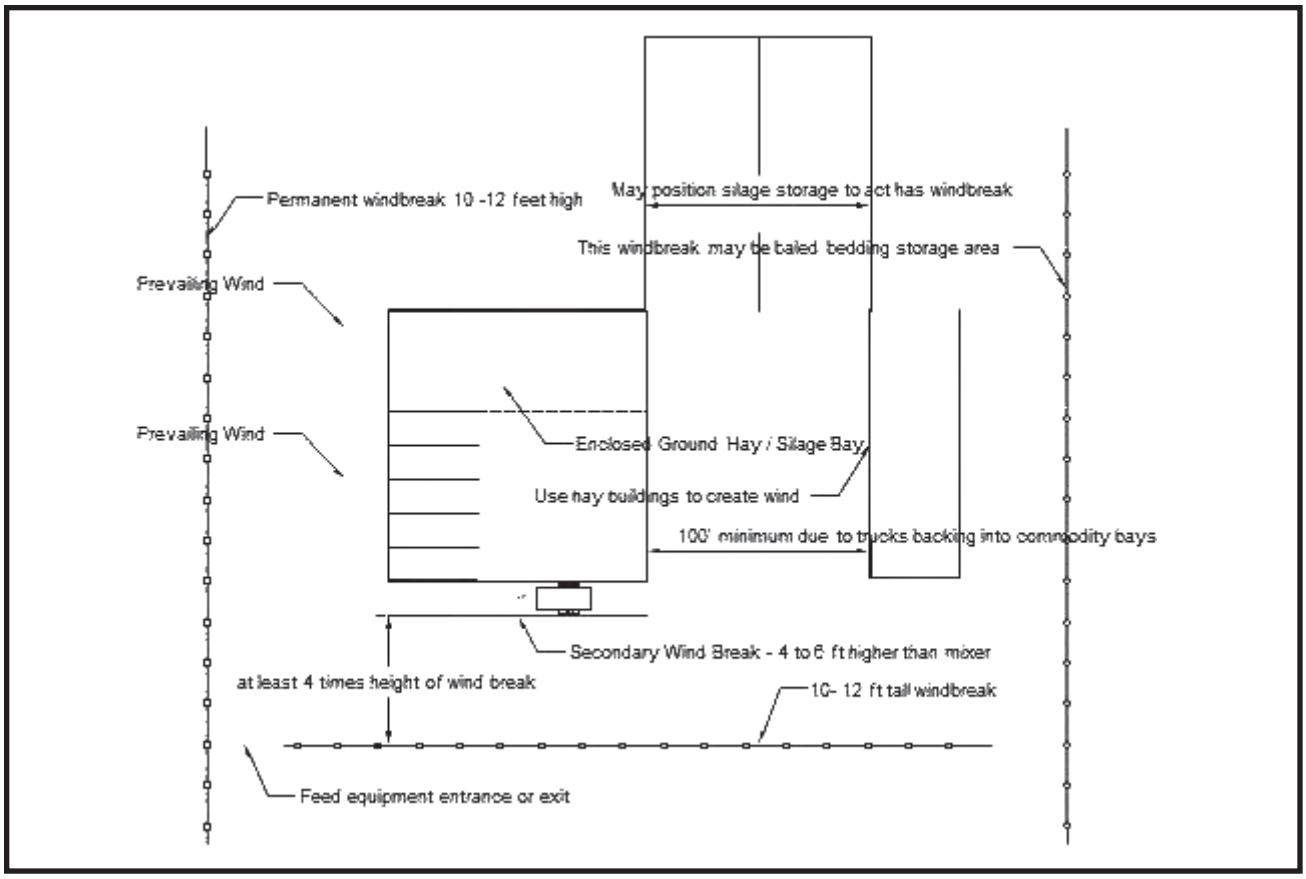

Figure 1. Utilization of buildings and windbreaks to minimize shrinkage due to wind (Harner et al., 2011).

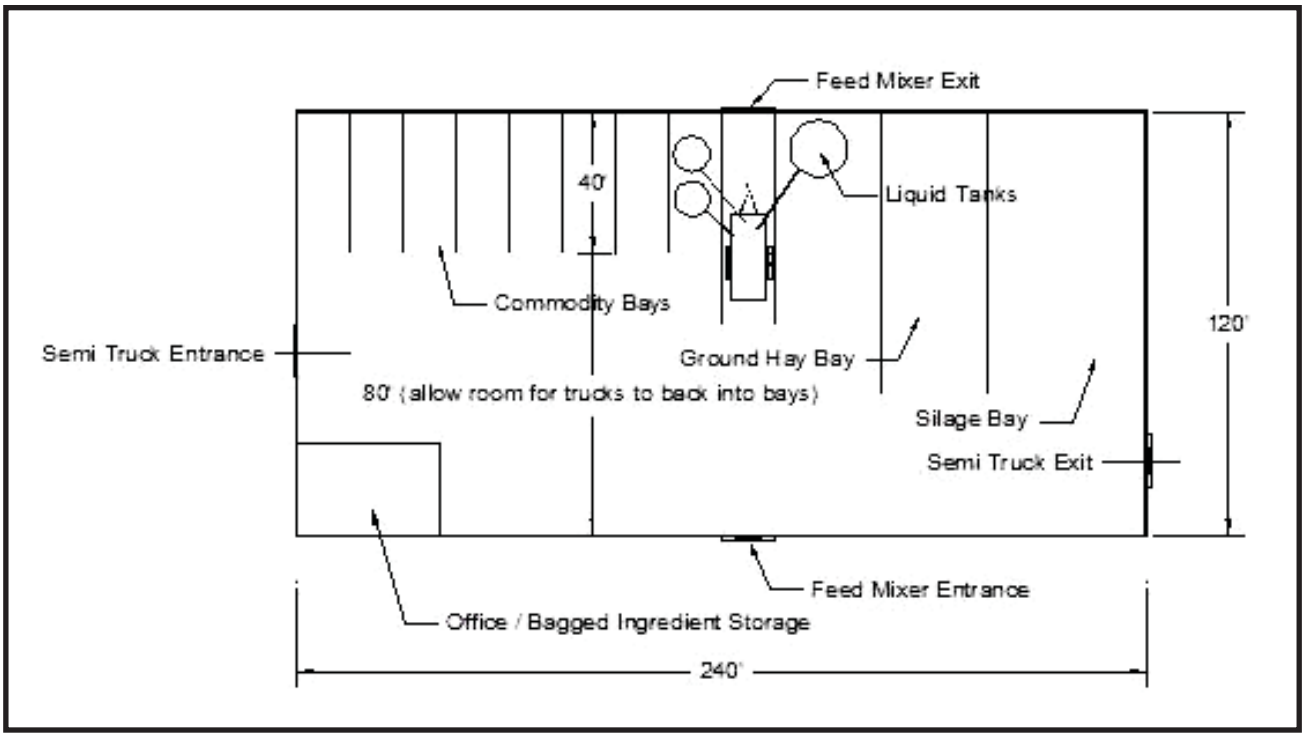

Figure 2. Illustration of totally enclosed commodity building using a portable mixer (Harner et al., 2011).

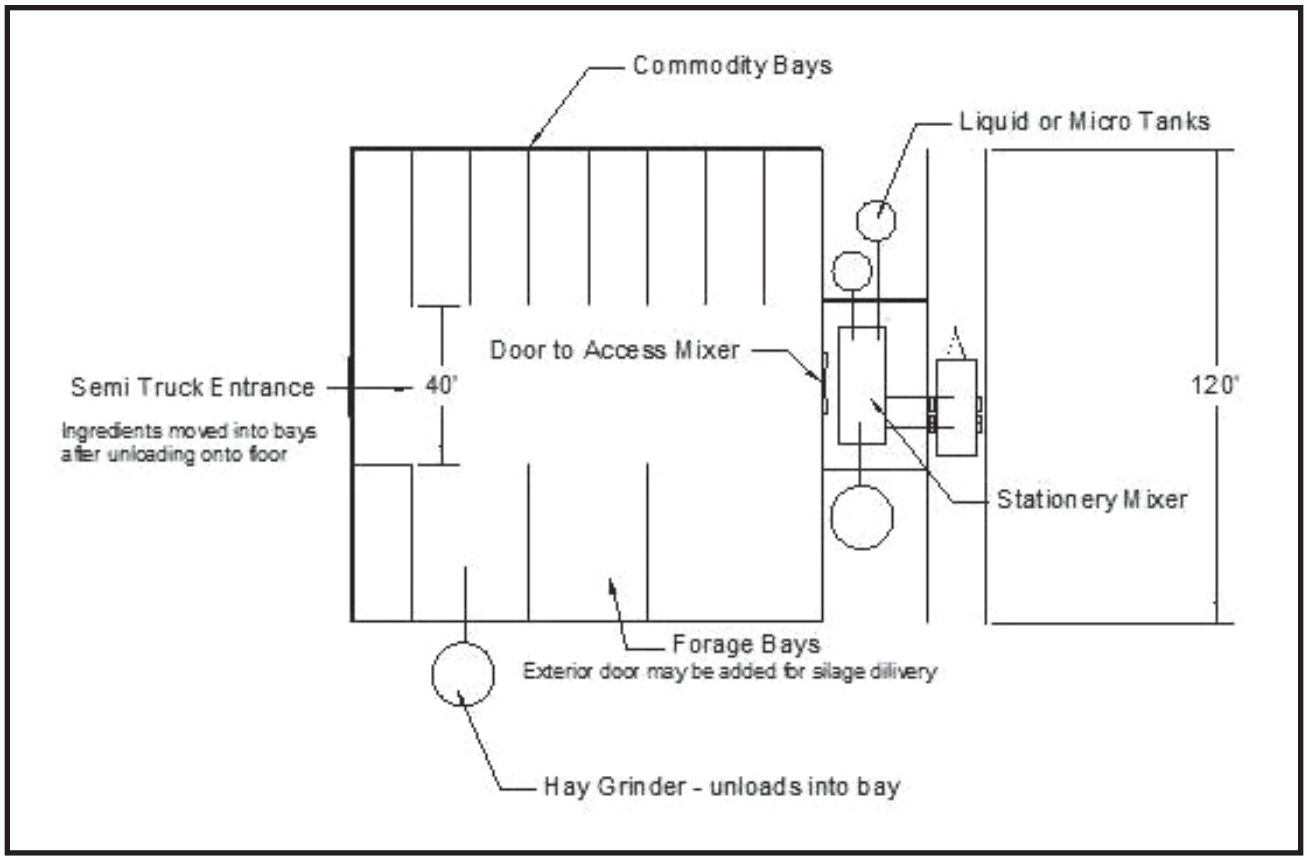

Figure 3. Illustration of totally enclosed commodity building using a portable mixer (Harner et al., 2011).

Don't Drive Into Smoke: Evaluating Data

Normand R. St-Pierre[1]
Department of Animal Sciences
The Ohio State University

Abstract

All observations (data) contain errors. Understanding the sources of these errors is important to reach the correct decision from the data, or else you risk driving into smoke. Some sources of errors are linked to the physical limitations of the measuring devices. This is the type of errors that people working in the physical sciences are accustomed to. Reporting data with more digits than what is legitimate from the precision of the instrument is frequent, but very misleading. People working with live things, such as cows, must understand that data also contain errors because living entities vary. For example, the milk production and body weight of a given cow continuously vary. The sizes of the daily variation of many traits within a cow are such that little can be inferred from one single datum. In addition, there is variation amongst animals treated alike, which is the basis of replication in research. Because cows within a pen are not independent, any factors common to a pen will affect all animals within it. Looking at feed analyses, data contain errors (variation) that are intrinsic to the feed (i.e., true), and errors that are due to the observer. In most instances, the sampling variation in forages is such that little can be inferred from a single sample. Much progress would be made if 2 independent samples were taken and assayed each time a nutritionist need data on feed composition.

Introduction

Little did we know that the first implementation of the transistor by 3 American physicists in 1947 would lead to the mountains of electronic data now inundating the scientific disciplines. Data are now so much embedded into the scientific process that some have expressed doubts whether Einstein would be a successful scientist had his career been delayed by one century. Massive amount of data are invading not only the scientific world but also the management of various processes of which agriculture, in general and dairying in particular, have vastly benefited from. We have reached a time when observations must be quantified in the form of data if they are to carry credibility and be acted upon. Unfortunately, too often people forget that data contain inherent errors, that these errors are of many types, and which in the end, substantially affects their interpretation. In this paper, we review the different types of errors using different examples. This leads us to many cautions regarding possible misuse and abuse of data.

Data Contain Errors

Imagine for a second that you are part of a photo safari in the Australian Outback with the specific goal of taking pictures of *Macrofus rufus*, better known as red kangaroos. Soon after you disrupted a large mob of kangaroos

[1]Contact at: 2029 Fyffe Court, 221A Animal Science Building, Columbus, OH-43210-1095, (614) 292-6507, FAX: (614) 292-1515, Email: st-pierre.8@osu.edu.

from their afternoon nap, you find yourself hanging for dear life in the passenger seat of an Australian ute (better known in North America as a pick-up truck), as the driver speeds through the arid landscape in reckless pursuit of the bouncing animals. Before long, a large male is isolated from the rest of the group, bouncing at full speed in a direction parallel to that of your vehicle. The animal is perfectly positioned, perpendicular to your vehicle. You take your video-camera out and point it toward the animal through the side window. For sure, the animal is bouncing up and down: that's how kangaroos "run". But as you put the camera's viewfinder to your eye, the animal appears to be bouncing even more. That's because the bounces of your camera are being added to the bounces of the kangaroos. The total (apparent) bounces are made of two parts: the intrinsic or true bounces of the kangaroo, and the extrinsic (or virtual) bounces of the camera. If you try to measure the true height of a bounce of a given kangaroo, you must factor out the bounces of the camera/instrument doing the measurement. Likewise, all measurements contain errors. As in our kangaroo example, some error components represent true variation, whereas other components are linked to the observer and add to the noise.

Errors in Measuring Milk Yield and Body Weight

Let's take the task of measuring milk yield and body weight in a herd as examples. What are the different types of errors?

Physical measurement errors

Even if the total milk production from a given cow at last milking is put in a milk can, which is weighed, we still don't know the exact value of her milk production. The precision of our measurement is determined by the precision of the measuring instrument. We might be able to say that her production was above 41 lb and less than 42 lb, or that it was "around" 41.2 lb, but we likely will not have a scale with a precision down to ±1 μg. For management purposes, we know that this degree of precision is not needed, but that doesn't negate the fact there is, and always will be, some measurement errors. This type of errors is what people working in the physical sciences generally have to deal with. In measuring the diameter of (say) a bolt, ever more precise measuring devices can be used, but an error always remains. Repeated measurement of the same bolt produces slightly different measurements (data) of the diameter of the bolt, but this is not due to the one bolt changing its diameter. This type of error is entirely due to the observer (the camera in our kangaroo example). The physical error involved in measuring milk yield may or may not be of practical consequence; this depends on the precision of the measuring device. But for other types of data acquired on a dairy farm, the measurement error may be consequential. Think of the scales on mixer wagons; typically, what is their precision? Most of the scales I have worked with have a precision of ±10 lb. Hence if the scale indicates that 320 lb of supplement were added to the mixer, the correct interpretation would be that somewhere between 310 and 330 lb of the supplement were added. This error may no longer be insignificant. Likewise, most livestock scales also have an error of ±10 lb. Say that you weigh your animals once per day (automatic scale on the return alley). The weight on a given animal will have a physical measurement error of ±10 lb each time the animal is weighed. If Bertha weighed 1,350 (±10 lb) yesterday and 1,340 (±10 lb) today, I cannot conclude that she has lost 10 lb in 1 day! To gain precision would require a more precise scale.

Unfortunately, data are often being reported with considerably more digits than what is warranted by the precision of the instrument

(or method) generating the data. There is no reason to report in vitro digestibility of a single forage sample with 2 decimal digits when the error of the method is somewhere around ±5%.

Variation in the unit itself

In the physical sciences, what is being measured doesn't change: the diameter of the one bolt being measured doesn't change (we ignore the effect of changing temperature, etc., for the sake of simplicity here). But biological entities keep changing through time. We know that we have a physical measurement error when we measured Bertha's milk production yesterday morning and that we also had physical measurement errors when we measured her milk production this morning. But these errors generally pale in comparison to the size of the variation (errors) due to the cow (the biological unit). On a well-managed farm, the standard deviation (**SD**) of daily milk yield on the same animal over a period of one week is generally in the 7 lb/day range. So if Bertha produced 100 lb yesterday and 95 lb today, we really cannot say that she is down 5 lb/day in production. Our data say that the amount measured today was 5 lb less than the amount measured yesterday, but we really cannot say much about the production status of Bertha.

The total weight of a cow is the sum of her true physical weight (generally expressed as empty body weight) plus all of her gut and bladder contents (plus milk in her udder, which technically is no longer part of her body – at least for some of the milk). Graduate students doing their first digestion trial with full collection of feces and urine are always amazed at the amount of feces and urine that an average cow excretes in a day (roughly 150 lb). Whenever Bertha drinks, she easily gains 10 lb (she easily drinks 200 to 250 lb/day of water). Whenever she defecates, she looses 10 lb. All of a sudden, the error with a one point in time measurement of her body weight is no longer just the precision of the scale (±10 lb), but also the variation of Bertha's apparent weight (±10 lb), which is not really Bertha's true weight to begin with.

Variation among biological units

Whenever someone says that the cows in the first pen are producing (say) 90 lb/day, they really mean that they are *averaging* about 90 lb/day. Of course, by now we understand that the 90 lb is an approximation because of the measurement error and the variation within a cow. But there is more error than that when we look at milk production for a given pen. In that pen, there are some Berthas producing over 110 lb/day, while other Berthas are below 70 lb/day. Hence, the pen contains at a minimum the sum of the errors of all the animals it contains. Fortunately, some of these errors cancel each other. *If* all the cows in a 100-cow pen were *independent* and *if* the daily SD on each animal is 7 lb/day, then we would expect the SD of milk production for the whole pen to be $7/\sqrt{100} = 0.7$ lb/day. In practice, the SD of milk production from a 100-cow pen is always greater than that; sometimes much greater than that. The reason being that cows within a pen are not independent of one another. A pen of cows is not milked at exactly the same time every day of the week: "things" happen… If the waterline to the high pen froze during the night, pretty much all Berthas in that one pen will be down in milk the next day, and they will all have lost apparent weight. A frozen pipe is an easily identifiable factor, but there are 50,000 things that affect cow production – some of which are known, whereas others are not. As nutritionists, we tend to see things through the glasses of nutrition. When we investigate the cause for an apparent drop in milk production, we tend to focus on nutrition because that's what we do and sometimes sell. I am afraid, however, that all too

often, we fix non-existent problems by changing the nutrition (we cure a non existent "disease"), or we fix a self-curable, non-nutritional problem by changing the nutrition. The analogy that I have used is that of a kid coming back from school not feeling well. You give him a teaspoon of a magic elixir and send him to bed. He feels great the next morning. Maybe the kid was just dead tired!

The issue with the pen variation is that too many people deny that it even exists. This is exactly what is being implied by anybody who conducts "field research" with one pen fed a control diet and one pen fed the "treatment" diet, and uses the individual cows as experimental units, as if they were independent of one another. How often have you heard "the 2 pens were identical"? Well, if they were, the variation between replicated pens would be very, very small and an experiment with 2 pens on a control diet and 2 pens on a treatment diets should detect statistically significant differences that would be incredibly small. Four pens of 100 cows each would detect differences in milk yield of less than 0.1 lb/day in a 60 day production trial. To my knowledge, every time that replicated pens have been correctly used in a field trial, the power of the experiment was considerably less than one would expect if the pen had a small effect. The pen effect is real and considerably greater than what most people think. Hence, the so-called experiments with one pen per treatment lead to pure statistical fantasy, vastly incorrect P-values, amounting to a momentous drive through a big cloud of smoke. In fact, one would suspect that the experimenters may have inhaled too much of the smoke themselves. Reporting wrong probabilities is far worse than not reporting any probability at all.

Errors in Feed Composition

Suppose that you receive 5 loads of distillers dried grains with solubles (**DDGS**). You sample each one and send the 5 samples to a feed laboratory and request a neutral detergent fiber (**NDF**) assay. Results for the 5 samples are: 27, 29, 30, 31, and 33% NDF. The mean (arithmetic average, which represents the expectation) of the 5 samples is 30%. But how would you express the variation between the 5 samples? One could use the range, which is the difference between the maximum and the minimum values. In our example, the range is 33 – 27 = 5%. This gives an idea of the variation, but it is sensitive to only the 2 extreme values: the NDF content of the 3 other samples are not part of the variation assessment. This makes the range very sensitive to outliers, which is not a good thing. Statisticians have long used a measure of variation that expresses the spread of observations in a manner that is less sensitive to outliers than the range and also uses all the measurements in its determination. This is the variance. Expressed in words, it is the sum of the squares of the difference between each measurement and the mean, with said sum divided by the total number of observations minus one. For our simple example:

$$Var(NDF) = \frac{(27-30)^2 + (29-30)^2 + (30-30)^2 + (31-30)^2 + (33-30)^2}{5-1} = 5$$

The immediate issue one has with the variance is with its units of expression: the result (i.e., 5) is not in the same units as the measurements. The variance is not 5% because the expression is a sum of squared percentages: it is 5%-squared, a highly inconvenient, if not completely mentally, intractable unit. The solution is simply to take the square root of the variance (i.e., the SD). Hence, in our example:

$$SD(NDF) = \sqrt{5} = 2.23$$

The standard deviation is expressed in the same units as the measurements themselves. Therefore, we can summarize the results from our 5 samples as: mean = 30%, SD = 2.23%.

If the sample is moderately large and follows what is known as the normal distribution (the infamous bell-shaped curve), then approximately 2/3 of the observations will be within +/- 1 SD of the mean, and approximately 95% will be within +/- 2 SD of the mean. The sample in our example was not very large (n = 5), but we would expect that approximately 67% of all loads of DDGS to have an NDF between 30 – 2.23 = 27.8% and 30 + 2.23 = 32.2%.

The reason that we examined variance as an expression of variation is because we want to decompose the total variation in measurements into separate components. However, these components are additive only in the variance scale and not in the standard deviation scale. As long as the components (factors) are independent, we have:

$$\text{Var(whole)} = \text{Var(factor A)} + \text{Var (factor B)} + \ldots$$

but

$$\text{SD(whole)} \neq \text{SD(factor A)} + \text{SD(factor B)} + \ldots$$

This will be important in our understanding of the factors contributing to the variances of various feedstuffs and their partitioning into components.

Sources of variation in forages: short-term

Over a total of 14 consecutives days, we had nutritionists and trained farm personnel take multiple samples of corn and haycrop silages on 14 Ohio and Vermont farms (St-Pierre and Weiss, 2015). To be more precise, the sampler took 2 independent samples of each forage on each farm and on each day of the 14-day sampling period. At the lab, each assay was run in duplicate on each of the 2 samples from each silage, from a given farm on a given day. This elaborate sampling scheme allowed us to separate the total variance of a given nutrient into 4 distinct components. First is the variation due to farm. This component is easy to understand: it represents how much the true values of a given nutrient (e.g., NDF) in corn and haycrop silages vary from farm to farm. The second component is the variation due to day. This component quantifies how much the true values of a given nutrient in corn and haycrop silages vary from day to day on a given farm. The third component quantifies the variation due to sampling, or how much the true value of a given nutrient in corn or haycrop silages varies from sample to sample taken on the same farm and on the same day. The fourth and last component is labeled 'analytical' and identifies the variation within a single lab of a given assay on a set sample. One should note that all assays were conducted in our research lab. Hence, the variation that would exist between assays conducted on the same sample but by different labs was not present in our study. Depending on the assay, the lab-to-lab variation can be substantial. Some components of this variance decomposition are real (intrinsic): the variation due to farm and day represent true variation in the composition of the forage. Other components are extrinsic (virtual): the variation due to sampling and analytical variance are part of the noise inherent to the measurements. The variation due to laboratory would be added to the virtual components had it been measured. As in the Australian safari analogy, the virtual components do not contribute to the true feed variation, but they add to the total, overall perception of variation. Conceptually, all the variation could be in the virtual components, indicating a perfectly uniform feed that appears to vary just because of the errors in the multiple steps of the measurements: the kangaroo would be completely still, but the binoculars are bouncing all over the place.

Table 1 summarizes the measurements for 4 nutrients/chemical groups for corn and

haycrop silages. The means are close to what one would find in standard tables of feed composition, such as those of NRC (2001). The table also shows that there is considerable variation around the means. The coefficient of variation (**CV**) is simply the ratio of the SD divided by the mean, multiplied by 100 to have a metric expressed as a percentage. For corn silage, the CV of DM (14.1%) is about the same as the CV of ash (14.0%). But the variance components are very different between the two. Table 2 shows the decomposition of the variance for the 2 feeds and the 4 nutrients/chemicals. The only components relevant to a given farm are the variation due to day, sampling, and analytical. How much a forage varies from farm to farm doesn't affect how much it varies on my farm. Although the CV of DM and ash in corn silage are nearly identical, the sources of the variation are entirely different. For a given farm, nearly half (46.8%) of the DM variance is from day-to-day (true variation). Hence, DM of corn silage should be measured frequently. The situation is entirely different for ash where only 17.8% of the variance is due from day-to-day variation and over 80% is due to sampling (i.e., noise). Therefore, frequent measurements of ash in corn silage would be mostly a waste of time and money.

For all nutrients and both silages, analytical variation was the smallest contributor to variation within a given farm. In general, the SD for assay were substantially greater for corn silage than haylage. This can be explained by the greater degree of difficulty in sub-sampling corn silage in the lab due to the large differences in nutrient composition among particles of corn silage. On-farm sampling was the greatest source of variation for nutrients other than DM. The substantial amount of observer variation (sampling + analytical) relative to the amount of true day-to-day variation indicates the followings:

1. A change in nutrient composition between 2 samples of silages taken over a short period of time is often just noise (i.e., not true). Modifying the diet on an apparent change in composition from one forage sample is generally not wise. Most of the time you will be driving through smoke!

2. Much progress would be made in controlling variation in forage composition if a minimum of 2 *independent* samples were taken and sent to the lab any time that the forage is sampled. Here, the word *independent* is critical. The whole sampling process has to be repeated.

Sources of variation in forages: long-term

In a parallel study to the one we have already briefly described, 14 nutritionists took monthly samples of every major feed (forage and concentrates) and high group TMR on 47 farms throughout the United States (St-Pierre and Weiss, 2015). Results for the mean composition and variance components of the forages that were sampled and for the major nutrients are reported in Table 3. As expected, monthly variation was greater than daily variation. Although sampling variation generally made up a smaller proportion of within-farm variation when silages were sampled over a 12-mo period than when sampled over a 2-wk period, sampling variation was still substantial. This suggests that duplicate, independent samples and averaging is beneficial for many different sampling schedules.

Conclusions

A number is meaningless unless you have quantified its error.

Acknowledgement

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Table 1. Descriptive statistics for corn silage and haycrop silages sampled over 14 consecutive days on 11 Ohio and Vermont farms (% of DM) (St-Pierre and Weiss, 2015).

Item	Mean	SD	CV	Range	10th to 90th Percentile
Corn silage (n = 504)					
DM	37.0	5.23	14.2	26.2-49.0	30.3-44.0
NDF	39.1	4.03	10.3	30.8-50.9	34.3-45.0
Starch	32.8	4.33	13.2	14.3-44.0	27.1-38.6
Ash	3.57	0.50	14.0	2.4-8.3	3.1-4.2
Haycrop silage (n = 504)					
DM	41.7	8.00	19.2	28.3-70.5	31.9-52.1
NDF	49.9	6.61	13.2	32.7-65.2	43.0-59.5
CP	16.3	2.72	16.7	10.8-23.2	12.7-19.5
Ash	9.30	1.86	20.0	6.3-15.3	6.9-11.6

Table 2. Farm, sampling, analytical, and true day-to-day variation in nutrient composition (% of DM) of corn silage and haycrop silage sampled over 14 consecutive days on 11 Ohio and Vermont farms (St-Pierre and Weiss, 2015).

	SD				% of within-farm variance		
Item	Farm	Day	Sampling	Analytical	Day	Sampling	Analytical
Corn silage							
DM	5.00	1.21	0.96	0.86	46.8	29.5	23.7
NDF	3.68	1.31	1.61	0.89	33.6	50.9	15.5
Starch	4.22	1.29	2.10	0.82	24.7	65.3	10.0
Ash	0.34	0.16	0.34	0.05	17.8	80.6	1.6
Haycrop silage							
DM	7.37	2.71	1.89	0.74	64.0	31.2	4.8
NDF	6.97	1.67	1.61	0.75	46.9	43.6	9.5
CP	2.47	0.59	0.89	0.44	26.1	59.4	14.5
Ash	1.86	0.33	0.59	0.10	23.4	74.7	1.9

Table 3. Mean composition and estimates of total, farm-to-farm, and within-farm variation (i.e., residual) for various forages on 47 farms over a period of 12 months (St-Pierre and Weiss, 2015).

			Standard Deviations		
	Mean	10-90%tile	Total	Farm	Residual
Corn silage (n = 627)					
DM, %	34.1	29.8 – 38.7	3.70	2.54	2.83
CP, %	8.00	7.0 – 8.9	1.03	0.84	0.60
NDF, %	40.8	36.3 – 46.4	4.23	3.81	2.66
Ash, %	4.3	3.1 – 6.6	1.46	1.29	0.62
Legume hay (n = 263)					
DM, %	88.4	85.3 – 91.6	3.37	2.04	2.80
CP, %	21.4	18.5 – 24.4	2.41	1.51	2.00
NDF, %	36.7	31.0 – 43.3	5.03	3.45	3.92
Ash, %	10.9	9.1 – 12.8	1.95	0.95	1.74
Legume silage (n = 453)					
DM, %	44.2	32.8 – 55.6	9.12	7.74	6.22
CP, %	21.7	19.0 – 24.2	1.99	1.10	1.68
NDF, %	40.0	34.7 – 45.8	4.55	3.02	3.51
Ash, %	11.1	9.3 – 13.4	1.80	1.38	1.22
Mixed hay (n = 41)					
DM, %	86.1	82.7 – 88.4	2.95	2.26	2.37
CP, %	15.2	10.2 – 19.6	3.39	2.61	2.69
NDF, %	54.8	48.2 – 61.9	5.83	0	5.83
Ash, %	8.7	7.2 – 10.4	1.72	1.13	1.43
Mixed silage (n = 101)					
DM, %	43.5	31.2 – 58.5	10.45	8.63	7.80
CP, %	18.1	15.6 – 20.3	1.92	0.97	1.70
NDF, %	48.3	43.2 – 53.8	4.67	2.81	4.00
Ash, %	9.7	8.5 – 11.2	1.27	0.77	1.04
Small grain silage (n = 94)					
DM, %	35.2	29.8 – 40.3	7.08	9.20	3.47
CP, %	12.8	9.1 – 17.2	3.17	3.32	1.63
NDF, %	53.9	46.1 – 63.1	6.56	5.82	3.73
Ash, %	12.8	10.1 – 15.0	3.73	3.13	2.91
Straw (n = 127)					
DM, %	88.0	84.0 – 92.3	5.14	1.44	4.95
CP, %	4.8	3.4 – 6.6	1.48	0.43	1.42
NDF, %	78.7	72.1 – 83.1	5.06	3.83	3.75
Ash, %	7.6	4.8 – 11.6	2.84	2.57	1.47

What We Need to Know to Improve the Utilization of Fat in Diets

Tom Jenkins[1]
Department of Animal & Veterinary Sciences
Clemson University

Abstract

High fat ingredients are commonplace in diets fed to dairy cattle and include commercial fat supplements designed for convenient transport and mixing, oilseeds such as cottonseed or soybeans, or byproducts such as distillers grains, tallow, or food processing wastes. Strategies for optimizing benefits from feeding additional fat remain focused today, as in the past, on minimizing problems with intake, rumen function, and digestibility. All of these limitations are a function of several important fat attributes, including its fatty acid content, the relative proportions of saturated and unsaturated fatty acids, the concentration of free fatty acids, accessibility of the fat to microbial exposure, and the extent of chemical alteration such as calcium salts. When fed properly, animal performance benefits from feeding additional fat are well documented and extend beyond just the expected improvements in lactation performance based solely on the fat energy value. These additional benefits have included improvements in efficiency, reproductive performance, and even the immune system and disease resistance. However, many exciting future benefits of feeding additional fat to dairy cattle may be on the horizon. These might include managing the rumen production of biohydrogenation trans intermediates to take advantage of metabolic benefits, or managing the absorption of selected fatty acids to enhance their function as precursors for signaling molecules, and perhaps even feeding fatty acids prepartum for fetal imprinting and potential lifetime production benefits.

Introduction

The information needed to improve the utilization of fat for dairy cows is dependent on whether the timeframe for utilization is on the present or on the future.

Present day fat uses:

- Maximize fat as an energy source for milk yield or to restore body weight,
- Avoid problems with intake, rumen function, or milk components, and
- Take advantage of reproduction and possible immune benefits.

Possible future fat uses:

- All the above present day benefits plus,
- Manage the rumen production of biohydrogenation trans intermediates to take advantage of their physiologic and metabolic benefits,
- Manage ratios of selected fatty acids to control interactions that enhance their function as precursors for signaling molecules, and
- Feed selected fatty acids prepartum for fetal imprinting and potential lifetime production benefits.

[1]Contact at: 117 Poole Agricultural Center, Clemson, SC 29634, (864) 656-2707, FAX: (864) 656-5151, Email: tjnkns@clemson.edu.

Future fat benefits are backed by scientific findings and already have documented benefits in nonruminant species, including humans. The prospects for dairy cattle are even more exciting given the complexity of fatty acid isomers synthesized daily by the rumen microbial population and their possible transfer to body tissues. However, because the volume of information is too large to cover both present and future aims, and there remains a need to better utilize fats for present day needs, this paper will focus only on some main points that enhance present day fat utilization opportunities.

To address present day issues, this paper will take the approach that a nutritionist is presented with an unknown fat source for possible inclusion in a dairy total-mixed ration (**TMR**) and examines the information that should then be obtained to improve its utilization. Some of the key points and a brief explanation are given below.

Understand the Fat Characteristics Affecting Utilization

Total fatty acid content

The fatty acid portion of fat supplements provides all the energy and tissue benefits so it is important to verify its content. Caution is advised when obtaining fats from unknown vendors to be sure that considerable impurities do not still remain in the product that lower the fatty acid and energy contents. Fatty acid content of fat supplements can be diluted by nonfatty acid components that have lower or no energy value. Fat content has traditionally been determined as the ether-extractable component of the feed. When defined in this manner, there can be considerable variation in fat content among feed ingredients. Among the lowest is the ether extract in grains and forages. In addition to extracting fat, ether also extracts some carbohydrate, vitamins, and pigments. Therefore, the ether extract in cereal grains, forages, and the total mixed ration often contain less than 60% fatty acids (Palmquist and Jenkins, 2003). Because of the problems inherent with ether extract, many laboratories have moved to determining fatty acid content of feeds instead of ether extract.

Most plant oils contain 100% ether extract, with a high percentage of fatty acids. The impurities extracted, such as water and pigments, are removed during refining, leaving the commercial plant (soybean oil, canola oil, corn oil, etc) and animal (tallow, grease, etc.) fats with mainly triglycerides consisting of 90 to 93% fatty acids. The remaining 7 to 10% is mainly glycerol. Glycerol is readily utilized as an energy source, but only contains the energy of carbohydrates. Rather than guessing, it pays to have a sample of the fat analyzed for fatty acid content and profile.

Fatty acid composition

Fatty acids are chains of carbons that end in an acid group, or carboxyl group as is referred to in biochemistry. An example of a common fatty acid is stearic acid with 18 carbons and no double bonds.

Fatty acids, such as stearic acid, are referred to as saturated (Figure 1) because all the carbons are holding the maximum number of hydrogens possible, or the fatty acid is “saturated” with hydrogen. Stearic acid is low in plant oils but present in higher amounts in animal fats, particularly in fats obtained from ruminant species, such as beef tallow.

Oleic acid and linoleic acid are examples of unsaturated fatty acids containing one or more double bonds. Oleic acid has a single double bond between carbons 9 and 10, and

is referred to as a monounsaturated fatty acid. Linoleic acid is a polyunsaturated fatty acid containing two double bonds between carbons 9 and 10, and between carbons 12 and 13. Oleic acid is the predominant fatty acid in animal fats and some plant oils (Table 1). Linoleic acid is the predominant fatty acid in many plant oils, including cottonseed oil, soybean oil, and corn oil. Linolenic acid is the predominant fatty acid in most forage species, followed by linoleic acid (Hatfield et al., 2007). Linolenic acid follows a similar seasonal pattern (Bauchart et al., 1984); as linolenic acid declines over the summer months, percentages of palmitic and linoleic acid increases.

Saturated and unsaturated fatty acids have different effects on rumen function and also do not have equal intestinal digestibilities. Therefore, information on fatty acid composition will help users to develop reasonable expectations on utilization of the fat source and animal performance.

Percentage of free fatty acids

Lipid extracted from plants contains fatty acids that are predominately bound to the carbon backbone of glycerol. In vegetable oils all three glycerol carbons have fatty acids attached giving the name triglycerides. Forage lipids more commonly have fatty acids attached to only two of the three glycerol carbons. Fatty acids released from the glycerol backbone are called free fatty acids (**FFA**). Fatty acids can be released from glycerol by lipase enzymes of plant or ruminal origin.

Triglycerides often exhibit reduced antibacterial effects compared to an equal quantity of free acids. Methane production in cultures of washed ruminal microbes, for example, was inhibited more by the addition of linseed oil fatty acids than by the addition of an equal amount of linseed oil triglycerides (Demeyer and Henderick, 1967). In another in vitro study, tallow added to cultures as free acids reduced the ratio of acetate to propionate by 43 to 66% compared to only a 4 to 6% reduction in the ratio when tallow was added in triglyceride form (Chalupa et al., 1984). A recent study with lactating dairy cows showed no differences in milk or components when diets were supplemented with 2% soybean triglycerides or soybean FFA (Boerman and Lock, 2014). Discrepancies between in vitro rates of lipolysis versus in vivo rates may account for part of the esterification effect. Lower rates of lipolysis would release FFA over a longer time period, thus diminishing the effects on fermentation and rumen lipid metabolism.

Calcium salts

Calcium salts of fatty acids were originally developed in the early 1980's at The Ohio State University as a form of rumen-inert (by-pass) fat to avoid ruminal fermentation and digestion problems. As long as the bond with Ca is maintained in the rumen, fatty acids do not express antimicrobial effects or interfere with the microbial population. Release of fatty acids from the Ca bond is enhanced as ruminal pH declines. The release by low pH also is greater as unsaturation increases.

By the early 1990's, calcium salts were receiving some attention for partially escaping biohydrogenation. For instance, Wu et al. (1991) reported 49% biohydrogenation of fatty acids from calcium salts of palm oil compared to 80 and 62% biohydrogenation for animal-vegetable fat and the control diet, respectively. Klusmeyer and Clark (1991) similarly found lower biohydrogenation for diets supplemented with calcium salts compared to a control diet. Based on the results of these early studies, several rumen-protected fat products have

emerged commercially in recent years that vary in the type and concentration of polyunsaturated fatty acids. If oilseeds are excluded, it is difficult to locate rumen-protected fat sources that are commercially available other than those containing calcium salts of unsaturated fatty acids.

How Fat Characteristics Can be Used to Overcome Limitations and Improve Utilization

Intake limitations

Fat added to dairy rations can reduce feed intake, which can greatly reduce or even eliminate a positive production response. Even as little as 0.5 kg (1.1 lb) less feed intake can neutralize any energy advantage coming from typical levels of added fat, thus preventing a positive production response. Reductions in feed intake have been reported for a wide variety of fat sources, and often the intake depressions are less severe for animal fats than for vegetable oils or some commercial fat supplements. In general, intake depression problems were more severe when fat supplements were higher in unsaturated fatty acids than when they were higher in saturated fats acids.

For instance, across a summary of more than 20 dairy studies feeding tallow or grease, only two studies showed significant depressions in feed intake (Allen, 2000). A summary of the literature by Onetti et al. (2004) showed that the intake effects of tallow were dependent on forage source. Tallow added to corn silage diets reduced intake and failed to increase milk production. However, a positive milk production response was seen when tallow was fed in alfalfa-based diets, or in diets with similar alfalfa and corn silage proportions. Rabiee et al. (2012) also reported greater decreases in DMI for oilseeds and Ca salts of unsaturated fatty acids than for saturated fatty acids or tallow (Figure 2).

Several causes for the depression in feed intake by unsaturated fatty acids are under consideration. These include reduced gut motility, reduced acceptability of diets with added fat, release of gut hormones, and oxidation of fat in the liver (Allen, 2000). Refer to Allen (2000) for a description of each factor and a comparison of fat sources. Gut hormones continue to receive considerable attention as regulators of food intake. Depressed feed intake in cows fed fat supplements has been attributed to changes in cholecystokinen (Choi and Palmquist, 1996) and glucagon-like peptide 1 (Benson and Reynolds, 2001). Other peptides of gut origin, such as peptide YY, pancreatic glucagons, glicentin, and oxyntomodulin, have been linked to reduced feed intake patterns in animals fed fat (Holst, 2000). Past work has shown that abomasal infusion of unsaturated fatty acids causes greater feed intake depression than infusion of saturated fatty acids (Drackley et al., 1992; Bremmer et al., 1998). A study by Litherland et al. (2005) showed that the intake depression was greater following abomasal infusion of unsaturated free fatty acids than it was following infusion of unsaturated triglycerides. Also, as intake declined in the study by Litherland et al. (2005), the concentration of plasma glucagon-like peptide 1 increased but plasma concentration of cholecystokinen did not change.

Rumen limitations

Fat supplements must be limited to just a few percentage units in ruminant diets to avoid ruminal digestibility problems resulting from antimicrobial activity of their constituent fatty acids (Stoeffel et al., 2015). Fat sources that have the potential to cause ruminal fermentation problems are referred to as rumen-active fats. Antibacterial effects of fatty acids in the rumen are complex and depend on interrelationships among fatty acid structure, fatty acid concentration, the presence of feed

particles, and rumen pH (Jenkins, 2002). Fatty acid structural features that enhance antibacterial activity in the rumen include a free acid group on the carbon chain and the presence of one or more double bonds (Table 2). Therefore, enhancing FFA and fatty acid unsaturation in fat sources generally reduces the amount that can be included in cattle diets. Several commercial fats minimize ruminal fermentation problems by enhancing the concentration of the less antibacterial saturated fatty acids. These are referred to as rumen-inert fats to signify their lower antimicrobial effects in the rumen.

The microbial population in the rumen also is responsible for extensive transformation of dietary lipid. Lipid transformations include lipolysis to release free fatty acids from complex plant lipids, and biohydrogenation to convert unsaturated fatty acids in plant matter to more saturated lipid end products. The biohydrogenation of linoleic acid in the rumen (Figure 3) begins with its conversion to conjugated linoleic acid (**CLA**). In this initial step, the number of double bonds remains the same but one of the double bonds is shifted to a new position by microbial enzymes. Normally, the double bonds in linoleic acid are separated by two single bonds, but in CLA, the double bonds are only separated by one single bond. Many types of CLA are produced in the rumen of dairy cows (Bauman and Lock, 2006), but a common CLA produced from biohydrogenation of linoleic acid is *cis*-9, *trans*-11 C18:2. Recent research results link milk fat depression with the formation of bioactive *trans* fatty acid intermediates produced from biohydrogenation (**BH**) of unsaturated fatty acids by the rumen microbial population. Among the most potent intermediates causing milk fat deprression are several CLA isomers, such as *trans*-10, *cis*-12. Baumgard et al. (2000) reported that *trans*-10, *cis*-12 infused post-ruminally in lactating dairy cows decreased milk fat content 42% and milk fat yield 48%. *Trans*-9, *cis*-11 CLA and *cis*-10, *trans*-12 CLA were also reported to inhibit milk fat synthesis in dairy cows (Sæbø et al., 2005; Perfield II et al., 2007), with the former causing a 15% reduction in milk fat yield.

As biohydrogenation progresses, double bonds in the CLA intermediates are then hydrogenated further to trans fatty acids having only one double bond. *Trans* double bonds only differ from *cis* double bonds in the placement of the hydrogens. The hydrogens are located on opposite sides of the double bond for *trans* fatty acids, but on the same side of the double bond for *cis* fatty acids. Although the difference in structure between *trans* and *cis* fatty acids appears small, it causes significant differences in their physical and metabolic properties. A final hydrogenation step by the ruminal microbes eliminates the last double bond yielding stearic acid as the final end product. As a result of biohydrogenation, there is extensive loss of unsaturated fatty acids from the mouth to the duodenum of the animal.

Intestinal digestibility limitations

Low intestinal digestibility of fatty acids in fat supplements can be another factor reducing their digestible energy (**DE**) value for ruminant diets. Differences in DE values among fat sources published in NRC for Dairy Cattle (2001) are due mainly to differences in their true digestibilities. True digestibilities assumed by NRC for Dairy Cattle (2001) ranged from a high of 86% for vegetable oils and calcium salts to a low of 43% for partially-hydrogenated tallow. Tallow was assigned an intermediate digestibility of 68% in NRC for Dairy Cattle (2001).

It was not surprising, based on results from previous studies, that feeding partially hydrogenated tallow reduced fatty acid

digestibility. Hydrogenation of yellow grease to reduce its iodine value (**IV**) from 56 to 18 reduced apparent fatty acid digestibility in the total tract from 67.8 to 47.4% (Jenkins and Jenny, 1989). Fatty acid digestibilities pooled from 11 studies were normal (similar to control values) when IV exceeded 40 (Firkins and Eastridge, 1994), but below IV 40 fatty acid digestibility progressively dropped as IV declined.

Lower digestibility of hydrogenated fats may be related to their higher content of saturated fatty acids. The presence of 1, 2, or 3 double bonds increased fatty acid digestibility a similar amount. Grummer and Rabelo (1998) also reported similar improvements in apparent fatty acid digestibility from the presence of one or more double bonds. True digestibility of stearic acid was 53% and lowest among the 18 carbon fatty acids. Introducing a single double bond improved true digestibility to 78.4%. It should be pointed out that some studies did not distinguish between flows of *cis* or *trans* 18:1 to the duodenum, which might tend to lower 18:1 digestibilities.

Jenkins (2006) summarized fatty acid digestibilities from studies that included data only on lactating dairy cows fed a control diet with no high fat ingredients and fat sources that were not combined with other fats. A total of 32 published studies met all criteria and 45 studies were rejected. The selective criteria limited the number of observations for some fat sources, especially oilseeds and vegetable oils that were usually fed in combination with other fat sources.

Among the fat sources examined, only tallow and calcium salts of palm fatty acids had mean total tract digestibilities that were numerically higher than the control diets. The ranking was similar when digestibilities of the fat sources were estimated by difference. Conversely, the hydrogenated fat sources had substantially lower fatty acid digestibilities whether expressed as apparent digestibilites, or were calculated by difference. The hydrogenated fat sources also had the highest standard deviations, suggesting that wider variation exists in digestibility values of hydrogenated fats compared to other fat sources. Further examination of the data revealed that about 80% of the hydrogenated fat cases depressed diet fatty acid digestibilities more than 5%. Tallow depressed diet fatty acid digestibilities more than 5% from control fatty acids in only 27% of the cases examined.

There have been several other summaries of fatty acid digestibility reported in ruminants, including dairy cows, over the last 12 years (Table 3). Duodenal to feces digestibilities in dairy cattle were reported by Moate et al. (2004) from 8 studies, giving a total of 36 observations. Their summary excluded hydrogenated tallow and whole soybeans. Glasser et al. (2008) did a meta-analysis of C18 fatty acid digestibilities involving 294 observations in 77 studies. They included duodenal to ileal digestibilities for dairy, beef, and sheep data but found no significant species difference. They also excluded data on hydrogenated tallow. A more recent meta-analysis on duodenal to ileum digestibilites in lactating dairy cows had up to 18 observations and excluded partially-hydrogenated tallow (Boerman et al., 2015). When digestibility data was averaged across all studies, digestibility of unsaturated fatty acids were higher than saturated fatty acids, and stearic acid had the lowest digestibility.

Fatty Acid Outflow from the Rumen and Animal Performance

Meeting essential fatty acid demands

Omega fatty acids belong to one of three families, the ω-9, ω-6, or ω-3 family. Each family has a parent fatty acid that is converted to other biologically-active acids within the same omega family (Figure 4). The only parent fatty acid that can be made by body tissues is oleic acid. The ω-6 and ω-3 parent compounds (linoleic and linolenic acids) cannot be synthesized by body tissues and, therefore, must be supplied in the diet. Thus, linoleic and linolenic acids are regarded as essential because they are required for normal tissue function but cannot be synthesized by body tissues.

A typical total mixed ration of grains and forages generally contains adequate essential fatty acids to meet the needs of the animal. However, the majority of the dietary essential fatty acids are destroyed by microorganisms through biohydrogenation.

Part of the interest in omega fatty acids in dairy cattle is to enhance their concentration in milk for value-added opportunities, and part of the interest is to enhance their concentration in body tissues of the cow to enhance production and health. Omega fatty acids in milk are increased to improve manufacturing properties and to increase fatty acid nutraceuticals known to enhance human health. Increasing omega fatty acids in tissues of the cow has potential benefits on reproductive performance, immunity, and disease resistance, and positive hormonal shifts.

In a few studies, feeding fat to lactating dairy cows has improved reproductive performance, implying possible benefits on lifetime production potential. Reported improvements of reproductive performance from added fat include higher conception rates (Schneider et al., 1988; Sklan et al., 1989), increased pregnancy rates (Schneider et al., 1988; Sklan et al., 1991), and reduced open days (Sklan et al., 1991). However, supplemental fat has had little or no benefit on reproductive efficiency in other studies (Carroll et al., 1990). An extensive meta-analysis (Rodney et al., 2015) of 17 studies examining fat effects on reproductive performance in cows reported that fat caused a 27% increase in pregnancy to service and a reduction in calving to pregnancy interval. They also reported from the meta-analysis that feeding fat has a positive effect on fertility and production when fed during the transition period.

The mechanism of how fat supplements alter reproductive performance is not clear. Fat may function in one capacity by providing additional energy during early lactation to support improved productive functions, including reproduction. Negative energy balance delays ovulation and the initiation of the first normal luteal phase (Butler et al., 1981). However, recent studies also suggest that the mechanism involves an energy independent response to fat.

When an equal quantity of energy from glucose, saturated animal fat (tallow), or unsaturated fat (yellow grease) were infused into lactating dairy cows via the abomasum, the fat but not carbohydrate decreased plasma estradiol and increased progesterone (Oldick et al., 1997). The study by Oldick et al. (1997) also demonstrated the potential to decrease prostaglandin $F_{2\alpha}$ (**$PGF_{2\alpha}$**) synthesis by supplying elevated concentrations of polyunsaturated fatty acids (**PUFA**). These results were similar to previous reports that intravenous infusion of unsaturated fatty acids from a soy oil emulsion increased plasma $F_{2\alpha}$ and number and size of follicles (Lucy et al., 1990, 1991). Ovarian follicular growth was

also stimulated more in Brahman x Hereford cattle by fat compared to equal energy from carbohydrate, with a greater effect observed for fats with higher PUFA (Thomas et al., 1997). Hinckley et al. (1996) provided further support of the role of PUFA on reproductive function in ruminants. In their study, dispersed bovine luteal cells had a dose-dependent decline in progesterone production and an increase in production of prostaglandin as PUFA in the media increased. Results such as these continue to demonstrate a reproductive advantage from increased absorption of PUFA compared to other fat sources, such as monounsaturated fats.

Immune system

CLA decreased the growth rate in chicks and rats after they were injected with endotoxin (lipopolysaccharide; **LPS**). This probably was caused by release of cytokines and the prevention of the catabolic effects (Cook et al., 1993). Miller et al. (1994) examined endotoxin-induced growth suppression in mice fed with 0.5% fish oil and CLA. The fish oil fed-group lost twice as much body weight after the inoculation with endotoxin than the CLA-fed groups. These researchers found that the CLA in the endotoxin injection inhibited anorexia (a decreased sensation of appetite) and increased splenocyte blastogenesis, concluding that it might inhibit arachidonic acid synthesis, thus preventing the catabolism of tissue by removing eicosanoid precursors. In addition, Bontempo et al. (2004) examined the effects of CLA on the immunological variables of lactating sows and piglets fed with a 0.5% CLA diet. They found that CLA-fed sows exhibited increased colostrum IgG and serum leptin, and IgG and lysozyme. Nursing piglets of CLA-fed sows also exhibited higher levels of IgG and lysozyme. As these results show, dietary CLA enhanced the effect of immunological variables in lactating sows and piglets.

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Table 1. Representative fatty acid (FA) content and composition in grains, forages, and oilseeds included in livestock rations.

		% of Total FA				
Feedstuff	FA, % of DM	16:0	18:0	18:1	18:2	18:3
Barley	1.6	27.6	1.5	20.5	43.3	4.3
Corn	3.2	16.3	2.6	30.9	47.8	2.3
Dehydrated Alfalfa	1.4	28.5	3.8	6.5	18.4	39.0
Ryegrass	4 to 7	11.9	1.0	2.2	14.6	68.2
Cottonseed	18.6	25.3	2.8	17.1	53.2	0.1

Table 2. Added fatty acids (3.5%) on 24 h rumen in vitro from Zhang et al. (2008).

	Control	Stearic	Oleic	Linoleic	Linolenic
Ac/Pr	5.27[a]	4.87[a]	4.13[b]	2.90[c]	2.08[d]
F. succinogenes	2.04[c]	2.69[a]	2.26[b]	1.37[d]	1.13[e]
Methane, mmol	1.03[a]	0.99[ab]	0.94[b]	0.75[c]	0.56[d]
Protozoa	2.99[a]	2.26[b]	1.96[c]	1.80[c]	1.30[c]

[abcd]Means with different superscripts within a row differ ($P < 0.05$).

Table 3. Fractional digestibilties of individual fatty acids in ruminants as reported in several data summaries. Differences among summaries are shown according to sections of intestinal tract, species of ruminants, and fat sources omitted.[1]

	Moate et al. (2004)	Glasser et al. (2008)	Boerman et al. (2015)
6:0	0.725		0.771
18:0	0.728	0.63	0.728
18:1	0.669	0.86	0.802
18:2	0.776	0.80	0.735
18:3	0.775	0.74	0.805
Duodenum to feces	X (Intestinal BH NS)		
Duodenum to ileum		X	X
Species	Dairy	Dairy, beef, sheep (NS)	Lactating dairy
n (studies, obs)	8,36	77, 294	?, 10-18
Outliers deleted	HT, WS	HT	PHT

[1]Abbreviations: BH = biohydrogenation, HT = hydrogenated tallow, PHT = partially hydrogenated tallow, WS = whole soybeans, NS = not significant.

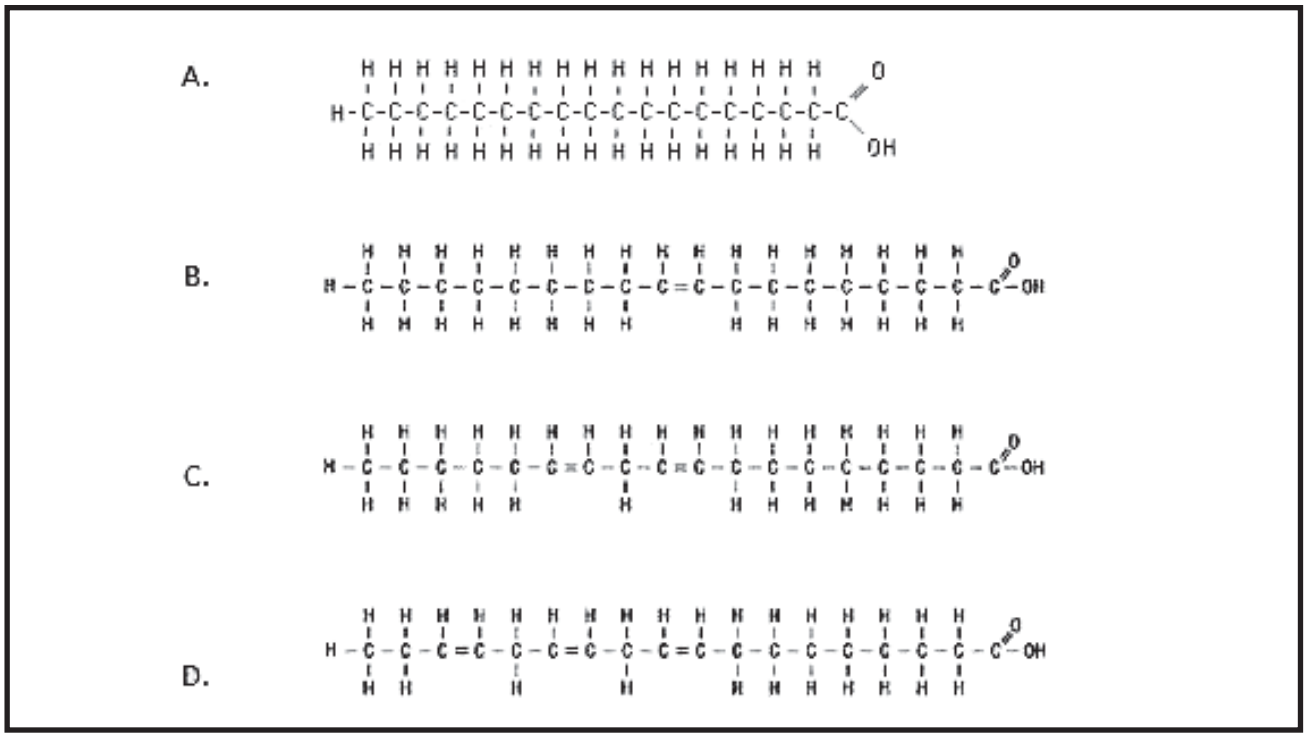

Figure 1. Structures of A) stearic acid, a saturated fatty acid, and the three primary unsaturated fatty acids consumed by cattle, B) oleic acid, C) linoleic acid, and D) linolenic acid.

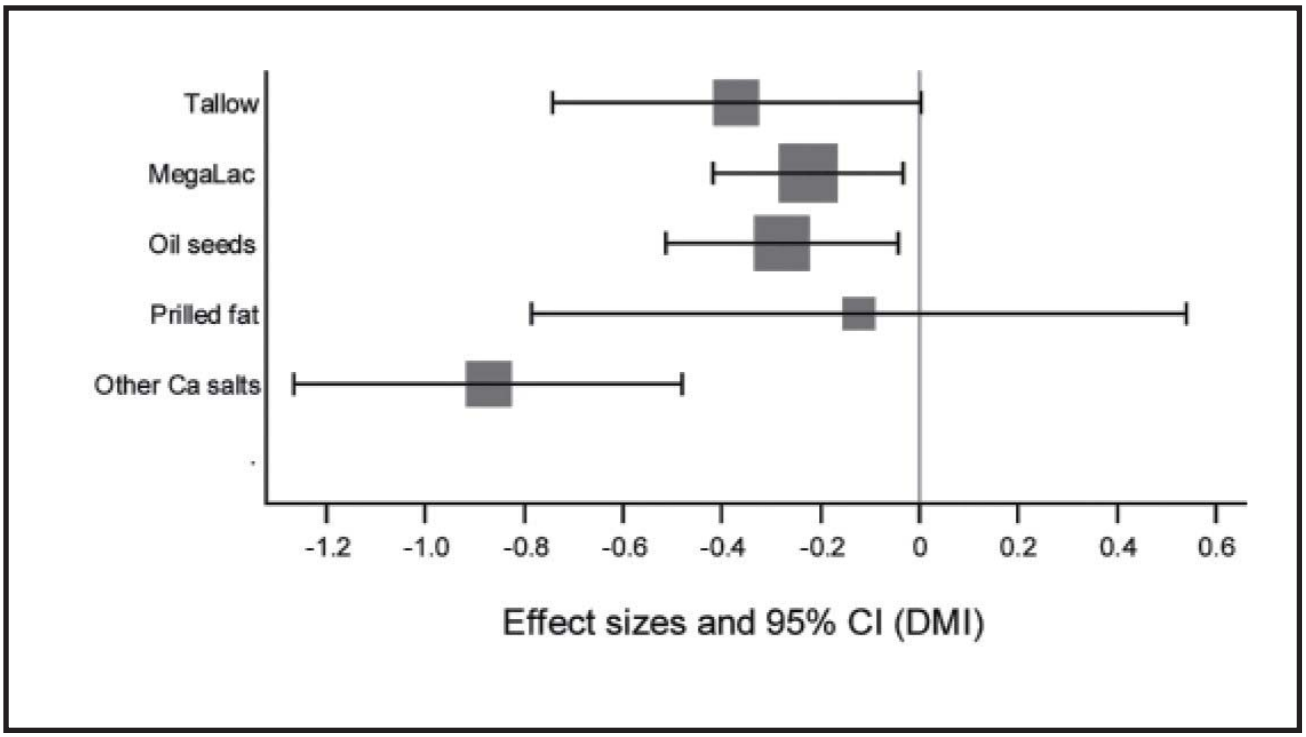

Figure 2. Forest plots taken from the meta-analysis of Rabiee et al. (2012) showing the variability in dry matter intake responses when fat was added to dairy diets. Box sizes are proportional to the inverse variance of the estimates. The upper and lower limit of the line connected to the square represents the upper and lower 95% CI for the effect size.

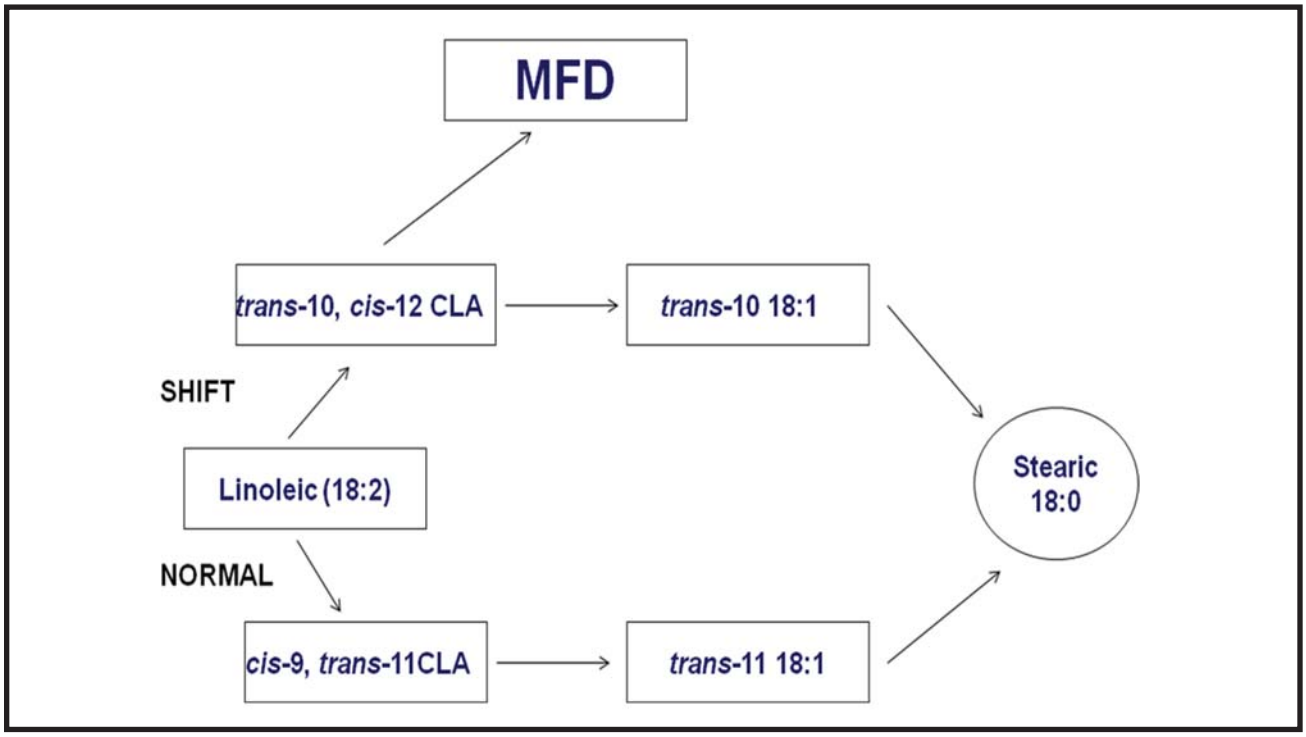

Figure 3. The shift in intermediates produced from biohydrogenation of linoleic acid in ruminal contents as a result of a diet-induced microbial shift (CLA = conjugated linoleic acid; MFD = milk fat depression.

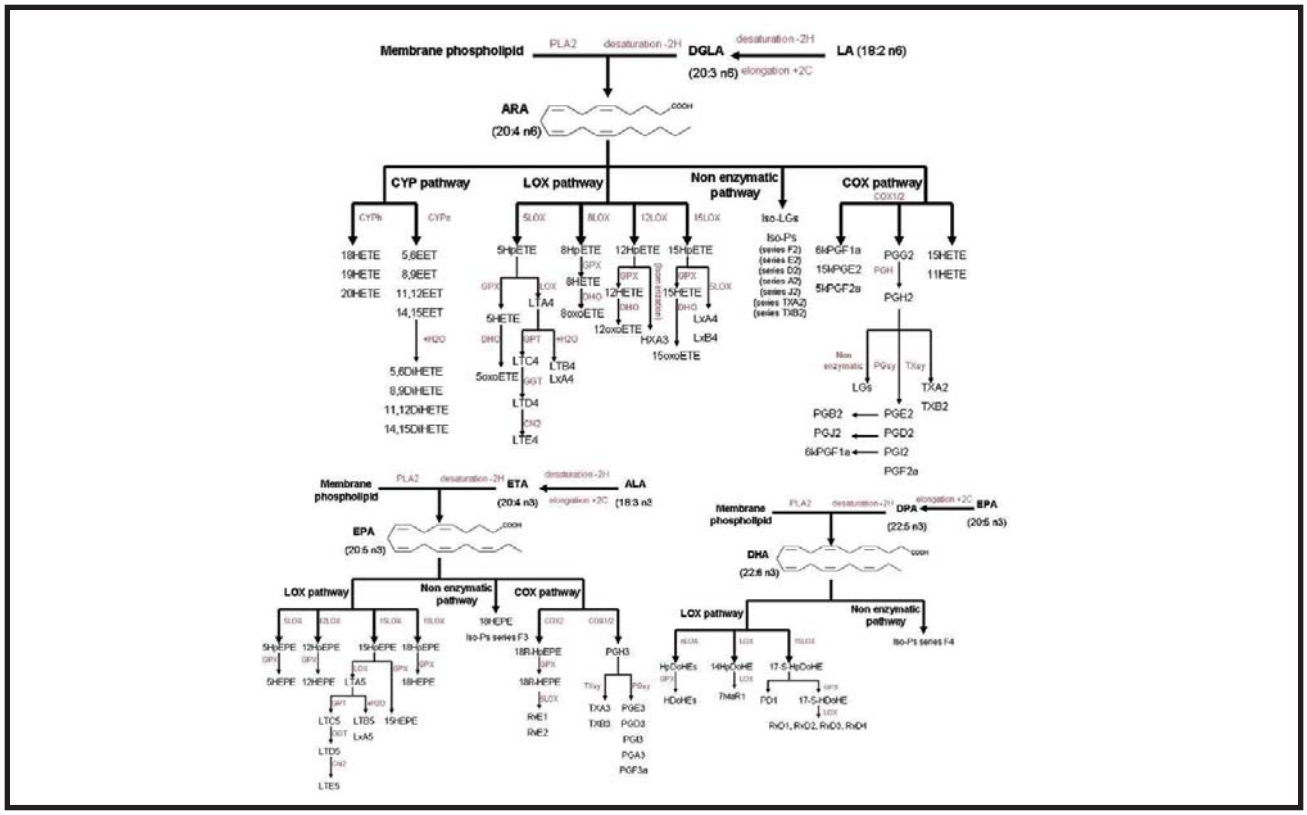

Figure 4. Parent fatty acids and major metabolites within each of the three omega fatty acid families (Dasilva et al., 2015).

Impact of Nutritional Grouping on the Economics of Dairy Production Efficiency

Victor E. Cabrera[1]
Department of Dairy Science
University of Wisconsin-Madison

Abstract

This paper is an adapted excerpt of a published paper. The economic efficiency of nutritional grouping strategies in 5 Wisconsin commercial dairy herds was studied using a daily dynamic stochastic Monte Carlo simulation model. Each month, the clustering method was used to homogeneously regroup cows according to their nutrient concentration requirements. The average net energy for lactation (**NE_L**) and metabolizable protein (**MP**) +1 standard deviation (**SD**) concentration of the group were used to formulate the group diet. The calculated income over feed costs gain (**IOFC**, $/cow/yr) of having >1 nutritional groups among the herds ranged from $33 to 58, with an average of $39 for 2 groups and from $42 to 58, with an average of $46 for 3 groups. The improved IOFC was explained by increased milk sales and lower feed costs. Higher milk sales were a result of fewer cows having a milk loss associated with low body condition score (**BCS**) in multi-group scenarios. Lower feed costs were mainly due to less rumen undegradable protein (**RUP**) consumption in multi-group scenarios. The percentage of total NE_L consumed and captured in milk for >1 nutritional group was slightly lower than that for 1 nutritional group due to better distribution of energy throughout the lactation and higher energy retained in body tissue, which resulted in better herd BCS distribution.

Introduction

Grouping lactating cows for nutritional purposes, also referred as nutritional grouping, is a herd management strategy that provides different diets to different groups of lactating cows to better fulfill their nutrient requirements. Hence, nutritional grouping can be beneficial by saving feed costs, improving productivity, improving herd health, and decreasing nutrient emissions to the environment (Cabrera and Kalantari, 2016). Total mixed rations have become an industry standard for feeding management, and many dairy farms are using just 1 total mixed ration (**TMR**) for all lactating cows, despite major differences in nutritional requirements of dairy cows in different lactation stages (Allen, 2008). For example, 58% of Wisconsin and Michigan dairy farms used the same TMR for all lactating cows (Contreras-Govea et al., 2015). The adoption and application of a single TMR as a common practice has resulted in more over-conditioned cows and greater nutrient excretion issues (Allen, 2009). Cows in similar lactation stages could have different nutritional requirements because of their productivity and genetic potential. When feeding only 1 TMR diet, it is usually formulated for high-producing cows to ensure that these cows reach their full milk production potential, which results in overfeeding lower-producing cows (Cabrera and Kalantari, 2016). A strategy to relieve this problem is adopting nutritional groups

[1]Contact at: 1675 Observatory Dr., Madison, WI 53706, (608) 265-8506, Email: vcabrera@wisc.edu.

with more precise diets, which will increase profitability and economic efficiency due to the better-tailored diet to the cow requirements in a group, even when it could require more capital management and labor costs (VandeHaar, 2011). Nutritional grouping of lactating cows promotes optimal body condition and health (Allen, 2009), an additional advantage that could translate into economic benefits (Cabrera and Kalantari, 2016). More precise diets would also improve milk productivity (Bach, 2014). Grouping decreases within-group and increases across-group variation of diets' nutrient density, reducing competition at the feed bunk (Grant and Albright, 2001). Within this context, Kalantari et al. (2016) studied by simulation modeling the economic efficiency of nutritional grouping in 5 Wisconsin commercial herds. This paper is an adapted excerpt of that study, highlighting its practical and applicable results.

Materials and Methods

A daily dynamic stochastic Monte Carlo simulation was developed to model individual cows after first parturition in a dairy herd. The next-event scheduling approach (De Vries, 2001) scheduled stochastic events that could happen to cows during each reproductive cycle. First, a data set of all the cows in a herd and their current status were loaded (i.e., lactation number, day postpartum, reproductive status). Then, a list of possible stochastic events was scheduled for each cow at the beginning of the simulation and the list was renewed after starting their next lactation. These events included involuntary culling, death, pregnancy, abortion, dry-off, and parturition. For each event, a 2-step process was followed: 1) determining the binary outcome of the event (it happens or not during the cow's current lactation) and, if it happens, 2) the day of the occurrence (schedule). For each cow, milk, fat, and protein production; body weight (**BW**) and BCS changes, and NE_L and MP requirements were simulated and monitored according to diets. The BCS was restricted to 2.0 and 4.5 in a scale of 1 to 5. If BCS was calculated to go below or above these limits, milk production or dry matter intake (**DMI**) was decreased, respectively, to maintain BCS within these limits. For all specific details of the underlying simulation model algorithms, please refer to Kalantari et al. (2016).

Nutritional grouping

Within the simulation framework portrayed above, nutritional grouping strategies were studied on post-fresh lactating cows (DIM>21) to test their effect in the overall IOFC [IOFC = milk value minus rumen degradable protein (**RDP**), RUP, and NE_L costs]. To be consistent among herds, the sizes of nutritional groups were chosen to be approximately equal among them (total available cows divided by the number of defined nutritional groups). The monthly regrouping process of groups started by ranking the cows based on their NE_L and MP requirements (clustering method; McGilliard et al., 1983). Different strategies have been explored in the literature to determine the NE_L and crude protein (**CP**) concentrations of a diet for a group of cows, but in general, all used average milk production of a group as the basis for calculating lead factors, or the levels at which the diet should be formulated. These methods include, for example, the use of the 83rd percentile in each group (Stallings and McGilliard, 1984) or the use of differentiated levels according to several groups (Stallings, 2011). Kalantari et al. (2016) used individual cow's daily NE_L and MP requirements to formulate more precise diet nutrient concentrations in simulated groups of cows. This method minimized the within-group variability of individual animal nutrient requirements expressed as the concentration of NE_L and MP in the diet. Then, the diet for the group was formulated based on NE_L and

MP requirements of the group. Different levels of NE_L concentrations, average NE_L, average NEL+0.5SD, and average NE_L+1SD, were considered, but it was found that formulating the diet for above the average NE_L concentration changed the body energy contents of the cows in the herd, resulting in an undesirable proportion of obese cows in the herd. For that reason, only average NE_L concentration was used. Regarding MP, the base scenario used MP+1SD.

Economic parameters

Economic parameters for the base scenario were set as 10-yr Wisconsin average prices from 2005 to 2014. Thus, milk price was set to $0.39/ kg of milk. FeedVal 6.0 decision support tool (http://dairymgt.info/tools.php) was used to calculate the nutrient prices of NE_L, RDP, and RUP. The calculated nutrient prices were: $0.1/Mcal of NE_L, $0.18/kg of RDP, and $1.04/ kg of RUP.

Scenario analyses

Two extreme scenarios were analyzed. The worst-case scenario was designed by coupling the lowest milk price with the highest nutrient costs and vice versa for the best-case scenario. Ten-year annual average of milk price was used to set the highest ($0.52/kg) and lowest milk ($0.29/kg) prices. The highest (lowest) nutrient costs were set at $0.14/ Mcal of NE_L ($0.05), $0.26/kg RDP ($0.09), and $1.52/ kg RUP ($0.52).

Considering the large differences among studies regarding milk losses when grouping cows (Smith et al., 1978; Hasegawa et al., 1997; Zwald and Shaver, 2012), possible milk loss due to regrouping lactating cows was explored with a base scenario without any milk loss and another scenario with extreme milk losses of 1.82 kg/ day during 5 days after grouping (Cabrera and Kalantari, 2014). In addition, the effect of having first-lactation cows as a separate nutritional group was studied.

Case study herds and projection timeline

Five Holstein herds from Wisconsin using a TMR feeding management system were studied (Table 1). The model captured current cow and herd profiles (day = 0 of the simulation) and then projected individual cow and herd performance daily for a year (day = 365) with 1,000 replications.

Results and Discussion

Grouping

Post-fresh lactating cows (592) from the 787-cow herd at 300 d in the simulation are shown in Figure 1A, ranked according to their NE_L concentration requirements. It is clear that lactating cow requirements vary substantially on a given day because of differences in lactation stage, pregnancy status, BW, and milk production. In this example, the highest NE_L concentration requirement was from a cow in third lactation, 23 days postpartum, and with milk yield 20% above herd average. The lowest NE_L concentration requirement was from a cow in third lactation, 385 days postpartum, and with 10% below average milk yield. To cope with this high variability, precision feeding according to an individual cow's requirements would be ideal, but unfortunately this is not yet practical, especially in larger herds (Sniffen et al., 1993). On the other hand, preparing a diet of just 1 TMR for all cows could result in large overfeeding or underfeeding problems. A diet is usually formulated for high-producing cows to ensure that milk production is maintained (Weiss, 2014), but that is inefficient. A practical way to overcome this high variability is to group them according to their requirements.

The effect of grouping these 592 post-fresh lactating cows is illustrated in Figure 1B, where the difference between offered and the required NE_L concentrations are depicted for 3 cases of nutritional groupings. Figure 1B shows that when feeding all the cows as one group and formulating the diet based on the average NE_L concentration of the group, approximately half of the cows are overfed and the other half underfed. However, it should be noted that the NE_L concentration of the requirements is not necessarily normally distributed. Thus, formulating based on the average NE_L concentration does not always result in overfeeding half the cows and underfeeding the other half. It was observed that the distribution was strongly affected by herd structure at the point of regrouping the cows. Specifically, it depended on the percentages of fresh animals that were moving into optional groups (>21 days postpartum)—cows with the highest requirements—which caused right skewedness in the distribution. It was also dependent on the percentages of late-lactation cows moving to the dry group, which caused left skewedness in the distribution. Figure 1B shows that increasing the number of groups decreases the variability among the cows within the group, which is especially beneficial in offering the cows a diet closer to individual cow requirements in terms of health, environment, and economics. This benefit is more pronounced in the case of large herds and when the distribution of the requirements is not normal (McGilliard et al., 1983). The difference between offered and required MP for the cows in the group when feeding the group of cows average MP+1SD shows a pattern similar to that for NE_L (data not shown).

Economic value of nutritional grouping

The economic value of nutritional grouping measured in terms of IOFC is displayed as the difference from 2 to 4 TMR and 1 TMR in Figure 2. It is clear that an economic gain results from nutritional grouping. These gains depended on the number of groups and varied from ($/cow/yr) $39 for 2 groups, to $46 for 3 groups, and to $47 for 4 groups (Figure 2). The gain in IOFC with more nutritional groups was due to higher milk production and lower feed costs. Higher milk production for more than 1 group was due to fewer cows having milk loss for low BCS (BCS <2.0). The lower feed costs with 2 and 3 groups were mainly due to less RUP cost (Figure 2). Compared with RUP cost, other components of IOFC (RDP and NE_L costs and milk revenue) were more stable across different grouping numbers and MP concentrations in the diet. The largest relative IOFC gain was obtained when moving from 1 group to 2 groups. Comparing 1 group and 2 groups, the IOFC gain ranged ($/cow/yr) from $33 (570-cow herd) to $49 (787-cow herd). The overall (average of 5 herds in the study) gain in IOFC ($/cow/yr) from 1 group to 2 groups was $39 ± 6 and from 1 group to 3 groups was $46 ± 7 (Figure 2). Economic gains found in other studies are different because of differences in the model and input values used in those studies. For example, Williams and Oltenacu (1992) reported that the mean annual IOFC ($/cow/yr) of 3 nutritional groups were $21, 33, and 40 higher than that of 2 groups at production levels of 8,000, 9,000, and 10,000 kg/cow/305-d lactation, respectively. St-Pierre and Thraen (1999), using economic optimized lead factors for CP and NE_L for different group numbers, calculated average economic gains ($/cow/yr) of $44 and 77 when comparing 2 and 3 groups with 1 group, respectively. These values are comparable to those found in this study. A study by Østergaard et al. (1996) used a dynamic stochastic simulation model to compare different grouping strategies under different reproductive and culling management, where feeding of the cows was not according to the calculated nutrient requirements but was specified by a feeding regimen of TMR with up to 3 different

groups. Although the differences in the feeding systems make it difficult to compare the current study with that of Østergaard et al. (1996), they also showed that, overall, 1 group was inferior to other grouping strategies mainly due to the economic effect of lower milk production and higher amount of concentrate intake in 1 group. They also found that marginal net revenue per cow per year was lower under 1 group compared with 2 or 3 groups under all scenarios of milk production and reproductive and culling management. It should be noted that Kalantari et al. (2016) used the actual requirements of the cows to determine the offered diet concentration of NE_L and MP and included the dynamics of the herd throughout lactation, which might provide a better approximation of the economic gain of nutritional grouping. The other important factor in economic evaluation of grouping lactating cows is the extra labor needed to formulate, prepare, and deliver feeds, and the extra costs of running mixers for preparing the TMR for each group separately. In addition, there is a labor cost related to moving cows among groups. These costs are usually farm specific and vary among herds (Østergaard et al., 1996), and for simplification, they were not included in Kalantari et al. (2016). Overall, profitability and feasibility of nutritional grouping are highly farm and market dependent. Farm size has an effect on the feasibility of nutritional grouping. For example, the extra labor for regrouping and moving cows might be less important in larger herds than in smaller herds (Østergaard et al., 1996). Also, when market conditions determine high feed costs and low milk prices, nutritional grouping could be more economically appealing (Allen, 2008; Hutjens, 2013). Simulation studies (Pecsok et al., 1992; Williams and Oltenacu, 1992) have suggested dividing lactating cows into 3 nutritional groups for optimal efficiency. Results from this study corroborate those previous reports indicating that economic gain and efficiency increase up to 3 nutritional groups. Also, the rate of improvement of IOFC with each additional grouping followed the law of diminishing returns.

Formulated diet

The average NE_L, RDP, and RUP concentrations in DM under 3 levels of offered MP concentrations are summarized in Table 2. The formulated diet for 1 group had a concentration of 1.50 Mcal/kg of DM. Having more groups divides the cows into more homogeneous NE_L concentration groups and hence higher and lower concentrations of NE_L in the diet. A similar pattern was observed in RDP and RUP percentages in the diet. The reported NE_L concentrations by McGilliard et al. (1983) using a clustering method with 2 groups were 1.62 (high) and 1.42 (low) Mcal/kg, which are comparable to those obtained here (1.59 and 1.41 Mcal/kg, respectively). The optimal allocation of NE_L concentration found in the St-Pierre and Thraen (1999) was much less variable and higher than that reported by Kalantari et al. (2016) or in the McGilliard et al. (1983) study. The optimum allocation of NE_L found in St-Pierre and Thraen (1999) study was 1.78 (Mcal/kg) in the 1-group case and remained above 1.70, even in the case of 3 groups. Previous studies have used CP to estimate required protein in the group; whereas, this study used the MP requirement of the cows. The CP percentage (RDP + RUP/0.8) in this study was higher than the reported optimum allocation of CP by St-Pierre and Thraen (1999), which used milk production as the proxy for diet formulations. In 1 group, the estimated range of CP was 18, 18.5, and 19% for average, 0.5SD, and 1SD above average, respectively. In the current study, the difference of CP in different group numbers were approximately 2, 3, and 3.8 percentage points for 2, 3, and 4 groups, respectively. The differences for the optimum allocation of CP reported by St-Pierre and Thraen (1999) were 1 and 2 percentage points for 2 and 3 groups, respectively.

Nutrients captured in milk and BCS

The results of the current study could be explained by studying the detailed charts of the NE_L concentration in the diet (Figure 3) and the distribution of the retained body energy in terms of BCS (Figure 4). A greater proportion of the cows in the herd were underfed in the case of 1 group than with more groups and therefore the total NE_L consumption and milk yield (milk yield depended on the energy in the body as captured in BCS) for just 1 group was less than that with 2 and 3 groups. Utilizing 2 or 3 groups increased the diet NE_L concentration in early lactation (the time that is most needed) until around 150 d postpartum (Figure 3). After this point, 2 and 3 groups had a lower NE_L concentration in the diet than did 1 group. The overall lower NE_L concentration required for late-lactation cows was generally lower than the higher NE_L concentration required for early-lactation cows, and therefore, the total NE_L consumed was higher for multi-groups than for 1 group. Cows in 1 group were then fed close to the average of the group NE_L concentration of their requirements (approximately 1.50 Mcal/kg of DM), which remained almost unchanged until around 300 DIM. At this point, the increasing proportion of low producing, late-lactation cows reduced the average NE_L concentration. On the other hand, in the case of 2 and 3 groups, there was a curvilinear pattern, which is explained by the fact that cows were fed closer to their requirements (and at higher concentrations than in 1 group) when the energy requirements were high. After passing the critical point of early lactation, NE_L concentration decreased for 2 and 3 groups compared with 1 group. Two and 3 groups assure that late-lactation cows have enough energy in the diet but not much more than required. Overall, it is clear that use of 2 or 3 groups distributes NE_L more efficiently based on DIM and productivity, which might increase overall NE_L consumption in the herd.

Excess energy in late-lactation cows is associated with greater BCS and over-conditioned cows that can have complications in the next lactation (Cameron et al., 1998). The effect of several nutritional groups on BW and BCS can be seen in Figure 4, which compares the effect of 1 and 3 nutritional groups on BW and BCS distributions of the 787-cow herd. The left panel of Figure 4 shows that the BW density plot of 2 grouping strategies (1 vs. 3 groups) does not differ considerably; they both have similar distributions. This indicates that use of 1 and 3 groups did not result in overall BW changes of the cows in the herds. The stable BW among different grouping numbers has also been reported in field trials (Smith et al., 1978; Clark et al., 1980; Kroll et al., 1987). The right panel of Figure 4 illustrates the effect of nutritional grouping on the distribution of the cows' body energy content (**BCS**). The 1 group represented by a dark-shaded density plot has a different distribution than 3 groups (light shading). With 1 group, the distribution is thick-tailed, which means the model projects that many cows are either under-conditioned (BCS = 2.0) or over-conditioned (BCS = 4.5), and it has a mode around BCS = 2.75. On the other hand, use of 3 groups shows a rather normal distribution curve with the mode around BCS = 3.25. Similar distribution was observed in the case of 2 groups and in the other studied herds (data not shown). Having 2 or 3 groups appears to ensure that the consumed energy is better-distributed, promoting healthier cows.

The overall MP trend is similar. In the 1 group case, the MP consumption decreased to 11 g/100 g of DM post freshening, and stayed at the same level until about 300 days postpartum, when it decreased consistently through the rest of the lactation (Figure 3). However, in 2 and 3 groups, the provided MP in the diet was closer to the actual requirements. Therefore, with 2 or 3 groups, cows were fed more MP until

about 100 days postpartum and thereafter fed lesser MP than the 1-group case. This higher N consumption in late lactation for 1 group compared with more groups is consistent with the literature (VandeHaar, 2014). Having 3 groups and formulating the diet at 1 SD above the MP average improved N efficiency by 2.7%. The main economic gain of having more groups could be attributed to an increased percentage of N captured in milk, which in turn decreases feed cost related to RUP. Having more groups clearly improves the percentage of N captured in milk, which, at the same time, improves environmental stewardship by decreasing the amount of N excreted (VandeHaar, 2014).

Scenario analyses

Results from scenario analyses on the input price, inclusion of milk loss, and separation of the first-lactation cows from older cows are depicted in Table 3. The results show that even in the worst economic conditions (lowest milk price with highest nutrient costs), grouping cows had a similar average IOFC gain compared with the base scenario. Comparing the base and best case scenarios over all herds, the average IOFC gain ($/cow/yr) was $6 higher in 2 groups and $4 in 3 groups. Comparing the IOFC gain ($/cow/yr) of 2 and 3 groups, the relative gain was highest in the worst case scenario ($10) and the lowest relative IOFC gain of having 3 groups instead of 2 groups was under the best case scenario ($6). This emphasizes the importance of grouping lactating cows in tough economic conditions, when the milk price is low compared with feed price. Even though the relative IOFC gain was greater in the worst conditions, the highest IOFC gain in absolute terms was when the milk price was high compared with feed costs (i.e., best case; Table 3). Assumed milk loss (1.82 kg/day for 5 days) due to regrouping decreased the average 5 herds' IOFC of 2 groups by $18 across all the herds and by $20 for 3 groups compared with 1 group (Table 3). The data showed that even under the assumption of milk loss because of regrouping, there is still an overall economic gain. However, considering milk loss for all cows, as was assumed in this study, resulted in the lowest economic gain among all the scenarios, including the worst-case scenario. The amount of IOFC gain ($/cow/yr) ranged from $14 to 32 when comparing 1 and 2 groups and the IOFC gain ranged from $19 to 38 when comparing 1 and 3 groups. The amount of loss depended on the number of times cows were reassigned to a different group, and it was affected by cow characteristics (i.e., milk production and DIM that determine cow requirements) and the nutrient requirement variations among the cows in the groups. The trend when having milk loss because of regrouping was consistent with the base scenario in that the largest gain was observed between 1 and 2 groups. Smith et al. (1978), in a field study, compared lactating cows grouped into 1 and 2 groups. In that study, the average decline in milk production was found to be 2 kg/cow/day for 7 days, and this amount was affected by parity (less milk loss for first-lactation compared with older cows). Even with this amount of milk loss, the IOFC of 2 groups was $30/cow/year greater than that of 1 group, as a result of less concentrate fed (Smith et al., 1978). This amount of gain in IOFC is in the range of values found in this study. In another field study by Zwald and Shaver (2012), the milk loss due to change in groups was reported to be insignificant. Overall, the effects of grouping on the milk production of the cows in inconclusive (Clark et al., 1980), and based on those field studies mentioned above, it seems that the assumed amount of milk loss in this study (total of 9.1 kg in 5 days) could be either underestimated or overestimated. Thus, the true amount of milk loss is unknown, and studies have shown that it could be affected by parity (Smith et al., 1978) and could vary among cows based on their days in milk (**DIM**)

(Kroll et al., 1987) and other characteristics. It seems safe to assume that not every cow might experience the same amount of loss and the duration could vary among cows based on their characteristics. However, the amount of saving in the feed cost due to grouping could exceed the loss in the milk production (Smith et al., 1978; Clark et al., 1980). Adding first-lactation cows as a separate group also affected the economics of nutritional groupings and is summarized in Table 3. The average IOFC gain among all the herds was lower than that of the base scenario by $7/cow/year. This smaller gain when separating first-lactation cows was mostly due to the fact that having a separate group of first-lactation animals ensures a diet tailored more closely for those cows and older cows, similar to having a separate nutritional group. Table 2 summarizes the formulated diet when separating first-lactation cows into their own group. Regardless of the number of groups, the formulated diet of first-lactation cows was the same across different group numbers and herds. However, separating the first-lactation cows into a group increased the nutrient concentration of the diet of older cow groups, thus the higher feed costs (higher RUP costs) and smaller IOFC gain in this scenario. It should be mentioned that the model did not consider the possible benefit of separating first-lactation animals due to social hierarchy among the younger cows and older cows, which could result in decreases in feed intake and milk production of first-lactation cows (Botheras, 2007). Considering this issue could increase the reported economic gain of separately grouping first-lactation cows.

Conclusions

Economic gains of nutritional grouping measured as milk income minus NEL and MP costs were $15.2 ± 5.5, 30.5 ± 6.0, and 46.6 ± 6.6 for 2, 3, and 4 nutritional groups compared to 1 group. Economic gains were explained mainly due to higher milk production and lower RUP costs when grouping, and gain was emphasized during tough economic conditions. The effect of a possible constant milk loss when regrouping cows would have a deleterious economic effect but not high enough to overcome the gains.

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Table 1. Studied dairy herds.

Characteristics	Herd Size (Lactating + Dry)				
	331	570	727	787	1,460
Average Herd ME305[1] (kg/cow/yr)	13,348	16,140	13,897	12,884	14,188
1st Lactation (%)	38	43	39	39	45
Average days in milk[2] (days)	193	169	181	165	174
Average days in pregnancy (days)	134	140	141	133	157
Average lactation number (#)	2.03	1.99	2.29	2.21	2.02
21-days Pregnancy rate[3] (%)	17	18	19	19	18
Conception rate[3] (%)	35	32	36	37	40
Estrus detection[3] (%)	49	57	51	51	45
Culling[3] (%/yr)	35	32	36	37	40
Abortion[3] (%/gestation)	16	7	11	11	7

[1]305-day mature equivalent milk production.
[2]Average days in lactation.
[3]As defined and calculated in DairyComp305 (Valley Agricultural Software, Tulare, CA).

Table 2. Formulated diet components for different nutritional group numbers and scenarios obtained by averaging 5 herds (±SD within herds) throughout the simulation of 12 monthly grouping periods

Group number	Groups	NE_L (Mcal/kg DM)	RDP (% of DM)	RUP (% of DM)		
				0xSD	0.5xSD	1xSD
Grouping post-fresh lactating cows						
1	G1	1.50±0.004	9.34±0.0002	5.06±0.0004	5.46±0.0004	5.85±0.0005
2	G1	1.59±0.005	9.89±0.0003	5.35±0.0004	5.63±0.0005	5.90±0.0005
	G2	1.41±0.005	8.83±0.0003	4.78±0.0005	5.01±0.0005	5.22±0.0006
3	G1	1.66±0.006	10.27±0.0003	5.42±0.0005	5.68±0.0005	5.95±0.0006
	G2	1.48±0.005	9.25±0.0003	5.15±0.0003	5.27±0.0005	5.36±0.0004
	G3	1.38±0.006	8.67±0.0003	4.67±0.0004	4.85±0.0006	5.02±0.0006
4[1]	G1	1.72	10.60	5.42	5.68	5.95
	G2	1.52	9.49	5.24	5.38	5.50
	G3	1.45	9.07	4.99	5.08	5.18
	G4	1.37	8.59	4.61	4.75	4.93
Separating first lactation cows from older lactating cows						
First lactation[2]		1.50±0.008	9.34±0.0005	4.93±0.0007	5.24±0.0006	5.55±0.0005
1	G1	1.50±0.003	9.35±0.0002	5.15±0.0003	5.57±0.0004	6.00±0.0005
2	G1	1.61±0.005	9.97±0.0002	5.46±0.0004	5.75±0.0005	6.03±0.0005
	G2	1.40±0.002	8.77±0.0002	4.85±0.0002	5.08±0.0002	5.31±0.0002
3	G1	1.67±0.006	10.33±0.0004	5.53±0.0005	5.80±0.0006	6.07±0.0006
	G2	1.48±0.003	9.24±0.0002	5.24±0.0003	5.35±0.0003	5.46±0.0004
	G3	1.37±0.004	8.60±0.0002	4.72±0.0003	4.90±0.0002	5.09±0.0002
4[1]	G1	1.72	10.6	5.54	5.81	6.08
	G2	1.52	9.49	5.28	5.46	5.60
	G3	1.44	9.03	4.95	5.13	5.28
	G4	1.35	8.55	4.62	4.78	4.98

[1]4 groups were studied only on the largest herd (1,460-cow herd).
[2]The average formulated diet for first lactation cows separated from older cows was similar across all the grouping numbers and herds.

Table 3. Average economic gain in IOFC of grouping strategies of 5 studied herds.

Scenario	Difference between grouping strategies and 1 group ($/cow/yr)		
	2 Groups	3 Groups	4 Groups[1]
Base[2]	38.66	46.24	46.90
Worst[3]	35.48	44.94	47.40
Best[4]	44.34	50.18	48.80
Milk loss[5]	20.46	25.90	23.50
1st lactation[6]	32.64	38.76	38.50

[1]4 groups were studied only on the largest herd (1,460-cow herd).

[2]Base scenario running on the average NE_L concentration and average MP+1xSD with 10 years average annual milk price ($0.39/kg) and nutrient costs (NE_L=$0.10/Mcal, RDP=$0.18/kg, and RUP = $1.04/kg).

[3]Worst case scenario couples the lowest milk price with the highest feed price from historical 10 years annual average (Milk price=$0.29/kg, NE_L=$0.14/Mcal, RDP=$0.26/kg, and RUP=$1.52/kg).

[4]Best case scenario couples the highest milk price with the lowest feed price from historical 10 years annual average (Milk price=$0.52/kg, NE_L=$0.05/Mcal, RDP=$0.09/kg, and RUP=$0.52/kg).

[5]Adding 5 days of 1.82 kg/day milk loss for cows changing to another group under base scenario.

[6]Including 1st lactation cows as a separate obligatory group under base scenario. In this scenario, the 1 group itself has 2 groups: 1st lactating cows and ≥ 2nd lactating cows. Thus, in addition to the number of groups for older cows, one group is just for first lactation cows.

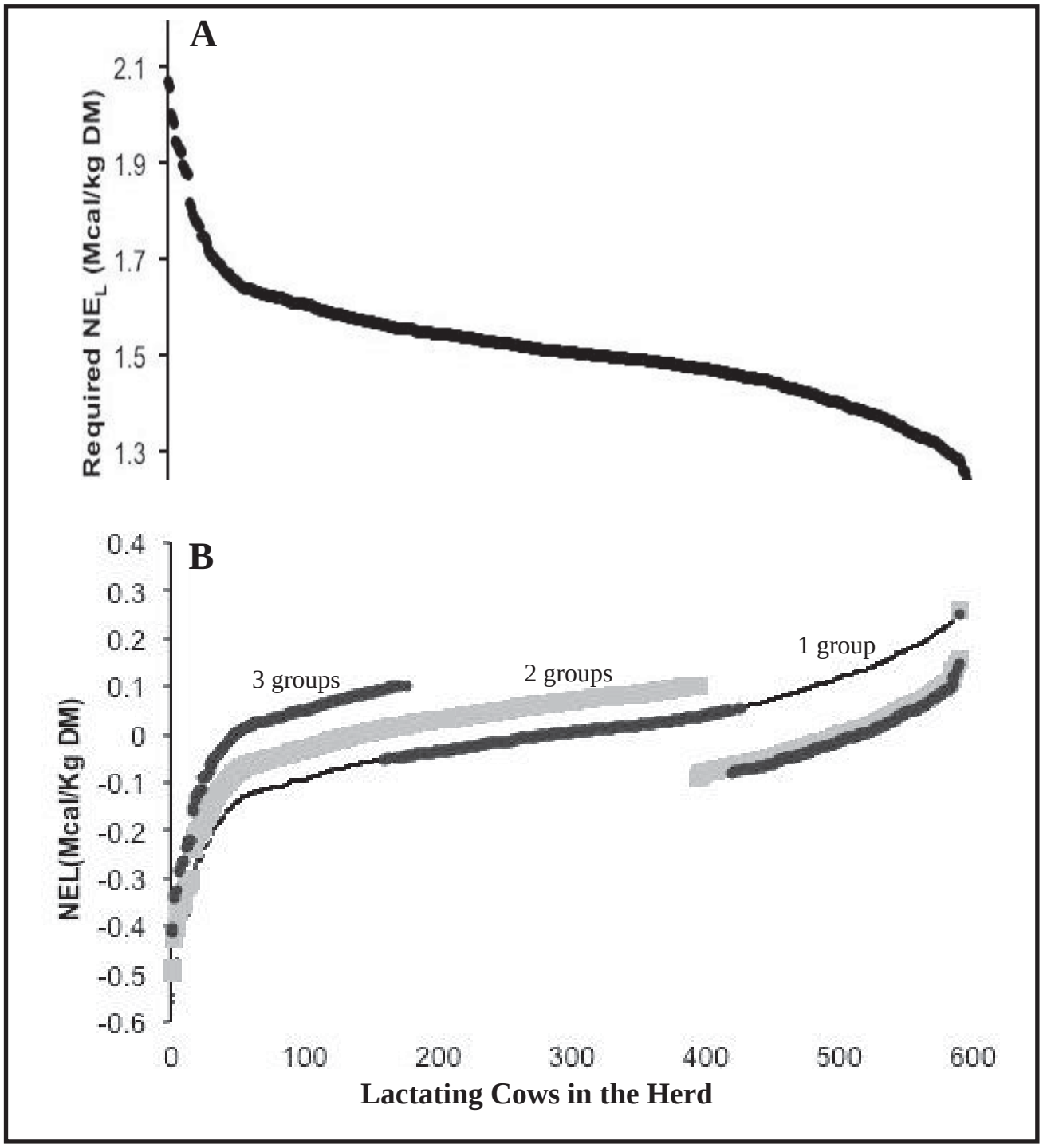

Figure 1. Nutrient NE_L required and provided to 592 post-fresh lactating cows from the 787-cow herd at d=300 in simulation. A) NE_L concentration of the requirements. B) Difference between provided and required NE_L concentration (offered NE_L – required NE_L, Mcal/kg) under 1, 2, and 3 nutritional groups based on the diet offered at the average NE_L concentration of the group.

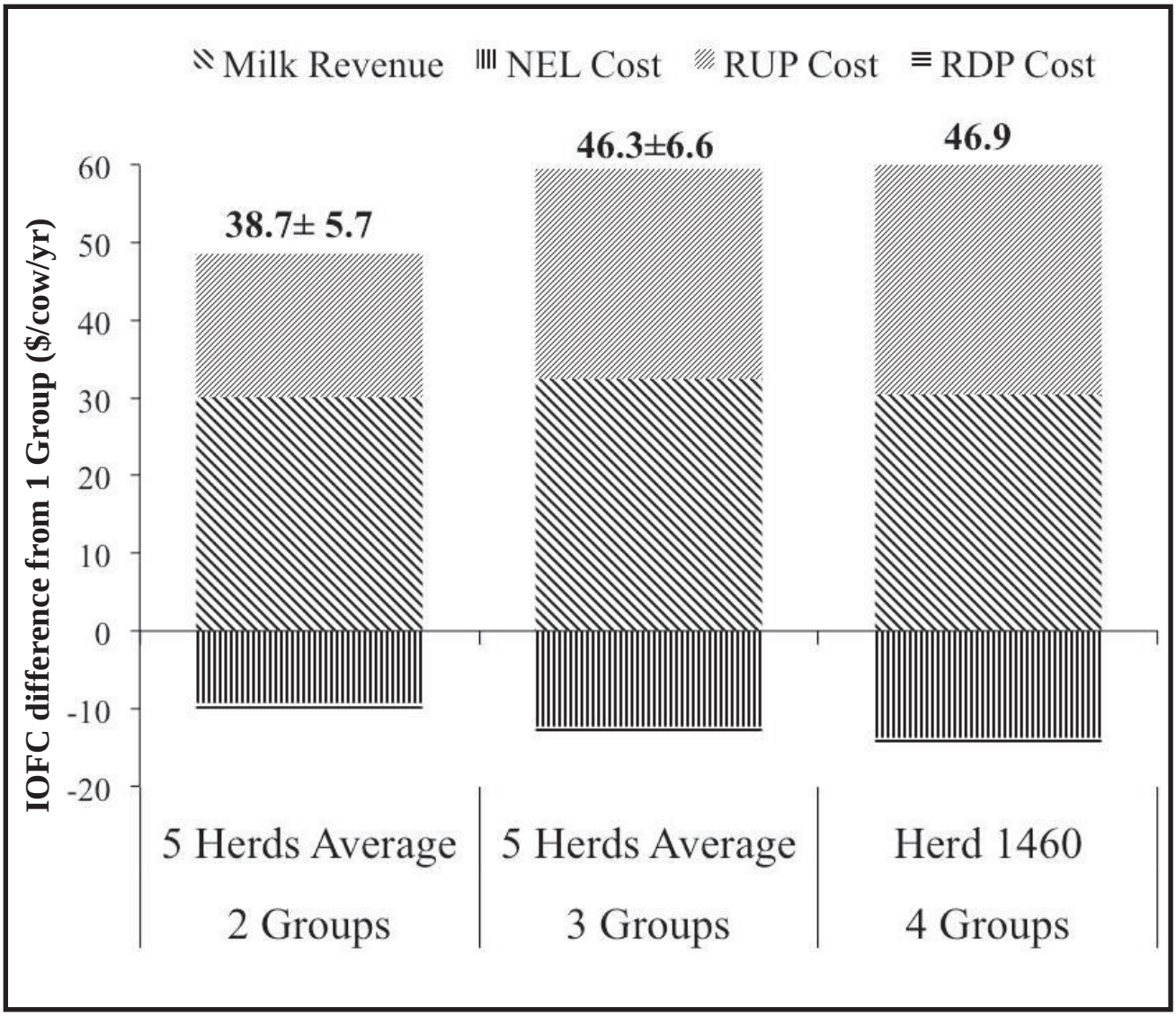

Figure 2. Difference in income over feed cost (IOFC) of 2, 3, and 4 nutritional groups and 1 nutritional group disaggregated in its components: cost of rumen degradable protein (RDP), cost of rumen undegradable protein (RUP), cost of NEL, and milk revenue. The zero line is the average IOFC obtained by 1 group was equal to $2,822 for diet formulated at average MP+1xSD. The labels on top of the bars are the additional IOFC (± SD among the herds) above 1 group. Four nutritional groups were applied only to the largest herd (1,460-cow herd).

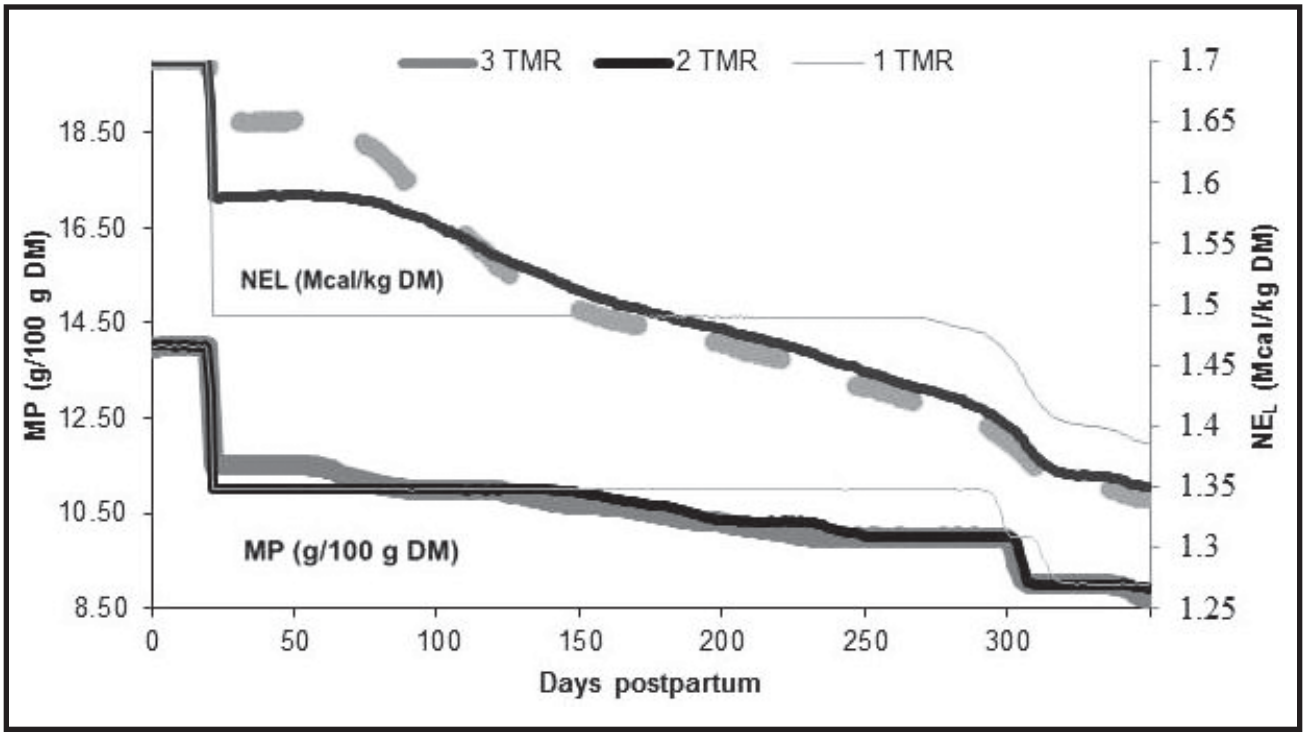

Figure 3. Offered diet average NE_L and metabolizable protein (MP) after calving for the 727-cow herd under different number of nutritional groups.

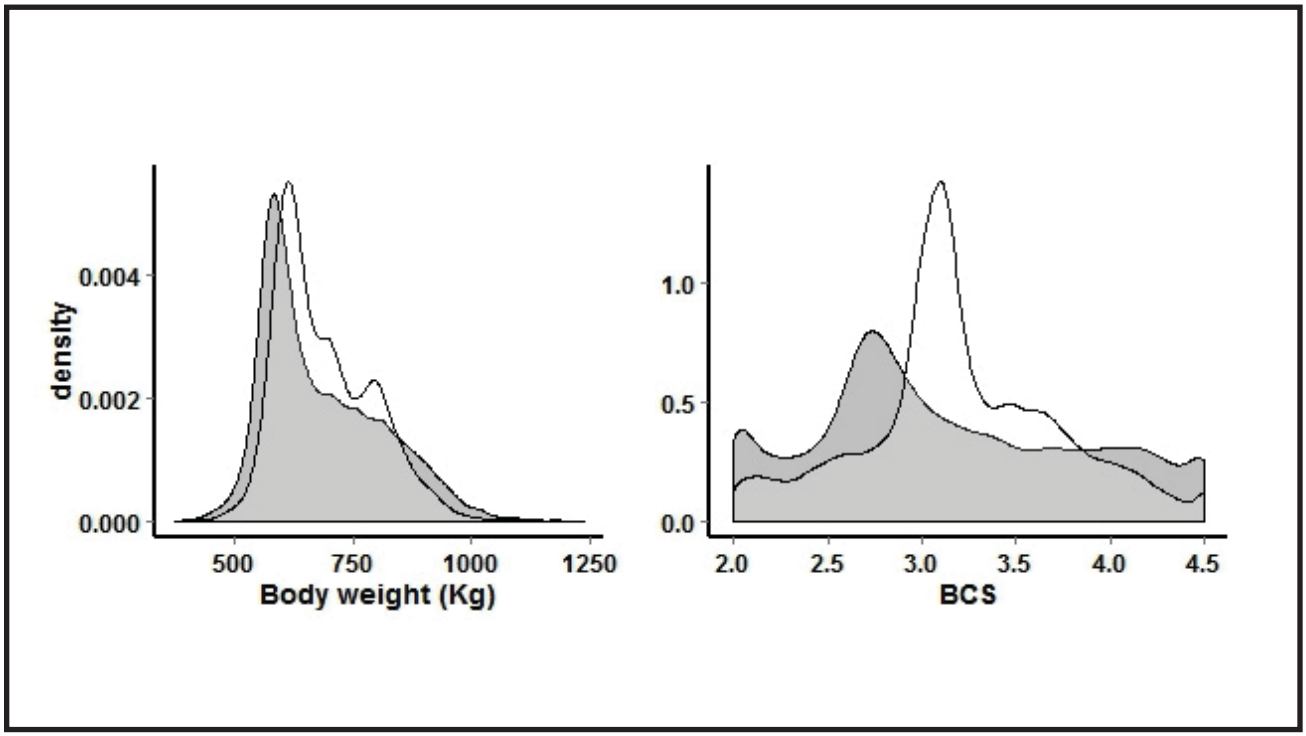

Figure 4. Body weight (left) and BCS (right) density plot from the 787-cow herd for 1 (dark shade) and 3 (light shade) nutritional groups. The BCS average ± SD for 1 and 3 nutritional groups are 3.0±0.7 and 3.25±0.5, respectively. Total area under the curves adds to 1.