Four-State Dairy Nutrition and Management Conference

June 11 & 12, 2014 Dubuque, Iowa

Cooperative Extension for:
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Factors that Affect Vitamin Availability in Feed and Premixes
  Mike Crepeah, Adisseo ................................................................. 1
Basic Aspects of Amino Acid Nutrition in Lactating Cattle
  Chuck Schwab, Professor Emeritus, University of New Hampshire .............. 6
The Benefits of Feeding Methionine During the Transition Phase
  Dan Luchini, Adisseo ......................................................................... 14
Potential Benefits of Feeding Methionine on Reproductive Efficiency of Lactating Dairy Cows
  Milo Wiltbank, University of Wisconsin.................................................. 19

4-State Dairy Nutrition and Management Conference

Dairy Feed Efficency: Feeding and Genetic Factors

Improving Feed Efficiency in Dairy Cattle
  Mike VandeHaar, Michigan State University ........................................... 27
Will Genomic Selection be the Key to Improving Feed Efficiency in Dairy Cattle?
  Kent Weigel, University of Wisconsin ................................................... 34
Feed Parameters and Strategies on our Dairy Farm
  Doug Block, Hunter Haven Farm, Pearl City, IA ................................... 41
Intensified Calf Feeding Programs
  Mike VandeHaar, Michigan State University ........................................... 44
What Do the Cows Have to Say About NDF and Starch Digestion?
  John Goeser, Rock River Laboratory, Inc. ............................................. 47
Using Genomics to Improve the Genetic Potential and Management of Your Herd
  Kent Weigel, University of Wisconsin ................................................... 56
Transitioning with Efficiency, is it possible?
  Phil Cardoso, University of Illinois ..................................................... 62
What’s New with Corn Silage?
  Randy Shaver, University of Wisconsin ................................................. 69
The Compromise Dairy Safety Net Solution
  John Newton, University of Illinois ...................................................... 73
How are Robotic Milking Dairies Feeding Their Cows
  Jim Salfer, University of Minnesota .................................................... 77

Breakfast Sponsored by Quality Liquid Feeds (QLF)

Transition to Global Marketer
  Michael Swanson, PhD, Ag Economist –
  Senior Vice President, Wells Fargo Bank N.A. ........................................ 80
Calf Management

The First 60 Days: Can We Make it Better?
Sheila McGuirk, University of Wisconsin ................................................................. 86

Automatic Calf Feeding Systems Producer Surveys
Jennifer Bentley, Iowa State University ................................................................. 90

Automated Calf Feeder Study Update
Marcia Endres, University of Minnesota ............................................................... 93

Can Amino Acid Supplementation Improve Use of Non-Milk Proteins in Milk Replacers?
Phil Cardoso and James Drackley, University of Illinois ...................................... 94

Real Herds...Real Heifers: The Cost of Raising Heifers
Mark Hagedorn, University of Wisconsin ............................................................... 100

Wisconsin Cost of Raising Dairy Replacements Survey Results
Mark Hagedorn, University of Wisconsin ............................................................... 105

Effects of Close Up Dry Period Stocking Density on Behavior and Health of Dairy Cows
Marcia Endres, University of Minnesota ............................................................... 110

Transition Cow Health: Meeting the Demands of Lactation while Maintaining a Healthy Liver
Heather White, University of Wisconsin ............................................................... 113

Economics of Automatic Calf Feeders
Jennifer Bentley, Iowa State University ............................................................... 119

Diagnostic Dilemmas – How to Understand Mastitis Diagnostic Results from Labs, Farms and PCR Tests
Pam Ruegg, University of Wisconsin ................................................................. 122

Hemorrhagic Bowel Syndrome: Update and Observations
Sheila McGuirk, University of Wisconsin ............................................................... 128
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### Platinum Co-Sponsors

<table>
<thead>
<tr>
<th>Adisseo</th>
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</tr>
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<tbody>
<tr>
<td>Platinum Co-Sponsors</td>
<td></td>
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<td>Papillon Agricultural Company</td>
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<td>QualiTech Inc.</td>
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<td>Rock River Laboratory</td>
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<td>Trouw Nutrition USA</td>
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<tr>
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<td>Westway Feed Products</td>
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### Silver

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<td>BioZyme, Inc.</td>
<td>Prince Agri Products</td>
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<tr>
<td>Byron Seeds, LLC</td>
<td>Quality Roasting, Inc.</td>
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<tr>
<td>Cumberland Valley Analytical Services</td>
<td>SCR Dairy</td>
</tr>
<tr>
<td>DHI-Provo/Ezfeed</td>
<td>Shredlage, LLC</td>
</tr>
<tr>
<td>Digi-Star</td>
<td>SoyBest</td>
</tr>
<tr>
<td>Dinamica Generale US, Inc.</td>
<td>SoyPLUS/SoyChlor</td>
</tr>
<tr>
<td>Enz-A-Bac Advanced Products</td>
<td>Virtus Nutrition</td>
</tr>
<tr>
<td>Farmeron</td>
<td>Zinpro Performance Minerals</td>
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<td>Micronutrients</td>
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<td>Milk Specialties Global</td>
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<td>MIN-AD, Inc.</td>
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<td>Perdue AgSolutions LLC</td>
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**Upcoming Conference Dates**

- June 10 & 11, 2015
- June 15 & 16, 2016
- June 14 & 15, 2017
Vitamins are labile molecules susceptible to degradation by heat, light, moisture, pH and interactions with other feed ingredients. Vitamins vary in their resistance to external stressors and manufacturers have developed various strategies to improve stability. However, premixes and other packages used in dairy nutrition to carry vitamins are commonly highly basic, hygroscopic and contain minerals which are deleterious to vitamin stability. Further, vitamins are required in very small amounts and proper dispersion in the feed delivered to the animal is critical to optimize vitamin supplementation. Too little consideration is commonly given to the composition of premixes and how heterogeneously-sized particles will remain uniformly dispersed in the feed. The focus of this discussion is to review the vitamins commonly fed to dairy animals with an emphasis in understanding how to mitigate deleterious interactions followed by a review of particle segregation and ways to improve premix quality.

Vitamin A

The active form of vitamin A, retinol, is highly unstable outside the body. Therefore, a common industry practice is to manufacture retinyl esters which animals convert to retinol. Less susceptible to degradation, the retinyl esters (acetate, propionate & palmitate) are the most common forms of vitamin A. Retinyl acetate is the molecule used in dry forms of vitamin A. Although more stable than retinol, it still loses activity from exposure to air, moisture, heat, light and minerals. For this reason, retinyl acetate is coated with either a starch-gelatin emulsion or a simple coating consisting mainly of starch (spray-drying). The starch-gelatin emulsion followed by a cross-linking reaction that forms hard spherical beadlets offers the best protection (Fig. 1). Several droplets of retinyl acetate are distinctly surrounded by the cross-linked beadlet. These beadlets are relatively insoluble and provide a good barrier against moisture and minerals (Fig. 2).
**Vitamin E**

Tocopherol is the active form of vitamin E. It is widely distributed in the body. Its role as a cellular antioxidant, protecting skin and other tissues from damage, is well known. However, outside of the body, tocopherol is extremely unstable. For that reason, tocopherol is esterified industrially to form tocopheryl acetate which is very stable and is converted to tocopherol in the body by digestive enzymes. However, our skin lacks the necessary enzymes to convert the acetate to tocopherol. Since tocopheryl acetate is so stable, it is sprayed on silica which effectively adsorbs the oil to form a flowable, dry product. Typically, most commercial products have a concentration of 50% vitamin E (500 IU/g). The silica has effectively adsorbed its weight equivalent in E oil (Fig. 2).

Although stability of tocopheryl acetate is generally not a problem, it is sensitive to environments with a pH above 8. Also, if moisture is present, the silica will preferentially adsorb water and expel the vitamin E oil which could lead to handling and dispersion problems.

Fig. 2. Vitamin E. Tocopheryl acetate adsorbed on silica

**Vitamin D**

The critical requirement of vitamin D for proper bone development is well known. More recent research has shown that vitamin D is also required for normal immune function, insulin metabolism and acts as an inhibitor of certain forms of cancer. There are two forms of vitamin D; D3, or cholecalciferol, found in animals and, D2 or ergocalciferol, found in plants. Commercially, in animal nutrition, only vitamin D3 is produced since D2 is poorly absorbed by poultry.

Commercial production of cholecalciferol or D3 ultimately derives from the wool of sheep. Lanolin is isolated from the wool and converted through a series of reactions into cholecalciferol which is a thick, highly concentrated resin.

Vitamin D3 is not a biologically stable molecule. It will lose activity in the presence of stressors such as moisture, minerals, heat and extreme pH. For that reason, in dry feed applications, D3 is coated with a protective compound. Most commonly, D3, by itself, is spray-dried with a thin coating of starch and, possibly, gelatin (Fig. 3). D3 is also available in combination with vitamin A in a cross-linked beadlet similar to the vitamin A beadlet described earlier.

Spray-drying technology improves handling of the D3 and confers some protection. However, the starch coating will dissolve in the presence of moisture allowing minerals and other stressors to act on the exposed D3. As a result, using a spray-dried source of vitamin D3 is not a particularly good strategy to maximize stability. Also, the concentration of commonly available spray-dried forms of D3 is 500,000 IU/g which might be too concentrated for certain applications and result in poor dispersion.

There are many advantages to using vitamin D3 in combination with vitamin A in a cross-linked beadlet. The common concentration is 1 million IU/g of vitamin A and 200,000 IU/g of D3. The D3 is in a more dilute form and the higher number of particles per gram will result in better dispersion in the premix and feed. Also, the D3 in the cross-linked beadlet benefits from the best protective coating available and superior stability compared to spray-dried forms of D3.

Fig. 3. Spray-dried vitamin D3

**B Vitamins**

B vitamins fed to dairy animals include biotin, niacin, choline and, possibly B9 and B12. Biotin may be
spray-dried to improve handling but most commonly B vitamins are not coated but rather diluted with a carrier to the appropriate concentration.

**Vitamin Stability**

We’ll examine the effect of pH, heat, moisture, minerals and light on the stability of vitamins fed to dairy animals. pH is an important factor because dairy premixes are often basic due to the addition of limestone, buffers and anionic salts. Potassium carbonate, in particular, can raise the pH of dairy premixes to 10. Generally, a neutral pH range is preferred for optimum stability (Fig. 4). Extreme pH conditions can easily result in losses in excess of 10-20% per month in vitamin activity.

**Fig. 4.** PH Range for Optimal Stability

<table>
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<th>pH Range of Vitamins for Optimal Stability</th>
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<tr>
<td>1</td>
</tr>
<tr>
<td>Vitamin A</td>
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<td>Vitamin D3</td>
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<td>Niacinamide</td>
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<td>Biotin</td>
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Water in any form is a primary cause of vitamin destruction. The water can be present in a liquid ingredient, as humidity in the air or as moisture in other ingredients. Water will provide an environment that will promote increased oxidation/reduction reactions through the action of minerals, oxygen and pH effects. Hygroscopicity, the potential of a compound to absorb moisture, is an important concept to understand when examining vitamin stability. Some products such as salt, calcium chloride and urea are highly hygroscopic (>40%) but other ingredients such as sulfate minerals and vegetable material, under humid conditions, can also absorb up to 20-25% of their weight in water.

The rate of vitamin degradation will increase with temperature. In cold, winter conditions, vitamin losses may be negligible but potency losses will roughly double for every temperature increase of about 25°F.

The presence of minerals will accelerate vitamin degradation. Sulfates are most deleterious because of their higher solubility. For example, the rate of degradation of vitamin A might increase from 2% to 8% per month in a premix with minerals.

It is also important to consider that an estimate of the stability of vitamins in a premix needs to consider the additive effects of pH, hygroscopicity, heat and minerals.

Table 1 adapted from work done by M. Coelho (2002) provides an estimate of losses per month of vitamin activity under various conditions. It is important to note that these measurements were done in neutral environment. More basic or acidic conditions as well as higher temperatures (> 25°C) would increase the rate of degradation.

### Table 1. Losses per month (%) in vitamin activity in premixes

<table>
<thead>
<tr>
<th></th>
<th>Dry premix w/o minerals</th>
<th>Premix w/moisture &amp; w/o minerals</th>
<th>Dry premix w/ minerals</th>
<th>Premix w/moisture &amp; minerals</th>
</tr>
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<tbody>
<tr>
<td>A beadlet</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>E acetate 50%</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>D3 spray-dried</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Biotin</td>
<td>&lt;1</td>
<td>2</td>
<td>3</td>
<td>5</td>
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<tr>
<td>Niacin</td>
<td>&lt;1</td>
<td>2</td>
<td>3</td>
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**Evaluation of Premix Quality**

Two factors regarding feeding vitamins and micronutrients should concern formulators, nutritionists and producers; stability and dispersion.

Vitamins are delivered on-farm in premix of varying concentrations. In western dairies, vitamins are added to minerals without the addition of any protein material. In the Midwest, it seems that higher inclusion packages including vegetable protein is more common. The pH of the product carrying the vitamins should be measured. This can be done simply with the use of pH strips (Fig. 5). Add one part material with four parts water, stir and dip pH strip in material. A chart on the box easily provides an accurate estimate of the pH of the material.
A pH of 8-9 is common. Expect that this will cause some vitamin degradation maybe in the range of 10-20% per month. However, pH levels exceeding 9 will accelerate the rate of degradation in an exponential manner.

The determination of the hygroscopicity of the premix should also be measured. This is done by drying a test sample in an oven at 40°C overnight. Weigh out a specific amount (10 g) and insert in an air tight container that also contains water (wet sponges work well). Leave the sample in the container for 12 hours. After, weigh the sample and subtract the additional weight from the weight of the original sample to determine the % moisture absorbed. Any level above 20% can be a cause for concern particularly if this is during a summer period when temperatures and humidity are elevated. In addition, hygroscopic ingredients used in dairy supplements are often highly basic. A hygroscopic, high pH supplement with or without the addition of vegetable protein material will be harmful to vitamin stability.

The dispersion of ingredients in a supplement should also be considered. It is not possible to keep heterogeneously-sized particles well dispersed. Transport and unloading will cause segregation of larger and smaller particles (Fig. 6).

Fig. 6. Segregation of heterogeneously-sized particles

A device commonly referred to as an “ant farm” is an effective tool to evaluate the potential for segregation (Fig. 7). Material is poured through the funnel and the resultant pattern is examined.

Fig. 7. Ant Farm with funnel and sample material

Figures 8, 9 & 10 show examples of particle segregation on a premix. Finer particles accumulate in the center while coarser particles flow to the edges of the ant farm. This phenomenon results in poor distribution of micronutrients. The result in the feed will be, at the least, a wide variation on micronutrient content between batches. At worst, production might be hindered by animals receiving uneven amounts of micronutrients on a daily basis.

Fig. 8. Segregation as evidenced by striations of separate material

Fig. 9. Close-up of segregated material in ant farm

Fig. 10. Coarse material on sides and fine particles in middle of ant farm
Not all premixes exhibit signs of segregation. The premix shown in Fig. 11 is homogeneous and well-dispersed. Attention has been paid to the use of an appropriate carrier, particle size and binder.

**Fig. 11.** Example of evenly-dispersed, homogeneous premix

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**Carriers:**

Attention should be give to the choice of carrier used to carry powders. Limestone is not an effective carrier. Neither are cracked soybeans or DDG. Rice hulls by virtue of their shape are the ideal carrier (Fig. 12). They benefit from a high surface area to volume ratio and their size allows powders to adhere firmly to the rice hulls. The use of rice hulls in a premix causes the particle size distribution to become narrower and more homogeneous. The poultry and pet food industry have historically used rice hulls to produce well-dispersed premixes.

**Fig. 12.** Rice hulls

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**Binders:**

The use of a liquid when manufacturing supplements is important. A product, like mineral oil, that can be well dispersed is desired. The binder should coat the carrier material prior to the addition of powders. The smaller particles will then effectively adhere to the carrier. Also, the amount of binder used should be dependent on the amount of powders in the mix. Remember, dust is segregation! An increased addition of binder material above 1% and up to 2.5% can improve homogeneity, allay dust and maintain ingredients dispersed.

**Considerations on vitamin assay results**

Frequently, a feed or premix will be sent to a lab by a veterinarian or nutritionist who suspects a vitamin deficiency. If the assay results are below specification, the vitamin manufacturer is the first culprit to get the blame. However, in my experience, this is the least likely cause of the low assay result. In order, I would estimate the following causes are more likely to impact results: Aggressive premix leading to vitamin degradation, premix segregation, poor sampling, improper storage and shipping conditions to lab, lab error, incorrect addition of vitamins at the mill and poor vitamin quality.

Labs that provide vitamin assays vary a lot in the quality of their work. A variation of 5% for vitamins A & E and 10% for vitamin D3 is good. Result variation will increase as the expected vitamin levels decrease. Also, lab results can vary between labs and internally as well. Analytical error by third-party non-specialized labs is common. The best accuracy available is generally provided by the vitamin manufacturers themselves.

**Conclusions**

Vitamins are labile molecules. Their incorporation with minerals and other ingredients leads to degradation due to the action of heat, moisture, pH and minerals. Formulators should have an estimate of the conditions under which the vitamins will be exposed until consumption by the animal. Also, segregation of micronutrients is a common problem under current dairy feeding practices. Powders will adhere to an appropriate carrier, increase the effective particle size and greatly reduce segregation. Also, dust is a form of segregation and modifying the quantity of binder used in the premix will improve allay dust and improve quality. In sum, the considerations given to maximize vitamin stability and dispersion in the feed also apply to other micronutrients and end-result should be more predictable animal performance.
Basic Aspects of Amino Acid Nutrition in Lactating Cattle

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TAKE-HOME MESSAGES

• Rumen-degradable protein (RDP) is required by rumen microorganisms and amino acids (AA) are required by the cow

• Research continues to confirm that methionine (Met) and lysine (Lys) are the most limiting AA, and that Met is almost always more limiting than Lys

• Balancing for more optimum supplies of RDP and greater supplies of Met typically reduces feed costs

• Balancing for Lys and Met can provide significant opportunities for minimizing the risk of cows experiencing AA deficiencies and for reducing the need for protein supplements

• There is growing evidence that the increases in milk protein and fat concentrations observed with Lys and Met balancing reflect an improved protein status that can have far-reaching effects on health and performance

• While the benefits of AA balancing might be the most noticeable in transition and early lactation cows, benefits exist throughout lactation

• Rumen-protected Met and Lys supplements should not be fed without confirmed estimates of metabolic “bioavailability” at commercial levels of supplementation

INTRODUCTION

Amino acid balancing continues to be more widely accepted. Contributing factors to increased AA balancing include the desire to feed lower protein diets, high prices for protein supplements, an overall trend of higher milk protein prices, and continued refinement and improvement of nutrition models. With the exception of only a few months since the introduction of multiple-component pricing (MCP) of milk 14 years ago, milk protein has been valued higher than milk fat. Also, a year after the introduction of MCP pricing, the 2001 Dairy NRC model was released. This was the first dairy NRC model to allow for evaluation of diets for adequacy of RDP, RUP and for Lys and Met in metabolizable protein (MP). Because of its excellent ability to predict the balance of AA in duodenal protein (Pacheco et al., 2012), along with the success that users of the model have had with AA balancing, the model has served to stimulate improvements and refinements to other nutritional models. As a result of factors such as these, sales of RP-Met supplements continue to increase with current demand for the leading supplements exceeding supplies. Several RP-Lys supplements have also been introduced.

Achieving success with AA balancing requires acceptance of several basic aspects of AA nutrition and “letting go” of balancing for CP. Several of these basic aspects of AA nutrition will be discussed along with some proven steps for implementing AA balancing.

BASIC ASPECTS OF AMINO ACID NUTRITION

Amino acids are required nutrients

There are over 700 AA that exist in nature (Wu, 2013). Twenty serve as building blocks for protein. Of these 20 “protein” AA, 10 are classified as nutritionally essential (indispensable), meaning they cannot be synthesized in the body and must be provided by the diet and absorbed in the amounts needed.

Protein AA are needed for the synthesis of 100’s of different tissue, regulatory, protective, and secretory proteins. Protein synthesis is a genetically determined event, and as a consequence, the AA composition of each protein, while having its own unique AA composition, is the same every time it is synthesized. Besides their role in protein synthesis, which affects virtually every aspect of metabolism in every living cell (e.g., all enzymes are proteins), free AA (both protein and non-protein AA) are also key regulators of various pathological and physiological processes, including immune responses. They are also used for the synthesis of the other N-containing compounds in the body, which includes dozens of compounds
such as hormones, neurotransmitters, nucleotides (RNA and DNA), histamine, polyamines, etc.

The rest of the AA are referred to as “nonprotein” AA. These are found in physiological fluid and play important roles in metabolism, regulation of metabolism, and therefore, in health and production. For example, three widely known examples of nonprotein AA are homocysteine, glutathione and taurine. Incidentally, all are synthesized from Met. As noted in Figure 3 in the companion paper by Luchini and Loor (2014), homocysteine is a key intermediate in the “Methionine Metabolic Cycle” (Martinov et al., 2010). The Met cycle is a highly regulated metabolic pathway, continually balancing the availability of Met with requirements for protein synthesis, the need for glutathione and taurine, and the need for methyl (CH3) groups. Taurine and glutathione not only serve as major antioxidants in the body, as indicated by Luchini and Loor (2014), but they also have other important functions. For example, taurine serves as a modulator of the digestion and absorption of fat and fat-soluble vitamins, as a regulator of intracellular osmolality and retinal photoreceptor activity, and as a key component of the nerve conduction network (Wu, 2013). Glutathione has an even longer list of other roles in metabolism and regulation (Wu, 2013). These include synthesis of prostaglandins, signal transduction, gene expression, DNA and protein synthesis, cell proliferation (including hepatocytes, lymphocytes and intestinal epithelial cells), and elicitation of immune responses (activation of T-lymphocytes, polymorphonuclear leucocytes, and for cytokine production). Glutathione also plays an important role in spermatogenesis, sperm maturation and oocyte development, and thus, in both male and female reproduction.

Regarding the role of Met in methylation reactions, a recent review (Betolo and McBreairty, 2013) indicated that methyl groups can consume a significant amount of absorbed Met, and that the synthesis of creatine and phosphatidylcholine consume most of the methyl groups. While Met has been established as a primary source of methyl groups, demethylated Met can be remethylated by methyl groups from methyltransferase (via folate) and betaine (synthesized from choline) (Betolo and McBreairty, 2013). As indicated in Figure 3 in Luchini and Loor (2014), Met is first converted to S-adenosylmethionine (SAM) which in turn is the actual methyl donor. SAM participates in more than 50 different methylation reactions (Greenberg, 1963). In summary, these observations highlight some of the important functions that AA have in metabolism and underscore the importance that optimizing AA nutrition can have on health, fertility and production in dairy cows. In a companion paper, Wiltbank et al. (2014) discusses the potential benefits of Met supplementation on reproductive efficiency.

Sources of absorbed amino acids

In ruminants, AA are provided by ruminally synthesized microbial protein, rumen-undegradable protein (RUP, and, to a lesser extent, endogenous protein. Microbial protein refers to the constituent proteins of the bacteria, protozoa, and fungi that are in the rumen. RUP is that portion of feed protein that escapes or resists ruminal degradation. Endogenous protein refers to protein originating in the body. Sources of endogenous protein include mucoproteins in saliva, sloughed epithelial cells (from the respiratory tract, mouth, esophagus, rumen, omasum, and abomasum), and enzyme secretions into the abomasum. The endogenous contribution to the duodenum includes free endogenous secretions as well as endogenous proteins incorporated into microbial cells.

Microbial protein typically supplies a majority of the AA. However, RUP may supply more than 50% of the absorbed AA in high-producing cows fed a high-concentrate diet that is balanced to meet requirements for rumen-degradable protein (RDP) and RUP. The quantity of AA provided by endogenous protein secretions is smaller, assumed to account for less than 10% of total absorbed AA (NRC, 2001 and H. Lapierre, personal communication))

Limiting amino acids

Methionine and Lys have been identified most frequently as the two most limiting AA for lactating dairy cows fed corn-based rations (NRC, 2001). Research conducted since the publication of NRC (2001) has confirmed these findings (e.g., Appuhamy et al., 2011, Chen et al., 2011; Lee et al., 2012; Noftsgger and St-Pierre, 2003; Noftsgger et al., 2005; Ordway et al., 2009; Osorio et al., 2013, Socha et al., 2005; St-Pierre and Sylvestre, 2005). That Met and Lys are the first two limiting AA in most feeding situations is not surprising given their low concentrations in most feed proteins relative to concentrations in rumen bacteria and in milk and tissue protein (Table 1).

“What’s the next AA we should be worrying about?” That has become a frequently asked question from those that have become aggressive with AA balancing. The answer is “maybe histidine (His)”, particularly when lower RUP diets are fed. There are two reasons to suggest that. The first is that European researchers have identified His as the first limiting AA for milk and milk protein yields when high forage, grass silage diets, supplemented with barley and oats, with or without feather meal as a sole or primary source of supplemental RUP, were fed (Kim et
al., 1999, 2000, 2001a, 2001b; Huhtanen et al., 2002; Korhonen et al., 2000; Vanhatalo et al., 1999). None of the diets contained corn or corn byproducts. That His was identified as first limiting maybe shouldn’t be surprising because barley, oats and feather meal all have lower concentrations of His in CP than corn and other protein supplements (Table 1). Also, it is known that microbial protein contributes more, and RUP less, of the total protein flowing to the small intestine when these types of diets are fed. And finally, as seen in Table 1, His concentrations in rumen bacterial microprotein are lower than in most feed proteins. So knowing this information, along with all that is known about Lys and Met being most limiting when corn-based diets are fed, that His might be first limiting when these high forage, no-corn, low-RUP diets are fed.

The second reason for suggesting that His should become an AA to “watch” is that there are now two experiments that have been published where cows fed corn-containing diets, already supplied with supplemental Lys and Met, responded to His supplementation. Lee et al. (2012) fed an adequate RUP containing diet (5.9% of DM), a low RUP diet (4.5% of DM), the low RUP diet supplemented with RP-Lys and RP-Met, and the low RUP diet supplemented with RP-Lys, RP-Met and RP-His. All diets contained (% of DM) corn silage (40.2), alfalfa haylage (16.6), grass hay (5.8), bakery by-product meal (7.5), molasses (4.2), cottonseed hulls (1.1), corn grain, heated soybeans, SoyPlus, mechanically extracted canola meal, and supplemental minerals and vitamins (2.9). Amounts of corn grain, soybeans, SoyPlus, and canola meal were varied between the two basal diets to achieve the two levels of dietary RUP. Because a readily degradable N supplement like urea was not added to the low RUP diets, predicted RDP concentrations decreased from 9.8% of diet DM for the adequate RUP diet to 9.0% for the low RUP diet (NRC, 2001). Predicted concentrations of Lys, Met and His in MP in the MP-deficient diets, without consideration of the supplemental AA, were 6.49, 1.88 and 2.11%, respectively. Total tract digestibility was decreased for OM, NDF and ADF by all of the MP-deficient diets, apparently the result of underfeeding RDP. Milk and milk component yields were decreased by the MP-deficient basal diet as compared to the protein-adequate positive control diet, the apparent result of decreases in N (494 vs. 623 g/d) and DM intake (23.0 vs. 24.5 kg/d). Milk urea N concentrations were also decreased (10.3 vs. 13.0 mg/dL); however, milk component percentages were not affected. Supple-

menting the MP-deficient basal diet with RP-Lys and Met diminished the differences in DM intake and milk and milk component yields between the protein-adequate and deficient diets, and additional supplementation with RP-His eliminated it. That DM intake and milk and milk component yields were restored back to positive control levels with supplemental Lys, Met and His, even though RDP appeared to be deficient, support three basic tenants of AA nutrition: 1) that cows have requirements for individual AA, 2) that the cow’s capacity for protein synthesis is impacted by the supply of the most limiting AA rather than by the supply of MP, and 3) that the efficiency of use of MP for milk protein production is affected by its AA composition. Although milk protein percentages were not significantly affected by treatment, there was a trend for changes that paralleled the changes in DM intake and yield of milk components; values were 2.98, 2.94, 2.99 and 3.03 for diets 1-4, respectively.

Hadrova et al. (2012) evaluated the effects of supplemental His when cows were fed a corn silage-barley and oat based diet with enhanced supplies of absorbable Lys, Met and Leu. The basal diet contained (% of DM): 48.0 corn silage, 8.2 alfalfa hay, 18.8 barley, 8.0 oats, 2.2 linseed meal, 2.2 soybean meal, 11.0 peas and 1.6 supplemental minerals and vitamins. Mid-lactation, duodenally-cannulated Holstein cows were allocated to one of two treatments, a control treatment (infusion of Lys, Met, and Leu) and a His supplemented treatment (infusion of Lys, Met, Leu and His). His infusion increased yields of milk, lactose, protein and casein. However, milk component concentrations were not affected. That milk component concentrations were not affected by supplemental His, but yields of milk (27.9 vs. 26.8 kg) and milk protein (1015 vs. 960 g/d) were, is consistent with observations of others (e.g., Vanhatalo et al., 1999, Korhonen et al., 2000; Huhtanen et al., 2002). Predicted RDP and RUP concentrations, based on an NRC (2001) evaluation of the basal diet by the author, were 10.5 and 3.6% of DM, respectively. Calculated average RDP and RUP balances (g/d) were +60 and -580, respectively. Predicted concentrations of Lys, Met and His in MP, without consideration of infused AA, were 6.95, 1.96 and 2.11%, respectively. These results along with those of Lee et al. (2012) indicate that His concentrations in MP should be monitored, and that at least when using the 2001 NRC model, predicted concentrations of 2.11% or lower are not high enough when balancing for higher targeted levels of Lys and Met in MP (e.g., 6.6 and 2.2%, respectively).

Other essential AA have also been evaluated for their possible limitation after Lys and Met supplemen-


tation. Particular attention has been given to the branched-chain AA (BCAA; isoleucine, leucine and valine), in part because some models predict them as more limiting than other AA. However, Appu-

hamy et al. (2011) saw no evidence of increased milk protein synthesis in early lactation, high producing Holstein cows provided with jugular-infused BCAA when provided in addition to jugular-infused Lys and
Met. Significant increases in milk protein content and yield were observed with supplemental Lys and Met. However, there were no additional responses with the BCAA. The cows averaged nearly 116 lb of milk during the 5-wk experiment. NRC (2001) predicted percentage concentrations of Lys, Met, His, Ile, Leu, and Val in MP with the basal diet were 6.1, 1.8, 2.2, 4.7, 8.9, and 5.3%, respectively.

BALANCING FOR AMINO ACIDS

Considerable progress has been made in recent years to build nutritional models that do a better job of predicting supplies of absorbed AA for dairy cows. While some models also predict requirements, it has long been the authors’ opinion that the most immediate progress in balancing diets for AA would be made by establishing the optimal concentrations in MP of the most limiting AA for one’s model of choice, formulating diets to come as close as possible to meeting those optimal concentrations, and reducing the RUP content of the diet as much as possible without sacrificing any of the production benefits realized by balancing for AA. This first step to balancing for Lys and Met (i.e., establishing the optimal concentrations in MP) was accepted by NRC (2001) and has served the industry very well. As discussed in the NRC publication, this approach not only eliminates the need for validated AA requirements, which didn’t exist when the model was developed (and still don’t exist), but it has the decided advantage of allowing for the establishment of optimal concentrations of the most limiting AA in MP (see Figures 5-12 and 5-13 in NRC 2001) with the same model used for day-to-day ration balancing or diet evaluations. With this information as background, the following AA balancing guidelines, which many of us have used since NRC (2001) was released, are provided.

Guideline #1: Feed a mixture of high quality forages, processed grains, and byproduct feeds that will provide a blend of fermentable carbohydrates and physically effective fiber that optimizes rumen health and maximizes feed intake, milk production, and yield of microbial protein. Microbial protein has an apparent excellent AA composition for lactating dairy cows, particularly with respect to Lys and Met (see Table 1).

Guideline #2: Feed adequate but not excessive levels of RDP to meet rumen bacterial requirements for AA and ammonia. Realizing the benefits of feeding a balanced supply of fermentable carbohydrates on maximizing yields of microbial protein requires balancing diets for RDP. Rumen degraded feed protein is the second largest requirement for rumen bacteria. It supplies the bacteria with peptides, AA, and ammonia that are needed for microbial protein synthesis. Diet evaluation models differ in their estimates of RDP in feeds and animal requirements. The NRC (2001) model typically predicts RDP requirements of 10 to 11% of diet DM. Regardless of the model used, it is important to use the predicted requirements only as a guide and to fine tune according to animal performance. Feed intake, fecal consistency, milk/feed N ratios, milk fat concentrations, and MUN are all useful pieces of information. A common target value for MUN is 8-10 mg/dl. Most important, track and monitor model-predicted RDP levels relative to cow performance so you don’t underfeed it, because doing so can decrease rumen digestion, microbial protein synthesis, and milk yield.

Guideline #3: Feed high-Lys protein supplements, or a combination of high-Lys protein supplements and a RP-Lys supplement, to achieve concentrations of Lys in MP that come close to meeting the optimal concentration as determined for your model (Table 2). While experience indicates it is seldom if ever cost effective to achieve these “required” concentrations, experience indicates it is usually cost-effective to be within 95 to 97% of the indicated values. If you want to feed a RP-Lys supplement, do not feed it until you have seen convincing research results that confirm its “bioavailability” (i.e., the amount of the Lys in the product that actually gets absorbed when fed). In short, you need to know that it will increase plasma Lys concentrations when fed in the amounts that you will feed it as well as knowing how much of it will be absorbed.

Guideline #4: Feed a RP-Met supplement in amounts needed to achieve the optimal Lys/Met ratio in MP for your model (Table 2)...then fine-tune as needed for maximum milk protein concentrations. You may have to feed more than you think, or maybe you can feed less than what you think, but like RP-Lys supplements, you need to know before feeding it that it will increase plasma Met concentrations when fed in the amounts that you will feed it as well as knowing how much of it will be absorbed. If it’s a Met analog product, like MetaSmart (Adisseo) for example, then the question is “how much gets absorbed and converted to Met”? The analog must also demonstrate an ability to increase blood plasma Met concentrations when fed at normal amounts. Like RP-Lys supplements, over-estimating the efficacy of a RP-Met supplement usually leads to disappointing production outcomes, and more often than not, leaves the nutritionist and dairy producer believing that balancing for Lys and Met has little or no value.

Guideline #5: After the transition phase or once peak DM intake is achieved, limit RUP supplementation to what the cows say is needed...not what your model
says. Reductions of 1.5 to 2.0 percentage units are common when balancing for Lys and Met. Most models do not adjust MP requirements, and thus RUP requirements, for changes in predicted concentrations of Lys and Met in MP. This is a serious deficiency, and until models are designed to predict milk and milk protein yields from supplies of MP-Lys and MP-Met, rather than supplies of MP, just know that the MP requirement, and therefore the RUP requirement, for a given yield of milk and milk protein decreases with higher concentrations of Lys and Met in MP (Table 3). Research (e.g., Noftsger and St-Pierre, 2003; Chen et al., 2011) and field observations alike support the conclusions from Table 3.

Guideline #6: Monitor His levels in MP closely. There is a lack of studies analogous to those that exist for Lys and Met to generate dose-response plots that relate changes in content or yield of milk protein to predicted concentrations of His in MP. Such data is needed to establish reliable estimates of the required concentrations of His in MP for maximal content and yield of milk protein, as has been done for Lys and Met. However, the author believes it is desirable to maintain a His level in MP that is at least 0.1 percentage unit higher than Met. The recommendation that His should be slightly higher in MP than Met is based largely on NRC (2001) evaluations of the aforementioned experiments where researchers obtained milk protein yield responses to intravenous or intestinal infusions of His.

BENEFITS OF BALANCING FOR AA

The benefits of AA balancing, with the focus being almost entirely on Lys and Met thus far, are well known and have been summarized (e.g., Schwab, 2010, 2012). These benefits include reducing the risk of cows experiencing an AA deficiency, optimizing transition cow health, increasing milk and milk component yields, and feeding less RUP to post-transition cows. Feeding less RUP not only decreases feed costs but it also allows for increased carbohydrate feeding. The consequence is increased synthesis of microbial protein, a protein of high quality, and increased synthesis of volatile fatty acids, important substrates for lactose and fat synthesis. The benefits of AA balancing are clearly the most noticeable in transition and early lactation cows (Schwab, 2012), but benefits exist throughout lactation.

Amino acid balancing can have profound effects in early lactation cows. As discussed by Luchini and Loor (2014), this was readily apparent in the experiment by Osorio et al. (2012). In that experiment, when high-Lys basal pre- and post-calving diets were supplemented with either Smartamine M or MetaSmart, marked responses in milk and milk component yields resulted. Several indicators of metabolic health were also positively influenced. In a series of earlier Ajinomoto sponsored experiments (prior to 1999), researchers conducted 8 experiments where cows were provided supplemental RP-Lys and RP-Met from calving to 4-12 wk of lactation. Results indicated an average milk yield response of 8.5 lb with a range of 4.4 to 12.1 lb (Izuru Shinzato, personal communication). Considerably more research is needed with transition cows to better identify what the ideal AA balance is and that when provided, its impact on health, reproductive efficiency, and milk and milk component production.

CONCLUSIONS

Amino acids are the required nutrients, not crude protein. Because AA have numerous and important functions in metabolism, providing them to the lactating dairy cow in a better balance has been shown to provide significant opportunities for minimizing the risk of cows experiencing AA deficiencies, for reducing the need for supplemental RUP, and for optimizing health, production and dairy herd profitability. Balancing for AA has, without question, been a contributing factor to higher milk yields, higher milk component levels, and greater dairy herd profitability for many dairy producers.

REFERENCES


Whitehouse, N., C. Schwab, D. Luchini, T. Tylutki, and B. Sloan. 2009. Comparison of optimal lysine and methionine concentrations in metabolizable protein estimated by the NRC (2001), CPM-Dairy (v.3.0.10) and AMTS.Cattle (v.2.1.1) models. J. Dairy Sci. 92 (Suppl. 1):103. (Abstr.)


Table1. A comparison of Lys and Met concentrations in CP of lean tissue, milk, rumen bacteria and common feedstuffs.

<table>
<thead>
<tr>
<th></th>
<th>Lys</th>
<th>Met</th>
<th>His</th>
<th></th>
<th>Lys</th>
<th>Met</th>
<th>His</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean tissue 1</td>
<td>6.4</td>
<td>2.2</td>
<td>2.5</td>
<td>Brewer’s grains</td>
<td>4.1</td>
<td>1.7</td>
<td>2.0</td>
</tr>
<tr>
<td>Lean tissue 2</td>
<td>6.3</td>
<td>1.8</td>
<td>2.4</td>
<td>Canola meal</td>
<td>5.6</td>
<td>1.9</td>
<td>2.8</td>
</tr>
<tr>
<td>Milk</td>
<td>7.6</td>
<td>2.7</td>
<td>2.7</td>
<td>Corn DDG w/sol</td>
<td>2.2</td>
<td>1.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Rumen bacteria</td>
<td>7.9</td>
<td>2.6</td>
<td>2.0</td>
<td>Corn gluten meal</td>
<td>1.7</td>
<td>2.4</td>
<td>2.1</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cottonseed meal</td>
<td>4.1</td>
<td>1.6</td>
<td>2.8</td>
</tr>
<tr>
<td>Alfalfa silage</td>
<td>4.4</td>
<td>1.4</td>
<td>1.7</td>
<td>Soybean meal</td>
<td>6.3</td>
<td>1.4</td>
<td>2.8</td>
</tr>
<tr>
<td>Corn silage</td>
<td>2.5</td>
<td>1.5</td>
<td>1.8</td>
<td>Sunflower meal</td>
<td>3.6</td>
<td>2.3</td>
<td>2.6</td>
</tr>
<tr>
<td>Grass silage</td>
<td>3.3</td>
<td>1.2</td>
<td>1.7</td>
<td>Blood meal</td>
<td>9.0</td>
<td>1.2</td>
<td>6.4</td>
</tr>
<tr>
<td>Barley</td>
<td>3.6</td>
<td>1.7</td>
<td>2.3</td>
<td>Feather meal</td>
<td>2.6</td>
<td>0.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Corn</td>
<td>2.8</td>
<td>2.1</td>
<td>3.1</td>
<td>Fish meal</td>
<td>7.7</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Oats</td>
<td>4.2</td>
<td>2.9</td>
<td>2.4</td>
<td>Meat &amp; bone meal</td>
<td>5.2</td>
<td>1.4</td>
<td>1.9</td>
</tr>
<tr>
<td>Wheat</td>
<td>2.8</td>
<td>1.6</td>
<td>2.4</td>
<td>Meat meal</td>
<td>5.4</td>
<td>1.4</td>
<td>2.1</td>
</tr>
</tbody>
</table>

1Values reported by O’Conner et al. (1993), 2Tylutki et al. (2008), and 3NRC (2001).
Table 2. Current knowledge regarding required Lys and Met concentrations in MP for maximal milk protein concentrations as determined for three different nutrition models.

<table>
<thead>
<tr>
<th>Model</th>
<th>Lys</th>
<th>Met</th>
<th>Optimal Lys/Met ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRC (2001)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Original release¹</td>
<td>6.80</td>
<td>2.29</td>
<td>2.97</td>
</tr>
<tr>
<td>Revised 2001 v.1.1.9³</td>
<td>6.83</td>
<td>2.28</td>
<td>3.00</td>
</tr>
<tr>
<td>CPM-Dairy v.3.0.102</td>
<td>7.46</td>
<td>2.57</td>
<td>2.90</td>
</tr>
<tr>
<td>AMTS.Cattle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v.2.1.12</td>
<td>6.68</td>
<td>2.40</td>
<td>2.78</td>
</tr>
<tr>
<td>v.3.3.43</td>
<td>6.97</td>
<td>2.53</td>
<td>2.75</td>
</tr>
</tbody>
</table>

¹Determined by Schwab et al. (2009), ²Whitehouse et al. (2009), ³Whitehouse et al. (2013).

Table 3. Effect of different Lys and Met concentrations in MP on amounts of RUP needed to provide 180 g of total MP-Lys and 60 g of MP-Met³.

<table>
<thead>
<tr>
<th>Lys in MP (%)</th>
<th>MP required (g/d)</th>
<th>Microbial MP² (g/d)</th>
<th>Endogenous MP (g/d)</th>
<th>Required MP from RUP (g/d)</th>
<th>Required RUP³ (g/d)</th>
<th>Required RUP (% of DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.7/1.9</td>
<td>3157</td>
<td>1390</td>
<td>121</td>
<td>1646</td>
<td>2058</td>
<td>8.1</td>
</tr>
<tr>
<td>6.0/2.0</td>
<td>3000</td>
<td>1390</td>
<td>121</td>
<td>1489</td>
<td>1861</td>
<td>7.3</td>
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<tr>
<td>6.3/2.1</td>
<td>2857</td>
<td>1390</td>
<td>121</td>
<td>1346</td>
<td>1683</td>
<td>6.6</td>
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<tr>
<td>6.6/2.2</td>
<td>2727</td>
<td>1390</td>
<td>121</td>
<td>1216</td>
<td>1520</td>
<td>6.0</td>
</tr>
<tr>
<td>6.9/2.3</td>
<td>2609</td>
<td>1390</td>
<td>121</td>
<td>1098</td>
<td>1372</td>
<td>5.4</td>
</tr>
</tbody>
</table>

¹ NRC (2001) was used as the model of choice. Intake of DM was assumed to be 25.5 kg. ² Assumed that feeding less RUP and more carbohydrates would not increase microbial MP supply. ³ Assumed that microbial protein has an average RUP digestibility of 80%.
Immediately after calving, the cows are at the highest risk of suffering a disease; a high incidence of diseases during this period impacts their performance on the rest of the lactation and often, impacts their ability to reproduce normally. Since they cannot consume enough feed to keep-up with their milk production, they lose a great deal of body weight. Cows will lose over 100 pounds immediately after calving to meet the high demand for nutrients. Body weight loss after calving is normal, in fact, it is accepted that cows will lose between 0.5 and 1 point of body condition score within the first quarter of the lactation cycle.

Nutrition management during the periparturient period may have implications for the immune function and metabolic health (Waldron, 2014). During this period of negative nutrient balance, the cows mobilize body reserves, including fat, protein and glycogen for milk production, direct oxidation and hepatic gluconeogenesis. Despite much attention have been devoted to the mobilization of fatty acids and its impact on liver health, it is important to highlight that cows lose up to 44 lbs of protein during early lactation (Khula et al., 2011).

Van der Drift et al., 2012, hypothesized that much of this protein breakdown may be used as amino acid donors for liver gluconeogenesis, therefore, muscle breakdown would serve as glucose precursor during periods of negative energy balance. The authors evaluated the mobilization of muscle protein by analysis of plasma 3-methylhistidine, an indicator of muscle protein breakdown and concluded that higher mobilization of protein around calving might restrict ketone body production due to higher availability of glucogenic precursors. Khula et al. concluded that muscle and amino acid losses continually progress within the first weeks of lactation, muscle glycogen and fat storages are already exhausted immediately after parturition. The authors stated that there is a fast (within hours) allocation of glucose (from glycogen) and fatty acids and a later allocation of amino acids. Therefore, the body mass losses experienced by the cow during the transition period are due to the quick use of glycogen, and the longer and chronic use of fat and protein. While protein and amino acids losses are continuous during the first few weeks of lactation, muscle glycogen and fat storages are readily exhausted immediately after parturition (Figure 1).

**Figure 1:** Muscle glycogen, fat and protein content of cows (% of wet weight) during the periparturient period.

McCarthy et al. (1968) hypothesized that Methionine (Met) deficiency in ruminants may limit hepatic very-low density lipoprotein (VLDL) synthesis and be a causative factor of ketosis. Rate of hepatic VLDL synthesis was subsequently demonstrated to be lower in ruminants than monogastrics (Pullen et al., 1990). This inherent feature of ruminants is particularly important at parturition when the homeorhetic adaptations in the animal lead to marked increases in blood non-esterified acids (NEFA) which are taken up by liver, hence, increasing the susceptibility for hepatic lipidosis (Grummer, 1993).

Grummer (1993) proposed that utilization of triacylglycerol (TAG) for VLDL synthesis after parturition is impaired when the level of hepatic Met is insufficient. Feeding a diet enriched with methionine is important in the synthesis of Apoprotein B and in the synthesis of Phosphatidyl Choline, both necessary for the formation of Very Low Density Lipoproteins; that are required for ensuring transport of the fat away...
from the liver (Durand, 1992). More recent work has established an association between low levels of serum Met during the first 14 days postpartum and severe hepatic lipodosis (Shibano and Kawamura, 2006). The work of Dalbach et al. (2011) demonstrated that it is feasible to increase the serum concentration of Met during the first 2-weeks postpartum by feeding rumen-protected Met. This is particularly important for the animal not only because of the key role of Met in milk protein synthesis but also for intra-hepatic VLDL synthesis, production of glutathione and taurine [intracellular antioxidants; (Atmaca, 2004)], and provision of methyl groups (Finkelstein, 1990). At least in non-ruminants, the latter has been demonstrated to be an important aspect of overall Met utilization in liver namely because methylation serves as a way to regulate gene expression, protein function, and RNA processing.

Cows during the transition period are immuno suppressed (Goff, 2006) this predisposes the cow to be susceptible to infections. If the cow suffers a disease like mastitis or metritis the immune system responds with inflammation, increased body temperature, heart and respiration rate. Under such stressful conditions, reactive oxygen metabolites (ROM) are an end product of the metabolism. When present in excessive concentration, (ROM) can be toxic to the cells. Lipid peroxides are linked to systemic inflammation. They are generated when intracellular lipids react with ROM and when they are present; they are the cause of inflammation (Bradford, 2012). One of the most common ways that nutrients are involved in animal health is due to their role as antioxidants (Waldron, 2014). Severe inflammation or marginal antioxidant protection can lead to extensive tissue damage (Zhao and Lacasse, 2008).

The onset of lactation is a time when the ROM increase drastically, at least in part because of the doubling of metabolic rate in the liver. ROM are oxygen containing molecules that are chemically reactive. They are the result of normal metabolism of oxygen and the cells defend against ROM damage with enzymes referred to as “antioxidants”. Increased ROM are significant contributors (or consequence of) to systemic inflammation. Reducing the oxidative stress can only be beneficial to the cow, particularly during the transition phase. If ROM are produced in excess and the cell’s antioxidant enzymes are unable to counteract this effect in the short-term, ROM can cause significant cellular damage. Antioxidants help the cow to control the ROM, Vitamin E and A and Se are know antioxidants and their impact on cow’s health during transition is well reported (Sordillo et al., 2009). Preventing ROM accumulation and also providing substrates for antioxidant enzymes during the transition phase may help the cow to have a healthier lactation and better overall performance.

A current model of the interrelationships between

### Figure 2

Current model depicting the likely causes of tissue damage (e.g. liver, rumen epithelium, mammary gland, reproductive tract) and the inflammatory response during the transition period with and without the incidence of infectious disease (Bertoni and Trevisi, 2013).
inflammation and oxidative stress was reported recently (Figure 2).

The inflammatory events induced by an infectious agent, oxidative stress, and/or their combination act directly on the liver through the pro-inflammatory cytokines including IL-6, TNFα, and IL-1. The liver (hepatocytes) has intracellular proteins (receptors) that can sense the cytokines, which upon binding to these receptors (e.g. nuclear factor kappa-beta (NFKB) responds by altering the gene expression (mRNA), and subsequently protein synthesis, of a selected group of proteins classified as the “acute-phase proteins (APP)”. The so-called “positive AAP” are increased by inflammation, while the “negative APP” are decreased (Figure 2). Therefore, by following the temporal change in their concentrations we can evaluate the relative state of inflammation of cows during the transition phase.

Methionine is another well-established source of the antioxidants glutathione and taurine (Atmaca, 2004) and its antioxidant properties in other species have been demonstrated (Geumsoo et al., 2014). One of the key antioxidant enzymes in tissues, including the liver, is glutathione peroxidase. This enzyme can be derived in part via methionine (Figure 3). Preventing ROS accumulation and also providing substrates for antioxidant enzymes during the transition phase may help the cow to have a healthier lactation and better overall performance.

**Figure 3:** The role of methionine in the cow’s metabolism
Results from a research trial that validated the impact of feeding a MET enriched diet on the oxidative stress and immune status of cows during transition were recently published (Osorio et al, 2013, 2014). Three groups of cows were fed the same basal diet from 21 days before expected calving day until 28 days after calving. One group of cows received the basal diet deficient in MET, the other two groups were fed the same basal diet enriched with one of two commercially MET sources to achieve a LYS:MET ratio of 2.8:1. The cows fed the MET enriched diets consumed an average of 4.7 extra pounds of feed per day and increased their Energy Corrected Milk (ECM) by 8.6 pounds per day during the first 28 days in milk (Table 1).

Table 1: Dry matter intake, milk, protein, fat yield and ECM from cows fed a Control and methionine enriched diets (MetaSmart and Smartamine) (Osorio et al., 2013)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>MetaSmart</th>
<th>Smartamine</th>
<th>Diet P-value*</th>
<th>Met P-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI (lb/d)</td>
<td>29.3</td>
<td>33.5</td>
<td>34.4</td>
<td>.18</td>
<td>.06</td>
</tr>
<tr>
<td>Milk yield (lb/d)</td>
<td>78.6</td>
<td>83.9</td>
<td>88.1</td>
<td>.15</td>
<td>.08</td>
</tr>
<tr>
<td>Milk protein (%)</td>
<td>3.04</td>
<td>3.26</td>
<td>3.19</td>
<td>.13</td>
<td>.05</td>
</tr>
<tr>
<td>Milk fat (%)</td>
<td>4.27</td>
<td>4.68</td>
<td>4.09</td>
<td>.59</td>
<td>.36</td>
</tr>
<tr>
<td>Milk protein yield (lb/d)</td>
<td>2.44</td>
<td>2.71</td>
<td>2.73</td>
<td>.08</td>
<td>.03</td>
</tr>
<tr>
<td>Milk fat yield (lb/d)</td>
<td>3.61</td>
<td>4.05</td>
<td>3.98</td>
<td>.11</td>
<td>.04</td>
</tr>
<tr>
<td>ECM (lb/d)</td>
<td>90.3</td>
<td>98.6</td>
<td>99.1</td>
<td>.09</td>
<td>.03</td>
</tr>
</tbody>
</table>

* Met: Contrast statement of Control vs. MetaSmart + Smartamine

Also, the cows fed the MET enriched diets had higher concentrations of carnitine, essential for the transport of NEFA from the cytosol into the mitochondria for subsequent fatty acid oxidation (Drackley, 1999); a tendency to lower concentration of phosphatidyl choline, important in the assembly/export of fat out of the liver via the formation of VLDL, suggesting a greater potential for liver fatty acid oxidation and a better transport of fat out of the liver via the formation of VLDL (Osorio et al, 2014). Further, the cows fed the methionine enriched diets had lower blood concentrations of Ceruloplasmin and Serum Amyloid A (both “positive APP”) indicating a reduced inflammatory response, those cows also had a better antioxidant status indicated by a higher oxygen radical absorbance capacity and glutathione concentration (Table 2).

Table 2: Carnitine, Phosphatidyl Choline, Ceruloplasmin, Serum Amyloid A, Oxygen Radical Absorbance Capacity and Glutathione from cows fed a Control or methionine enriched diet (MetaSmart or Smartamine) (Osorio et al., 2014)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>MetaSmart</th>
<th>Smartamine</th>
<th>Diet P-value*</th>
<th>Met P-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carnitine, mg/L</td>
<td>37.5</td>
<td>98.2</td>
<td>66.0</td>
<td>.01</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Phosphatidyl Choline, uM/g of tissue</td>
<td>10.6</td>
<td>7.7</td>
<td>9.1</td>
<td>.15</td>
<td>.07</td>
</tr>
<tr>
<td>Ceruloplasmin, umol/l</td>
<td>3.02</td>
<td>2.68</td>
<td>2.71</td>
<td>.03</td>
<td>.009</td>
</tr>
<tr>
<td>Serum amiloyd A, ug/ml</td>
<td>61</td>
<td>40.7</td>
<td>43.5</td>
<td>.17</td>
<td>.06</td>
</tr>
<tr>
<td>Oxygen Radical Absorbance Capacity, mol/L</td>
<td>11.9</td>
<td>12.9</td>
<td>12.4</td>
<td>.05</td>
<td>.04</td>
</tr>
<tr>
<td>Glutathione, mM</td>
<td>1.27</td>
<td>1.55</td>
<td>1.73</td>
<td>.09</td>
<td>.04</td>
</tr>
</tbody>
</table>

* Met: Contrast statement of Control vs. MetaSmart + Smartamine
The authors concluded that the cows fed the MET enriched diets during the transition period had higher dry matter intake post-partum, produced more ECM, had a lower systemic inflammatory state, an enhanced liver function and a greater antioxidant capability.

Methionine is a key nutrient in transition cow nutrition, not only as a building block for protein synthesis but as a key intermediate to enhance the metabolic processes. This can lead to better liver function, oxidative and inflammatory status, allowing the cow to withstand the challenges of the transition phase of lactation. The results shown by Osorio et al. support the hypothesis that feeding a MET enriched diet during the transition period is beneficial to cows.

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Osorio, J. S., E. Trevisi, P. Ji, J. K. Drackley, D. Luchini, G. Bertoni, and J. J. Loor. 2014. Biomarkers of inflammation, metabolism, and oxidative stress in blood, liver, and milk reveal a better immunometabolic status in peripartal cows supplemented with Smartamine M or MetaSmart. (Submitted)


**Potential Benefits of Feeding Methionine on Reproductive Efficiency of Lactating Dairy Cows**

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**Introduction**

Enhancing reproductive efficiency can improve the economic performance of commercial dairy operations by increasing the number of high-producing lactating cows in the ideal portion of the lactation curve, as well as enhancing culling practices, increasing numbers of replacement heifers, and reducing reproduction costs. Researchers for more than a century have attempted to enhance productivity and reproduction in dairy cattle by optimizing nutritional strategies. Researchers have focused on optimizing energy intake and body condition scores of cows in order to improve reproduction (Cardoso et al., 2013, Carvalho et al., 2014, Chapinal et al., 2012, Garverick et al., 2013, López-Gatius et al., 2003). Other researchers have attempted to supplement nutritional components that may act as nutraceuticals, such as specific poly-unsaturated fatty acids, in order to enhance processes that would optimize reproduction (Juchem et al., 2010, Thatcher et al., 2006). Studies in this area are consistent with the idea that dairy cattle reproduction can be altered by diet modifications and nutritional strategies.

Protein nutrition has also been investigated in relation to reproductive efficiency in dairy cows in many types of studies. One major idea is that elevated crude protein or protein degradability in the diet leads to elevated urea nitrogen. This high urea nitrogen, measured in blood or milk is associated with, and may be the cause of, reduced fertility in lactating dairy cows. A recent meta-analysis evaluated the results from 32 treatment comparisons published in 21 studies (Lean et al., 2012). In these studies, increased dietary protein or increased degradability of dietary protein decreased risk of pregnancy by 9%. However there was no association between blood urea nitrogen (BUN) and risk of pregnancy, possibly due to technical aspects of BUN quantification or a relatively minor role of this metabolite in the reduced fertility. Nevertheless, there are many reasons to reduce crude protein in dairy cow diets including costs, environmental impacts, and efficiency of nitrogen utilization (Sinclair et al., 2014). Therefore, a negative effect of high crude protein is likely to not be a major factor in the reduction in dairy cattle fertility in most situations.

Less emphasis has been placed on potential positive effects that amino acid supplementation can have on reproduction in dairy cattle. Some amino acids are limiting for optimal milk production as evidenced by an increase in milk yield, percentage of milk protein, and milk protein yield after supplementation with specific, rumen-protected amino acids (Cho et al., 2007, Patton, 2010, Socha et al., 2005). Generally the first three rate limiting amino acids for milk production are considered to be Met, Lys, and His. In addition, many amino acids can have positive effects on physiological processes that are independent of their effects on synthesis of proteins. This has been termed “functional effects” of amino acids and methionine and arginine effects are the best studied “functional amino acids” that have been linked to reproduction (Bazer et al., 2010, Penagaricano et al., 2013). This review will focus on concentrations of amino acids in oviduct and uterus, followed by discussion of reproductive stages that may be altered by amino acids.

**Concentrations of amino acid in oviductal and uterine fluid**

Fertilization and the first few days of embryo development occur in the oviduct. By about 5 days after estrus the embryo arrives in the uterine horn. The embryo reaches the blastocyst stage by 6 to 7 days after estrus. The embryo hatches from the zona pellucida by about Day 9 after estrus and then elongates on Days 14-19. The elongating embryo secretes the protein interferon-tau that is essential for rescue of the corpus luteum and continuation of the pregnancy. By Day 25-28 the embryo attaches to the caruncles of the uterus and begins to establish...
a vascular relationship with the dam through the placenta. During all the time prior to embryo attachment, the embryo is free-floating and is dependent upon uterine secretions for energy and the building blocks for development, including amino acids. Thus, it is critical to understand the changes in amino acid concentrations in the uterus that accompany these different stages of embryo development.

Table 1 summarizes the concentrations of amino acids in plasma, in the oviduct (average of Days 0, 2, 3, 4, and 6 of estrous cycle), and in the uterus (average Days 6, 8, and 14 of estrous cycle). The data are from the elegant study of Hugentobler et al., 2007 done in crossbred beef heifers. There was no effect of day of the cycle on oviductal concentrations so the average of all measured days is shown. The plasma concentrations are the average of the same days as oviductal measurements. Nine of the 20 amino acids were present at significantly greater concentrations in the oviduct than plasma indicating that mechanisms are present in the cells of the oviduct that allow concentration of amino acids. The uterus also had greater concentrations of many amino acids than found in plasma from cows on the same days of the estrous cycle. The amino acids that were most dramatically elevated in uterus, Asp, Asn, Glu, were mostly similar to the oviduct. One major difference is that the concentration of Tau is much greater in uterus compared to oviduct, where Tau was not concentrated compared to plasma (Table 1).

### Table 1. Concentrations of 19 amino acids in plasma, oviduct, and uterus based on results from Hugentobler et al., 2006. In addition, the last column compares amino acid concentrations in pregnant vs. non-pregnant uterus near embryo elongation (Day 15 in sheep; Day 18 in cattle).

<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>Oviductal [μM]</th>
<th>Plasma [μM]</th>
<th>Uterine [μM]</th>
<th>Oviduct / Plasma, %</th>
<th>Uterus / Plasma %</th>
<th>Fold Increase in pregnant uterus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ala</td>
<td>592.2</td>
<td>252.52</td>
<td>353.07</td>
<td>235%</td>
<td>156%</td>
<td>2.87X</td>
</tr>
<tr>
<td>Arg</td>
<td>133.3</td>
<td>94.50</td>
<td>193.87</td>
<td>141%</td>
<td>196%</td>
<td>7.58X</td>
</tr>
<tr>
<td>Asn</td>
<td>41.0</td>
<td>19.60</td>
<td>72.17</td>
<td>209%</td>
<td>357%</td>
<td>5.5X</td>
</tr>
<tr>
<td>Asp</td>
<td>135.5</td>
<td>6.72</td>
<td>120.80</td>
<td>2016%</td>
<td>2059%</td>
<td>4.93X</td>
</tr>
<tr>
<td>Gln</td>
<td>194.7</td>
<td>236.80</td>
<td>208.57</td>
<td>82%</td>
<td>89%</td>
<td>4.06X</td>
</tr>
<tr>
<td>Glu</td>
<td>346.3</td>
<td>62.12</td>
<td>217.63</td>
<td>558%</td>
<td>341%</td>
<td>3.45X</td>
</tr>
<tr>
<td>Gly</td>
<td>1557.6</td>
<td>680.88</td>
<td>1215.73</td>
<td>229%</td>
<td>183%</td>
<td>1.24X</td>
</tr>
<tr>
<td>His</td>
<td>68.8</td>
<td>57.04</td>
<td>109.23</td>
<td>121%</td>
<td>195%</td>
<td>11.48X</td>
</tr>
<tr>
<td>Ile</td>
<td>87.6</td>
<td>86.10</td>
<td>94.10</td>
<td>102%</td>
<td>103%</td>
<td>7.06X</td>
</tr>
<tr>
<td>Leu</td>
<td>192.2</td>
<td>154.72</td>
<td>201.03</td>
<td>124%</td>
<td>121%</td>
<td>4.41X</td>
</tr>
<tr>
<td>Lys</td>
<td>223.7</td>
<td>105.34</td>
<td>209.23</td>
<td>212%</td>
<td>176%</td>
<td>14.39X</td>
</tr>
<tr>
<td>Met</td>
<td>39.8</td>
<td>24.88</td>
<td>40.40</td>
<td>160%</td>
<td>201%</td>
<td>12.39X</td>
</tr>
<tr>
<td>Phe</td>
<td>68.1</td>
<td>38.42</td>
<td>75.50</td>
<td>177%</td>
<td>175%</td>
<td>7.31X</td>
</tr>
<tr>
<td>Ser</td>
<td>172.7</td>
<td>85.54</td>
<td>252.73</td>
<td>202%</td>
<td>301%</td>
<td>2.52X</td>
</tr>
<tr>
<td>Tau</td>
<td>49.4</td>
<td>47.34</td>
<td>440.03</td>
<td>104%</td>
<td>783%</td>
<td>1.09X</td>
</tr>
<tr>
<td>Thr</td>
<td>162.6</td>
<td>133.60</td>
<td>144.60</td>
<td>122%</td>
<td>96%</td>
<td>3.29X</td>
</tr>
<tr>
<td>Trp</td>
<td>36.1</td>
<td>27.52</td>
<td>38.40</td>
<td>131%</td>
<td>134%</td>
<td>4.99X</td>
</tr>
<tr>
<td>Tyr</td>
<td>54.4</td>
<td>25.62</td>
<td>63.73</td>
<td>212%</td>
<td>227%</td>
<td>5.3X</td>
</tr>
<tr>
<td>Val</td>
<td>181.4</td>
<td>170.04</td>
<td>192.47</td>
<td>107%</td>
<td>106%</td>
<td>4.63X</td>
</tr>
</tbody>
</table>
In addition to the mechanisms that concentrate amino acids in the uterus in non-pregnant ruminants, there are additional mechanisms that result in further increases in concentrations of amino acids in the uterine lumen in pregnant ruminants near the time of embryo elongation (Day 14-18). Three studies have provided amino acid concentrations near the time of embryo elongation; two in sheep (Gao et al., 2009c) and one in cattle (Groebner et al., 2011). Although there seems to be very little change in amino acid concentrations between Day 10 and 16 in non-pregnant sheep, there are dramatic increases from 3 to 23-fold in specific amino acids in the uterine lumen of pregnant sheep (Gao et al., 2009c). In order to provide some idea of changes in uterine amino acids during early pregnancy, we have combined the results from these 3 studies into a fold increase in amino acids during the time of embryo elongation. As shown in Table 1, there is an increase in almost all amino acids at the time of embryo elongation. Of particular interest for dairy cattle, the three amino acids that are considered rate-limiting for milk production, Met, His, and Lys, are the amino acids with the greatest increase in concentrations in the uterine lumen during embryo elongation (>10-fold increase on average from all three studies). Arginine is another amino acid that has been studied extensively in relation to reproduction (Lassala et al., 2011, Li et al., 2014, Wu et al., 2013) and it is also highly concentrated in the pregnant uterus. No study has evaluated these increases in lactating dairy cows, particularly in dairy cows that are deficient vs. sufficient in particular amino acids. In a sheep model, maternal nutrient restriction can dramatically reduce plasma, uterine, and fetal fluid concentrations of amino acids (Kwon et al., 2004) and cause fetal growth restriction. This growth restriction can be overcome by provision of arginine or sildenafil citrate (Viagra) that both increase uterine blood flow and amino acid concentrations in the uterine fluid (Lassala et al., 2010, Satterfield et al., 2010). Thus, Arg, although not considered rate-limiting for milk production under most circumstances, could be limiting for uterine blood flow and thereby limit reproductive efficiency of dairy cattle. Inadequate supply of other amino acids, particularly the rate-limiting amino acids, Met, His, and Lys, could hinder the rapid growth of the embryo that occurs between Day 14 and 19 in the pregnant cow or subsequent growth of embryonic, fetal, and placental tissues. The increase in specific amino acids in the uterus near the time of embryo elongation appears to be due to an induction of specific amino acid transporters in the uterine endometrial cells (Gao et al., 2009a, b, Groebner et al., 2011). The induction of these amino acid transporters is most likely induced by the protein interferon-tau that is secreted by the elongating embryo. For example, interferon-tau treatment dramatically increased one specific amino acid transporter, SLC15A3, in both glandular epithelial (36-fold) and stromal epithelial (177-fold) uterine cells (Groebner et al., 2011). Thus, there is likely a positive feedback system occurring during this critical time of embryo elongation with uterine amino acids being essential for rapid embryo growth and embryonic interferon-tau production; whereas, interferon-tau stimulates active amino acid transport through the uterine epithelial cells to increase amino acid supply to the elongating embryo. Disturbances in the temporal relationship between uterine blood flow, induction of uterine amino acid transport, uterine amino acid concentrations, embryonic growth, embryonic interferon-tau production, and rescue/regression of the corpus luteum may reduce fertility and increase pregnancy losses.

Effect of supplementing specific rumen-protected amino acids on fertility

Numerous studies have evaluated the effects of rumen-protected amino acids, particularly methionine, on productivity. For example, a recent meta-analysis (Vyas and Erdman, 2009) evaluated the results from 35 experiments on production effects of postruminal supplementation with methionine. At low methionine intakes (25 g per cow per day) there were dramatic increases in milk protein (16 g of milk protein per gram of metabolizable methionine intake); whereas, the production response was more muted at high methionine intake (70 g per cow per day; increase of 4 g of milk protein per g of metabolizable methionine intake). Unfortunately, we have been unable to find studies in the scientific literature, which were specifically designed and adequately powered to evaluate the effects of specific amino acids on reproductive efficiency of lactating dairy cows. The largest study (Polan et al., 1991) combined results from 259 cows at 6 Universities evaluating rumen-protected methionine and lysine supplementation. They detected no significant effect on days to first service, services per conception, or calving interval, although no details were provided on reproductive measures in each specific treatment group. It is obvious that large studies are needed to validly evaluate the effects of supplementing amino acids on measures of reproductive efficiency in lactating dairy cows.

One of the reasons for the poor definition of the role of specific amino acids in dairy cattle reproduction has been the use of experimental designs that generally are not optimal for making firm conclusions.
about reproductive traits. Some nutrition-reproduction studies use individually fed cattle, generally at university facilities, providing data that are valid for quantitative variables, such as milk production and hormonal concentrations, but are underpowered (too few cows per treatment) for evaluating binomial variables such as fertility. Alternatively, researchers use sufficient numbers of cows on commercial operations but nutritional strategies are applied to too few pens to allow valid statistical analyses as previously discussed (Tempelman, 2009). To detect a 10% difference in pregnancies per AI (P/AI) there would need to be at least 180 cows per treatment group. Detection of smaller differences would require much greater numbers of cows in the experiment. In one manuscript the authors state “As nutritional scientists, we tend to put production responses above all other responses . . . However, maintaining the health of the cow also has its economic benefits and we must consider health responses when evaluating the effects and benefits of using supplemental Met sources during the periparturient period” (Ordway et al., 2009). In other species, fecundity and embryo development are dependent upon optimal methionine balance (Coelho and Klein, 1990, Coelho et al., 1989, Grandison et al., 2009, Rosenkrans et al., 1989). For example, supplementation of culture media with methionine increased percentage of porcine embryos that initiated hatching (measure of normal embryo development) from 56% to 89% (Rosenkrans et al., 1989).

**Effect of methionine on embryo development**

One particularly interesting study (Coelho et al., 1989) used serum from lactating dairy cows in the media to grow head-fold stage rat embryos (Day 9.5 after breeding). Complete development of these embryos requires serum and development is normal in rat serum. When embryos are grown in serum from dairy cows embryonic development is abnormal (Table 2-Line 1) when measured as total embryo protein, somite pairs, or percentage of the embryos that are abnormal (no neural tube closure, abnormal shape, no development of eyes and branchial arches). Supplementation of bovine serum with amino acids and vitamins produced normal development (Line 2). Amino acid supplementation alone but not vitamin supplementation produced normal development. Supplementation of methionine alone was sufficient to produce normal development of the rat embryos in cow serum (Next to last line of Table 2). In a separate experiment, use of serum from cows that were supplemented with rumen-protected methionine (110 g/d) also produced normal embryo development. Thus, bovine serum has such low methionine concentrations that normal development of rat embryos is retarded.

**Table 2.** Effect of supplementation of various components on development of head-fold stage rat embryos in bovine serum. Data from (Coelho et al., 1989).

<table>
<thead>
<tr>
<th>Cow serum with:</th>
<th>Embryo Protein</th>
<th>Somite Pairs</th>
<th>% Abnormal</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>73.7 + 8.6a</td>
<td>12.5 + 1.3a</td>
<td>100%</td>
</tr>
<tr>
<td>Amino acids + vitamins</td>
<td>130.0 + 7.7b</td>
<td>21.5 + 0.6b</td>
<td>0%</td>
</tr>
<tr>
<td>Amino acids</td>
<td>117.1 + 8.5b</td>
<td>21.3 + 0.2b</td>
<td>0%</td>
</tr>
<tr>
<td>Vitamins</td>
<td>56.6 + 5.76a</td>
<td>9.3 + 0.8a</td>
<td>100%</td>
</tr>
<tr>
<td>Amino acids w/o methionine</td>
<td>82.9 + 8.7a</td>
<td>11.0 + 0.7a</td>
<td>100%</td>
</tr>
<tr>
<td>Methionine</td>
<td>133.7 + 5.5b</td>
<td>22.3 + 0.4b</td>
<td>0%</td>
</tr>
<tr>
<td>Serum from cow supplemented with 110 g/d rumen-protected Met</td>
<td>135.2 + 9.1 (Separate study)</td>
<td>Not measured</td>
<td>0%</td>
</tr>
</tbody>
</table>
The requirements for complete development of bovine embryos have not yet been determined. Current culture conditions allow production of bovine embryos to the blastocyst stage (Day 7-8) and even allow hatching of a percentage of embryos (Day 9), however conditions have not been developed that allow elongation of embryos in vitro, and definitely do not allow culture of bovine embryos to the head-fold stage that was analyzed in the rat embryo experiments. The methionine requirements for cultured preimplantation bovine embryos (Day 7-8) was recently determined in studies from University of Florida (Bonilla et al., 2010). There was a surprisingly low methionine requirement (7 μM) for development of embryos to the blastocyst stage by Day 7, however development to the advanced blastocyst stage by Day 7 appeared to be optimized at about 21 μM (Bonilla et al., 2010). Thus, the results of this study indicated that development of morphologically normal bovine embryos did not require elevated methionine concentrations (>21 μM), at least during the first week after fertilization.

A recent study (Ikeda et al., 2012) evaluated whether methionine metabolism was required for normal development of bovine embryos. The researchers added ethionine or additional methionine to cultures of bovine embryos. Ethionine blocks metabolism of methionine into the one-carbon pathway (termed antimetabolite of methionine). Ethionine did not block development to the morula stage but blocked development to the blastocyst stage (Control=38.5%; Ethionine=1.5%). Thus, methionine has an essential role in the development of the bovine embryo from morula to blastocyst.

We recently evaluated the effect of supplementation with rumen-protected methionine on early embryo development in superovulated cows. We used superovulated animals so that we would have sufficient statistical power by evaluating numerous embryos in order to validly test the in vivo effects of methionine supplementation on early embryo development in lactating dairy cows. In this experiment, animals were blocked by parity and calving date and randomly assigned to two treatments differing in level of dietary methionine supplementation: 1) Methionine (MET); diet composed of (%DM) corn silage (39.7), alfalfa silage (21.8), HMSC (17.2), roasted soybeans (8.6), grass hay (4.6), canola meal (4.0), mineral-vitamin mix (2.7) and ProVAAL Ultra (w/Smartamine®, 1.4), formulated to deliver 2875 g MP with 6.8 Lys %MP and 2.43 Met %MP; 2) Control (CON); cows fed the same basal diet but replacing ProVAAL Ultra by ProVAAL Advantage (no added Smartamine®), formulated to deliver 2875 gr MP with 6.8 Lys %MP and 1.89 Met %MP. As shown in Figure 1, there was an increase in both kg of milk protein produced and percentage of protein in the milk. Thus, from a protein production standpoint, methionine appeared to be rate-limiting. We measured plasma methionine concentrations in this study and found a large effect of feeding rumen-protected methionine on circulating methionine concentrations (Control=16.8 μM vs. Met-supplemented=22.9 μM).

**Figure 1.** Effect of methionine supplementation with Smartamine®, 1.4 on kg of milk protein produced per day (left panel) or percentage of milk protein (right panel). *P<0.05; **P<0.10
Our primary interest was the effect of supplemental Met on embryo quality. We evaluated a total of 570 embryos in this experiment and found no differences in fertilization or embryo quality (Table 3). Thus, methionine supplementation did not alter early production, at least grossly.

Even though methionine supplementation during the later stages of follicle development and early embryo development may not have produced morphological changes in the early embryo, it is well known that methionine during this time can have dramatic effects on the epigenome of the embryo. This means that the genes can be changed in such a way that they are not expressed in the same way due to addition of groups, generally methyl groups to the DNA of the cells. For example, a previous study in sheep restricted methyl donors by restricting methionine, vitamin B12, and folate before and for the first 6 days after breeding. They then transferred normally-appearing embryos into control sheep and then evaluated the lambs after parturition. The embryos that were produced in low methionine produced lambs that had substantial differences in blood pressure and immune function. To test this idea in cattle, we evaluated whether the embryos that were recovered from cows that had been supplemented or not supplemented with methionine had differences in gene expression (Penagaricano et al., 2013).

The objective of this part of the study was to evaluate the effect of maternal methionine supplementation on the transcriptome of bovine preimplantation embryos (Penagaricano et al., 2013). Only high quality embryos from individual cows were pooled and then analyzed by a powerful technique that allows evaluation of all genes that are expressed in these embryos, called RNA sequencing. Remarkably, the small difference that we produced in circulating methionine produced a substantial difference in expression of genes in the embryo. A total of 10,662 genes were significantly expressed in the bovine embryos. A total of 276 genes were expressed significantly differently in embryos from cows supplemented or not supplemented with methionine. Most of these genes were turned off in embryos from cows that were supplemented with methionine. This would be expected since methionine supplementation leads to methylation of the DNA and this inhibits expression of a gene until the appropriate stage of development. Thus methionine supplementation seemed to change gene expression in a way that may lead to improved pregnancy outcomes and improved physiology of offspring. Many of the genes are involved in immune function and later stages of embryo development that may be critical for pregnancy progression and normal immune function after birth. Further studies are needed to determine if these gene expression changes lead to changes in embryo development, reduced pregnancy loss, and altered physiology of the offspring.

Table 3. Effect of methionine supplementation with Smartamine®, 1.4 on reproductive parameters in superovulated lactating dairy cows.

<table>
<thead>
<tr>
<th>number of superovulated cows</th>
<th>MET</th>
<th>CON</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL number</td>
<td>17.0 ± 1.3</td>
<td>17.7 ± 1.5</td>
<td>0.90</td>
</tr>
<tr>
<td>Total ova/embryos recovered</td>
<td>9.1 ± 1.4</td>
<td>6.8 ± 1.0</td>
<td>0.18</td>
</tr>
<tr>
<td>Number of fertilized ova</td>
<td>6.5 ± 1.1</td>
<td>5.5 ± 0.9</td>
<td>0.56</td>
</tr>
<tr>
<td>% Fertilized ova</td>
<td>74.7 ± 5.6</td>
<td>82.2 ± 3.8</td>
<td>0.27</td>
</tr>
<tr>
<td>Number of transferable embryos</td>
<td>5.0 ± 0.9</td>
<td>4.3 ± 0.1</td>
<td>0.57</td>
</tr>
<tr>
<td>% Transferable embryos</td>
<td>56.3 ± 6.5</td>
<td>62.5 ± 6.0</td>
<td>0.49</td>
</tr>
<tr>
<td>Number of degenerate embryos</td>
<td>1.5 ± 0.4</td>
<td>1.3 ± 0.4</td>
<td>0.75</td>
</tr>
<tr>
<td>% Degenerate embryos</td>
<td>18.5 ± 4.6</td>
<td>19.7 ± 4.7</td>
<td>0.83</td>
</tr>
<tr>
<td>% Degenerate of fertilized ova</td>
<td>25.1 ± 5.8</td>
<td>27.5 ± 6.0</td>
<td>0.74</td>
</tr>
</tbody>
</table>
Conclusions

Supplementation of rate-limiting amino acids can have substantial effects on milk protein content and yield, however, effects on reproduction have not yet been adequately evaluated. The dramatic induction of the rate-limiting amino acids, Met, His, and Lys, in the uterine fluid of pregnant cows near the time of embryo elongation suggests that elevated amounts of these amino acids may be critical for this important stage of embryo development. Supplementation of cows with methionine during the final stages of follicular development and early embryo development, until Day 7 after breeding, did not lead to gross morphological changes in the embryos but did result in dramatic differences in gene expression in the embryo. Further studies are needed to evaluate whether supplementation with these essential amino acids to lactating cows would have a beneficial impact on embryo survival and if these changes in the early embryo translate into changes pregnancy outcomes or physiology of the resulting calf.

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Improving Feed Efficiency in Dairy Cattle

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Introduction

Feed efficiency, or the efficiency of converting feed to milk, matters on farms because it has a major influence on farm profitability and environmental stewardship in the dairy industry. Dairy feed efficiency in North America has doubled in the past 50 years, largely as a byproduct of selecting and managing cows for increased productivity. Increasing productivity results in a greater percentage of total feed intake being used for milk instead of cow maintenance. Elite dairy cattle in the US currently partition three times more feed energy toward milk than toward maintenance. We are not likely to continue to make major advances in feed efficiency simply by increasing milk per cow. Instead, we also must focus on how to get more milk from each unit of feed.

How should we define feed efficiency?

The simplest way to define feed efficiency is milk per unit feed, but this does not give adequate consideration to energy density of different feeds in a diet and the composition of milk, nor to gains or losses in body energy. Thus, I prefer to discuss the efficiency of converting feed energy to the energy of milk and body tissues.

Figure 1. Energy flow in a cow.

Gross energy (GE) is the total chemical energy of a feed and is independent of how efficiently the cow uses it. Not all GE is useful because some of it is not digested but rather is lost as fecal energy. Some digested energy is lost as gaseous energy, primarily methane produced during fermentation, and as urinary energy, primarily urea produced to remove extra N from the body. Digested energy also is lost as heat associated with the metabolic work of fermenting, digesting, and processing nutrients. The remaining energy is known as net energy (NE). Some NE is used to support maintenance functions and is all lost as heat. Some NE is the chemical energy of secreted milk and accreted body tissue and conceptus. Energetic efficiency is the energy captured in products divided by the energy consumed by a cow in her lifetime.

At the farm level, efficiency also should account for feed wastage and the saleability of products, as well as the economic value of feed and milk components. To define efficiency on a global scale, we should consider inputs and outputs of fuels and greenhouse gases, land use, effects on native ecosystems, and whether foods could be consumed directly by humans. For this paper, however, I will discuss mostly energetic efficiency.

Level of Production and Feed Efficiency

The major factors that affect feed efficiency on farms include a) milk energy yield relative to cow body weight (BW), b) the percentage of lifetime a cow spends in lactation, c) nutritional accuracy in feeding, and d) the efficiency of converting feed GE to NE.

A cow’s maintenance requirement is considered to be constant and related to its BW. The typical Holstein cow has a maintenance requirement of ~10 Mcal of NE/day (equivalent to ~25 Mcal of GE and 20 to 30 lb of feed). If a cow eats at maintenance and produces no milk, her feed efficiency is 0%. Any extra feed can be converted to milk or body tissues. If the cow eats twice as much feed—20 Mcal NE or 2X maintenance, only half of her feed would be used for maintenance with the remaining half used for milk. As she eats more feed, the portion used for maintenance becomes a smaller fraction of total feed intake; this "dilution of maintenance" increases efficiency. However, as intake increases, the marginal increase in efficiency from diluting maintenance diminishes with each successive increase in feed intake. For example, the increase in efficiency is less going from 3X to 4X maintenance than from 2X to 3X (solid line, Figure 2). Furthermore, as cows eat more, the percentage of feed that is digested is depressed. At high intakes, the digestibility depression may even outweigh the dilution of maintenance and efficiency may decline with increased intake. In fact, according to the equations used in the NRC (2001), efficiency peaks at ~4X
Maintenance intake (dotted line, Figure 2), which is ~100 lb milk (3.5% fat) per day for a 1500-lb cow.

The digestibility depression is not well quantified for cows consuming >4X maintenance (VandeHaar, 1998), and NRC 2001 likely depresses digestibility too much. Current data from our USDA feed efficiency project support the idea that the true change in efficiency is somewhere between the two lines of Figure 2. In any case, at about 4X intake, feed efficiency is close to maximum. Elite cows (>4X, or >30,000 lb/305-d lactation) are already near, at, or possibly above the optimal multiple of maintenance for maximal efficiency during lactation.

**Figure 2.** Efficiency (assuming no change in BW) in response to intake for a lactating cow with no change in digestibility (solid line) or with digestibility depressed as per the NRC 2001 system (dashed line). Productivity for each multiple of maintenance is approximately 33, 67, 100, and 133 lb of milk for 2X, 3X, 4X, and 5X, respectively.

![Graph showing efficiency of feed use](image)

Feed efficiency at the herd level requires accounting for body tissue gain and the feed consumed by heifers and dry cows, which is 15-30% of the feed a cow eats during her lifetime. Thus, cows that average 4X intake during lactation are about 3X on a lifetime basis. The average Holstein in North America currently produces ~22,000 lb milk/year and captures ~21% of her lifetime GE intake as milk and body tissues. Many top US herds produce >30,000 lb/yr and therefore are getting close to maximum biological efficiency based on multiples of maintenance. Given that 2/3 of North American Holsteins are from AI sires, the limitation to greater production and efficiency for most cows is probably feeding and management. Therefore, we are not likely to continue to make major advances in feed efficiency by simply breeding for increased milk yield relative to BW. We must do a better job of managing the cows we have to increase production and efficiency, and we must begin focusing more on efficiency in breeding.

Importantly, the impact of multiples of maintenance on efficiency is likely the same whether we achieve more milk at a specific BW, or the same milk with smaller BW. Breeding for smaller cows is probably not going to help much, which will be discussed later.

Level of production also alters profitability and the efficiency of using human-consumable foods, on land use, and on greenhouse gas emissions.

**Profitability.** Because greater milk yield per cow increases feed efficiency, and because feed is a major farm expense, greater production per cow generally increases profit per cow. Data from commercial farms bears this out (Rodriguez et al., 2012). However, feed efficiency is only one factor that influences profitability. Greater production per cow decreases the proportion of total farm expenses that are fixed; thus, even if we reach the optimal production per cow to maximize biological efficiency, economics still favors higher production per cow to dilute out farm fixed costs. More importantly, the cost of feed does matter! Using expensive feeds to achieve high production or high feed efficiency will sometimes decrease profitability.

**Use of human-consumable foods.** Although the efficiency of total feed use in the US dairy industry is 20-25% for energy and 20-30% for protein, the returns on human-digestible inputs ranges from 60 to 130% for energy and 100 to 280% for protein (Oltjen and Beckett, 1996). This is because cows eat many feeds that humans do not consume; examples include cottonseeds, soyhulls, and distillers grains. However, these fibrous by-product feeds are generally less digestible than grains and may limit the ability of cows to produce the highest levels of milk. Thus, maximizing total feed efficiency will not be possible at the same time as maximizing efficiency of human-consumable foods. As competition for food grains increases in the future, the ability of cows to convert non-human-consumable foods into milk and meat for people will become more important, and the optimal level of production might be less in the future than it is today. At present, however, using byproduct feeds extensively for heifers, dry cows, and late lactation cows and thoughtfully for cows in early lactation should enhance efficiency of total feed and human-consumable foods.

**Land use.** Using land to produce grains and legume seeds for direct human consumption would be the most efficient way to feed people. Using land to grow feeds for dairy cattle producing 22,000 lb/yr results in only half as much food for people (VandeHaar and St-Pierre, 2006). However, milk output per acre increases with greater milk production per cow. More importantly, if byproduct feeds make up one-third of
the feed used by a dairy herd producing 33,000 lb/y, then using land for milk production yields 90% as much food for humans as do grains and legumes. In my opinion, an efficient dairy industry will be part of our food production system long into the future.

Environmental stewardship. To properly consider environmental impact, one must consider all inputs and outputs for the dairy industry, including even the fuel used to till the land to grow the crops. This is called a Life Cycle Analysis and, although it is fraught with potential inaccuracies, there is no other way to consider the big picture. Two recent studies highlight the value of increased productivity to enhance environmental stewardship. Thomassen et al (2008) compared conventional and organic Dutch dairy farms. Milk yield per cow was 18,000 lb/y for the conventional farms and 13,000 lb/y for the organic farms. When considering all inputs (which included feeds being shipped in from outside the country), conventional farms used 60% more energy and caused 50% more eutrophication per unit of milk produced, but the organic farms required 40% more land. Acidification and climate change were not different for the two systems. In my view, the decreased need for land gives the advantage to the conventional system as the unneeded land could be used to produce biofuels or put into native habitats. This is consistent with a study by Capper et al. (2009) showing that in the last 60 years, the US dairy industry has decreased greenhouse gas emissions by 60% per unit of milk produced, mostly because of the enhanced feed efficiency from higher productivity. Thus, increased productivity (up to 4X) increases efficiency, and increased efficiency generally is good for the environment—we can feed more people with less resources and less negative environmental impact. Improving efficiency of milk production by using new technologies seems the responsible thing to do for the environment, at least in the foreseeable future, until average milk production exceeds 30,000 lb/year.

Management To Improve Feed Efficiency

The average Holstein currently produces about 21,000 lb milk/year and captures ~21% of her lifetime GE intake as milk and body tissues. Feed efficiency likely plateaus at about 33,000 lb milk for cows with mature BW of 1600 lb, so increases in productivity will continue to improve efficiency for most North American dairy farms. Using a model described in VandeHaar (1998), the impacts of various management changes on efficiency were predicted. Increasing average daily milk production by 10% increases lifetime energetic efficiency 0.7%. Increasing cow longevity from 3 to 4 lactations, reducing the age at first calving from 26 to 22 months, or reducing calving interval from 14 to 12.5 months could achieve similar improvements in lifetime efficiency. Thus, how we feed and manage cows at each stage of life can increase milk yield per day of life, thereby diluting maintenance, and increasing efficiency. These management changes promote similar improvements in the efficiency of converting feed protein to milk or body protein. However, the single biggest impact farms could make on efficiency of protein use is to simply quit overfeeding protein, as is often done in late lactation. Feeding cows past 150 days postpartum a diet with 2 percent less protein (15 vs 17% CP) would increase efficiency of protein use by 1.3%.

One often-overlooked management aspect of feed efficiency is feed management. The amount of feed wasted on some farms is considerable. To minimize feed wastage requires an annual evaluation of procedures for harvesting, transporting, and storing feeds, mixing diets, and managing bunks. However, when managing bunks, it is important to remember that maximizing feed intake for lactating cows increases milk per cow and farm-wide efficiency. Maximum feed intake occurs when cows are comfortable and have plenty of water and fresh, well-balanced feed available most of the day. This topic has been discussed considerably in the past 20 years, with general agreement and no need for continued discussion here. Even if some extra feed must be discarded, strategies to improve intake per cow overall will yield improved efficiency, profitability, and stewardship.

Feeding Cows for Greater Feed Efficiency

Nutrient requirements vary as lactation progresses, and the optimal diet for maximum efficiency and profitability changes as well. Most farms feed totally mixed rations (TMR) instead of feeding grain to each cow separately and individually. Use of TMR feeding improves productivity and efficiency because cows theoretically eat the same thing in every bite and rumen pH is more consistent. However, with TMR feeding, cows are less likely to receive a diet that matches their individual requirements; this is especially true if all lactating cows (other than perhaps the fresh cows) are fed the same TMR. Feeding a single TMR across lactation can never maximize production and efficiency. A single TMR is usually formulated for the higher producing cows and is more nutrient-dense than optimal for cows in later lactation, resulting in inefficient use of most nutrients (for example, protein). In addition, although a single TMR is formulated for the high producers, it likely will not maximize milk for the herd. Diets low in fiber and high in digestible starch optimize production and reproduction in peak lactation, but this type of diet would have inadequate fiber for fresh cows and would promote over-fatten-
ing in late lactation cows. Fat cows are more susceptible to health problems at next calving, resulting in less saleable milk and followed by increased body fat mobilization, impaired fertility, and extended lactation interval. Consequently, cows culled in single TMR situations may be those that cannot adapt to suboptimal management, rather than those that are least efficient, productive, and profitable. Moreover, single TMR systems do not allow maximum returns from expensive feeds that may profitably increase production in fresh or high producing cows but have negative return in lower producers. This is relatively obvious for supplements designed to improve fresh cow health or for protein supplements high in rumen-undegraded protein that benefit early lactation but not late lactation. This is less obvious but equally important in forage selection. Not all lactating cows benefit equally from highly digestible fiber; a single TMR prevents optimal allocation of forages. Cheap byproduct feeds are especially useful in late lactation to improve profitability and overall efficiency of the dairy industry. One argument used by farms against multiple ration groups is that milk production decreases when cows are switched to a different group with a different ration. However, many factors affect milk production during a grouping change (examples include days in milk, stocking density, and cow social interactions), and we are quick to notice temporary drops in production.

The number of rations on any farm depends on many factors, but I recommend at least three based on feeding goals (Figure 3). Fresh cows should be fed for optimal health and expensive supplements are warranted. Cows in peak lactation should be fed for maximum milk; because their intake is limited by rumen fill, they should be fed minimum fiber diets with plenty of digestible starch to maximize energy intake. Cows in later lactation should be fed to optimize milk and body condition; they should be fed less fermentable starch and more fermentable fiber to promote partitioning of nutrients toward milk instead of body tissues and thus minimize fattening. The decision on when to switch cows from the early to late lactation diet should be based on body condition, parity, milk yield, and reproductive status. Of these, perhaps the most important criteria for switching to the lower starch ration is whether a cow has achieved a body condition score of 3. In addition, late lactation cows should be fed lower protein diets to maximize efficiency of protein use. Expensive supplements are most useful in early lactation. Cheap feeds are best used in late lactation.

Figure 3. Considerations in nutritional grouping.

Nutritional grouping and multiple TMR undoubtedly do increase capital, management, and labor costs; however, the economic returns can be significant in both the short and long term. Moreover, feeding cows according to requirements enables feed allocation to maximize production and profitability, improves efficiency of protein use, decreases N and P excretion, and improves sustainability of the industry. If you currently feed a single TMR, I encourage you to seriously consider how you can make this work. Even small farms can devise creative ways to feed cows according to requirements. One approach might be to feed cows supplements individually using a computerized feeding system that recognizes cows and dispenses specific mixes at timed intervals throughout the day.

Although poor feed efficiency usually decreases profitability, maximizing efficiency will not necessarily maximize profitability—feed costs do matter! Expensive energy sources like fats usually improve feed efficiency but sometimes decrease profitability. Cheap bulky feeds may decrease efficiency but improve profitability (especially in late lactation). Feeding extra protein usually decreases efficiency of protein use but sometimes, even if the protein is expensive, it might improve profitability if it enhances production. Some nutrition programs attempt to formulate diets using a mathematical model for profit maximization. However, in real life, it is virtually impossible to accurately predict how a diet will affect appetite, nutrient partitioning, and milk yield and components. Thus, monitoring the actual response is essential for optimal farm management. High production is almost always more important for high profitability than is low feed cost, but managing feed costs is still prudent.
Selecting Cows For Greater Feed Efficiency

In the past, genetic selection for milk production traits has relied heavily on quantification of the phenotype in daughters of young sires; sires with outstanding daughters are deemed genetically superior. Although milk production traits are routinely measured on many commercial farms, feed intakes of individual cows are not known. Thus, we have not been able to directly select cows for feed efficiency. Genomics may enable selection for feed efficiency in the future.

Through a grant from the National Institute of Food and Agriculture of USDA, we currently are determining if SNP genotypes can be used to improve feed efficiency. We are measuring individual feed intakes, BW, and production data on 8000 cows in research dairy herds from several countries. Our goal is to characterize the relationship of SNP genotype to feed efficiency in our reference population of 8000 cows and then to use SNP genotyping to identify potential sires that should confer higher feed efficiency to their offspring. Some information on our project can be found at www.dairy-efficiency.org/ or you can search the USDA web site. The topic of using genomics to select for greater feed efficiency is covered in greater detail by Dr. Weigel, a co-investigator in our USDA project.

As mentioned earlier, we already know that higher milk yield per day dilutes maintenance and improves efficiency up to 4X intake. Our goal in this project is to find cows with a better ability to digest feed or convert digested feed to net energy or with a lower than expected maintenance requirement. To assess feed efficiency independent of production level, we will use residual feed intake (RFI), which is a measure of actual versus predicted intake for an individual (Figure 4). Predicted intake is determined statistically as the deviation from the average intake of other cows that are fed and managed the same based on a cow’s body weight, milk production, and BW change. Our initial analyses for dairy feed efficiency are based on 4300 Holstein cows in the US, Scotland, and the Netherlands. Based on this data, the heritability of RFI in lactating cows is ~0.18. Previous studies, using small numbers of cows, reported values of 0.01 to 0.40 for the heritability of RFI in lactating cows (Berry and Crowley, 2013; Connor et al., 2013).

If selection for efficiency is to be realized, it is important that RFI is a repeatable trait. Our project will examine this more fully, but preliminary results from our lab and others are promising. We fed 109 cows diets with ~14 or 30% starch in a cross-over design and found the correlation for RFI of a cow when fed a high starch diet with RFI when fed a low starch diet to be 0.7. Based on our preliminary data and others, RFI also seems to be repeatable across lactations, stages within a lactation, and stages of life (Burczynski et al., 2013; Connor et al., 2013; MacDonald et al., 2013). Genomic selection for efficiency likely will be possible within 2 to 3 years, but it is important to note that RFI is only part of feed efficiency. Selection for optimal levels of milk production relative to body weight so that the percent of feed used for maintenance is also a key to overall farm efficiency. Moreover, improvements in feed efficiency must not occur at the expense of health and fertility of dairy cows. Thus, we will carefully consider relationships among measures of feed efficiency, energy balance, production, and fitness traits.

Figure 4. Residual feed intake as a measure of feed efficiency.
Until direct selection for efficiency is possible, some have suggested we breed for smaller cows to minimize maintenance. Selecting for both high milk and small body size should enhance lifetime milk per unit feed and therefore decrease the percentage of feed used for maintenance. One problem with this approach is that once a cow is above 4X maintenance intake, we cannot predict how efficiency changes as cow size decreases (see Figure 2). More importantly, however, breeding for smaller size lessens our ability to select for traits we know to be profitable, such as milk income, health, and fertility. Table 1 shows an example of possible results of breeding for smaller size or for more milk in a herd that currently has large cows (1760 lb mature BW) and milk production at 28,750 lb/yr at maturity. The magnitude of change for each breeding scenario was chosen to give the same effect on efficiency as lifetime multiple of maintenance. Note that, in this example, achieving a 15% smaller BW increases lifetime income over feed cost by $310 per year, because of lower maintenance requirements, but achieving 11% greater milk yield increases lifetime income over feed cost by $1230, because of greater milk income. Thus, either way, increasing milk output relative to BW resulted in greater efficiency and profitability. However, whereas the improvement in efficiency was equal, the improvement in income over feed costs was 4 times greater if the enhanced efficiency was achieved by increased milk instead of by decreased BW.

In our data of 4500 lactating cows eating on average at almost 4X maintenance, we find very little phenotypic or genetic relationship between body weight and gross feed efficiency. Based on genetic correlations, bigger cows eat more (r=0.40), produce slightly more milk (r=0.07), and consequently have a slightly lower gross feed efficiency (r=-0.14). However, more milk was strongly correlated with greater feed efficiency (r=0.61). Thus, breeding for more milk seems more important for greater feed efficiency than does breeding for smaller BW. Moreover, more milk means greater milk income, which is more important than lower feed costs. The bigger cows producing more milk would be more profitable, unless they had poorer health or fertility or did not fit in the stalls! In my opinion, we should stop using size (big or small) as a criterion in sire selection, unless the goal is to have cows of a uniform size to fit stalls; instead, choose sires to produce healthy, fertile cows that give more milk income!

Table 1: Possible results from breeding for size instead of milk.

<table>
<thead>
<tr>
<th>BW at maturity lb</th>
<th>Lifetime multiple of maintenance</th>
<th>Milk yield at maturity lb/year</th>
<th>Lifetime income over feed cost $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current cows</td>
<td>1760</td>
<td>2.8</td>
<td>28,750</td>
</tr>
<tr>
<td>Select for size</td>
<td>1500</td>
<td>3.0</td>
<td>28,750</td>
</tr>
<tr>
<td>Select for milk</td>
<td>1760</td>
<td>3.0</td>
<td>31,970</td>
</tr>
</tbody>
</table>

1 Assumes milk is 3.5% fat.
2 Assumes milk at $0.18/lb, cull cows at $0.80/lb, and feed at 15¢/Mcal NE (~11¢/lb) for lactating cows and 12¢/Mcal NE for heifers and dry cows
Summary

We can improve feed efficiency by improving how we feed, breed, and manage cows. Improved feed efficiency occurs because as cows produce more milk relative to their body weight, the percentage of feed used for maintenance decreases. This “dilution of maintenance” effect is especially important for cows that produce at less than 3 times their maintenance requirement on a lifetime basis. For higher producing cows, maintenance is already mostly diluted out and we should consider focusing more directly on feed efficiency in animal selection; genomics will likely help do this. A measure of feed efficiency that might be used for animal selection is RFI, but RFI is only part of feed efficiency. We also want animals that operate at a high multiple of maintenance, so produce lots of milk relative to their body weight. Moreover, feed efficiency is only one contributor to farm profitability; high productivity is and will remain a major factor. Likewise, when we feed and manage cows, high production is key to improving profits. Focusing too much on milk/feed will be a mistake. Instead we should focus on maximizing milk income after subtracting the cost of feed. Grouping cows according to their nutritional needs can help us optimize efficiency and profitability by enabling cows in early lactation to be fed diets that maximize milk income and cows in later lactation to be fed diets that optimize milk income while minimizing excess body condition gain. Feeding these groups of cows optimally requires that cow responses to diet changes be carefully monitored and recorded.

Conclusion

We have made major gains in feed efficiency in the past 50 years as a byproduct of selecting, feeding, and managing cows for increased productivity. Improvements in management and feeding that increase milk yield to ~30,000 lb/yr will likely continue to improve efficiency. However, most cows have the genetics for high production already; genomic tools should enable us to directly select for feed efficiency in the future. Greater efficiency will improve profitability and environmental sustainability, but continued focus on production, health, and fertility will still be important for farm profitability.

References


Will Genomic Selection be the Key to Improving Feed Efficiency in Dairy Cattle?

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Introduction

The efficiency of feed utilization on dairy farms can be influenced by a variety of practices that are beyond the scope of this paper, including many aspects of the harvesting, storage, mixing, and delivery of feed components, as well as the grouping of animals according to nutritional needs. Two practices that will be addressed are: 1) improvement of the biological efficiency of lactating cows through genetic or genomic selection for enhanced feed efficiency, and 2) reduction of feed costs through genome-guided management of the replacement heifer inventory. Both approaches have potential for improving the production efficiency of modern dairy farms, which will improve the economic viability of dairy farmers, the affordability of dairy products for consumers, and the environmental footprint of dairy operations.

Feed efficiency is a complex trait in all food animal species, but in beef cattle, swine, and poultry it is possible to limit the focus of selection to the efficiency of feed utilization during the growing and fattening periods of meat animals. The dairy cow poses a particularly challenging problem because of the need to balance the competing process of lactation, reproduction, health, maintenance, and (in young cows) growth. Up to this point in time, selection programs for dairy cattle have focused on increasing milk production, improving milk composition, and reducing the incidence of infectious diseases, metabolic disorders, infertility, and premature culling. Improvements in health, fertility, and longevity have been modest, because for many years producers focused their attention on improved physical conformation. However, in the past two decades the quantity and quality of genetic evaluations for functional traits have improved considerably. The next frontier of genetic selection in dairy cattle will be improvement of the biological efficiency of feed utilization, a trait for which cost effective tools and strategies have been lacking.

Impact of increased milk yield per cow on biological efficiency

As noted by VandeHaar and St-Pierre (2006), a modern dairy cow producing 45 kg of milk per day needs 4 times as much energy for milk production than for maintenance, and the net energy for lactation (NEL) of an elite dairy cow producing 90 kg of milk per day is 7 times the 10 Mcal of energy the cow needs each day for maintenance. Improvements in average milk production per cow due to genetic selection and enhanced management are well documented, and these have led to dramatic gains in production efficiency. However, it is important to recognize that, as milk production per cow continues to increase, the marginal savings in feed costs per unit of milk produced are diminishing. For example, assume that a typical dairy cow uses the first 6 kg of feed consumed each day for maintenance. If the cow eats 12 kg of feed per day, with the remainder going toward milk production (or growth) she is consuming 2X maintenance requirements, and if the cow eats 18 kg of feed per day she is consuming 3X maintenance. As noted earlier, modern dairy cows can consume 4X maintenance throughout much of the lactation, and elite cows often consume more than 7X maintenance during peak lactation. The critical point is that the gain in efficiency associated with an increase from 2X to 3X maintenance is greater than the gain in efficiency when going from 3X to 4X, which is in turn greater than the gain when going from 4X to 5X. Based on this concept, which is known as dilution of maintenance, we are at or near a plateau in efficiency in terms of multiples of maintenance. Furthermore, digestive efficiency may become depressed as cows consume increasingly large quantities of feed. This is an additional barrier to improving feed efficiency, and when coupled with dilution of maintenance, it appears that we have already captured most of the gains that can be achieved in feed efficiency simply by increasing milk production per cow.
Potential for decreasing maintenance costs by selecting for smaller body size

VanRaden (2004) noted that body size composite, as calculated from linear scores for body traits in the type classification program, has been a component of the Net Merit index (NM$) used to select Holsteins in the USA since 2000. Milk revenues and feed costs associated with differences in milk yield of cows with greater or lesser body size are already considered in the NM$ index, so the economic weight applied to body size composite reflects the marginal costs associated with greater maintenance and housing costs and the marginal revenues associated with greater salvage and calf values. Table 1 shows estimated genetic correlations between metabolic body weight (MBW), dry matter intake (DMI), NEL, and linear type scores for 714 Holstein cows in six research herds (University of Florida, Iowa State University, Michigan State University, USDA-ARS Dairy Forage Research Center, University of Wisconsin, and Virginia Tech University). Genetic correlations of MBW with stature, strength, body depth, and thurl width were 0.71, 0.84, 0.65, and 0.57 respectively, confirming that these linear type traits can serve as an effective proxy for body weight, which is not measured routinely on commercial farms. Several udder traits were positively correlated with MBW as well, particularly udder depth (0.47), which is known to be phenotypically correlated with stature. Genetic correlations of DMI with stature, strength, and body depth were also relatively high, with estimates of 0.40, 0.46, and 0.36, respectively. Presumably this reflects greater feed intake for maintenance among larger animals, as well as a tendency for higher NEL requirements among larger cows, as indicated by genetic correlations of 0.31, 0.41, and 0.42 with stature, strength, and body depth, respectively. Most udder traits had negative genetic correlations with DMI, possibly due to deeper udders and weaker attachments among cows producing very large quantities of milk. As evidence of the latter, genetic correlations between NEL and fore udder, rear udder height, rear udder width, udder depth, and front teat placement were -0.12, -0.27, -0.47, -0.40, and -0.59, respectively. Dairy form was negatively correlated with MBW (-0.22), positively correlated with NEL (0.37), and uncorrelated with DMI (-0.02). Because cows with larger body size have higher DMI but also tend to have greater NEL requirements due to higher milk production, it appears that the solution to improving feed efficiency in dairy cattle is not as simple as just selecting for smaller body size. At the same time, these data provide no evidence that selecting for larger body size will enhance feed efficiency. In reality, selection for larger body size in US Holsteins continues, and at a rapid pace. For example, very few bulls that sire below average stature have semen available for purchase by dairy farmers, and the genetic trend for increasing stature is consistently greater than that of most or all other type traits. The presence of a negative weight on body size composite in the NM$ index for more than a decade has done little to dampen breeders’ enthusiasm for large cattle, and situations in which the cows outgrow housing or milking facilities are common. In addition, a long-term selection project by Becker et al. (2012) reported that Holstein cows selected for large body size had significantly greater health costs than their more moderately sized contemporaries, particularly displaced abomasums. However, attitudes toward selection for body size are unlikely to change unless very large penalties are applied to size-related traits in NM$ and other selection indices.

Challenges in measuring individual feed intakes in dairy cattle

Extensive research on the phenotypic, genetic, and economic relationships between dry matter intake, body weight (BWT), metabolic body weight, milk production, and residual feed intake (RFI) was carried out nearly two decades ago, most notably the work of Veerkamp et al. (1995), Veerkamp and Evans (1995), and Veerkamp (1998). However, the insurmountable costs and challenges associated with measuring individual feed intake data on a sufficient number of animals in a conventional progeny testing program precluded implementation of this work in practical breeding programs. For example, assume that it costs $200 per cow to measure a feed intake phenotype, and that we must measure 100 daughters of each of the 1,500 dairy bulls that are progeny tested in the USA each year. The annual cost of measuring these 150,000 phenotypes would be $30 million, which comes out to $20,000 per bull for a predicted transmitting ability (PTA) for DMI or RFI. Interest in selection for feed efficiency was renewed with the advent of genomic selection, which allows measurement of difficult and costly phenotypes in a reference population of (tens of) thousands of animals, followed by implementation of selection for these traits in the general population. Revisiting our previous example, consider the possibility of spending $200 per cow to measure a feed intake phenotype in an initial reference population of 20,000 cows, with 2,000 new cows added each year. Further assume that genomic testing costs $100 per animal, and that we must genotype all cows in the reference population plus 5,000 young bulls each year. Total cost of the program would be approximately $1.37 million per year or about $275 per bull for a genomic PTA for DMI or RFI. Therefore, it is no surprise that research groups around the world have embarked on studies that aim to facilitate genomic selection for improved feed efficiency.
Genomic selection has already become routine practice in the USA and many other countries, and this has greatly reduced the generation interval, particularly in the “sires to produce sires” and “sires to produce cows” pathways (Schefers and Weigel, 2012). For example, Hutchison et al. (2014) reported that 51 and 52% of inseminations to Holstein and Jersey sires, respectively, in the USA in 2012 involved genome-tested young sires less than 4 years of age. Therefore, if genomic PTA values of young bulls for DMI, RFI, or other measures of feed efficiency become available, widespread implementation by farmers and breeding companies is likely.

Genomic selection for feed efficiency using dry matter intake

Berry et al. (2014) described an enormous multiple-country effort to characterize DMI in Holstein cattle, assess consistencies in trait expression between countries or production systems, and evaluate its suitability as a selection criterion. Data represented 10,068 lactation records from 6,953 lactating cows in Australia, Canada, Denmark, Germany, Ireland, The Netherlands, UK, and the USA. Predicted DMI was computed for lactating cows at 70 days postpartum using a random regression model; means ranged from 15.6 kg per day in Australia to 24.2 kg per day in the USA. Heritability estimates from a single-step genomic BLUP analysis ranged from 0.11 in Canada to 0.46 in Denmark. Genetic correlations were estimated for DMI in different production systems, including North America (Canada + USA), EU high-input (Denmark + Germany + Netherlands + UK high-input cohort), EU low-input (UK low-input cohort), and Grazing (Australia + Ireland). Estimates between the EU low-input, EU high-input, and North America groups ranged from 0.76 to 0.84, whereas estimates between the aforementioned groups and Grazing ranged from 0.14 to 0.57. However, it is important to note that the number of common sires and maternal grandsires between Grazing and the other three groups ranged from 4 to 28, as compared with a range of 10 to 144 between North American and the two EU groups, and additional data are needed to confirm whether DMI measurements in different management systems reflect the expression of genetically distinct traits. In general, selection for improved feed efficiency using DMI is a reasonable option, and this trait is more understandable to dairy producers than RFI. On the other hand, as shown in Table 1, large positive or negative genetic correlations exist between DMI and many traits that are already included in the breeding goal, so proper accounting for genetic relationships with other traits will be a critical prerequisite to effective use of DMI in a selection program.

Genomic selection for feed efficiency using residual feed intake

Statistically, RFI represents the amount by which a given cow over-consumes or under-consumes feed, as compared with other cows in her cohort, after adjustment for energy sinks such as MBW, change in body weight (ΔBW), body condition score (BCS), and the NEL of the milk she produces. A major effort involving six research stations located throughout the USA, three in The Netherlands, and two in the United Kingdom is currently underway, with the objectives of enhancing our understanding of RFI and its components and developing a resource population of Holstein cows to facilitate the development of a genomic selection program for reduced RFI (Tempelman et al., 2014). At present, the data include 84,645 weekly records from 6,133 lactations of 4,376 Holstein cows. Heritability estimates for RFI during the period from 75 to 175 days postpartum ranged from 0.08 to 0.23, depending on country and stage of lactation, with an estimate of 0.17 for the multiple-country data set at 125 days postpartum. Within-lactation repeatability estimates for weekly RFI measurements ranged from 0.55 to 0.88, with an estimate of 0.74 in the multiple-country data set at 125 days postpartum, whereas between-lactation repeatability estimates ranged from 0.14 to 0.37, with an estimate of 0.30 in the multiple-country data set at 125 days postpartum.

Estimated genetic correlations between linear type traits and RFI based on 714 Holstein cows in the six aforementioned research herds are also shown in Table 1. Genetic correlations between RFI and the body size traits, namely stature, strength, body depth, and thrul width, were all between -0.05 and 0.23, which is expected given that RFI is constructed to be phenotypically independent of MBW. Therefore, selection for RFI should neither increase nor decrease the size and strength of Holstein cattle. Because RFI is also calculated to be phenotypically independent of milk yield and milk composition, those traits should be unaffected, as should traits related to udder conformation, which had genetic correlations that averaged -0.17 and ranged from -0.37 to 0.11. Lastly, genetic correlations between RFI and mobility traits were negligible and ranged from -0.17 to 0.01. While this is encouraging, as regards our ability to avoid unintended correlated responses to selection for improved RFI, it will be important to assess genetic relationships with early postpartum health and female fertility prior to its inclusion in a selection index. If RFI is independent of these traits as well, preliminary selection index calculations suggest that it could warrant a relative economic weight that would represent 10 to 20% of the overall breeding goal.
Relationships with energy balance

Spurlock et al. (2012) estimated genetic parameters for energy balance (EB), energy-corrected milk (ECM), DMI, BW, BCS, and gross feed efficiency (GFE) from calving to 150 days postpartum in Holstein cattle. Conceptually similar to RFI, EB was calculated as the difference between energy consumed as DMI and the energy expended as MBW for maintenance and as NEL for milk production in each of the first five months postpartum. Meanwhile, GFE was calculated as the quotient of the sum of daily ECM and the sum of daily DMI during the first 150 days postpartum, as well as in the first and second half of that time period. On average, EB was negative for the first 60 days postpartum in primiparous cows and the first 70 days postpartum in multiparous cows. Genetic correlations between EB and GFE ranged from -0.73 to -0.99 in a given month of lactation. Genetic correlations between ECM and GFE averaged 0.59 and ranged from 0.42 to 0.72 in a given month, whereas genetic correlations between ECM and EB averaged -0.31 and ranged from -0.02 to -0.53. Among the linear type traits shown in Table 1, dairy form is the most indicative of EB, and its estimated genetic correlation with RFI was -0.09.

Identification of major genes associated with feed efficiency

Most genome-wide association studies (GWAS) in dairy cattle consider only additive allele substitution effects, in part because deregressed sire PTA values or daughter averages are often used as the input phenotypes. However, it is unlikely that all genes affecting RFI act independently and in an additive manner, and building the aforementioned genomic reference populations for feed efficiency necessitates genotyping and phenotyping large numbers of females. In a recent study involving 395 Holstein cows with 42,275 SNP genotypes, Yao et al. (2013) used a random forest algorithm to study possible epistatic interactions between pairs of SNPs that were associated with RFI. By analyzing the structure of decision trees within the forests, the authors were able to identify descendant pairs of SNPs that showed up repeatedly within the same branch in various trees. In many cases, the SNPs that occurred most frequently in descendant pairs were not among those with the largest additive effects in a Bayesian regression analysis that ignored possible interactions. Furthermore, many of the SNPs implicated in the random forest analysis were in common with SNPs associated with RFI in a previous study in beef cattle (Sherman et al., 2009). It is important to consider that RFI is a composite trait that represents the sum of several other traits and numerous underlying physiological processes. Furthermore, other than DMI, most of the individual traits that make up RFI (with the exception of DMI) have been the subject of dozens of GWAS that aimed to identify SNP or microsatellite markers with large effects. Therefore, one might expect that the current GWAS for RFI will lead to candidate SNPs or haplotypes that tend to be fairly numerous but with relatively modest effects on RFI.

Using genomic predictions to manage heifer inventories

The cost of raising dairy replacement heifers represents 20 to 25% of the total cost of producing milk on a typical commercial dairy farm, and feed costs constitute 60 to 65% of total heifer rearing costs. At the same time, the availability of gender-enhanced semen, coupled with the widespread implementation of sand bedding and other advancements in animal housing and husbandry, have led to an excess of potential replacement heifers on many farms. Therefore, for the first time, many farmers are faced with the decision of whether to rear all of the available heifers or to cull some potentially inferior heifers in order to reduce feed costs.

Due to availability of inexpensive low-density genotyping platforms, coupled with accurate imputation to high-density using established reference populations (Weigel et al. (2010a), Weigel et al. (2010b)), genomic testing of young calves and yearling heifers has increased dramatically in the past three years. Weigel et al. (2012) showed via simulation that using genomic testing to identify inferior heifer calves for early culling can be a cost-effective way to improve the production potential of dairy replacements, not to mention the corresponding savings in foregone feed costs.

Do genomic predictions at 2 or 3 months of age provide enough information about future phenotypes to allow confidence in culling decisions at this early stage? Figure 1 shows the relationship between genomic PTA values at 12 months of age and projected or actual 305-day mature-equivalent milk yield phenotypes for 309 first lactation Holstein cows in the University of Wisconsin herd. Average milk yield for the lowest quartile of heifers, as ranked by genomic PTA at 12 months of age, was 11,790 kg, as compared with 12,091, 12,754, and 13,623 kg for heifers in the second, third, and highest quartiles. On average, heifers in the lowest quartile produced 3.4 kg less milk per day than their counterparts in the other three quartiles, and as such they would have been good candidates for early culling.

Figure 1 also shows the regression of 305-day mature equivalent milk yield on the genomic PTA from 12 months of age. The value of 3.2 kg of milk per kg of genomic PTA exceeds its expectation of 2.0, and in general one can use this regression coefficient as an
assessment of whether the management level on a given farm is sufficient to fully capitalize on the herd’s genetic potential. Closer inspection of Figure 1 shows that individual cows that deviate widely from their expectation tend to be those for which management has failed, most notably protocols for managing animal health in the early postpartum period.

Although the coupling of low-density chips and genotype imputation as made genomic predictions more affordable, routine genomic testing of all heifer calves is limited to a small minority of commercial dairy farms. A significant reduction in the cost of genomic testing is unlikely without another technological breakthrough in chip design or processing capacity. Work by de los Campos et al. (2009) and Vazquez et al. (2010) showed that prediction accuracy using a subset of several hundred selected SNPs that have strong associations with the NMS index could be beneficial, but the cost of such testing would have to be substantially reduced in order to compensate for the loss in prediction accuracy relative to the current strategy of low-density genotyping and imputation to higher density.

Prediction of future phenotypes using SNP genotypes and health history phenotypes

As noted earlier, a calf’s future phenotype for milk yield and other economically important traits is influenced by its health history as well as its genetic predisposition. Therefore, farmers will need to develop holistic replacement management protocols in which the decision to keep or cull a specific calf, to breed a certain heifer with conventional or gender-enhanced semen, or to make a given animal an embryo transfer donor or recipient depends on its genomic test result, birth weight, growth rate, and health history. With regard to genomic prediction of RFI and other future phenotypes, we may not be interested in only the animal’s PTA or estimated breeding value (EBV), but rather the sum of the animal’s EBV and its permanent environmental effects. This quantity is commonly known as predicted producing ability or estimated relative producing ability, and it refers to the animal’s total broad-sense genetic effects (additive, dominance, and epistasis) plus carry-over effects associated with its management, nutrition, and health history. In our recent work, information regarding 57,541 SNP genotypes for 465 Holstein cows was combined with data regarding the incidence of 13 health disorders during the rearing period and early postpartum period (Yao and Weigel, 2014). Future phenotypes for NEL, DMI, RFI, and MBW were predicted from SNPs only or SNPs plus health history using random forest and support vector machine algorithms. Several health-related traits, including birth weight, calving weight, mastitis, metabolic disorders (ketosis, milk fever, and displaced abomasum), respiratory disease, and scours affected future phenotypes significantly. Correlations between predicted values and future phenotypes averaged 27.5% with SNPs only and 27.8% with SNPs and health history. It is likely that the small magnitude of improvement reflected a lack of precision in the diagnosis or reporting of health problems, coupled with the fact that whole-genome SNPs already contain substantial information about an animal’s predisposition for traits such as body weight and susceptibility to infectious diseases and metabolic disorders.

Conclusions

Improvements in average milk yield per cow due to genetic selection and enhanced management have resulted in substantial gains in efficiency over the past half-century, but additional gains will be modest unless individual animal intakes are measured directly. Genomic selection has allowed renewed interest in breeding for feed efficiency, because genomic predictions for DMI and RFI derived from deeply phenotyped reference populations are roughly 100-fold cheaper than predictions derived from conventional progeny testing schemes. Due to the limited size of these reference populations, reliability values for feed efficiency will be lower than reliabilities for milk production and most other important traits. However, the high economic value of feed efficiency will necessitate a large relative weight in the breeding index. Preliminary research suggests that RFI may be an attractive choice for improving biological efficiency, due to its apparent genetic and phenotypic independence from milk production, milk composition, body size, udder conformation, and mobility. However, more research is needed to confirm associations between RFI and functional traits, such as early postpartum health and female fertility. Lastly, strategies for using genome-based predictions of future phenotypes to manage heifer inventories appear to be cost effective, particularly in herds with low rates of involuntary culling or significant use of gender-enhanced semen.

Conclusions

The results presented herein reflect the contributions of numerous collaborators, most notably Mike VandeHaar and Rob Tempelman (Michigan State University), Lou Armentano and Chen Yao (University of Wisconsin - Madison), and Diane Spurlock (Iowa State University), and their work is gratefully acknowledged. This research was supported by Agriculture and Food Research Initiative Competitive Grant #2011-68004-30340 from the USDA National Institute of Food and Agriculture, as well as Hatch Project WIS01757 from the Wisconsin Agricultural Experiment Station.
Table 1: Genetic correlations between linear scores for type traits and metabolic body weight (MBW), dry matter intake (DMI), net energy of lactation (NEL), and residual feed intake (RFI).

<table>
<thead>
<tr>
<th>Trait</th>
<th>MBW</th>
<th>DMI</th>
<th>NEL</th>
<th>RFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stature</td>
<td>0.71</td>
<td>0.40</td>
<td>0.31</td>
<td>0.13</td>
</tr>
<tr>
<td>Strength</td>
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<td>0.46</td>
<td>0.41</td>
<td>0.23</td>
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<td>Body Depth</td>
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<td>0.36</td>
<td>0.42</td>
<td>0.06</td>
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<td>Rear Legs Side View</td>
<td>-0.27</td>
<td>0.13</td>
<td>0.34</td>
<td>-0.06</td>
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<td>-0.01</td>
<td>-0.38</td>
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<td>Udder Depth</td>
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<td>Teat Length</td>
<td>0.44</td>
<td>0.19</td>
<td>0.53</td>
<td>-0.18</td>
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Literature Cited


Figure 1: Relationship between genomic predicted transmitting abilities for milk yield at 12 months of age and daily milk yield phenotypes in first lactation.
Feed Parameters and Strategies on our Dairy Farm
Doug and Tom Block Families
5th Generations Dairy Farmers

Feeding Parameters and Strategies on Our Dairy Farm
Doug Block
Four State Dairy Nutrition and Management Conference
Dubuque, Iowa
June 11, 2014

Hunter Haven Farms, Inc
Pearl City, Illinois
Doug & Tom Block Families
5th Generation Dairy Farmers

About Hunter Haven...
- 760 Milking Cows
- 110 dry cows
- 870 heifers
- 1,800 Crop Acres (1,030 owned)
Employees
- Milkers & Pushers (13 full time & 1 part time)
- Parlor manager & calf feeder (young)
- Foot trimmer & calf feeder (older)
- Feeder & helper (calf barns, cow movement)
- Assistant herd manager
- Feeder & helper (calf barns, cow movement)
- Doug – Dairy supervisor
- Tom – Field supervisor

Cross trained
Milk 3X (8am, 4pm, Midnight)
2 milkers & 1 pusher/shift
9 hour shift
6 to 7 day on
3 to 2 days off
45 to 50 hours/week

Hunter Haven About the Feed.....
- Fat Corrected Milk: 98 pounds
- Feed Efficiency: 1.6 to 1.7
- Feed Cost: $0.14 per lb of dry matter
- Feed Cost/cwt: $7.97

Hunter Haven 2013 Stats...
- 90 lbs. milk
- 3.76% B.F.
- 3.04% Protein
- 230 SCC
- MUN goals

905 Cows in 10 Groups
79 Do not breed, Mastitis, Cows to be sold
20 Milk not for sale (Treated & just fresh)
164 1st and 2nd lactation
157 Small mature cows
155 1st lactation
103 Large mature cows
81 Post fresh (4 weeks)
56 Dry Cows
62 Prefresh Cows
28 Prefresh Heifers

Ration Ingredients in Pounds of Dry Matter
<table>
<thead>
<tr>
<th></th>
<th>Milking</th>
<th>Early Lact</th>
<th>Prefresh</th>
<th>Far-off</th>
</tr>
</thead>
<tbody>
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<td>12.7</td>
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<tr>
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<td>Corn</td>
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<td>Wet Distillers Mod</td>
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<td>Cottonseed</td>
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<tr>
<td>Corn Gluten Feed</td>
<td>2.4</td>
<td>1.6</td>
<td></td>
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</tbody>
</table>
| Fat Corrected Milk: 98 pounds
| Energy Booster | 0.5     |            |          |         |
| Various Mixes  | 4.7     | 4.3        | 3.4      | 0.2     |
| Water (AsFed)  | 17.0    | 13.0       | 13.0     | 5.0     |
| TMR (Dry Matter) | 12.8 | 12.8       | 12.8     | 12.8    |

Nutrient Analysis of Rations
<table>
<thead>
<tr>
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<th>Early Lact</th>
<th>Prefresh</th>
<th>Far-off</th>
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<td>42.8</td>
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<td>CP %</td>
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<td>Sugar %</td>
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<td>2.4</td>
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### Milking Ration

<table>
<thead>
<tr>
<th>Ingredient</th>
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### Early Lactation Ration

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### Hunter Haven

#### Three areas to improve feed efficiency

1. Eliminate procedural drift
2. Increase feed quality (emphasis on quality and quantity of forage)
3. Watch dry matter intake

#### Hunter Haven

#### Three things we would do differently

1. Creating enough feed storage
2. Too slow to concentrate on hoof health and cow comfort
3. Falling behind on breeding program
Intensified Calf Feeding Programs

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Intensified calf feeding programs involve feeding of more milk replacer than in conventional programs, such that calves consume about twice as much dry milk replacer solids. Potential advantages of these programs are that they enable heifers to grow to breeding size earlier. Disadvantages include increased costs for milk replacer and increased management attention needed at the time of weaning to dry feed. Our research and review of other research reports support the concept that intensified feeding programs will not impair future milk production and will provide sufficient returns to pay for the additional investment in milk replacer. Additional benefits beyond those resulting from excellent calf management are unclear.

Introduction

Milk or milk replacer is the major nutrient source for calves for about 3 weeks after birth. Because the calf's digestive system is not yet mature enough to digest grain efficiently, growth and maintenance needs must be satisfied by milk intake. Traditional milk-feeding programs for heifer calves were designed to provide nutrients for limited body growth along with maintenance. Because of the cost and labor involved, a main goal of the pre-weaning period has been to facilitate transition of calves from milk to dry feed (calf starter). Traditional milk replacers contained 20% crude protein and 20% fat, and yielded body weight gains of less than 1.0 lb per day. Research in Israel in the 1990’s demonstrated that calves consuming whole milk gained weight faster, and produced more milk as cows. This knowledge stimulated the development of new milk replacers that would promote growth similar to that possible with whole milk feeding.

Intensified feeding programs

Intensified feeding of calves involves feeding approximately twice as much milk replacer powder (2 to 2.5 lb per day) as traditional feeding programs (1 to 1.25 lb per day). The milk replacers contain 25 to 28% crude protein to support the potential of young calves for rapid lean growth, and 15 to 20% fat. Interestingly, the protein to energy ratio of intensified milk replacers is higher than it is for whole milk. Traditional 20:20 replacers are ~45 g CP/Mcal ME.

Whole milk is ~50 g/Mcal. Most intensified milk replacers, however, are 65-70 g/Mcal. It is not clear to us why this higher protein is required, but perhaps it is due to differences in AA composition and protein digestibility of whole milk compared to intensified milk replacers.

Unlike traditional programs, milk replacer is fed in increasing amounts as calves grow older. Calves are fed about 1.25 lb of powder starting with the first feeding after colostrum feeding, and amount fed increases to around 2 lb per day before weaning. Milk replacers are also recommended to be fed at a higher concentration of the liquid mix (15 to 17% solids) than are traditional milk replacers (13%). Some Michigan producers have noted improved calf health since diluting the milk replacer to a lower concentration more similar to traditional milk replacers. Because calves are consuming more milk, gradual weaning is important to provide time for calves to gradually increase their consumption of calf starter to avoid a growth slump after weaning.

Growth and Milk Yield

We fed 80 calves at the MSU Dairy Farm either a conventional 20:20 milk replacer at 1.2% of BW or an intensified 28:15 milk replacer at 2.1% of BW (Davis-Rincker et al., 2011). Intensified calves grew faster before weaning (1.4 vs 1.0 lb/d). All calves were weaned completely at 42 d, with weaning occurring gradually in the preceeding week. Calves were managed similarly after weaning and bred by size. Calves on the intensified program tended to calve at an earlier age (701 vs 715 d) at similar BW. After adjusting milk yield for genetics using parent average milk, first lactation projected 305-d ME milk yield tended to be 4% higher for calves on the intensified program. However, calves in our traditional program were fed calf starter at a restricted intake to limit gains to 1.0 lb/d, whereas calves on the intensified program had calf starter provided ad libitum. If calves on the traditional program had been given calf starter ad libitum, they almost surely would have grown faster; the impacts on subsequent milk production are not known.

In the past 10 years, several other studies have been completed that add to our knowledge of the ef-
fects of accelerated growth on animal performance. Heinrichs and Jones (2011) reviewed the studies investigating treatment effects on milk yield and concluded that overall, there were no significant effects of feeding for accelerated growth on milk yield. On the other hand, Soberon and Van Amburgh (2013) did a meta-analysis on the studies in the literature and found that intensified feeding programs before weaning increased milk production by almost 1000 lb in the first lactation, or about 160 lb of milk for every 0.1 lb extra body weight gain per day before weaning. Why the opposite conclusions from the same available literature? Well, both conclusions followed from criteria of accepting data. Heinrichs and Jones only accepted conclusions based on more than ten calves per treatment using milk replacers and published in peer-reviewed publications. Soberon and Van Amburgh used publications that had not been peer-reviewed or had not actually compared intensive vs. traditional treatments. Most notably, they included results from a retrospective analysis comparing growth rates before weaning and subsequent lactation performance in calves at the Cornell dairy farm that had all been raised under an intensified feeding program (Soberon and van Amburgh, 2012). Differences in growth rates were confounded with, and largely the result of, season (temperature and photoperiod) and genetics. Most importantly, they did not impose nutritional treatments to investigate whether feeding for greater gain preweaning might enhance later milk production. Their conclusion should have been: calves that grow faster preweaning because of season, health, or genetics, produce more milk as cows. Whether faster growth from feeding a high protein milk replacer at a high rate of intake also increases milk yield was never tested.

Our conclusion from the literature is that intensified milk-feeding programs likely increase first-lactation milk yield. We wonder, however, if the high protein to energy ratio of intensified milk replacers is really needed (especially in cold weather). Furthermore, we wonder if methods to enhance grain intake might not achieve similar results.

Calf starter and grain mixes

Traditional calf starters contain about 18% crude protein on an as fed basis. Starters used in accelerated growth programs often contain 22% CP, with the goal of promoting continued optimal growth; whether this is necessary is not clear. As with traditional programs, calves should be consuming 2 lb of starter per day for at least 3 days before weaning.

The general recommendation is that calves on accelerated programs should be fed calf starter with higher crude protein content for several weeks after weaning. Whether this is necessary is not clear. By the time of weaning, calves on accelerated programs will be about 2 inches taller and 25 to 30 lb heavier than calves on traditional programs. If weaning is difficult and calves do not maintain their growth rates, the advantage in body size of the accelerated program will be lost in the first 1-2 months after weaning.

Potential pitfalls

Intensified feeding programs are not for everyone. Excellent calf management is required to benefit from their use. The general recommendation is that the amount of milk replacer fed to calves must be increased with age, which requires additional management and communication with calf feeders. As with traditional programs, inconsistency in mixing and feeding can produce digestive upsets. Starter intake is important for rumen development, and increased milk consumption reduces intake of starter. Careful attention to gradual weaning and maintenance of starter intake is essential to realize advantages of intensified feeding programs. One way to do this is to feed milk only once per day for several days to encourage greater intake of starter. Calf stools may be looser with calves on intensified programs, requiring greater attention to correctly identify sick and scouring calves. Additionally, more bedding may be required to maintain a clean, dry environment for the calf.

Costs and Returns

Intensified feeding programs will cost about $35 to $55 more in milk replacer and starter than traditional programs. Calves will grow faster and attain breeding size earlier, and may even produce slightly more milk. Results from our most recent study indicated that while feed costs were $1.27 higher per day than the traditional program, a decrease in age at first calving and a trend toward higher milk yield in first lactation resulted in no difference in total returns. If the sale price of milk is high, the return will likely be positive. In fact, our data support the idea that the economic advantage of accelerated growth programs could be almost three times the initial extra cost of milk replacer, and likely would not be negative (Davis Rincker et al., 2011). This suggests that the decision about whether or not to use accelerated programs should be based on factors other than the economics of subsequent milk production. In any case, there is no question that conventional programs often have not done a good job of handling cold weather; a switch to a well-managed intensified milk program from a poorly managed conventional program will likely be profitable. However, a well-managed program with intermediate levels of milk might be even more profitable.
Summary

Intensified feeding programs can produce larger calves at weaning and heifers that reach breeding size at a younger age. Calves may have looser stools during the pre-weaning period although health status is not affected. Milk yield tends to be higher in calves on intensified feeding programs. Economically, intensified and traditional feeding programs were not significantly different in cost, indicating producers can consider other farm-specific factors in selection of a feeding program for their calves. Overall, it is clear that emphasis on calf health and growth from the delivery process through weaning will pay off in healthier, more productive cows in first lactation but whether high protein milk replacers fed at 2% of BW are necessary to achieve these benefits is not clear.

References


What do the Cows Have to Say About NDF and Starch Digestion?

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Adjunct Asst. Professor
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University of Wisconsin – Madison

Introduction

Livestock nutrition programs began many years ago with the recognition that animal health and performance improved when livestock were fed supplemental mineral and protein to meet mineral and nutrient requirements.

All living beings have nutrient requirements. Nutrients by definition are those that furnish nourishment (Miriam-Webster, 2014 accessed online). Protein and minerals are nutrients. Fiber and starch are major sources of energy and energy can also be considered a nutrient, but determining feedstuff energetic content for ruminants is complex. One method for determining energy content of diets is to sum the energy supplied from digested fat, protein, fiber, starch and other non-fiber carbohydrates. Energy values for forages are determined this way in the Nutrient Requirements of Dairy Cattle: Seventh Revised Edition, 2001. The ‘summative’ approach is described as

\[
TDN1x = dCP + 2.25x(dfat) + dNFC + dNDF - 7, \]

where ‘d’ is the digestibility coefficient of CP, Fat, NFC or NDF, respectively.

Digested fat and protein contain more calories per gram (g), 9.4 and 5.6 calories per g, respectively, than carbohydrates, 4.2 calories per g (NRC, 2001). Both fiber (Neutral Detergent Fiber, NDF) and starch are carbohydrates yet when we need more energy in a ruminant diet we often include more starch (grain) and less fiber. Why is this? The answer is carbohydrate digestibility.

In ruminants, feedstuff energetic values are a function of both total nutrient content and digestion coefficients (Weiss, 1998). As nutritionists, we use computer ration formulation models with summative equations that incorporate nutrient level and digestibility to optimize nutrition on farm. We reasonably understand feedstuff nutrient content but have monumental opportunities to learn more about digestion. Hence, the remainder of this paper will focus on accurately describing nutrient digestion. Digestion takes place in the rumen as well as the rest of digestive tract, with the aim in ruminant nutrition being improving rumen digestion for optimal feed conversion efficiency. Hence, rumen digestion measures have been extensively sought out but remain difficult to predict.

The difficulty lies in the fact that digestion coefficients are not fixed measures (e.g. fiber digestibility potential at 30 h). Feedstuff digestion is dynamic and depends upon a variety of factors including:

- Feed genetic and chemical characteristics
  - Such as grain vitreousness (Correa et al., 2002 or fiber lignification (Jung and Deetz, 1993)
- Physical properties
  - Example: grain particle size (Callison et al., 2001; Hoffman et al., 2012) and forage particle length (Bal et al., 2000)
- Feed passage rate through multiple digestive chambers (Waldo and Smith, 1972)

The same feed will have different energy values when processed differently, or fed to a dry cow (longer rumen retention time) or a high producing cow (shorter rumen retention time). These factors lead us to an important question: how do we estimate in vivo (real, cow-level) digestion values for use within our computer programs? What opportunities do we have to improve model performance?

The objective of this paper is to briefly review practical approaches to feedstuff digestion, discuss digestion measure application within nutrition programs, and summarize published in vivo dairy cattle digestion data for use in evaluating laboratory technique accuracy or ration formulation program outputs.

Evolution of assessing feedstuff digestibility

Measuring diet and feed digestion potential is not a new concept. Bergeim (1926) first measured food digestion nearly 100 years ago with an in vivo approach however this approach was not useful for individual feedstuffs in many cases and instead applied to the total diet.
During the late 1800’s the proximate feed analysis system was developed. The proximate system evaluated individual feedstuff nutritive value by dividing animal feeds into six fractions: moisture, ether extract, protein, ash, crude fiber (CF) and nitrogen free extract (NFE). Crampton and Maynard (1932) however suggested that partitioning feedstuffs into cellulose, lignin and other carbohydrates instead of CF and NFE was a more accurate approach to determine nutritive value of feeds. Weiss et al. (1992) later developed a model for predicting total digestible nutrient content incorporating the detergent system (Goering and Van Soest, 1970) for nutrient analysis. Lignin became a focus for determining fiber and feedstuff digestibility and has been extensively studied as described by Jung (2012). However Jung (2012) also described limitations to using lignin as a digestion indicator and our industry has moved beyond lignin based digestion estimates although the NRC (2001) and other similar programs still have lignin based digestibility calculators built in.

Nearly 20 years after Crampton and Maynard (1932), found that lignin was related to feed nutritive value, Burroughs et al. (1950) described one of the first in vitro methods to measure digestion. In vitro rumen digestion evolved into a routinely used commercial laboratory method. However, the technique has substantial drawbacks due to being completely removed from the cow (lab bench method). In vivo and in situ digestion methods are also laboratory digestion analyses, taking place partially and completely within animals, which are now evolving as routine options for livestock nutrition measures.

The three levels of practically measuring nutrient digestion: simple explanations, benefits and drawbacks

Lab bench: in vitro, meaning outside the body (Miri-am-Webster, 2014)

Rumen and intestine in vitro digestion measures are completely removed from the animal and are meant to simulate digestion within the rumen or intestines. Rumen in vitro digestion gained popularity for routine forage analyses following developmental work by Tilley and Terry (1963) and later modified by Goering and Van Soest (1970) as published in the USDA Forage Fiber Analyses handbook. Goering and Van Soest (1970) described various forage analyses and a widely cited modified rumen in vitro digestion technique. Ruminant feedstuff protein intestinal in vitro digestion gained in popularity with the technique published by Calsamiglia and Stern (1995) and later modified by Gargallo et al. (2006) and evaluated by Boucher et al. (2009). Hundreds if not thousands of peer reviewed studies have since evaluated in vitro digestion techniques and applications.

The benefits to practical lab bench in vitro measures are:

- Speed and flexibility
- The ability to make many measurements over the course of a day or week
- The ability to analyze several feeds at one time
- Sample analysis is completely contained within a flask or test tube
- Cost effective relative to other digestion approaches
- Individual feed nutrient degradation can be assessed and isolated from other interactions
- The digestion process is tightly controlled by controlling temperature, pH and maintaining an anaerobic environment to optimize bacterial digestion
- Pool size of digestible feed component (fiber, starch or protein) and rates of digestion (kd) values can be used within diet formulation software

In vitro lab bench measures are used to assess feedstuff genetic and chemical-related digestion parameters and to rank feeds from most digestible to least. Using multiple digestion measurements over time has value for measuring feedstuff degradation rates (kd) and potentially digestible nutrient fractions or pool sizes. The digestion rate and pool size parameters are necessary for mechanistic nutrition models such as the Cornell Net Carbohydrate and Protein System (CNCPS, Tylutki et al., 2008).

In vitro digestion technique drawbacks include, but are not limited to:

- Inaccuracy due to removal from the animal
- Isolation from other ingredients and rumen interactions
- Digestion occurring beyond the rumen is not accounted for
- Consistency of rumen fluid varies between donor animals and can impact digestion results
- Poor repeatability within and across laboratories due to rumen fluid and technique variability
• Reducing or eliminating particle size effects because samples are ground to small particles sizes (1 to 4 mm).

**Rumen or intestinal incubation:** in situ, meaning in the natural or original position (Miriam-Webster, 2014)

Simulating the rumen environment and dynamic feedstuffs interactions within digestion chambers can prove difficult (Vanzant et al., 1998). As a result, rumen and intestine in situ digestion techniques have been used in commercial laboratories to estimate nutrient digestion.

In this approach, feedstuffs are placed in small-pored bags, akin to tea bags, and incubated within the desired region of digestive tract. Feedstuff digestion potential is determined by measuring nutrient disappearance from the porous bags.

The benefits to in situ rumen or intestine measures include:

• Feedstuffs are exposed to complex digestion and interactions occurring within the animal that are difficult to replicate in a closed in vitro flask or test tube.
  
  — Multiple animals can be used to improve precision

• Greater sample sizes and larger particle sizes (from 4 mm to unground) can be used

• Flexibility
  
  — Multiple digestion measures in time can be made
  
  — Estimate kd and pool sizes

• Multiple nutrients can be assessed for digestion at the same time using the same incubated sample

• Individual feed nutrient degradation can be assessed
  
  — Pool size and kd values can be used within diet formulation software

Drawbacks to in situ techniques include, but are not limited to:

• Increased cost relative to in vitro approaches

• Need for multiple cannulated animals in desired performance or production state

  — E.g. To assess digestion in context of a lactating Holstein cow complex rumen environment, feed must be digested within lactating Holstein cows’ rumens

• In situ samples and nutrients are not subject to feedstuff passage rates that may occur in vivo
  
  — For example, starch kₚ appears to be associated with feed type or density (published data summarized by Allen, 2012)

• Poor repeatability across laboratories due to technique variability

• Sample disappearance from bags may be attributed to either loss through pores, or digestion

Considerable in situ developmental and evaluator work has been accomplished over the past 50 years. Vanzant et al. (1998) reviewed published literature and offered suggestions to standardize techniques. Rumen in situ techniques further gained in commercial popularity for assessing protein digestion partly following the techniques application within the Nutrient Requirements of Dairy Cattle: Seventh Revised Edition (NRC, 2001).

Yet, Stern et al. (1997) suggested both in vitro and in situ protein digestion estimates were challenging to relate to in vivo measures. Further, commercially available in vitro and in situ techniques, each differing in some aspect from published literature (e.g. technique or donor cattle and diet), have little to no published relationship with commercial dairy cattle performance (Schalla et al., 2012). Hence in many cases practicing nutritionists rely on assumptions that greater digestion is positively related to performance in ratios such as the widely cited work published by Oba and Allen (1999) or assume kₚ measures over time and pool size estimates are accurate.

**Within the animal:** in vivo, meaning in the living body of a plant or animal; in real life situation (Miriam-Webster, 2014).

Under circumstances where simulating digestion or partially assessing feedstuff digestion within animals can prove problematic, in vivo digestion techniques can be utilized. Through in vivo techniques, nutritionists and scientists can assess compartmental or total tract nutrient digestion through high performing cattle using either total collection or indigestible markers along with TMR and fecal nutrient measures.

Total collection methods and rare-earth metal marker in vivo measures are not practical for routine application. However lignin, acid-insoluble ash and indigest-
ible NDF (iNDF) are inherent within feedstuffs and have utility under practical circumstances for assessing apparent diet digestion coefficients.

Lignin has long been used to estimate nutrient digestion within academic research and under practical circumstances (J. Ferguson, unpublished), however lignin should only be used as a digestibility marker when fecal lignin recovery is high (Fahey and Jung, 1983).

Under commercial dairy circumstances, iNDF has been used as an internal marker to assess in vivo digestion and results were related to dairy performance offering validity to this approach for routine application (Schalla et al., 2012). Further, acid-insoluble ash has recently been compared to iNDF and iNDF was found more dependable (Lee and Hristov, 2013).

**Benefits to in vivo digestion measures include:**
- Assess diet digestion through high performing cattle
  - Most accurate approach
- Capture total diet performance without making assumptions regarding digestion chamber interactions or passage rates

**Limitations to practical in vivo digestion measures include but are not limited to:**
- Only the Total Mixed Ration (TMR) can be assessed
  - Results cannot be directly used within most formulation software programs
- Costly and time consuming relative to in vitro or in situ approaches
- Must sample both TMR and feces
  - Must assume minimal TMR variability and sampling accuracy
- Endogenous nutrient contributions complicate interpretation (Sniffen, personal communication)

**How do we use digestion data within ration models? Can we improve ration program performance? What do the cows have to say?**

Having described several levels of practical digestion measures, the livestock nutrition industry and consultants in the field are continually striving to improve accuracy and precision within animal nutrition software and feeding programs. One aim is to improve software and animal performance by implementing more accurate and precise nutrient digestion measures. Be mindful that ration models are merely a guide and many factors beyond formulation affect performance (Allen, 2012). Prior to discussing ration model basics, we should understand terminology for measures used within computer programs.

- **Digestion coefficient (e.g. NDFD or StarchD) = % of nutrient that is digested**
  - This is the end result value used within ration programs to calculate TDN1x, microbial CP and energy available for performance
  - This value may or may not be directly entered into the program
  - There are two basic ways to determine digestion coefficients
    - Direct measurement (e.g. in vitro, in situ or in vivo measures)
    - Calculate using pool size, digestion and passage rates
  - **k = rate coefficient**
    - Corresponding to a nutrient or passage disappearing at a certain % per h
  - **k_d = digestion rate coefficient (e.g. NDF k_d or Starch k_d)**
    - “k_d rate” is often used in the field to describe digestion rate; however this is redundant, and incorrect terminology
  - **k_p = passage rate coefficient (e.g. liquid or forage)**
  - **Pool size = nutrient amount (% total nutrient) available to the specified degradation and passage rate**
    - Pool sizes can range from 0 to 100% available

There are two basic approaches to estimating feed component digestion: empirical and mechanistic. Each approach requires different digestion inputs as outlined above; but both approaches generate digestion coefficients that are intended to describe digestion in vivo. The digestion coefficients determined by either approach are determined by regression or integrating pool sizes and rates of digestion of feed components with rate of passage. How do ration...
programs determine digestion coefficients? The $k_d$, $k_p$ and pool size (e.g. uNDF) measures, each by themselves, are useless. Only when the three measures are used together do they have practical application. **Empirical model digestion coefficients and opportunities**

Empirical models such as the National Research Council (NRC 2001) and Milk2006 (Shaver and Lauer, 2006) are built upon extensive published research, measurements and direct observations. Simply put, past observations and relationships drive future predictions. Total digestible nutrient (TDN1x) estimates for energy calculations within empirical models are built from summative equations (Weiss, 1998). Summative equations combine nutrient content and digestion coefficients.

Nutrient digestion coefficients within the NRC (2001), for example, are determined either from large databases or documented relationships. In some cases, nutrient digestion coefficients are left as static values due to limitations in prior published work. The summative TDN equation in place within the NRC (2001) is simplified here as:

$$\text{TDN at maintenance intake} = \text{Total digestible NFC} + \text{total digestible CP} + \text{total digestible fatty acids} + \text{total digestible NDF} - 7$$

Within empirical models such as NRC (2001), we have the opportunity to improve model accuracy by incorporating cow-level, research-backed carbohydrate digestion coefficients. Current or future digestion techniques for use in empirical models should be validated with, or closely agree with, in vivo rumen or total tract published results, such as those presented in **Appendix 1**.

As an example of this approach, Dr. David Combs (2013) recently developed a fiber digestion measure, titled Total Tract Neutral Detergent Fiber Digestibility (TTNDFD), which incorporates both mechanistic and empirical principles, and has utility within empirical models. The TTNDFD model pairs the NDF $k_p$ measured using *standardized* 24, 30 and 48 h NDFD values (Goeser and Combs, 2009), with an NDF passage rate adapted from Krizsan et al. (2010) using mechanistic principles. TTNDFD has further been validated against in vivo NDF digestion trial results, adhering to empirical principles. Typical TTNDFD values since 2010 are presented here for several feed and storage types (Rock River Laboratory, Inc., unpublished data).

<table>
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<td>Small Grains</td>
<td>Silage</td>
<td>43.34</td>
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**Mechanistic model opportunities**

Mechanistic models, such as the CNCPS model (Tylutki et al., 2008), are fundamentally different from the NRC model as described above because these models seek to fully model the complex rumen microbiology, individual nutrient metabolism and energetics. Mechanistic ruminant models break the diet down further than empirical models into core nutrients and predict how nutrients interact within the rumen and digestion tract. Both model types strive to predict future observations but mechanistic models apply theory as well as prior research and are meant to simulate true rumen and intestinal nutrient digestion.

In mechanistic based models, an extensive number of nutrient values and pool size estimates are paired against rumen and hind-gut $k_d$ and $k_p$ estimates to determine animal and diet specific nutrient digestion coefficients. Moreover, nutrient pool size is multiplied against the $k_d$ and $k_p$ ratios to calculate the nutrient digestion coefficient. After digestion coefficients for nutrients are determined, TDN, microbial protein, and energy available for performance are predicted similar to that of an empirical model.

Within mechanistic models, model performance can be improved by refining feedstuff $k_d$ and pool size estimates, assuming $k_p$ values are accurate. Feed $k_d$ and pool size measures can be improved using more robust digestion and mathematical techniques. We can then assess digestion technique and model accuracy by comparing mechanistic model digestion coefficient outputs against published in vivo rumen or total tract means and ranges, such as that presented in **Appendix 1**.
Regardless of approach used to assess feedstuff or diet performance potential, improving accuracy in addition to speed and precision will advance the livestock nutrition industry into the future.

The next 15 years

Feed and milk price volatility and income over feed costs ranging from roughly -$9 / cwt. to +$9 / cwt. for dairy farms require continued advancement. Further, agriculture’s environmental impact and carbon footprint is increasingly being scrutinized. In both cases, improvement in feed conversion efficiency is key to advancing the dairy industry and accurately assessing digestion potential is critical under this effort.

As mentioned previously, future innovations in digestion analyses and ration formulation should ensure agreement with in vivo digestion coefficient results. The meta-analyses summarized in Appendix 1 offer extensive published, in vivo lactating cow rumen and total-tract NDF and starch digestion results to compare against laboratory derived estimates of fiber and starch digestion.

Rather than offer a conclusive statement, I pose several questions regarding current, routinely utilized carbohydrate digestion measures for future consideration within nutrition programs:

1. With reported NDF and forage passage rates ranging from 1 to 6% / h (Kriszan et al., 2010; Seo et al. 2006; Allen, 2012) actual rumen NDF retention times range from 17 to 50 h. Assuming a 30 h rumen NDF retention time:
   a. Do 30 h in vitro or in situ NDFD results average 42% of NDF, similar to that shown in Appendix 1?
      i. Exemplary 30 h in vitro NDFD means (based on Goering and Van Soest, 1970 technique; Rock River Laboratory Inc., unpublished data):
         1. 43.7% for legume silage
         2. 54.6% for corn silage
   b. If in vitro NDFD results are inaccurate, do we have opportunities to more accurately formulate diets?
      i. Are resulting NDF Kd measures accurate?
   2. With reported starch and concentrate passage rates ranging from roughly 3 to 33% / h (Seo et al., 2006; Allen, 2012), rumen starch retention times range from 3 to 33 h. Assuming an 18 h rumen starch retention time:
      a. Do 7 h in vitro rumen starch digestion results align with the 59% in vivo rumen average shown in Appendix 1, assumed at 18 h?
         i. Moreover, if in vivo starch digestion averages 59% at 18 h, 7 h digestion averages should be substantially less than 59%
         ii. Exemplary 7 h in vitro NDFD means (based on Richards et al., 1995 technique):
            1. 69.2% for 10 different samples of TMR, corn silage, dry corn, high moisture corn, and snaplage (Heuer et al., 2013)
      a. Rumen in situ digestion averaged 56.4% at 7 h for the same samples

References


### Table 1: Summary of meta-analysis or review data for in vivo rumen and total-tract NDF and starch digestion coefficients (% of nutrient). *Mixed refers to a meta-analysis of lactating dairy studies and minor number of non-lactating heifer study means.

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<th>Description</th>
<th>Nutrient</th>
<th>Animal Type</th>
<th>Digestion Site</th>
<th>Author(s)</th>
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<td></td>
<td>658</td>
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Pedigree-Based Selection

For more than half a century, progeny testing has been the foundation of genetic selection programs in dairy cattle (Robertson and Rendel, 1950). Several factors make progeny testing especially advantageous in dairy cattle, most notably widespread use of artificial insemination (AI) with frozen semen and the fact that nearly all traits of economic importance, including milk production, milk composition, female fertility, length of productive life, calving ability, disease resistance, and physical conformation, are sex-limited and cannot be measured until females begin lactating. Progeny testing has led to rapid genetic gains in production traits; estimated breeding values (EBV) of North American Holsteins have increased by roughly 90 kg of milk, 3 kg of fat, and 3 kg of protein per year over the past decade. However, genetic progress is limited by long generation intervals of approximately 7.1 and 3.9 years, respectively, for sires and dams of AI bulls (Normal et al., 2001). Furthermore, progeny testing is not a cost-effective method for improving traits that are difficult or expensive to measure routinely on commercial dairy farms, such as feed efficiency.

Whole Genome Selection

Whole genome selection, more commonly known as genomic selection (Meuwissen et al., 2001), refers to the study of differences between individual animals in the bovine genome sequence (single nucleotide polymorphisms (SNPs)) that can be used to predict economically important traits, such as milk production, milk composition, health, fertility, or longevity. The genetic information for a given calf, heifer, cow, or bull is compared with that of a reference population of older animals of the same breed. This reference population is composed of animals with known phenotypes that have been genotyped previously, and their phenotypic and genomic information are stored in an extensive database at the USDA-ARS Animal Improvement Programs Laboratory (AIPL, Beltsville, MD). Dairy cattle are particularly well-suited for genomic selection, because individual animals with high EBV have sufficient value to offset the costs of genomic testing, and because large reference populations of bulls with high reliability (REL) predictions of genetic merit exist for the purpose of estimating SNP effects or calculating genomic predicted transmitting abilities (GPTA). More than 650,000 dairy bulls, cows, heifers, and calves have genomic data in the AIPL database, and genomic predictions are available for Holstein, Jersey, and Brown Swiss cattle. The current cost of genomic testing is roughly $45 per animal with a low-density (9K or 12K) chip, whereas the cost of medium-density (54K) or high-density (648K or 777K) genotyping is two- to five-fold greater.

In North America, as in most countries with well-developed genomic evaluation systems for dairy cattle, genotype information has been incorporated into genetic evaluation systems in a nearly seamless manner (Wiggans et al., 2011). Roughly 60,000 SNPs are used in routine genomic evaluations, and for animals that have been genotyped with low-density chips the remaining SNPs are imputed with 90 to 99% accuracy based on the medium- and high-density genotypes of reference animals of the same breed (Boichard et al., 2012; VanRaden et al., 2013). In this manner, inexpensive low-density genotyping of cows, heifers, and calves on commercial dairy farms is possible, and after genotype imputation their GPTA values are of sufficient accuracy for selection and culling decisions (Dassonneville et al., 2011; Weigel et al., 2010). For cows with phenotypes, as well as cows and bulls whose offspring have phenotypes, the published GPTA values represent a combination of pedigree, performance, and genomic information, whereas for young bulls and heifers without phenotypes the published GPTA values reflect pedigree and genomic information only. In both cases, the GPTA values are published with the same genetic base, scale, and units of measurement as for animals that have not been genotyped, with the only difference being higher REL for genotyped animals and a “G” indicator on their predicted transmitting ability (PTA) values and selection indices.
The increases in REL for young calves and heifers due to genomic testing are remarkable. In US Holters, the average gains in REL for production traits are 29, 31, and 23% for milk, fat, and protein, respectively, whereas gains for fitness traits are 22, 27, and 22% for daughter pregnancy rate, somatic cell score, and length of productive life, respectively. For protein yield, which has heritability of approximately 30%, the amount of information provided by a young calf’s pedigree is equivalent to about 7 milk-recorded offspring, whereas the amount of information provided by the calf’s genotype is equivalent to about 34 additional daughters. In contrast, for daughter pregnancy rate, which has heritability of about 4%, the amount of information provided by the calf’s genotype is equivalent to about 131 additional daughters.

**Genomic Selection of Males**

Selection of dairy bulls has changed dramatically in the era of genomic selection. North American dairy farmers currently have access to semen from hundreds of young genome-tested Holstein, Jersey, and Brown Swiss bulls that have no progeny of their own. In fact, the number of young AI bulls currently being marketed based on GPTA values exceeds the number of progeny-tested bulls being marketed, and several large breeding companies now derive more than 50% of their sales from young genome-tested bulls. Farmers that use young genome-tested bulls to produce their replacement heifers can reduce the generation interval for the “sires to produce daughters” selection pathway to about 30 months, as opposed to roughly 72 months with traditional progeny tested bulls. Furthermore, these young genome-tested bulls are often used to produce the next generation of AI bulls, and the impact on generation interval is dramatic, as shown in Figures 1 and 2 from Schefers and Weigel (2012).

In a traditional breeding program based on progeny testing, approximately 54 months are required for rearing a bull, collecting and distributing his semen, rearing his offspring, recording his offspring’s phenotypes, and predicting his breeding value using pedigree-based BLUP. At this point, the bull can be identified as a sire of future AI bulls, and if his semen is used immediately to inseminate elite cows and heifers his first sons will be born when he is about 63 months of age.

In an aggressive breeding program based on genomic selection, a young bull can be identified as a sire of future AI bulls as early as 1 or 2 months of age, and as soon as he reaches sexual maturity his semen can be used to inseminate elite cows and heifers (Schaeffer, 2006). His first sons will be born when he is roughly 21 months of age, which means that we can achieve a three-fold reduction in generation interval in the “sires to produce sons” selection pathway. An obvious extension of the aforementioned strategy is to use genomic selection to identify potential dams of future AI bulls at a young age and propagate them via embryo transfer (ET) or in vitro fertilization (IVF) as yearling heifers, as opposed to waiting for completion one or more lactation records. In this manner, the generation interval for the “dams to produce sons” selection pathway can also be reduced, from about 38 months to roughly 22 months. Furthermore, the GPTA values of elite cows and heifers based on genomic testing have much greater REL than their traditional PTA values based on pedigree and performance data only, and this further accelerates the rate of genetic progress per year.

**Genomic Selection of Females**

Historically, the weak link in dairy cattle improvement programs has been the “dams to produce daughters” selection pathway, due to poor accuracy and low selection intensity (Van Tassell and Van Vleck, 1991). The REL of traditional pedigree-based PTA values for cows on commercial farms has tended to be low, and high rates of culling due to illness, injury, or infertility have typically prevented the culling of genetically inferior replacement heifers. However, culling rates on modern, well-managed free-stall operations tend to be low, and widespread usage of gender-enhanced (sexed) semen has generated an excess of replacement heifers. For the first time in history, dairy producers have an opportunity to improve the genetic potential of their herds by culling inferior females at a young age and, more importantly, they can significantly reduce the feed costs associated with rearing animals that are unlikely to perform at a profitable level once they reach lactating age. Weigel et al. (2012) showed that, in herds that lack pedigree data, genomic testing all heifer calves and culling the poorest 10, 20, or 30% based on GPTA is a cost-effective herd improvement strategy. Similarly, in herds with known sire identification or complete pedigree information, genomic testing the bottom 50% of heifer calves based on pedigree index and culling the bottom 10, 20, or 30% based on GPTA is also a cost-effective herd improvement strategy.

In a recent study at the UW-Madison Integrated Dairy Facility (Arlington, Madison, and Marshfield, WI), the actual first-lactation performance of Holstein cows was evaluated relative to their genomic predictions derived from DNA testing prior to 12 months of age. Based on results of the genomic testing, heifers were divided into quartiles (Q1=high, Q2=high-medium, Q3=medium-low and Q4=low) of genomic potential for milk yield. Figure 3 shows a scatter plot of GPTA for milk production and average daily milk yield,
where each shape represents a different quartile. Animals with average GPTA milk and average daily milk yield are represented by the circle in the middle of the graph. As shown below, 83% of heifers in Q1 (highest GPTA milk) subsequently exceeded herd average for actual daily milk yield, as compared with 61% of heifers in Q2, 39% of heifers in Q3, and fewer than 17% of heifers in Q4. Furthermore, no heifers from Q4 ranked near the top for daily milk yield when they reached first lactation, and only one heifer from Q1 produced significantly less than herd average. As shown in Figure 4, average first lactation daily milk yield of heifers in Q1 exceeded that of heifers in Q2 and Q3 by approximately 10 pounds, and it exceeded that of heifers in Q4 by more than 15 pounds. Thus, it is clear that genomic testing of heifer calves at a young age can provide farmers with useful information for making selection and culling decisions, which can reduce feed costs.

Managing Inbreeding with Genomics

Inbreeding has long been a concern in dairy cattle breeding programs, and animal breeders try to achieve a balance between rapid genetic progress and maintenance of genetic diversity (Weigel, 2001). Genomic selection programs can provide greater selection response per year and, like traditional pedigree-based breeding programs, individual sires and cows can have a tremendous influence through AI and ET or IVF, respectively. However, an advantage of genomic selection is that it facilitates within-family selection decisions among animals with identical pedigrees (Hayes et al., 2009). For example, in a traditional pedigree-based selection program an elite cow might produce three full-sibling sons by ET, and one of these sons would be purchased by each of the major AI companies. In a modern genome-based selection program the cow would also produce three full-sibling sons by ET, and the son with highest GPTA would be purchased by the company that had the first-choice contract. The other two sons would be culled, and the other two AI companies would select first-choice bulls from other families, thereby enhancing the genetic diversity of the AI sire population. On the farm, dairy producers manage inbreeding and reduce the probability of inherited defects by using computerized mating programs (Weigel and Lin, 2000). Genomic data can provide more precise measures of inbreeding than pedigree-based inbreeding coefficients (Bjelland et al., 2013), which reflect expected inbreeding, and genome-based mating programs can accommodate both additive and dominance effects (Sun et al., 2013). Because virtually every AI sire in the major dairy breeds has been genotyped, dairy farmers who invest in genotyping their cows, heifers, and calves can readily utilize genome-based mate selection programs that consider average heterozygosity, dominance effects, and lethal defects.

Although the primary objective of genomic selection in dairy cattle is to increase the accuracy of estimated breeding values for young selection candidates, related activities such as fine-mapping of quantitative trait loci (QTL) and detection of inherited defects are greatly facilitated by the availability of hundreds of thousands of low-, medium-, and high-density SNP genotypes. For example, Cole et al. (2011) carried out a genome-wide association analysis that identified numerous candidate genes and chromosomal regions affecting production, health, fertility, and conformation traits in Holstein cattle. Interestingly, VanRaden et al. (2011) found that several SNP haplotypes were abundant in heterozygous form in Holstein, Jersey, and Brown Swiss cattle, but these haplotypes were never observed in homozygous form. Furthermore, sires that carried these haplotypes tended to exhibit reduced conception rate and increased stillbirth rate when mated to daughters of bulls that carried the same haplotypes. In one of these haplotypes, Sonstegard et al. (2013) identified a nonsense mutation in the CWC15 gene that appears to be responsible for decreased fertility in Jersey cattle.

Conclusions

In summary, the impact of genomics on dairy cattle breeding programs has been enormous, and the pace of change has been breath-taking. Within two years of the commercial availability of the first 50K array, the vast majority of AI bulls and elite cows were genotyped, and routine selection decisions utilized GPTA values rather than traditional pedigree-based PTA values. Genomic data are used to select every young bull that enters an AI company, and the overwhelming majority of cows, heifers, calves, and embryos that are consigned to public auctions are marketed based on genomic information. Progeny testing, in which selection and marketing decisions must wait until daughters’ phenotypes become available, has been replaced by genomic testing and progeny validation, in which selection and marketing decisions are made immediately and reviewed later, when the bull’s sons and grandsons are being marketed. New inherited defects have been discovered, and the search for QTL with large effects on performance, health, and fertility is faster, more precise, and much more efficient. Programs for mate selection and avoidance of inbreeding are changing rapidly, and widespread usage of genomic mating programs is imminent. Because of the availability of inexpensive low-density SNP arrays and highly accurate imputation algorithms, many farmers are using genomic testing in conjunction with sexed semen and
advances in cow comfort to generate extra females, cull inferior animals early, enhance genetic progress, and reduce feed costs. Lastly, genomic selection will allow the improvement of traits such as feed efficiency, which are too difficult and expensive to measure routinely on commercial farms but are feasible for measurement in smaller reference populations such as experimental herds.

**Acknowledgments**

The assistance of staff of the Marshfield (WI) Agricultural Experiment Station, most notably Pat Hoffman, is gratefully acknowledged, as is the generosity of Zoetis Animal Health (Kalamazoo, MI) for providing genotyping services and technical assistance for this research.

**Literature Cited**


Figure 1. Timeline of a traditional AI breeding program based on progeny testing (from Schefers and Weigel, 2012).

Figure 2. Timeline of an aggressive AI breeding program based on the use of genomic bulls as sires of sons (from Schefers and Weigel, 2012).
Figure 3. Comparison of GPTA for milk yield of 12-month old Holstein heifers in the UW-Madison herd with actual daily milk yield of the same animals during first lactation. The numbers shown on the graph reflect the percentage of animals in each GPTA quartile that exceeded herd average milk production during first lactation.

Figure 4. Average daily milk yield during first lactation, by quartile of GPTA for milk yield, for heifers that were genotyped prior to 12 months of age in the UW-Madison herd.
Transitioning With Efficiency, is it possible?

Dr. Phil Cardoso, DVM, PhD
Dairy Research and Extension
University of Illinois at Urbana-Champaign

So, how do we help this cow?

How should we feed and manage dry and transition cows to:
1) minimize health disorders,
2) maximize production and reproduction

Outline

- The transition period.
- Are we improving dairy farm efficiency?
- Controlled energy diets for dry cows.
- Summary and conclusions.
**Transition Period**

Usually identified as the 3 weeks prior to and the 3 weeks following parturition (Drackley, 1999; Grummer, 1995).

**Periparturient Period**

Gestating, non-lactating state → non-pregnant, lactating

**Typical Gestation-Lactation Cycle for Dairy Cattle**

Challenging period with most infectious diseases and metabolic disorders occurring during this time (Drackley, 1999; Grummer, 1995).
### Transition Period

<table>
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<th>Metabolic Disorder</th>
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<td>Ketosis</td>
<td>4.8</td>
<td>145</td>
<td>---</td>
</tr>
<tr>
<td>Pregnancy Rate</td>
<td></td>
<td></td>
<td>17 %</td>
</tr>
</tbody>
</table>

*Adapted from Kelton et al., 1998

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### Effects of three levels of energy intake during the close-up period on blood metabolites of dairy cows

A. Pineda, P. Cardoso, J. K. Drackley

University of Illinois

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### Objectives

- To assess if controlling energy intake during the dry period has negative effect on cow performance and blood metabolites during transition period.
- To evaluate if cows fed restricted energy diet have similar performance to controlled energy diet.
- To assess if cows fed high energy diet develop insulin resistance.

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### Goals for nutrition and management during the dry period

- Meet nutrient requirements for gestation and mammary development
- Minimize risk for peripartal metabolic disorders and infectious diseases
- Prepare cow for high milk production and high subsequent fertility
- Optimize costs and maximize profit

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### Material and Methods

**Experimental Units:**
- 27 multiparous Holstein cows
- Healthy (no DA, RP, or MET)
- Dried-off 50 days before expected calving

**Housing:**
- Free stalls during dry period
- Individual box stall close to calving
- Tie stall from calving to 28dd

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### Metabolic disorders during early lactation are linked to energy intake during the dry period

- Many research trials have stated potentially negative consequences of overfeeding cows during the dry period
- Our thesis: feeding a high-energy diet before calving to dairy cows will induce insulin resistance
Material and Methods

Composition of control energy and high energy diet in dry matter basis.

<table>
<thead>
<tr>
<th>Material and Methods</th>
<th>Control Energy</th>
<th>High Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DM, %</strong></td>
<td>Mean: 47.3</td>
<td>Mean: 43.4</td>
</tr>
<tr>
<td>CP, %</td>
<td>SD: 2.86</td>
<td>SD: 2.29</td>
</tr>
<tr>
<td>ADF, %</td>
<td>Mean: 31.1</td>
<td>Mean: 23.1</td>
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<tr>
<td>NDF, %</td>
<td>SD: 3.88</td>
<td>SD: 2.38</td>
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<tr>
<td>Lignin, %</td>
<td>Mean: 45.7</td>
<td>Mean: 36.8</td>
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<tr>
<td>NFC, %</td>
<td>SD: 0.07</td>
<td>SD: 4.3</td>
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<tr>
<td>TDF, %</td>
<td>Mean: 21.4</td>
<td>Mean: 35.9</td>
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<tr>
<td>NEL, Mcal/kg</td>
<td>SD: 0.02</td>
<td>SD: 0.21</td>
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</table>

Data Collected

Glucose tolerance test:
- Glucose (0.25 g/kg BW)
- 8d ± 4 pre-calving
- 8d post-calving

Insulin challenge:
- Insulin (0.05 IU/kg BW)
- 6d ± 4 pre-calving
- 6d post-calving

Blood Metabolites
- Calcium (Ca), magnesium (Mg), and beta-hydroxybutyrate (BHBA) concentration in plasma of cows fed control energy (CE), high energy (HE), and restricted energy (RE) diet wk-1 and wk +1 relative to calving.
- Trt: P = 0.03
- CE vs RE: P = 0.32
- CE and RE vs HE: P = 0.01

IC Pre-calving

Trt: P = 0.03
Why do controlled-energy diets decrease NEFA, BHBA, and liver fat?

Overfeeding and internal body fat stores in dry cows

- Research question:
  Do cows overfed during the dry period accumulate internal fat during the dry period?
“... describes the extent to which time, effort or cost is well used for the intended task or purpose. It is often used with the specific purpose of relaying the capability of a specific application of effort to produce a specific outcome effectively with a minimum amount or quantity of waste, expense, or unnecessary effort.”

EFFICIENCY

In general, efficiency is a measurable concept, quantitatively determined by the ratio of output to input.

Direct-Fed Microbial - DFM

- Direct-fed microbial (DFM) to describe microbial-based feed additives.
- DFM products are available in a variety of forms including powders, pastes, boluses, and capsules. In some applications, DFM may be mixed with feed or administered in the drinking water.

Activity Monitors

BHBA week 1 and activity

Activity (steps/hr) of cows classified at week 1 postpartum as High (BHBA $\geq 12$ mg/dL) or Low (BHBA $\leq 12$ mg/dL).
Activity (steps/hr) of cows diagnosed with displaced abomasum (DA) and Healthy cows matched by parity and milk production. Multiparous Holstein cows being represented. Median time to DA was 9 days in milk.

**TAKE HOME MESSAGE**

- Insulin sensitivity increased in cows fed a control energy diet or a restricted energy diet.
- High energy diet seems to be a model for insulin resistance in dairy cows around parturition.
- Measure the intake of your cows. Control variation.

**TAKE HOME MESSAGE**

- Insulin sensitivity increased in cows fed a control energy diet or a restricted energy diet.
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What’s New with Corn Silage?

What’s New with Corn Silage?

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Introduction

High quality whole-plant corn silage (WPCS) contributes greatly to supplying the energy, starch and forage neutral detergent fiber needs of high-producing dairy cows, reducing purchased feed costs from expensive grain and byproduct supplements, and generating milk revenues for dairy producers throughout the world. The purpose of this paper is to review selected recent developments and considerations for WPCS. Refer to Figure 1 for an overview of the factors that influence the nutritive value of WPCS.

Corn silage harvest practices

Processing and Length of Cut

Ferrareto and Shaver (2012) reported on an experiment to determine the effect of feeding a conventional WPCS hybrid harvested as Shredlage® (SHRD) compared to the same hybrid harvested as conventionally-processed WPCS (CPCS) on lactation performance by dairy cows. Both the percentage of material on the top screen of the Penn State shaker box and processing score were greater for SHRD (30 mm theoretical length of cut [TLOC] and 2.5 mm roll gap) than CPCS (19 mm TLOC and 2 mm roll gap). Cows fed SHRD tended to consume 0.7 kg/d more DM. Milk yield and milk composition were similar between treatments. Yield of 3.5% FCM tended to be 1 kg/day greater for cows fed SHRD. Ruminal in situ digestibility of starch, but not NDF, was greater for SHRD than CPCS. Total tract digestibility of dietary starch and NDF were greater for SHRD than CPCS.

We recently conducted a feeding trial to evaluate SHRD versus CPCS using a brown midrib (BMR) WPCS hybrid and also to determine the physically-effective NDF in SHRD compared to chopped hay in TMR fed to 120 high producing dairy cows. Dry matter intake, lactation performance, and total tract dietary starch and NDF digestibilities were determined, and rumination activity was determined using SCR collars. Data had not been not been summarized by the deadline for this paper, but preliminary results from the experiment will be presented at the conference.

Although alternative processing methods, greater speed differential with conventional rolls, and type of processor, intermeshing discs, are now being used in the field, there is a lack of information with regard to processing score, particle size, and TLOC capability or animal performance for them relative to CPCS or SHRD. These alternative approaches to WPCS processing will be discussed at the conference.

Silage Fermentation

Hoffman et al. (2011) reported that ensiling high-moisture corn (HMC) for 240 d reduced zein protein subunits that cross-link starch granules, and suggested that the starch-protein matrix was degraded by proteolytic activity over an extended ensiling period. The Larson and Hoffman (2008) turbidity assay did not detect a reduction in zein protein over the ensiling period for HMC as was measured by high-performance liquid chromatography (Hoffman et al., 2011).

Ammonia-N content increased, however, as HPLC zein protein subunits in HMC decreased (Hoffman et al., 2011), and ammonia-N was used in combination with mean particle size for modeling the effects of corn maturity, moisture content and extent of silage fermentation on ruminal and total-tract starch digestibilities for HMC at feed out (Hoffman et al., 2012a, b). Ferrareto et al. (2014c), using a data set comprised of 6,131 HMC samples (55 to 80% DM) obtained from a commercial feed analysis laboratory, reported that ammonia-N was positively related to ruminal in vitro starch digestibility (ivStarchD; R² = 0.61) and combined, ammonia-N, DM, soluble-CP and pH provided a good prediction of ivStarchD (adjusted R² = 0.70).

In WPCS fermented for 0, 45, 90, 180, 270, and 360 d, ammonia-N and soluble-CP contents and ivStarchD increased over time and soluble CP, but not ammonia-N, was highly correlated with ivStarchD (R² = 0.78
versus 0.24). Young et al. (2012) and Windle et al. (2014) reported that increases in WPCS ammonia-N and soluble-CP contents were accompanied by increases in ivStarchD in response to increased time of ensiling and exogenous protease addition.

Ferrare et al. (2014b) reported on a study where 8 WPCS hybrids (4 BMR and 4 leafy) were ensiled for 0, 30, 120 and 240 d. Fermentation profile, ammonia-N and soluble-CP contents, and ivStarchD were similar for the 2 hybrid types and there was no hybrid type x time of ensiling interaction detected. Increases in WPCS ammonia-N and soluble-CP contents were accompanied by increases in ivStarchD in response to increased time of ensiling. Positive relationships between ivStarchD and ammonia-N (R2 = 0.67) and soluble-CP (R2 = 0.55) were observed. Ammonia-N and soluble-CP were both good indicators of ivStarchD in WPCS as has been done for HMC, however, more research is needed especially with regard to combining the particle size of the kernels in WPCS along with these N measures into predictive models.

**Corn Silage Hybrid Type**

**UW Lactation Trial 1**

Ferrareto and Shaver (2014a) conducted a study to determine the effect of feeding a TMR containing a floury-leafy WPCS hybrid (LFY) compared to a BMR hybrid for intake, lactation performance, and total tract nutrient digestibility in dairy cows. The WPCS ivStarchD was greater for LFY than BMR, while ruminal in vitro NDF digestibility (ivNDFD) was greater for BMR than LFY. The DM content, Penn State shaker box, and processing score measures were similar for the 2 WPCS treatments. Both TMR contained 65% total forage of which 65% was WPCS (DM basis).

Cows fed BMR consumed 1.7 kg/d more DM than LFY (P < 0.01). Milk yield was greater (P < 0.01; 49.0 vs. 46.8 kg/d) and energy- and solids-corrected milk yields tended (P < 0.10) to be greater for BMR than LFY, however, feed efficiency measures (kg milk or component-corrected milk per kg DMI) did not differ by treatment (P > 0.10). Fat-corrected milk (50.3 kg/d on average) and milk fat yield (1.84 kg/d on average) were similar (P > 0.10), as milk fat content was greater (P < 0.01) for cows fed LFY (4.05%) than BMR (3.83%). Cows fed BMR had lower (P < 0.001) MUN concentration and greater (P < 0.05) milk protein and lactose yields compared to LFY. Total tract starch digestibility was 5%-units greater (P < 0.001) for cows fed the LFY. Trial results suggest that WPCS hybrid selection programs which focus on increasing starch digestibility by dairy cows through selection of softer kernel texture can be effective. Results also denote, however, the importance of NDF digestibility in WPCS hybrid selection programs.

**UW Lactation Trial 2**

Akins and Shaver (2012) reported on an experiment with its primary objective to determine lactation performance by dairy cows fed NutriDense® (ND; NutriDense 905823; BASF Plant Science, Raleigh, Durham, NC) compared to dual-purpose (DP; Pioneer Hi-Bred A DuPont Business, Des Moines, IA) and BMR (BM; Mycogen Seeds, Dow AgroSciences LLC, Indianapolis, IN) WPCS hybrids at the same concentration of WPCS in the treatment diets. This study was a follow-up to the report of Chase (2010) where greater milk production was observed for BM, while greater feed efficiency was observed for ND. A secondary objective of the UW trial was to determine lactation performance by dairy cows fed ND at two different concentrations of WPCS in the treatment diets.

Three treatments (DP40, BM40 and ND40) contained 60% forage DM with 2/3rd (40% of TMR DM) from the respective WPCS and 1/3rd alfalfa silage (DM basis). The fourth treatment contained 65% forage DM entirely from ND corn silage (ND65). All diets were formulated to be isonitrogenous. A 2-wk covariate period with all pens receiving a TMR containing equal DM proportions of DP40, BM40 and ND40 was followed by an 11-wk treatment period with pens (16 pens of 8 cows each) fed their assigned treatment TMR.

Although harvest of the three WPCS treatments commenced as soon as possible after being assessed at the one-half kernel milkline stage of maturity, the BM averaged 41.8% DM and was 6.6 and 4.5%-units drier than DP and ND, respectively. For the BM, five days elapsed between the decision to harvest and the actual harvest with weather conditions favoring a rapid dry-down during that time period which resulted in the DM content being greater than desired for that WPCS treatment. The concentrations of NDF and starch in WPCS were similar for DP and BM. The ND WPCS NDF content was 3.4%-units lower and starch content was 4.9%-units greater compared to the average for DP and BM. All three WPCS treatments were well processed with processing scores ranging from 68% to 77%.

The ivNDFD was 14%-units greater for BM than the average of DP and ND which were similar. The ivStarchD was similar ranging from 84% to 89% across the WPCS treatments. It should be noted that the WPCS treatments had been in the silo bags for ten months before commencing with the feeding trial and silage sampling over a subsequent four month period, which would likely have attenuated any inher-
ent differences in starch digestibility that may have existed between the WPCS hybrids.

Actual milk yield tended to be 1.9 kg/d greater (P = 0.09) and milk protein and lactose yields were greater (P < 0.01 and P = 0.03, respectively) for ND40 than DP40. Although DMI was similar (P = 0.15) the intakes of fat, NFC, starch and rumen digested starch were greater (P < 0.01) for ND40 than DP40, which could explain the production differences between these two treatments. Cows fed BM40 had 1.9 kg/d greater (P = 0.02) milk yield than DP40. The lack of DMI response (P = 0.71) for BM40 with its greater WPCS ivNDFD compared to ND40 or DP40 was surprising, but may have been related to the trial being performed on midlactation cows between 100 and 200 DIM where rumen fill may not be limiting energy intake relative to production requirements. The trial of Chase (2010) which found greater DMI and milk production for BM WPCS was conducted with early lactation cows.

Dry matter intake and milk yield were reduced by 1.8 (P < 0.01) and 2.2 kg/d (P = 0.02), respectively, for ND65 compared to ND40. Furthermore, milk fat content and yield were reduced by 0.45%-units (P = 0.01) and 0.33 kg/d (P < 0.01), respectively, for ND65 compared to ND40. Reduced DMI and thus nutrient intakes (OM, CP, fat, NFC, and starch; P < 0.01) and consequently milk yield along with reduced milk fat could be related to greater ruminal starch digestion for ND65 compared to ND40. Of the total dietary starch 52% for ND40 and 85% for ND65 was provided by WPCS with greater ruminal digestibility than the dry ground shelled corn which comprised most of the remainder of dietary starch. Coincident with the milk yield differences, yields of protein (P < 0.01) and lactose (P = 0.01) were reduced for ND65 compared to ND40. The resultant calculated yields of FCM, ECM and SCM were also reduced (P < 0.01) for ND65 compared to ND40. The MUN concentration was 12% greater (P < 0.01) for ND65 than ND40. This response may have been related to a reduced ruminal pH from greater starch digestibility, as suggested by milk fat depression, reducing the efficiency of rumen microbial protein synthesis. Results suggest that high ruminal starch digestibility may be a limitation to feeding diets comprised of a high proportion of long-ensiled WPCS.

References


The Compromise Dairy Safety Net Solution

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Key Findings:

- By focusing on the national average all milk price minus feed cost, a margin, and not milk price exclusively, dairy producers in the United States, regardless of geographic location or management style are provided self-selected levels of protection against severe downturns in the milk price, rising livestock feed prices, or a combination of both.
- Thought of as a type of ‘flexible option contract’ margin protection can be “in-the-money” and carry an intrinsic value when the coverage level (strike price) is above the expected production margin forecast using CME futures and options prices. Adverse gaming incentives increase as the intrinsic value of the coverage increases and can be reduced by instituting a gap between the sign-up date and the beginning of the coverage period.
- As a safety net, when close to being at-the-money this flexible option contract will result in a distribution of program benefits that closely mirrors the distribution of benefits under the previous MILC program.
- Small producers benefit under both at-the-money and in-the-money sign-up environments; however, during times when margin coverage is deep in-the-money, the per hundredweight payment is more uniform by scale and the distribution of program benefits will skew more toward the larger scale producers due to the absence of production or income caps on indemnity payments.

Newton, Thraen, and Bozic (2013a; 2013b) offered an independent analysis of the dairy margin protection programs put forth and passed by the U.S. House of Representatives and the U.S. Senate. This research demonstrated that a safety net program encompassing both the milk price and the feed price in the form of an income-over-feed-cost margin would succeed in providing need financial relief to dairy farmers during times of low milk production margins. Newton and Thraen (2013a; 2013b) also identified and discussed three significant issues: (i) adverse gaming, (ii) functional equity of dairy market stabilization, (iii) and the distribution of program benefits.

Recently The Agricultural Act of 2014 was passed by both Houses of Congress and signed into law by President Obama on February 7, 2014. In this article I will demonstrate how The Agricultural Act of 2014, through the Margin Protection Program for Dairy Producers, has partially addressed Newton and Thraen’s earlier concerns by (1) excluding the dairy market stabilization program and (2) altering the premium schedule for both small and large dairies. First, I review the margin protection provisions in the new law, and second I examine to what extent adverse gaming incentives and distributional effects may still exist. In addressing these issues I will demonstrate that the distribution of program benefits no longer follows closely the distribution of milk production and is more aligned with the benefit distribution of the Milk Income Loss Contract (MILC) program. I will also explain that adverse gaming incentives still exist, and in the absence of formal rate making procedures can be significantly reduced by instituting a gap between the sign-up date and the beginning of the coverage period.

What is the Margin Protection Program for Dairy Producers?

The dairy title of The Agricultural Act of 2014 would repeal a number of existing dairy safety net programs and replace them with two new programs: Margin Protection Program for Dairy Producers and a Dairy Product Donation Program. Both programs will become effective by September 1, 2014. The focus of this post is the margin protection program to replace MILC. The margin protection program is a voluntary program which pays indemnities when the average difference between the USDA national All-Milk price and a ration index reflecting the national cost of feeding dairy animals falls below a user selected coverage level. Over the 2000-2013 years the dairy production margin has ranged from a low of $2.25 to a high of $14.65 and averaged $8.26 per hundredweight (cwt). Margin protection is available from $4.00 to $8.00 per cwt in .50¢ increments and offers protection on...
up to 97% of the historical average margin. Enrolled producers may receive coverage on 25-90% of their milk production history. The production history is to be determined at sign-up in the first year of the program and is defined as the highest level of annual milk production during 2011, 2012, or 2013 calendar years. In subsequent years a farm’s production history will be updated by USDA to reflect only the increase in national average milk production. Individual milk production base growth above the national average will not be reflected in the updated production base.

In order to participate in the margin protection program and receive no cost $4.00 coverage dairy operations must annually pay an administrative fee of $100. Additional margin protection (strike price) on levels above $4.00 per cwt can be selected by a participating dairy at supplementary costs with premium rates depending on a farm’s production history. Premiums range from $0.01 for $4.50 coverage to as high as $1.36 for $8.00 coverage. The premium schedule is fixed for the life of the Farm Bill, but premium discounts of 25% are specified for the 2014 and 2015 calendar years for all but the $8.00 level. For a more detailed discussion of the specific dairy title provisions of the new 2014 Farm Bill see Bozic et al. (2014).

Revisiting the Distribution of Expected Benefits

Contrary to the existing MILC safety net program for dairy producers, the margin protection program does not include adjusted gross income limitations or fixed caps on production and therefore on the magnitude of potential benefits. In the final compromise the margin protection program was modified to be more accommodating to small and medium sized dairies by reducing the premium rates by as much as 50% for the first four million pounds of production history. Finally, the premium rates for production history in excess of 4 million pounds were increased by 20¢ to 30¢ for the $7.00 to $8.00 coverage options. Using average milk production of 21,806 lbs per cow per year the 4 million pound cap represents a 183 cow dairy, and just shy of 85% of U.S. dairies are below this threshold.

To evaluate the distribution of margin protection benefits following these premium adjustments, and using data on milk production provided by USDA, I compared simulation results of MILC, Dairy Freedom Act, Dairy Security Act, and the Agricultural Act of 2014, Figure 1. Under MILC, I estimated that dairies with less than 100 cows (approximately 70% of farms) account for about 39% of net expected benefits and dairies over 1,000 cows (3% of farms) account for 9% of net expected benefits. Under the Dairy Freedom and Security Acts I projected that farms over 1,000 cows would account for 36% of benefits during low margin outcomes (see here). Now, under the margin protection program in the Agricultural Act of 2014, I find that the distribution of net expected benefits closely aligns with those simulated under MILC. Farms with fewer than 100 cows would continue to receive approximately 38% of the expected benefits, and farms with over 1,000 cows would account for approximately 15% of benefits during low margin outcomes. For larger dairies this allocation represents an improvement over MILC considering that not only does the relative proportion of benefits increase (9% to 15%) but at the same time total outlays are also anticipated to be higher than MILC given the lack of payment limitations or hard eligibility constraints.

Through the altered premium structure, and given 2013 expected margins, the distribution of expected benefits no longer mirror the distribution of milk production and instead provide more coverage on a per cwt basis to smaller dairy operations. For example, during the simulated 2013 margins the average net payment for farms below 100 cows was $0.80 per cwt under $7.50 coverage. Meanwhile, for the herds with 1,000+ head the average net payment was only $0.14 per cwt under $6.50 coverage. The difference in per cwt net payments is due to the higher premiums rates applied to the largest dairy operations. Thus, by design the per cwt benefits are higher for small producers by means of the premium reductions and discounts but also due to higher premium rates effectively deterring participation at higher coverage levels for the largest dairy operations.

Only when the margin coverage levels of $7.00 and above are expected to be deeply “in-the-money” would a larger producer find it financially beneficial to purchase such protection. Under such a scenario, when margins are catastrophically low as was the case in 2009, and using data provided by USDA, I found indemnities with $8.00 coverage could exceed $6 million dollars per farm for some of the nation’s largest dairymen. When factoring in participation...
costs net payments were over $3 million dollars for some of the larger dairies in the simulation. Additionally over 10% of the 1,072 dairies in the 1,000+ head category had net payments above $1 million dollars given the 2009 margin simulation. Thus, I conclude that only when higher coverage levels are deep in-the-money will payments per cwt be more consistent across participating farm sizes and result in the distribution of net benefits following closely to the distribution of milk production.

**Does Adverse Gaming Still Exist?**

The concept of the margin protection coverage levels being “in-the-money” or “out-of-the-money” relates to the intrinsic value of the margin coverage level and borrows from the idea that upon the sign-up date the margin protection level, or strike price, which ranges from $4.00 to $8.00 per cwt, may be above (in-the-money), equal to (at-the-money), or below (out-of-the-money) the expected margin forecast using CME futures and options prices. Coverage levels can be categorized into one of the three categories during each sign-up/registration period because while the premium rates and coverage levels remain fixed, milk and feed markets are constantly updating to reflect new information on prices and expected volatility. When margin coverage is in-the-money it has intrinsic value and during the annual sign-up process dairy farmers can strategically select the coverage level that has the highest intrinsic value or expected financial returns.

As an example, consider in Figure 2 the expected production margins at the beginning of 2009, the beginning of 2014, and in October 2008 for the 2009 calendar year. Beginning-of-the-year 2009 expected margins were deeply in-the-money such that $8.00 coverage had the highest average intrinsic value of $2.85 per cwt. As a result, the expected benefits of participation would have warranted coverage as high as $8.00 per cwt for the largest dairy operations - despite paying premiums as high as $1.36 per cwt. Alternatively, given favorable 2013 crop production and robust demand for dairy products, expected margins for 2014 indicate a very low probability of indemnity payments and are categorized as out-of-the-money. Aside from opting completely out of the program, the lowest coverage level of $4.00 would have zero intrinsic value and would provide the greatest expected net benefits because it carries only the administrative fee of $100.

As demonstrated, the modifications to the premium structure alter, but do not eliminate, the financial incentives to strategically select margin protection coverage based on the anticipated risk environment and moneyness. Adverse gaming incentives still exist; however, a proposal put forth by Bozic, Newton, and Thraen (2013) could further reduce the adverse gaming potential by instituting a gap between the sign-up date and the beginning of the coverage period. Bozic, Newton, and Thraen propose that by “instituting a six-month gap between a sign-up date and the beginning of the coverage period, the ability to forecast margins over the coverage period is substantially reduced.”

While a six-month gap may not be politically feasible, a 60- or 90-day gap may be acceptable given that the term structure of income over feed cost margins exhibit mean-reverting behavior. The effect of a 90-day gap on the intrinsic value and moneyness is demonstrated in the third panel of figure 2. In this example a 90-day gap between the sign-up and coverage start date carries no intrinsic value at $8.00 and is closer to at-the-money thereby reducing the potential for strategically timed positive expected benefits of margin protection. When margin protection coverage is closer to at-the-money the adverse gaming incentives are reduced as future indemnities are less certain. As a result, the decision to participate in the program, and at what coverage level, would be made based on a farm’s appetite for risk and not on the ability to strategically game the program to one’s financial advantage.

**Summary**

The new dairy farm safety net program places an emphasis on protecting farm income over feed cost margins. By focusing on margins, and not milk price or countercyclical revenue support, dairy producers across the U.S. regardless of location and management style are better protected against severe downturns in the milk price, rising livestock feed prices, or a combination of both.
In this article we’ve demonstrated that except during times when margin coverage is deep in-the-money the distribution of program benefits will follow closely the distribution of benefits under the previous MILC program while simultaneously providing additional income support for the nation’s largest dairy operations. I also show that adverse gaming incentives still exist with the Dairy Margin Protection Program but can be mitigated by specifying an earlier sign-up date for coverage decisions, specifically I propose 60 or 90 days.

With the Agricultural Act of 2014 becoming law, the Secretary of Agriculture is provided the authority to define many of the rules by which the dairy programs will operate. At the time this article is posted many of these are not known. As the rules and regulations become known to us I will provide more information and insight in future articles.

References


Introduction

Over the past several years there has been a rapid adoption in the use of automatic milking systems (AMS) throughout the Midwest. It was estimated that over 500 US dairy farms were using AMS in 2011 (Rodenburg, 2011). Much of this growth is driven by the desire for smaller farms to expand without hiring labor and the larger farms desire to manage a smaller number of employees.

We are conducting a field study with 53 AMS farms in Minnesota and Wisconsin, that includes but it is not limited to, collecting housing and management information for each dairy, cow behavior and welfare, daily cow information from the AMS software, in addition to conducting a survey of nutritionists working with the farms. In this article, we summarize some of the key aspects we learned about feeding cows in AMS farms.

Overview:

The goal of every feeding program is to develop a low cost diet that meets the nutritional requirements of cows while optimizing milk production and cow health. In most conventional herds this is accomplished by feeding a total mixed ration where all the ingredients are mixed together and delivered to the cow. For AMS herds a partially mixed ration (PMR) is offered in the feed bunk with a portion of the concentrate being fed through the milking box. One of the challenges facing nutritionists is to balance the nutrients supplied in the PMR and in the feed offered in the milking box to entice cows to visit the milking stall on a regular basis.

Feeding management is one of the major factors for success in AMS. Feed offered in the AMS unit is the major motivating factor to attract cows to consistently visit the milking station.

Enticing cows to visit the milking station:

The interaction between cow behavior, activity, her diet, feed consumption and cow heath and production is complicated (Rodenburg, 2011). Because of this a poor performing AMS system can cause frustration for both the farmer and their nutritionist.

In our study, we asked nutritionists to rank five feeding factors they thought were keys to AMS feeding success: PMR energy content, PMR starch content, consistency of the PMR (consistent mixing and delivery), consistent delivery and push up of PMR, and palatability of the pellet. Nutritionists working with these dairies indicated that palatability of the pellet and consistent mixing were the two biggest feeding factors contributing to AMS success. These results agree with comments made by dairy producers on our visits and existing research. Rodenburg and Wheeler (2002) showed that in a free flow system when feeding a high quality pellet vs a low quality pellet, voluntary milkings increased from 1.72 to 2.06/cow/day. Many producers in our survey had tried feeding a meal instead of a pellet in the milking box. On every farm this proved unsuccessful and they reverted back to feeding a pellet. Pellets should be made from palatable ingredients, hard and free from fines. At farm start-up nutritionists and farmers focused on developing a pellet formula that encouraged milking box visits. Once they had a pellet that worked well, other factors became more important. Many producers commented that even minor changes in the PMR moisture, consistency of the mix (i.e. long hay that is difficult to process to a consistent length) and changes in forage quality affected visits.

These complicated interactions between feeding management, voluntary visits and milk production can be challenging. If feed moisture changes and rations are not adjusted promptly, visits may drop. This drop in visits will result in a decrease in milk production and an increase in number of fetch cows (cows that did not visit the robot voluntarily during a specified time period and need to be brought up to the milking box). The increase in fetch cows may disrupt other cow behaviors resulting in even a bigger decrease in visits and decrease in milk production leading to a downward spiral creating much frustration for the producer. It is important for nutritionist to educate producers on the importance of very consistent feeding in order to maintain high production and minimize the number of fetch cows.
Guided flow vs free flow:

In barns with free flow traffic cows can access all areas of the barn without restriction. In guided flow traffic, one way gates and selection gates are used to guide cows to milking, feeding and resting areas.

There are two types of guided flow traffic - feed first and milk first. In the milk first system, cows leaving the resting area must pass through a pre-selection gate that determines if she is eligible for milking. If she meets the requirement to be milked she is guided to a commitment pen that contains the AMS. If she is not eligible for milking she is allowed to enter the bunk area and can only enter the resting area through a one way gate. In the feed first system, cow traffic is the reversal of the milk first system. After eating the PMR cows enter a selection gate that determines if she is eligible for milking. The gate either guides her to the commitment pen for milking or to the resting area.

Farmer comments and our observations indicate that the milk first system is superior with the US style of dairying where economics demand high production. Our observation is that in feed first systems cows fill up on the PMR and tend to stand in the feed alley or commitment pen and chew cud without entering the selection gate or visiting the AMS. Producers in these systems had the same observations. Feed first systems work best in farms where the PMR is very low in energy and there is a drive for cows to consume the concentrate in the milking box (Rodriguez, 2013)

Our survey of nutritionists showed that feeding strategies were different for free flow and guided flow systems. A higher percent of the dry matter and nutrients were delivered through the PMR in guided flow systems because cows are guided to the milking box. One reason farmers install guided flow AMS is the desire to feed less of the pelleted feed through the milking box. The amount of pellets offered through the milking box ranged from 2 to 25 lbs/cow per day in free flow systems whereas in guided flow systems the minimum was also 2/lbs/cow/day but the maximum anyone fed was 18 lbs/cow/day. The average amount of pellets fed across all herds was 3 lbs/cow/day less with guided flow barns.

The PMR in guided flow systems tended to be slightly higher in energy (0.015 Mcal/b) and lower in NDF (2.1%) than the PMR in free flow systems. These ration differences are driven partly by the intended cow production level. In free flow herds the PMR was balanced for milk production levels of 10 to 30 lbs less than the herd’s average production. For guided flow herds the PMR was balanced for 9 to 20 lbs less than the average of the herd. This difference should be expected between the two systems. High energy density in the PMR in free flow barns may lead to decreased milking frequency resulting in less milk production per cow, whereas in guided flow barns cows are guided to the robot through the selection gate.

In a free flow system Bach et al. (2007) showed that increasing the amount of pellets offered in the robot box from 6.6 lbs/cow/day to 17.6 lbs/cow/day increased the frequency of visits from 2.4 to 2.7 milkings per day for cows not being fetched. However, increasing the feed offered in the robot box did not decrease the number of fetch cows. Something other than the amount of concentrate offered such as lameness, or fear was affecting the number of fetch cows.

Both guided flow systems and free flow systems can be successful. In our study, we have herds that averaged over 90 lbs/cow/day over an entire year of production with both free flow and guided flow systems. The key is to manage the system well to optimize production.

Conclusion

The rapid growth on the number of farms using AMS in the Upper Midwest is expected to continue. The complexity of balancing the ration in the PMR and feed offered in the milking box can be a challenging task for nutritionists. Based on research, nutritionist surveys and farmer comments, the most important factors affecting feeding success include a high quality, palatable pellet and excellent feed management. It is important to work with herd managers to educate them on the importance of feed management and to balance energy in the PMR with pellets fed through the milking box to optimize visits and minimize the number of fetch cows.

Acknowledgements

We would like to thank the AMS specialists from Lely and Delaval and their local dealers for their valuable input and help with AMS data collection. A special thanks to all of the cooperating nutritionists for sharing information with us and the many AMS users that allowed us to visit their farms and collect data and provided their valuable insight into their successes and challenges.
References


Transition to Global Marketer

Michael Swanson Ph.D.
Wells Fargo
June 2014

Key questions

1. What is milk worth?
2. Why is milk worth that?
3. Who gets what share?
4. What differentiates the producers?
5. What’s your “play”

Milk prices are profitable why?

Belief: International demand will be strong at these prices

How far can this trend run?

Net Exports as Percentage of Production

Pizza or powder?

New highs – for how long

National Milk and Corn Prices

Fonterra Auction Prices
Know your customer

Who are the players in the international market?

Who are the importers?

Who are the exporters?

The Wal*Mart Effect

So what are the Chinese buying?
What has happened in 2014 so far?

<table>
<thead>
<tr>
<th>Product</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>YTD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk</td>
<td>8.8</td>
<td>10.2</td>
<td>13.4</td>
<td>14.1</td>
<td>19.7</td>
<td>18.2</td>
<td>4.3</td>
<td>5.0</td>
</tr>
<tr>
<td>Intermediate</td>
<td>1.0</td>
<td>0.9</td>
<td>2.2</td>
<td>1.9</td>
<td>2.3</td>
<td>3.5</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Consumer Oriented</td>
<td>0.5</td>
<td>1.1</td>
<td>1.3</td>
<td>2.2</td>
<td>2.6</td>
<td>3.5</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Forest Products</td>
<td>(2.3)</td>
<td>(1.7)</td>
<td>(1.5)</td>
<td>(0.6)</td>
<td>(1.3)</td>
<td>(0.7)</td>
<td>(0.3)</td>
<td>(0.1)</td>
</tr>
<tr>
<td>Fish Products</td>
<td>(1.6)</td>
<td>(1.4)</td>
<td>(1.5)</td>
<td>(1.4)</td>
<td>(1.4)</td>
<td>(1.4)</td>
<td>(0.3)</td>
<td>(0.5)</td>
</tr>
<tr>
<td>Grand Total</td>
<td>6.5</td>
<td>9.1</td>
<td>13.8</td>
<td>16.1</td>
<td>22.0</td>
<td>23.1</td>
<td>4.4</td>
<td>5.4</td>
</tr>
</tbody>
</table>

How much will they allow?

Economic and Commodity Risk

Simple stories are simply wrong

Cause and effect? Is it constant?

Anticipating the feedback

How are the cycles linked?
Exchange rates are not about dairy

- Policy makers
  - Central banks
  - Government trade officials
- Current account balances
- Financial flows
  - Interest rate arbitrage
  - FDI and "hot money" flows
- Manias and mistaken beliefs

Question your assumptions

- Global demand growth
  - Population
  - GDP
  - Diet
- Global supply growth
  - Acreage
  - Productivity
  - Trade barriers
- Policy shocks

The global numbers are huge

The denominator of per capita

Higher income slows population growth
The rate of change is a challenge

Demographics and food

- Factors and offsets
  - Fewer children
  - Longer lifespans
  - Which one changes fastest?

- Income growth issues
  - Rate of change
  - From what base
  - Existing resource base

How much grain does the world need?

- Per capita
  - Best measure
  - Substitutes
    - Grain
    - Meat
  - Efficiency of conversion

- Diet
- Demographics
- Distribution

Big numbers all around

Energy and agriculture

Still a policy play
This is a policy shock

Feed, Seed and Industrial

Where did they bury the survivors?

What’s your play?

The survivor dividend

Percent: Profits Before Taxes / Total Assets

So what?

- Anticipation v. Forecast
  - Operations need forecasts
    - Short-term
    - No feedback
  - Management needs scenarios

- Global agricultural
  - Faster growth outside of the US
  - US land base fully priced for its advantages
  - Policy shocks will continue – as always

There is only one difference between a bad economist and a good one: the bad economist confines himself to the visible effect; the good economist takes into account both the effect that can be seen and those effects that must be foreseen.

Frédéric Bastiat 1850
The components of a successful calf raising operation are health, performance, production and profitability of the replacement heifers. Returns on the significant investment made to maximize each of these important components may be delayed but do reward the significant commitment to provide a comprehensive care package to all calves. The care package includes colostrum, a high plane of nutrition, an optimal calf environment and intensive health management. The goal of this presentation is to provide a practical approach to maximize performance in the first 60-days of the calf’s life, with an emphasis on ideas to improve colostrum, nutrition, environmental management and health in the first 60 days.

Reducing Mortality in the First 24-hours of Life

Most calves that die within the first 24-hours of life are alive at birth and simple strategies that do not rely on drugs or oxygen delivery may prevent death. Of foremost importance to improved survival in the first 24-hours is unassisted vaginal delivery of calves. With a normal presentation and sustained progress, observe calving from a distance and provide no assistance. For calving cows that are moved during second stage labor, expect labor to stop temporarily and allow time for labor to resume before providing assistance. In a recent study (Schuenemann et. al.), 65 minutes was suggested as the time from the appearance of feet outside the vulva to intervention for cows that need calving assistance.

After delivery, calving attendants should watch closely for behavior indicative of normal adaptation to life outside the uterus.

- Head righting begins within minutes.
- The calf is sitting in a sternal position within 5 minutes.
- The calf makes standing attempts made within 15 minutes.
- Shivering begins within 30 minutes of delivery.
- The calf is standing by 1 hour.
- The calf is suckling within 2 hours of delivery.

Without appropriate movement and reflex activity, the newborn calf’s body temperature declines from an elevated level at birth to 101-102° F within an hour. It will continue to decline if the calf is not active and shivering. Death due to hypothermia can occur within 1 to 2 hours, especially when the environmental temperature is below 58° F, the low end of a calf’s thermal neutral zone.

For calves that have flaccid muscles, are unresponsive to stimulation, have blue membrane color or are breathing irregularly, simple techniques may be used to revive the calf and stimulate regular breathing. Place the calf on a low platform, cart or table to facilitate the following procedures.

- Place the calf’s head over the edge of the raised platform for 10 to 15 seconds to get postural fluid drainage from the mouth and nose.
- Place the calf in a sitting position if possible. Take a clean, dry towel and rub the topline of the calf from the tailhead to the poll.
- Use the towel to stimulate the ears, eyelids and nose of the calf.
- Ice water can be poured onto the head or into the ear of the calf to stimulate breathing.
- Compress and then shake the trachea (wind pipe) high up in the neck to stimulate a cough reflex.
- Place pinpoint pressure right in the center of the muzzle between the nostrils or place finger pressure across the nasal septum where nose tongs would be placed to further stimulate breathing.

Put Colostrum Testing into Action

Failure of passive transfer of immunity (FPT) is recognized as a major problem that has negative short- and long-term consequences for the health and productivity of herd replacements. Many dairy calf raisers routinely monitor serum total protein (STP) concentration of calves but use the results in a limited way. Results can be used to classify individuals as high risk calves when STP concentration is < 5.0 gm/dl. High-risk calves can be marked so that intensified health screening procedures are used on these individuals.
To classify a herd as an FPT herd, a minimum of 10 to 12 STP results from calves less than 7 days of age are needed. When more than 20% have STP < 5.5 gm/dl or more than 10% have STP < 5.2 gm/dl, the colostrum program needs attention. When using STP data from refractometer readings, it is imperative that the refractometer is calibrated. The simplest calibration step is to verify that the specific gravity scale of the refractometer reads 1.00 after application of distilled water. Adjust as necessary. At least every 6 months, split serum samples and correlate STP concentrations between an accredited laboratory and the refractometer. Perform serum testing at room temperature.

A systematic review of colostrum protocols on the dairy usually is necessary to find the reason for herd based FPT. Colostrum volume, quality, cleanliness and absorption factors should be reviewed to find potential problems.

- Inadequate volume of colostrum is administered
  - Less than 4-quarts of colostrum is administered with an esophageal feeder.
  - Less than 3-qt of colostrum is given to calves that suckle.

- The colostrum quality is inadequate. Common reasons for reduced quality include:
  - High producing cows – colostrum dilution occurs soon after calving
  - Delayed milking – time between calving and milking exceeds 4 hours.
  - Calving cows are suckled before colostrum collection (Note: calves that remain with the cow for 30 to 60 minutes after birth frequently have suckled before they are removed from the pen.)
  - Calving cow has leaked milk or been pre-milked before calving.
  - The dry period length was less than 30 days.
  - There are significant nutritional problems with the close-up dry cows (Note: this problem usually results in reduced colostrum volume rather than the quality)
  - There are significant health problems in the calving cows (Note: the effect is usually reduced volume rather than the quality).
  - Limited or poor vaccination program (Note: Vaccination of the dry cows is important for immunity to specific diseases of calves. Vaccination does not have a quantitative impact that can be measured by colostrometer or Brix refractometer)

- Colostrum immunoglobulin absorption is impaired.
  - Colostrum feeding is delayed > 4-hours after birth.
  - There is excessive bacterial contamination (> 100,000 cfu/ml) of colostrum (Note: probiotics should not be added to colostrum)
  - Colostrum supplement or replacement powder is added to colostrum.
  - There is a high level of calving assistance

**Train Calf Care Providers to Use the Esophageal Feeder**

Comfort with proper use of the esophageal feeder amongst calf workers will improve herd FPT problems and reduce mortality due to diarrhea-induced dehydration. For colostrum administration, use a 4-qt capacity esophageal feeder. For the administration of an oral electrolyte solution, use a 2-qt esophageal feeder. Never use the esophageal feeder in a calf that cannot maintain sternal recumbency (standing position is preferred), in a calf that is having respiratory difficulty, or that has abdominal distension. While passing the esophageal feeder, maintain the head of the calf in a neutral position so that the nose is below the plane of the ears.

Esophageal feeders should be cleaned and soaked in a disinfectant between uses. Therefore, have as many esophageal feeders as will be used (maximum use) in a day. Do not use the esophageal feeder to force feed milk or milk replacer without a protocol from your veterinarian and an established limit to the number of successive forced feedings.

**Nutrition**

Have a nutritional plan that will allow calves to double birth weight by 60 days of age. Whether the diet is whole milk or milk replacer, use the Nutrient Requirements of Dairy Cattle (NRC) to make the feeding plan. Implement a winter-feeding program when the temperature falls below 55° F and determine what milk or milk replacer intake is needed to meet weekly goals for average daily gain (ADG). A winter feeding plan for calves on whole milk in Wisconsin may look like the one shown in Table 1.

**Table 1. Whole Milk Winter Feeding Plan for Holstein Calves in Wisconsin**

<table>
<thead>
<tr>
<th>Age</th>
<th>Whole Milk Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3 days</td>
<td>2 quarts twice daily</td>
</tr>
<tr>
<td>3-10 days</td>
<td>3 quarts twice daily</td>
</tr>
<tr>
<td>10-49 days</td>
<td>4 quarts twice daily</td>
</tr>
<tr>
<td>49-56 days</td>
<td>4 quarts twice daily</td>
</tr>
<tr>
<td>56-63 days</td>
<td>No milk</td>
</tr>
</tbody>
</table>
Understand what milk or milk replacer and starter intakes are needed to meet weekly goals for gain to double birth weight by 60 days. In Table 2 below, the NRC calculator was used to estimate the protein and energy allowable ADG for a 99 lb birth weight Holstein calf at two different temperatures. Looking for an ADG of 1.0 and 1.2 lb for weeks 1 and 2, respectively, current feeding rates of a 22:20 milk replacer do not meet ADG goals.

Table 2. As fed, this 99 lb birth weight Holstein calf will not meet expected ADG for weeks 1 and 2.

<table>
<thead>
<tr>
<th></th>
<th>Milk replacer intake (lb/day)</th>
<th>Estimated starter intake (lb/day)</th>
<th>Energy Allowable ADG (lb/day)</th>
<th>Protein Allowable ADG (lb/day)</th>
<th>Goal met/ Limiter</th>
<th>MR needed to meet goal (lb/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1 - 85°F</td>
<td>1.26</td>
<td>0.25</td>
<td>0.94</td>
<td>0.88</td>
<td>No (&lt; 1.0 lb)/ Protein</td>
<td>1.39</td>
</tr>
<tr>
<td>Week 1 - 32°F</td>
<td>1.26</td>
<td>0.25</td>
<td>0.24</td>
<td>0.88</td>
<td>No (&lt; 1.0 lb)/ Energy</td>
<td>1.77</td>
</tr>
<tr>
<td>Week 2 – 110 lb; 85°F</td>
<td>1.30</td>
<td>0.5</td>
<td>1.06</td>
<td>1.00</td>
<td>No (&lt; 1.2 lb)/ Protein</td>
<td>1.77</td>
</tr>
<tr>
<td>Week 2 – 110 lb; 32°F</td>
<td>1.30</td>
<td>0.5</td>
<td>0.37</td>
<td>1.00</td>
<td>No (&lt; 1.2 lb)/ Energy</td>
<td>2.08</td>
</tr>
</tbody>
</table>

Monitor feeding consistency on a regular basis. Calculate and measure total solids delivered in each batch of liquid feed. Consistency of the liquid feed (less than 1% difference) from the first calf fed to the last, from one feeding to the next and between feeders will reduce the risk for nutritional diarrhea, bloat, ulcers and abomasitis. Total solids should never be greater than 18%. Brix readings can be used to monitor liquid feed consistency.

Monitor the bacterial quality of the milk or milk replacer being fed to calves. Standard plate counts and selective bacterial counts can find post-pasteurization contamination of milk or contaminated nipples at automatic feeder stations. Bacterial contamination of milk or milk replacer puts calves at high risk for infection and may affect the nutritional value of the feed. Table 3 shows the effect of dirty nipples at automatic feeding stations on the bacterial quality of pasteurized whole milk.

Table 3. Milk replacer culture results

<table>
<thead>
<tr>
<th>Select Microorganisms Counts (CFU/ml)</th>
<th>Pen 1-1</th>
<th>Pen 1-2</th>
<th>Pen 2-1</th>
<th>Pen 2-2</th>
<th>Goal Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Plate Count (CFU/ml)</td>
<td>5,400,000</td>
<td>6,250,000</td>
<td>5,150,000</td>
<td>1,300,000</td>
<td>&lt; 10,000</td>
</tr>
<tr>
<td>Coliforms (lactose-positive)</td>
<td>1,750,000</td>
<td>150,000</td>
<td>2,550,000</td>
<td>200,000</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>Gram negative rods (lactose-negative)</td>
<td>0</td>
<td>3,400,000</td>
<td>350,000</td>
<td>300,000</td>
<td>&lt; 5,000</td>
</tr>
<tr>
<td>Streptococci (non-agalactiae)</td>
<td>3,350,000</td>
<td>2,600,000</td>
<td>2,000,000</td>
<td>750,000</td>
<td>&lt; 5,000</td>
</tr>
<tr>
<td>Staphylococci (coagulase-negative)</td>
<td>300,000</td>
<td>100,000</td>
<td>200,000</td>
<td>50,000</td>
<td>&lt; 5,000</td>
</tr>
<tr>
<td>Comments</td>
<td>Several lactose + morphologies</td>
<td>Probable <em>Pseudomonas</em> spp</td>
<td><em>Pseudomonas</em> and many lac + morphologies</td>
<td><em>Pseudomonas</em> and many lac + morphologies</td>
<td></td>
</tr>
</tbody>
</table>
Health Screening

One of the biggest challenges of raising calves is early detection of health problems. Instituting regular health screening exercises will reduce mortality, shorten disease duration and improve treatment outcomes. In the absence of activity, appetite, or fever monitoring technology, a daily chore is to find abnormal calves, calves that remain standing after feeding when 90% of the calves are sleeping, calves with diarrhea, sunken eyes, eye or nasal discharge, abnormal head posture (tilted or star-gazing) or coughing frequently. This daily observation can be coordinated with the pick up of refused feed. The abnormal calves, the pen or the calf hutch of the abnormal calves are marked, indicating that these calves need a complete examination by the trained individual(s) assigned to that duty. The components of the basic exam are:

- Head position (tilted, star-gazing)
- Eye or nasal discharge – color, consistency and amount
- Temperature
- Fecal consistency
- Breathing pattern (abdomen vs. chest) and effort (inspiration vs. expiration)
- Navel exam (diameter, temperature, exudate)
- Fecal consistency
- Lameness, joint swelling
- Abdominal size and contour

On a twice a weekly basis, a more detailed respiratory disease screening (http://www.vetmed.wisc.edu/dms/fapm/fapmtools/8calf/calf_respiratory_scoring_chart.pdf) is recommended for all calves between 3 weeks of age and weaning. For health screening, it is estimated that an additional 0.5 full time equivalent (FTE) is needed for each 150 to 200 calves. For all calves that die, a post mortem examination is recommended. Farm staff can be trained to open, examine and take pictures of lesions that can be routinely reviewed by the farm’s veterinarian. Samples from dead calves can be a valuable tool to refine protocols, identify training needs or diagnose herd problems.

Safe, Smart and Strategic with Calf Vaccinations

The goals for vaccinating young calves are to provide optimal immunity to the disease agents that calves are most likely to encounter so that they can be protected during the period of maximum challenge. In the face of maternal immunity from colostrum, the vaccination route is likely to be intranasal or oral. Vaccination is for healthy calves on a good plane of nutrition. Avoid repeated (weekly or every other week) vaccinations. Don’t use half-dose or alternate vaccination routes unless there is good evidence for safety, effectiveness and disease protection. At the very least, do no harm.

Summary

Maximize performance, health, welfare and profitability of replacement heifers by focusing on the first 60 days of the calf’s life: newborn survival, colostrum, nutrition, optimizing the calf environment and regularly screening for health problems.
Automatic Calf Feeding Systems
Producer Surveys

by ISU Extension and Outreach Dairy Team; Jennifer Bentley, Kevin Lager, Larry Tranel, Dairy Field Specialists in NE/SE/NW IA, Ron Lenth, Bremer County Director, Leo Timms and Lee Kilmer, State Dairy Specialists, and Megan Kregel, Northeast Iowa Dairy Foundation.

Introduction

Iowa State University Extension & Outreach conducted a survey in 2013 of producers who utilized an automatic calf feeder system (ACF) on their farm. Twenty producers responded to the survey. The average installation was 2.6 years old. The herds averaged 367 cows; two operations utilized ACFs for bull calves only. The average cost per ACF was $17,301 with software costs included. Two were purchased used with an average price of $5,500. Monthly costs associated with the ACF, excluding milk replacer costs, averaged $55/month. Additional costs included construction of new group housing or adaptation of existing structures to accommodate the feeders. Existing structures remodeled for the ACF included parlor/holding pen, hoop barn, existing building addition, and farrowing house. Average building cost associated with the ACF was $66,643.

Facility Management

Forty-seven percent of the farms used straw for bedding. Ten percent of the farms did not use any bedding as calves were housed on a raised grated floor; remainder of the farms used a combination of straw, sawdust, and cornstalk bedding. Cleaning out group pens varied from every one to two weeks, to every couple of months depending on stocking density. Farms provided an average of 34 square feet per calf.

Ventilation to minimize accumulation of moisture while not causing a draft on the calves is essential and can drive the success or failure of the ACF. Previous facilities included wooden huts, condos, and individual stalls inside a calf barn where natural ventilation was the primary air flow. New and existing structures utilized a combination of curtain sidewalls and fans for summer ventilation and positive pressure tubes for winter ventilation; two farms utilized a cross-ventilated system.

Automatic calf feeding systems were cleaned frequently with an automatic circuit clean programmed 2-3 times a day and manually cleaning in between. Farms ranged in cleaning nipples and lines from daily to weekly. Lines and nipples were replaced as needed or every four to six weeks. Cleaning solutions included a low acid dilution, soap, bleach and water, or purchased disinfectants.

Colostrum Management

Seventy-one and eighty-two percent of farms administered colostrum within 2 hours after birth when the calf was born between 5-11 am and 11 am – 5 pm. Between 11 pm – 5 am, 5% percent of calves received colostrum within 2 hours, 61% at 2-6 hours and 38% at 6-12 hours after birth. Seventy-eight percent of farms administered 1 gallon or more of colostrum at their first feeding. Sixty-seven percent of farms primarily fed fresh colostrum, 56% occasionally fed frozen colostrum or replacer, and 26% always fed colostrum replacer. Five percent of farms fed pasteurized colostrum.

Eighteen percent evaluated colostrum prior to feeding either visually or use of a colostrometer. Twenty-five percent periodically measured the success of passive transfer of immunity with a refractometer or serum test.

Feeding Management

Before the ACF, all producers fed two times per day with buckets or bottles. Forty-one percent of producers fed a total of 4 quarts per day, while 29% fed 5 or greater quarts per day before the ACF. For calves to consume their total daily intake in the ACF, calves averaged 4-6 meals per day. If the calf did not consume all of the milk during a meal, milk was retained for the next calf. If milk fell below feeding temperature, milk was discarded before next calf could consume it. Feeding programs varied depending on the system and if heifers or bulls were fed. Calves were fed between 140-150 grams of powder per liter and fed up to 10 liters per day. The last two weeks prior to weaning, liters fed was gradually backed down until they no longer received milk. Eighty-five percent were feeding milk replacer. Fifty-six percent were feeding protein content in the milk replacer between 20-22% and 38% were feeding protein content in the milk replacer between 25-28%. Twenty-five percent utilized pasteurized waste milk with the ACF.
Calf starter was offered free-choice to calves starting at Day 0-2 (39%) and Day 3-10 (44%). Calf starter was replaced as needed daily to weekly to keep it fresh. Seventy-three percent of producers had calves consuming between 3-5 pounds of calf starter at weaning age, while 13% reported calves eating greater than 5 pounds of calf starter at weaning age. Forty-four percent used a calf starter protein of 16-20% and 56% of producers fed 21-22% calf starter protein. Water was offered free-choice to calves, starting at day 0-2 (59%), day 3-10 (35%), and day 11-14 (6%).

**Labor Management**

Twenty-five percent of herd owners took care of calves, while 31% hired a calf manager, 19% herds-person, and 25% family members. If they were not the primary calf manager, other duties on the farm included general farm labor to overall management of farm. On average, time spent feeding calves was 2.2 hours per day. This time included feeding, monitoring, vaccinating, dehorning, bedding and sanitation. Time spent feeding, managing, and caring for calves transitioning to the ACF averaged 1 hour. Producers commented no labor time was saved; time was more flexible and the labor was replaced with management time. Others reported an average reduced labor by 1.5 hours per day, which allowed time to be more flexible and focus on other management factors. Utilizing the software is a key element to the ACF, but did not take much time to review the data. Producers’ usage of the software averaged .44 hours.

**Health Management**

Twenty-two percent fed colostrum and moved into group housing at birth. Thirty-three percent fed calves for 2-5 days prior to group housing. Forty-four percent of calves started on the ACF between 1-2 weeks of age. Sixty-nine percent used age for determining when to move calves to automatic calf feeder, while 31% used health of calf and 46% used consumption as an indicator to move to group housing.

Sixty-four percent of farms used bodyweights as the main measurement to evaluate calf performance. Mortality and morbidity rates are often used along with management records. Average mortality rate was 3%. Treatment for scours was 14% and respiratory treatment rate was 14%. Scour and respiratory treatment protocol included a combination electrolyte therapy with an antibiotic treatment and fever reducer.

Indicators used on the software to determine calf health included drinking speed and daily consumption of milk. Ninety-four percent responded that the feeder showed alarms for calves not consuming total allotment, while 6% were not alerted. Thirty-seven percent have monitored average daily gain and averaged 2.3 pounds per day from birth to weaning. Average weaning age for heifers was 8 weeks and bull calves were 7 weeks old.

If calves were vaccinated at birth, vaccines included Rota Corona, Clostridium C&D, E.Coli, Inforce 3, Bovine Ecolizer C. Within a few weeks of age, vaccines included Johnhes, Scour Boss 4, Inforce 3. At the time of weaning, vaccines included Presponse, Bovishield, and Johnes. For dehorning, 50% used the paste within a week of age; the remainder dehorned in group pen with a burner prior to weaning or a few weeks after weaning.

<table>
<thead>
<tr>
<th>Average</th>
<th>Range</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Value to Quality of Life</td>
<td>$6,800</td>
<td>$100-$15,000</td>
</tr>
<tr>
<td>Annual Value of ACF software</td>
<td>$1,300</td>
<td>$1,000-$2,000</td>
</tr>
<tr>
<td>Months since ACF installed</td>
<td>1.6</td>
<td>2-10 mos.</td>
</tr>
<tr>
<td>Herd &amp; Financial Assumptions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herd Size</td>
<td>367</td>
<td>170-880</td>
</tr>
<tr>
<td>Number of heifers fed yearly</td>
<td>146</td>
<td>0-375</td>
</tr>
<tr>
<td>Number of bulls fed yearly</td>
<td>179</td>
<td>0-1,250</td>
</tr>
<tr>
<td>Cost per ACF</td>
<td>$17,302</td>
<td>$1,800-$28,000</td>
</tr>
<tr>
<td>Cost of ACF facilities</td>
<td>$56,643</td>
<td>$1,000-$240,000</td>
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<tr>
<td>Monthly costs associated with ACF</td>
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<td>$30-$100</td>
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<tr>
<td>Labor Management</td>
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<tr>
<td>Labor for calves transitioning to ACF</td>
<td>1 hr.</td>
<td>0-2 hrs.</td>
</tr>
<tr>
<td>Labor for calves in ACF</td>
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<td>0.5-8 hrs.</td>
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<tr>
<td>Reduced hours of labor</td>
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<td>0-4 hrs.</td>
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<tr>
<td>Increased hours for records Mgt.</td>
<td>0.44 hr.</td>
<td>0-1 hr.</td>
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<tr>
<td>Calf Health &amp; Management</td>
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<tr>
<td>Square feet per calf</td>
<td>34 sq. ft</td>
<td>12-63 sq. ft</td>
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<tr>
<td>Calves per nipple station</td>
<td>21</td>
<td>15-27</td>
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<tr>
<td>Mortality</td>
<td>3%</td>
<td>1%-10%</td>
</tr>
<tr>
<td>Morbidity (Scours)</td>
<td>14%</td>
<td>0-80%</td>
</tr>
<tr>
<td>Morbidity (Respiratory)</td>
<td>14%</td>
<td>0-50%</td>
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<tr>
<td>Average Daily Gain</td>
<td>2.3 lbs./day</td>
<td>1.25-3.5 lbs./day</td>
</tr>
<tr>
<td>Weaning Age-heifers</td>
<td>56 days</td>
<td>45-77 days</td>
</tr>
<tr>
<td>Weaning Age-bulls</td>
<td>49 days</td>
<td>40 days</td>
</tr>
</tbody>
</table>

**Challenges with Automatic Calf Feeder**

Main challenges encountered with the ACF included learning the software and ID system, developing a feeding plan to control behavioral issues, and mechanical issues such as an occasional plug or sensor not working, replacing a small pump yearly, keeping system clean, and compatibility issues with pasteurizer system. Respiratory and facility ventilation were main challenges of moving calves to a group housing system.
Reasons for installing Automatic Calf Feeding System
The top reasons producers installed ACF in rank order:

1. **Labor efficiency**
   Focus labor more on management of calves rather than physical labor and flexibility of feeding schedule

2. **Calf health**
   Consistent, multiple feedings, temperature of milk always the same, increase space per calf, calf comfort

3. **New facility**
   Going to build anyways, needed more room, installed AMS for cows, and needed new project to challenge employees

**Management factors needed for success of Automatic Calf Feeder system**

The top management factors producers say key to success:

1. **Cleanliness**
   Detail oriented employees closely monitoring and cleaning of the lines, nipples, circuit, and cleanliness of calves

2. **Ventilation**
   Facility is designed with air quality being a key component of the system

3. **Management/Software**
   Software is invaluable, pays for itself, and worth the cost to catch sick calves earlier; watching calves is still important

**Summary**

Producer surveys showed success in switching from previous calf feeding systems to ACF systems. Although labor was not always reduced, physical labor was exchanged for management labor. Learning curves for software technology and facility management were noted, however feeding and housing efficiencies were gained. In sum, automatic calf feeders added value to quality of life and labor efficiency over previous system.
Automated Calf Feeder Study Update

Marcia I. Endres
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Research is very limited regarding best housing and management practices for automated calf feeding systems, particularly in terms of how these factors influence animal health and welfare. This ongoing study is characterizing health scores, morbidity and mortality of group-housed calves in US farms and relating these to housing and management practices. In addition, feeding behavior recorded daily by feeder software is being collected and will be used to characterize behavior at each farm and how behavior correlates with management practices and calf health.

The study involves visiting 38 dairy farms in MN, WI, and IA every 60 days for a total of 8 visits per farm. During each visit, calves (n=9,080 at the time of writing) are scored for health using four categories: attitude (0-4); ears (0-4); nose (0-3); eyes (0-3); and cleanliness (an indicator of diarrhea, 0-2), with 0 representing a normal, healthy calf. In addition, blood is drawn from any calves 1-5 days old (n=884 at time of writing) and serum protein concentration used to assess passive immunity transfer. During each season, milk samples are collected from the mixing container inside the feeder and the tube leading to the nipple for measurement of standard plate count (SPC) and coliform count. Pearson’s correlation coefficient was used to analyze the relationship between mean SPC and health scores.

We have preliminary results for 7 visits at the time of writing. There was a large variation between farms in calf health. On the 10 farms with the best health scores, a mean of 9.9% (range of 2.5–12.3) of animals displayed abnormal scores for attitude, 3.6% (1.5-5.1) for ears, 14.1% (8.9-17.4) for nose, 8.2% (4.4-12.0) for eyes, and 28.1% (20.7-33.5) for cleanliness. On the 10 farms with the worst health scores, a mean of 23.4% (17.7-32.1) of animals displayed abnormal scores for attitude, 14.6% (10.2-21.6) for ears, 29.9% (26.7-33.8) for nose, 32.2% (24.2-40.3) for eyes, and 56.8% (51.8-61.2) for cleanliness.

Mean serum protein across all samples was 5.40 ± 0.74 mg/dl. Mean serum protein by farm was 5.34 mg/dl (minimum=4.27, maximum=6.5). The highest overall bacterial counts were recorded in feeder tube samples (median, coliform=2,550 CFU/ml; SPC=330,000 CFU/ml; SPC Q3=3,350,000). No relationship was observed between tube SPC and attitude, ears, nose, or eyes scores; however, SPC was correlated with calf cleanliness scores (r = 0.26, P = 0.002).

The variation in health scores among farms shows that welfare in automated feeder systems can be improved. In addition, results indicate that the cleanliness of automated feeder equipment may influence calf health; however, further data collection and analyses of calf morbidity and mortality should provide a more complete understanding of risk factors.

This project is supported by Agriculture and Food Research Initiative competitive grant no. 2012-67021-19280 from the USDA National Institute of Food and Agriculture.
Can Amino Acid Supplementation Improve Use of Non-Milk Proteins in Milk Replacers?

James K. Drackley
Professor of Animal Sciences
University of Illinois
at Urbana-Champaign

Can amino acid supplementation improve use of non-milk proteins in milk replacers?

James K. Drackley
Professor of Animal Sciences
University of Illinois
at Urbana-Champaign

“Milk replacer”: an oxymoron?

• Primary ingredients:
  – Dried skim milk (originally; now little used in USA)
  – Whey
  – Whey protein concentrate
  – Delactosed whey

• In other words, lactose and milk proteins

Will cheese become a byproduct of whey production?

The brutal facts:

• Calves are born with the digestive machinery to use milk, and only milk, as their source of nutrients.

• Not starch or sucrose; not soy or wheat proteins, not not not not!!!

• Ability to use non-milk ingredients develops over the first 3 wk

• Greatest changes in the first 7 d of life?
Alternate (non-milk) proteins?

- A long-sought goal of milk replacer manufacturers: lower cost than milk proteins.
- Non-milk proteins generally reduce growth in calves less than 3 wk old.
- Biology discourages use of non-milk proteins for calves < ~3 wk old.

Potential problems with non-milk proteins in milk replacers if digestive function in immature

- Digestive upsets
- Decreased growth

Why lower growth? (Even in assumed absence of anti-nutritional factors)

- Decreased digestibility?
- Slower digestion, asynchrony with energy availability?
- Low energy intake (energy requirement for increased endogenous secretions)?
- Residual non-starch polysaccharide content?

Effects of processing on anti-nutritional factors in soybean proteins

<table>
<thead>
<tr>
<th>Anti-nutritive factor</th>
<th>Defatted</th>
<th>SBM/SBF</th>
<th>SPC</th>
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</thead>
<tbody>
<tr>
<td>Trypsin inhibitor, mg/g</td>
<td>15-60</td>
<td>6-8</td>
<td>2-6</td>
</tr>
<tr>
<td>Glycinin, mg/g</td>
<td>250–300</td>
<td>20–40</td>
<td>0-35</td>
</tr>
<tr>
<td>β-Conglycinin, ppm</td>
<td>150-200</td>
<td>15-35</td>
<td>0-25</td>
</tr>
<tr>
<td>Lectin, ppm</td>
<td>15</td>
<td>0-0.6</td>
<td>0-0.002</td>
</tr>
<tr>
<td>Mannans, %DM</td>
<td>1.2–1.3</td>
<td>1.1-1.2</td>
<td>0.97-1.1*</td>
</tr>
</tbody>
</table>

*Hot aqueous ethanol treatment (SPC) does not decrease mannan content.

SPC did not decrease performance or health at high milk feeding rate

- SPC replaced 50% of milk protein in 28% CP replacer fed at 1.0 to 1.5 kg DM daily
- All essential AA and minerals/osmolarity equalized
- ADG d 1-35 were 1.01 and 0.96 kg/d for all milk and SPC, respectively

Nabté-Solís and Van Amburgh
Why lower growth? (Even in assumed absence of anti-nutritional factors)

- Decreased digestibility?
- Slower digestion, asynchrony with energy availability?
- Low energy intake (energy requirement for increased endogenous secretions)?
- Residual non-starch polysaccharide content?
- Non-optimal amino acid balance?

Proposed AA profiles (relative to lysine)

<table>
<thead>
<tr>
<th></th>
<th>Cows' milk</th>
<th>Williams</th>
<th>Labussiere</th>
<th>Van Amburgh (MVA)</th>
</tr>
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<tbody>
<tr>
<td>Lys</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Met</td>
<td>32</td>
<td>27</td>
<td>--</td>
<td>29</td>
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<tr>
<td>Thr</td>
<td>56</td>
<td>63</td>
<td>66</td>
<td>62</td>
</tr>
<tr>
<td>Val</td>
<td>80</td>
<td>62</td>
<td>74</td>
<td>69</td>
</tr>
<tr>
<td>Ile</td>
<td>66</td>
<td>44</td>
<td>61</td>
<td>47</td>
</tr>
<tr>
<td>Leu</td>
<td>126</td>
<td>108</td>
<td>103</td>
<td>111</td>
</tr>
<tr>
<td>Phe</td>
<td>62</td>
<td>56</td>
<td>--</td>
<td>58</td>
</tr>
<tr>
<td>His</td>
<td>47</td>
<td>38</td>
<td>46</td>
<td>39</td>
</tr>
<tr>
<td>Trp</td>
<td>16</td>
<td>13</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Phe+Tyr</td>
<td>124</td>
<td>95</td>
<td>97</td>
<td>99</td>
</tr>
<tr>
<td>Met+Cys</td>
<td>44</td>
<td>47</td>
<td>55</td>
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</table>

Amino acid balancing – toward the “ideal protein” concept

<table>
<thead>
<tr>
<th></th>
<th>MVA ideal</th>
<th>WPC</th>
<th>50:25:25 WPC+MWP+PP</th>
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</thead>
<tbody>
<tr>
<td>Threonine</td>
<td>62</td>
<td>66</td>
<td>76</td>
</tr>
<tr>
<td>Valine</td>
<td>69</td>
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<td>69</td>
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<tr>
<td>Methionine</td>
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<tr>
<td>Cysteine</td>
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<td>Isoleucine</td>
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<tr>
<td>Phenylalanine</td>
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<tr>
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<td>100</td>
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<td>Histidine</td>
<td>39</td>
<td>21</td>
<td>33</td>
</tr>
<tr>
<td>Arginine</td>
<td>106</td>
<td>27</td>
<td>49</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>18</td>
<td>20</td>
<td>22</td>
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</tbody>
</table>

WPC = whey protein concentrate; MWP = modified wheat protein; PP = plasma protein

Amino acid balance of milk replacers:
Research at University of Illinois

Project 1

- Can the Amino Acid Profile of Whey Protein-Based Milk Replacers Be Improved for Growth in Dairy Calves?

Morgan et al., unpublished

Objectives

- 1. To compare the AA profile of current whey-protein based product to a profile based on proposed “ideal” for calves.
- 2. To determine whether additional arginine promotes calf growth.
- 3. To compare growth at two lysine concentrations with other amino acids balance to same profile
Experimental Diets

A. Standard whey profile (control)
B. Control plus AA to “ideal”
C. Control plus AA to “ideal but without supplemental Arg
D. As 2 but with lower Lys content

10 calves (5 male, 5 female) born at U of I dairy per treatment. Milk replacers only from d 3 to d 35; starter introduced at d 36. Calves on trial through d 56.

Formulated AA content (%)

<table>
<thead>
<tr>
<th>EAA</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Met</td>
<td>0.54</td>
<td>0.76</td>
<td>0.76</td>
<td>0.66</td>
</tr>
<tr>
<td>Cys</td>
<td>0.78</td>
<td>0.79</td>
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<tr>
<td>Lys</td>
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<td>2.61</td>
<td>2.61</td>
<td>2.25</td>
</tr>
<tr>
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<td>1.61</td>
</tr>
<tr>
<td>Val</td>
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Formulated ratios

<table>
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<tr>
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<th>A</th>
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<td>Trp</td>
<td>18</td>
<td>16</td>
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</table>

Analyzed AA content (%)

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<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<tbody>
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<td>0.81</td>
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<td>0.53</td>
</tr>
<tr>
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<td>0.59</td>
<td>0.60</td>
<td>0.53</td>
</tr>
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<td>2.44</td>
<td>2.43</td>
<td>2.18</td>
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<td>Thr</td>
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<td>1.68</td>
<td>1.75</td>
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</tr>
<tr>
<td>Val</td>
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<td>1.83</td>
<td>1.76</td>
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</tr>
<tr>
<td>Ile</td>
<td>1.64</td>
<td>1.70</td>
<td>1.71</td>
<td>1.50</td>
</tr>
<tr>
<td>Leu</td>
<td>2.71</td>
<td>2.88</td>
<td>2.92</td>
<td>2.54</td>
</tr>
<tr>
<td>Tyr</td>
<td>0.72</td>
<td>0.74</td>
<td>0.76</td>
<td>0.65</td>
</tr>
<tr>
<td>Phe</td>
<td>0.86</td>
<td>1.49</td>
<td>1.53</td>
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<td>0.51</td>
<td>1.07</td>
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<td>Arg</td>
<td>0.67</td>
<td>1.89</td>
<td>0.78</td>
<td>1.97</td>
</tr>
<tr>
<td>Trp</td>
<td>0.48</td>
<td>0.56</td>
<td>0.56</td>
<td>0.49</td>
</tr>
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</table>

Calf BW tended to be affected by dietary AA balance

Diet P = 0.09
Summary: With whey protein-based milk replacers...

1. Balancing full profile of AA tended (NS) to improve early growth.
2. Supplemental arginine did not improve calf growth.
3. Calf growth responded directly to dietary lysine content.

Objectives

• To determine if AA balance limits growth in calves fed milk protein-based milk replacer
• To determine the effect of increasing amounts of hydrolyzed wheat protein (HWP) when AA are balanced equivalent to milk protein
• To determine the effect of amount of AA supplementation for milk replacer containing a high level of HWP

Milk replacer formulations

• Milk replacers were formulated to contain 28.5% CP, 2.6% lysine, and 15% fat
• All diets contained ~36% skim milk protein
  • Hydrolyzed wheat protein (HWP; Nutrior, Chamtor) replaced whey proteins from whey protein concentrate
  • Addition of HWP at 4.5% and 9.0% of formula (plus AA) provided ~6% and 12% non-milk protein and replaced ~21% and 42% of milk protein
• Fat was provided from tallow and lard

AA formulation strategy

<table>
<thead>
<tr>
<th></th>
<th>MVA Ideal</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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<tbody>
<tr>
<td>Lys</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Met</td>
<td>29</td>
<td>25</td>
<td>36</td>
<td>39</td>
<td>41</td>
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</tr>
<tr>
<td>Thr</td>
<td>62</td>
<td>67</td>
<td>64</td>
<td>62</td>
<td>62</td>
<td>62</td>
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<td>Val</td>
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<td>69</td>
<td>69</td>
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<tr>
<td>Leu</td>
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<td>113</td>
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<td>Phe</td>
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<td>42</td>
<td>58</td>
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<td>58</td>
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<td>His</td>
<td>39</td>
<td>26</td>
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<td>39</td>
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<td></td>
</tr>
<tr>
<td>Trp</td>
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<td>19</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Phe+Tyr</td>
<td>99</td>
<td>82</td>
<td>96</td>
<td>96</td>
<td>96</td>
<td>85</td>
</tr>
<tr>
<td>Met+Cys</td>
<td>55</td>
<td>45</td>
<td>55</td>
<td>55</td>
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</tbody>
</table>

Project 2

• Protein source and amino acid balance for dairy calves fed milk replacer

Hwang et al., 2013
Milk replacer composition

<table>
<thead>
<tr>
<th>Component</th>
<th>A (%)</th>
<th>B (%)</th>
<th>C (%)</th>
<th>D (%)</th>
<th>E (%)</th>
<th>SE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>96.8</td>
<td>96.9</td>
<td>97.0</td>
<td>96.9</td>
<td>96.6</td>
<td>0.13</td>
</tr>
<tr>
<td>CP</td>
<td>28.7</td>
<td>29.0</td>
<td>28.8</td>
<td>29.2</td>
<td>28.8</td>
<td>0.17</td>
</tr>
<tr>
<td>Fat</td>
<td>16.1</td>
<td>15.5</td>
<td>16.0</td>
<td>15.8</td>
<td>16.5</td>
<td>0.54</td>
</tr>
<tr>
<td>Ash</td>
<td>8.2</td>
<td>7.7</td>
<td>7.8</td>
<td>7.8</td>
<td>7.7</td>
<td>0.04</td>
</tr>
<tr>
<td>Lys</td>
<td>2.59AB</td>
<td>2.62A</td>
<td>2.57AB</td>
<td>2.32B</td>
<td>2.32B</td>
<td>0.06</td>
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</table>

Mean intake and efficiency across wk 1-8

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<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>SE</th>
<th>T</th>
<th>T*W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk DMI (kg/d)</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
<td>0.84</td>
<td>0.003</td>
<td>0.056</td>
<td>0.44</td>
</tr>
<tr>
<td>Grain DMI (kg/d)</td>
<td>1.13</td>
<td>0.94</td>
<td>1.06</td>
<td>0.99</td>
<td>0.85</td>
<td>0.07</td>
<td>0.052</td>
<td>0.69</td>
</tr>
<tr>
<td>Gain:Feed (kg:kg)</td>
<td>0.69</td>
<td>0.81</td>
<td>0.59</td>
<td>0.57</td>
<td>0.56</td>
<td>0.02</td>
<td>0.50</td>
<td>0.30</td>
</tr>
<tr>
<td>Gain:Lysine (g/g), wk 1-4</td>
<td>28.6</td>
<td>28.7</td>
<td>29.1</td>
<td>29.3</td>
<td>27.5</td>
<td>1.38</td>
<td>0.90</td>
<td>0.63</td>
</tr>
<tr>
<td>Total DMI (kg/d)</td>
<td>1.21</td>
<td>1.14</td>
<td>1.17</td>
<td>1.17</td>
<td>1.08</td>
<td>0.02</td>
<td>0.001</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Summary

- Addition of essential AA to a skim milk-based milk replacer did not improve growth.
- Based on Lys intake, inclusion of 4.5% and 9% HWP in milk replacer did not significantly decrease ADG when AA were balanced.
- Although not conclusive, possible limiting AA beyond Lys, Met, and Thr in wheat protein should be investigated.

Mean growth across wk 1-8

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>SE</th>
<th>T</th>
<th>T*W</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW (kg)</td>
<td>61.4</td>
<td>61.6</td>
<td>61.5</td>
<td>60.1</td>
<td>59.5</td>
<td>0.57</td>
<td>0.03</td>
<td>0.68</td>
</tr>
<tr>
<td>Heart Girth (cm)</td>
<td>92.5</td>
<td>92.8</td>
<td>92.2</td>
<td>91.5</td>
<td>91.1</td>
<td>0.40</td>
<td>0.01</td>
<td>0.29</td>
</tr>
<tr>
<td>Withers Height (cm)</td>
<td>84.7</td>
<td>85.1</td>
<td>84.7</td>
<td>84.5</td>
<td>84.1</td>
<td>0.39</td>
<td>0.42</td>
<td>0.76</td>
</tr>
<tr>
<td>Hip Width (cm)</td>
<td>19.8</td>
<td>19.9</td>
<td>20.2</td>
<td>19.8</td>
<td>19.8</td>
<td>0.13</td>
<td>0.08</td>
<td>0.91</td>
</tr>
<tr>
<td>ADG (kg/d)</td>
<td>0.65</td>
<td>0.66</td>
<td>0.66</td>
<td>0.63</td>
<td>0.61</td>
<td>0.02</td>
<td>0.44</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Thank you
Real Herds...Real Heifers:
The Cost of Raising Heifers

Mark Hagedorn, Agriculture Agent
UW-Extension Eau Claire County
(715) 839-4712
mark.hagedorn@ces.uwex.edu

Contributions by:
Laurynn Vanderwerff, Scott Gunderson, Tina Kohlman & Pat Hoffman
University of Wisconsin-Extension

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- An analysis system that calculates producer-specific costs and labor efficiencies associated with raising dairy replacements
- Evaluates cost and labor efficiencies
- Provides economic and labor efficiency benchmarks for dairy herd replacements

---

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Steve Okonek
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Ryan Sterry
Sandy Stutgen
Trisha Wagner
Katie Wantoch

1Center for Dairy Profitability, University of Wisconsin-Madison
2Biological Systems Engineering, University of Wisconsin-Madison

---

2013 ICPA Project

- 36 Wisconsin operations
  - Tie-stall operations
  - Free-stall operations
  - Custom calf and/or heifer grower operations
- 12 different counties
- Two enterprises
  - Calf
  - Heifer

---
Calf Enterprise

- Calf - An animal raised from birth until she is moved to group housing
- 30 operations evaluated
  - 12 tie-stall operations
  - 13 free-stall operations
  - 5 custom calf growers
- Feeding, management, housing and labor data was collected

Cost of Raising a Calf in Wisconsin*

<table>
<thead>
<tr>
<th></th>
<th>1999</th>
<th>2007</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cost</td>
<td>$160.26</td>
<td>$326.07</td>
<td>$363.69</td>
</tr>
<tr>
<td>Daily Cost</td>
<td>$2.68</td>
<td>$5.31</td>
<td>$5.34</td>
</tr>
<tr>
<td>Days on Feed</td>
<td>59.7</td>
<td>61.36</td>
<td>68.6</td>
</tr>
<tr>
<td>Weaning Age (weeks)</td>
<td>7.4</td>
<td>7.04</td>
<td>7.61</td>
</tr>
</tbody>
</table>

*Does not include $150 calf value

Key Assumptions

<table>
<thead>
<tr>
<th>Item</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calf value</td>
<td>$150 per calf</td>
</tr>
<tr>
<td>Labor (paid and unpaid)</td>
<td>$13 per hour</td>
</tr>
<tr>
<td>Management (paid and unpaid)</td>
<td>$22 per hour</td>
</tr>
<tr>
<td>Interest rate</td>
<td>4.5 percent</td>
</tr>
<tr>
<td>Pasteurized Waste Milk</td>
<td>$5 per cwt</td>
</tr>
<tr>
<td>Replacement value of calf housing</td>
<td>$200</td>
</tr>
<tr>
<td>Homemade calf hutch</td>
<td>$200</td>
</tr>
<tr>
<td>Purchased calf hutch</td>
<td>$400</td>
</tr>
<tr>
<td>Greenhouse barn</td>
<td>$10 per square foot</td>
</tr>
<tr>
<td>Post-Frame calf barn</td>
<td>$15.50 per square foot</td>
</tr>
</tbody>
</table>

Comparison of Daily Calf Raising Costs*

*Does not include $150 calf value

Calf Cost Centers (also applicable for Heifers)

- Feed Costs
- Labor and Management
- Other Variable Costs
  - Bedding
  - Veterinary
  - Death loss
  - Interest
- Fixed Costs
  - Buildings
  - Equipment
Cost Per Day To Raise A Calf

<table>
<thead>
<tr>
<th></th>
<th>Tie-Stall</th>
<th>Free-Stall</th>
<th>Grower</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Costs</td>
<td>$2.44</td>
<td>$2.36</td>
<td>$2.00</td>
<td>$2.37</td>
</tr>
<tr>
<td>Labor &amp; Management</td>
<td>$2.29</td>
<td>$2.07</td>
<td>$0.96</td>
<td>$1.99</td>
</tr>
<tr>
<td>Other Variable Costs</td>
<td>$0.54</td>
<td>$0.66</td>
<td>$0.63</td>
<td>$0.64</td>
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<tr>
<td>Fixed Costs</td>
<td>$0.21</td>
<td>$0.50</td>
<td>$0.21</td>
<td>$0.35</td>
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<tr>
<td>Total Cost</td>
<td>$5.48</td>
<td>$5.59</td>
<td>$3.81</td>
<td>$5.34</td>
</tr>
</tbody>
</table>

*Does not include $150 calf value

Take Home Message(s)

- Calf starter prices tripled between 2007 and 2013.
- Due to increases in labor and management efficiency, labor and management costs to raise dairy calves decreased.

Comparison of Calf Raising Costs 1999 vs 2007 vs 2013

Heifer Enterprise

Heifer - An animal raised in group housing to time of freshening, or in the case of the custom heifer grower, the time the heifer is returned to the producer. Feeding, management, housing and labor data was collected.

Take Home Message(s)

- Almost all custom calf raisers used pasteurized milk instead of milk replacer. As a result, across all herds the cost of liquid feed fed to dairy calves only increased 9.3% between 2007 and 2013.

Key Assumptions...

<table>
<thead>
<tr>
<th>Item</th>
<th>Defined Inputs</th>
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</thead>
<tbody>
<tr>
<td>Feed Costs:</td>
<td></td>
</tr>
<tr>
<td>Legume Silage</td>
<td>$200 per ton DM</td>
</tr>
<tr>
<td>Corn Silage</td>
<td>$140 per ton DM</td>
</tr>
<tr>
<td>Corn</td>
<td>$250 per ton DM</td>
</tr>
<tr>
<td>Weigh-backs</td>
<td>$150 per ton DM</td>
</tr>
<tr>
<td>Soybean Meal</td>
<td>$375 per ton DM</td>
</tr>
<tr>
<td>Labor</td>
<td>$13.00 per hour</td>
</tr>
<tr>
<td>Management</td>
<td>$22.00 per hour</td>
</tr>
<tr>
<td>Interest rate</td>
<td>4.5%</td>
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</table>
Replacement Value of Heifer Facilities

<table>
<thead>
<tr>
<th>Item</th>
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<tbody>
<tr>
<td>Bedded Pack Barn</td>
<td>$18.50 per square foot</td>
</tr>
<tr>
<td>Freestall Barn</td>
<td>$20 per square foot</td>
</tr>
<tr>
<td>Mound System or Dirt Lot</td>
<td>$0.10 per square foot</td>
</tr>
<tr>
<td>Concrete Lot</td>
<td>$3 per square foot</td>
</tr>
</tbody>
</table>

32 operations evaluated
- 12 tie-stall operations
- 13 free-stall operations
- 7 custom heifer growers

Feeding, management, housing...

Comparison of Daily Heifer Raising Costs*

<table>
<thead>
<tr>
<th>Year</th>
<th>Tie Stall</th>
<th>Freestall</th>
<th>Grower</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>$1.66</td>
<td>$1.83</td>
<td>$1.55</td>
<td>$1.71</td>
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<tr>
<td>2007</td>
<td>$0.66</td>
<td>$0.51</td>
<td>$0.39</td>
<td>$0.54</td>
</tr>
<tr>
<td>2013</td>
<td>$0.46</td>
<td>$0.49</td>
<td>$0.35</td>
<td>$0.44</td>
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</tbody>
</table>

Cost Per Day To Raise A Heifer

<table>
<thead>
<tr>
<th>Item</th>
<th>1999</th>
<th>2007</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cost</td>
<td>$1099.12</td>
<td>$1322.70</td>
<td>$1863.19</td>
</tr>
<tr>
<td>Daily Cost</td>
<td>$1.61</td>
<td>$2.04</td>
<td>$3.04</td>
</tr>
<tr>
<td>Days on Feed</td>
<td>683</td>
<td>648</td>
<td>628</td>
</tr>
</tbody>
</table>
Take Home Message(s)

- Custom heifer growers do not typically raise dairy heifers to calving thus total days on feed are less for heifers raised on custom heifer rearing operations.
- The cost of semen and breeding services are sometimes paid by the owner therefore breeding cost may be artificially low.

Total Cost to Raise a Dairy Replacement from Birth to Freshening

<table>
<thead>
<tr>
<th></th>
<th>1999</th>
<th>2007</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cost</td>
<td>$1259.38</td>
<td>$1648.77</td>
<td>$2226.88</td>
</tr>
<tr>
<td>Days on Feed</td>
<td>743</td>
<td>709</td>
<td>696</td>
</tr>
<tr>
<td>Calving Age (months)</td>
<td>24.6</td>
<td>23.9</td>
<td>23.4</td>
</tr>
</tbody>
</table>

*Does not include $150 calf value.

The total cost to raise a dairy replacement from birth to calving on Wisconsin dairy and custom calf and heifer operations (not counting the opportunity cost of the calf) has increased approximately $600 from 2007 to 2013.

The majority of the increase is due to increased feed and labor costs.

For more information please refer to:

ICPA Information Website

tinyurl.com/kgd2npy
Wisconsin Cost of Raising Dairy Replacements Survey Results

Mark Hagedorn, Agriculture Agent
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  - Calf
  - Heifer

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<tr>
<td>Weaning Age (weeks)</td>
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<td>7.04</td>
<td>7.61</td>
</tr>
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</table>

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<tr>
<td>Interest rate</td>
<td>4.5 percent</td>
</tr>
<tr>
<td>Pasteurized Waste Milk</td>
<td>$5 per cwt</td>
</tr>
<tr>
<td>Replacement value of calf housing</td>
<td></td>
</tr>
<tr>
<td>Homemade calf hutch</td>
<td>$200</td>
</tr>
<tr>
<td>Purchased calf hutch</td>
<td>$400</td>
</tr>
<tr>
<td>Greenhouse barn</td>
<td>$10 per square foot</td>
</tr>
<tr>
<td>Post-Frame calf barn</td>
<td>$15.50 per square foot</td>
</tr>
</tbody>
</table>

*Does not include $150 calf value

Calf Cost Centers (also applicable for Heifers)

- Feed Costs
  - Labor and Management
  - Other Variable Costs
    - Bedding
    - Veterinary
    - Death loss
    - Interest
  - Fixed Costs
    - Buildings
    - Equipment
Cost Per Day To Raise A Calf

<table>
<thead>
<tr>
<th>Calf Cost per Day*</th>
<th>Tie-Stall</th>
<th>Free-Stall</th>
<th>Grower</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Costs</td>
<td>$2.44</td>
<td>$2.36</td>
<td>$2.00</td>
<td>$2.37</td>
</tr>
<tr>
<td>Labor &amp; Management</td>
<td>$2.29</td>
<td>$2.07</td>
<td>$0.96</td>
<td>$1.99</td>
</tr>
<tr>
<td>Other Variable Costs</td>
<td>$0.54</td>
<td>$0.66</td>
<td>$0.63</td>
<td>$0.64</td>
</tr>
<tr>
<td>Fixed Costs</td>
<td>$0.21</td>
<td>$0.50</td>
<td>$0.21</td>
<td>$0.35</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$5.48</td>
<td>$5.59</td>
<td>$3.81</td>
<td>$5.34</td>
</tr>
</tbody>
</table>

*Does not include $150 calf value

Comparison of Calf Raising Costs
1999 vs 2007 vs 2013

Take Home Message(s)

- Calf starter prices tripled between 2007 and 2013.
- Due to increases in labor and management efficiency, labor and management costs to raise dairy calves decreased.

Heifer Enterprise

Heifer - An animal raised in group housing to time of freshening, or in the case of the custom heifer grower, the time the heifer is returned to the producer.
Feeding, management, housing and labor data was collected.

Key Assumptions...

<table>
<thead>
<tr>
<th>Item</th>
<th>Defined Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Costs:</td>
<td></td>
</tr>
<tr>
<td>Legume Silage</td>
<td>$200 per ton DM</td>
</tr>
<tr>
<td>Corn Silage</td>
<td>$140 per ton DM</td>
</tr>
<tr>
<td>Corn</td>
<td>$250 per ton DM</td>
</tr>
<tr>
<td>Weigh-backs</td>
<td>$150 per ton DM</td>
</tr>
<tr>
<td>Soybean Meal</td>
<td>$375 per ton DM</td>
</tr>
<tr>
<td>Labor</td>
<td>$13.00 per hour</td>
</tr>
<tr>
<td>Management</td>
<td>$22.00 per hour</td>
</tr>
<tr>
<td>Interest rate</td>
<td>4.5%</td>
</tr>
</tbody>
</table>
Replacement Value of Heifer Facilities

<table>
<thead>
<tr>
<th>Item</th>
<th>Replacement Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedded Pack Barn</td>
<td>$18.50 per square foot</td>
</tr>
<tr>
<td>Freestall Barn</td>
<td>$20 per square foot</td>
</tr>
<tr>
<td>Mound System or Dirt Lot</td>
<td>$0.10 per square foot</td>
</tr>
<tr>
<td>Concrete Lot</td>
<td>$3 per square foot</td>
</tr>
</tbody>
</table>

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About the operations...

32 operations evaluated
- 12 tie-stall operations
- 13 free-stall operations
- 7 custom heifer growers
- Feeding, management, housing

Cost of Raising a Heifer in Wisconsin*

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Cost</th>
<th>Daily Cost</th>
<th>Days on Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>$1099.12</td>
<td>$1.61</td>
<td>683</td>
</tr>
<tr>
<td>2007</td>
<td>$1322.70</td>
<td>$2.04</td>
<td>648</td>
</tr>
<tr>
<td>2013</td>
<td>$1863.19</td>
<td>$3.04</td>
<td>628</td>
</tr>
</tbody>
</table>

*Does not include $150 calf value

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Comparison of Daily Heifer Raising Costs*

<table>
<thead>
<tr>
<th>Year</th>
<th>Feed Costs</th>
<th>Labor &amp; Management</th>
<th>Other Variable Costs</th>
<th>Fixed Costs</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>$1.66</td>
<td>$0.66</td>
<td>$0.46</td>
<td>$0.42</td>
<td>$3.20</td>
</tr>
<tr>
<td>2007</td>
<td>$1.83</td>
<td>$0.51</td>
<td>$0.49</td>
<td>$0.33</td>
<td>$3.15</td>
</tr>
<tr>
<td>2013</td>
<td>$1.55</td>
<td>$0.39</td>
<td>$0.35</td>
<td>$0.29</td>
<td>$2.57</td>
</tr>
</tbody>
</table>

Heifer Cost per Day*

<table>
<thead>
<tr>
<th></th>
<th>Tiestall</th>
<th>Freestall</th>
<th>Grower</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Costs</td>
<td>$1.66</td>
<td>$1.83</td>
<td>$1.55</td>
<td>$1.71</td>
</tr>
<tr>
<td>Labor &amp; Management</td>
<td>$0.66</td>
<td>$0.51</td>
<td>$0.39</td>
<td>$0.54</td>
</tr>
<tr>
<td>Other Variable Costs</td>
<td>$0.46</td>
<td>$0.49</td>
<td>$0.35</td>
<td>$0.44</td>
</tr>
<tr>
<td>Fixed Costs</td>
<td>$0.42</td>
<td>$0.33</td>
<td>$0.29</td>
<td>$0.35</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$3.20</td>
<td>$3.15</td>
<td>$2.57</td>
<td>$3.04</td>
</tr>
</tbody>
</table>

*Does not include $150 calf value

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Take Home Message(s)

- Custom heifer growers do not typically raise dairy heifers to calving thus total days on feed are less for heifers raised on custom heifer rearing operations.
- The cost of semen and breeding services are sometimes paid by the owner therefore breeding cost may be artificially low.

<table>
<thead>
<tr>
<th></th>
<th>1999</th>
<th>2007</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cost</td>
<td>$1259.38</td>
<td>$1648.77</td>
<td>$2226.88</td>
</tr>
<tr>
<td>Days on Feed</td>
<td>743</td>
<td>709</td>
<td>696</td>
</tr>
<tr>
<td>Calving Age (months)</td>
<td>24.6</td>
<td>23.9</td>
<td>23.4</td>
</tr>
</tbody>
</table>

*Does not include $150 calf value.

For more information please refer to:
ICPA Information Website
tinyurl.com/kgd2npy
Effect of Close-up Dry Period Stocking Density on Behavior and Health of Dairy Cows

Marcia Endres1, Ricardo Chebel2, Karen Lobeck-Luchterhand1 and Paula Basso Silva1,2
1Department of Animal Science, University of Minnesota, St. Paul, miendres@umn.edu
2Department of Veterinary Population Medicine, University of Minnesota, St. Paul

Introduction

In spite of the advancements made in transition cow nutrition and management, many herds still have challenges during this critical period in the life of a dairy cow. Dairy cows are genetically driven to produce large amounts of milk in early lactation, and most cows will be in a state of negative energy balance during that time. Anything that affects the cow negatively, such as poor nutrition, housing or management, will exacerbate transition problems experienced by that cow. We have learned of the importance of cow comfort to improve health and productivity in our dairy herds. During the critical transition period, that is even more important.

What has been recommended about stocking density during the close-up dry period? In a study designed to evaluate the effects of a dietary supplement on productive and health parameters of prepartum cows and heifers housed together, it was observed that for every 10 percentage unit increase in stocking density above 80% of headlocks there was a 1.5 lb/day decrease in milk yield among first lactation cows (Oetzel et al., 2007). Based on this and a small number of other studies, a common industry recommendation is to limit stocking density for close-up cows to 80% stocking density and to provide 30 inches of feed-bunk space per cow.

Stocking Density Study

We hypothesized that increasing prepartum stocking density would affect behavior and metabolic parameters and consequently affect health and performance of dairy cows in early lactation. The objectives of our study were to determine the effect of increasing prepartum stocking density from 80% (80SD) to 100% (100SD) of headlocks on the day of regrouping on behavior, metabolic, health, reproductive, and productive parameters of dairy cows.

The study was conducted at a large commercial Jersey dairy farm (6,400 lactating cows) in south-central Minnesota. We used a total of 728 animals allocated to the two treatments: 324 animals (141 first-calf heifers – pregnant for the first time and 183 cows – pregnant for their 2nd or greater lactation) for the 80SD treatment and 404 animals (173 first-calf heifers, 231 cows) for the 100SD treatment. First-calf heifers and cows were housed in separate pens, so there was no comingling of younger and older animals. Treatments were repeated 4 times with 2 pens per replication and a total of 8 pens per treatment.

Displacements from the feed bunk (indication of agonistic social behavior) were measured for 3 hours after fresh feed delivery on days 2, 5, and 7 of each week of the 5-week rep (when cows were not locked up by farm or research personnel). From continuous video observation, an interaction between two cows was considered a displacement from the feed bunk when physical contact initiated by one cow caused the receiving cow to stop feeding, back out and entirely remove her head from the headlock (Endres et al., 2005). Displacements from the feed bunk were summed daily for the entire 5-week observation period. Feeding behavior (time spent eating per day) was measured using 10-min video scan sampling for 24-hour periods on days 2, 5 and 7 on the first week of every rep and days 2 and 5 for the following 4 weeks. Lying behavior (time spent resting per day and number of lying bouts and their duration) was measured on a group of 297 focal cows using data loggers (Hobo G-pendant, Onset Corp) that record cow position every 30 seconds for 11 consecutive days. Loggers were attached to the rear leg of the cow on the first day after entrance to the pen and were left on for 12 days, removed for 7 days and reattached for 12 days or until the cow calved.

When cows demonstrated signs of calving, farm personnel moved the cows to an individual box stall. Video observation and use of data loggers for the behavior portion of the study ceased when the cows left the dry period treatment pens. At day 1 post-calving, cows were moved into a freestall pen with 240 stalls and 260 headlocks stocked at 100% based on the number of stalls for 21 days. Plasma NEFA concentration was measured weekly from day 3 to 24 post-calving and plasma β-hydroxybutyrate (BHB) was measured weekly from day 3 to 24 post-calving. Cows were examined on days 1, 4, 7, 10 and 13 post-calving for diagnosis of...
uterine diseases, and had their ovaries scanned by ultrasound on days 39 and 53 post-calving to determine resumption of ovarian cycles.

**Results**

Daily average stocking densities based on number of headlocks (80SD = 74.1%, 100SD = 94.5%) and stalls (80SD = 80.8%, 100SD = 103.1%) were different (P < 0.01) between treatments; therefore our goal of a 20% unit difference in stocking density between treatments was achieved.

**Social behavior**

The 100SD treatment resulted in a greater number of displacements from the feedbunk than the 80SD treatment independent of parity. Cows housed in the 80D feedbunk stocking density had 15.2 ± 0.7 (LSMean ± SE) displacements per day whereas the 100D had 21.3 ± 0.7 (P < 0.01).

**Feeding behavior**

There was a treatment × parity interaction for daily feeding time (P = 0.005). Mean daily feeding times for cows 100D, cows 80D, first-calf heifers 100D and first-calf heifers 80D were 293.4 ± 5.4, 300.9 ± 6.3, 256.5 ± 6.0, and 244.6 ± 6.0 min/d, respectively. First-calf heifers at 100D stocking density spent 11.9 ± 5.1 minutes/day more eating than 80D first-calf heifers (P = 0.015); however, there were no differences between cows 80D and 100D. Cows spent 46.5 ± 7.5 minutes/day more time eating than first-calf heifers (P < 0.001).

**Lying behavior**

Stocking density had no effect on lying time per day. Both 80D and 100D animals spent 13.0 ± 0.1 hours/day lying down (LSMean ± SE; P > 0.05). There was a parity effect as first-calf heifers spent 0.4 ± 0.1 h/d less time lying down than multiparous cows (P < 0.028). A treatment × day prepartum effect was observed (Figure 1; P = 0.004): 100D had longer lying times than 80D on days -33, -29, and -26 prepartum whereas on days -7, -5 and 0 80D had longer lying times than 100D (P < 0.05).

The 80D and 100D treatments had 15.4 ± 1.1 and 14.9 ± 1.1 lying bouts/day, respectively (P > 0.05). First-calf heifers had 16.7 ± 0.5 and cows had 14.0 ± 0.5 lying bouts/day (P < 0.001). Lying bout duration did not differ between the 80D or 100D stocking density treatments (1.1 ± 0.03 hours/bout). There was a significant difference in lying bout duration between first-calf heifers and cows (P < 0.01). Lying bout duration for first-calf heifers was 0.35 ± 0.04 hours/bout less than cows (0.9 ± 0.03 and 1.3 ± 0.03 h, respectively).

**Health and Performance**

Incidences of peripartum diseases were not different between 80SD and 100SD treatments (Table 1). Similarly, incidences of DA and mastitis in the first 60 d post-calving were not affected by treatment. Percentages of cows with locomotion score > 2 at 0, 35, and 56 days post-calving were not different between treatments. Similarly, treatment did not affect the likelihood of cows being removed from the herd within 60 d post-calving. The rate at which cows in the 100SD treatment were removed from the herd [adjusted hazard ratio (AHR) (95% CI) = 1.02 (0.75, 1.38)] did not differ from that of cows in the 80SD treatment. The mean intervals from calving to removal from the herd were 258.3 days for the 80SD treatment and 262.5 days for the 100SD treatment.

The percentage of cows characterized as cyclic by 35 and 45 DIM was not different between treatments. Similarly, the likelihood of cows being inseminated in estrus and the DIM at first postpartum AI were not different between treatments. The percentage of cows diagnosed pregnant 31 and 66 days after first and second postpartum AI was not different between treatments and the incidence of pregnancy loss between 31 and 66 days after first and second postpartum AI was not different between treatments. The interval from first to second postpartum AI and the DIM at second postpartum AI were not different between 80SD and 100SD treatments. Average daily milk, fat and protein yield from calving to 155 DIM
were not different between treatments.

### Table 1. Effects of prepartum stocking density (80SD vs. 100SD) on incidence of postpartum health disorders, lameness, and removal from the herd within 60 d postpartum

<table>
<thead>
<tr>
<th>Items</th>
<th>80SD,%</th>
<th>100SD,%</th>
<th>AOR (95% CI)</th>
<th>P–value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retained fetal membranes</td>
<td>5.1</td>
<td>7.8</td>
<td>1.55 (0.78, 3.07)</td>
<td>0.19</td>
</tr>
<tr>
<td>Metritis</td>
<td>21.2</td>
<td>16.7</td>
<td>0.71 (0.46, 1.09)</td>
<td>0.11</td>
</tr>
<tr>
<td>Acute metritis</td>
<td>9.9</td>
<td>9.4</td>
<td>0.87 (0.45, 1.66)</td>
<td>0.64</td>
</tr>
<tr>
<td>Vaginal purulent discharge at 35 ± 3 DIM</td>
<td>5.8</td>
<td>7.9</td>
<td>1.41 (0.65, 3.05)</td>
<td>0.35</td>
</tr>
<tr>
<td>Mastitis up to 60 DIM</td>
<td>2.9</td>
<td>4.6</td>
<td>1.94 (0.70, 5.39)</td>
<td>0.18</td>
</tr>
<tr>
<td>DAs up to 60 DIM</td>
<td>1.0</td>
<td>0.7</td>
<td>0.76 (0.10, 5.80)</td>
<td>0.78</td>
</tr>
<tr>
<td>Locomotion score &gt; 2 at 1 ± 1 DIM</td>
<td>0.6</td>
<td>0.0</td>
<td>0.26 (0.02, 3.19)</td>
<td>0.27</td>
</tr>
<tr>
<td>Locomotion score &gt; 2 at 35 ± 3 DIM</td>
<td>3.8</td>
<td>2.6</td>
<td>0.66 (0.25, 1.75)</td>
<td>0.37</td>
</tr>
<tr>
<td>Locomotion score &gt; 2 at 56 ± 3 DIM</td>
<td>3.5</td>
<td>2.1</td>
<td>0.56 (0.12, 2.69)</td>
<td>0.44</td>
</tr>
<tr>
<td>Removed within 60 DIM</td>
<td>6.1</td>
<td>5.1</td>
<td>0.84 (0.38, 1.83)</td>
<td>0.63</td>
</tr>
</tbody>
</table>

180SD = cows housed in prepartum pens with 80% target headlock stocking density (38/48); and, 100SD = cows housed in prepartum pens with 100% target headlock stocking density (48/48).

Body condition score was not affected by treatment. Concentration of NEFA (80SD = 251.5, 100SD = 245.9 μmol/L) was not different between treatments. Similarly, concentration of BHB (80SD = 508.2, 100SD = 490.9 μmol/L) was not different between treatments.

### Conclusions

Increasing average daily stocking density by 20 percentage units (from 80 to 100%) affected behavior of prepartum animals. However, changes in behavior associated with elevated stocking density had no impact on metabolic status or health, reproductive, and productive parameters in this study with Jersey cows and twice weekly entrance of groups of animals in the close-up pen to maintain stocking density, and separation between close-up first-calf heifers (pregnant nulliparous) and 2nd and greater lactation cows (pregnant primiparous and multiparous). More research is needed with greater stocking densities and Holsteins. We still are supporting a recommendation of less than 100% stocking density in the close-up pen, to avoid potentially overcrowding this group of cows during periods of the year when larger numbers of cows are calving and the stocking density could then go higher than 100%.

### Acknowledgments

Numerous undergraduate students and interns helped with data collection. Study was partially supported by the University of Minnesota Rapid Agricultural Response Fund, Novus International, and AES-Hatch funds.

### References


Transition Cow Health: Meeting the Demands of Lactation While Maintaining a Healthy Liver

Heather White, Ph.D.
Nutritional Physiology
Department of Dairy Science
University of Wisconsin-Madison

The Rumen Makes A Difference

Dietary Nutrient Profile × Absorbed Nutrient Profile
90 - 100% of glucose is generated de novo

The Transition Dairy Cow

2014 4-State Nutrition Meeting

Transition Cow Health: Meeting the demands of lactation while maintaining a healthy liver

Heather White, Ph.D.
Nutritional Physiology

The Transition Dairy Cow

Impact of Dysregulation: Ketosis and Fatty Liver

Research Goals

- Elucidate regulatory mechanisms that control hepatic carbon flux during the coordinated responses to physiological state, nutrition, and stress
- Focus on hepatic nutrient utilization and partitioning
  - improvement of metabolic capacity and efficiency, specifically during the transition to lactation
  - constant improvement of feeding strategies
  - development of intentional intervention strategies
  - identify genomic factors that contribute to predisposition of metabolic disorders

Combatting Sub-Clinical Ketosis (SCK)

- Physiology and Etiology of SCK
- Herd-level detection
- Cow-level testing and treatment
- Genomic predisposition
- Reduce Risk

Sub-Clinical Ketosis

- Sub-Clinical Ketosis: herd-specific 10-75%, average 45%
  - ketone level in urine, milk, or blood
  - blood 1.2 to 3.0 mmol/L
- Can be primary or secondary
- Silent killer

Sub-Clinical Ketosis

- Cumulative Negative Impacts
  - 2.4 vs. 1.2 mmol/L cow
  - 3x more likely to develop a DA
  - 50x more likely to be culled within 30d
  - less likely to conceive to first service
  - produce 180kg less milk in first 30d and whole lactation
- Costs
  - Can be managed!

Types of Ketosis

- Type I and Type II
  - roughly similar to Type I and II Diabetes in humans
  - reflects BCS and metabolism

Type I Ketosis

- “spontaneous” onset, 3 to 6 wks post-calving
- may be low BCS at calving or lose BC post-calving
  - milks off her back, too well
  - onset coincides with peak milk
  - secondary to “off-feed”
  - milk production is high
  - excellent prognosis
  - liver remains functional
  - shortage of glucose precursors
Type II Ketosis

- “fat cow” ketosis
- 1 to 2 wks post-calving
- over-conditioned cows
- liver dysregulation
  - store NEFA as liver lipids
- pre-fresh management/nutrition
- complex onset with poor prognosis
- fatty liver

Type I vs. II Ketosis

<table>
<thead>
<tr>
<th>Metabolic Differences</th>
<th>Type I</th>
<th>Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td>blood BHBA</td>
<td>very high</td>
<td>high</td>
</tr>
<tr>
<td>blood NEFA</td>
<td>high</td>
<td>high, may be high preparrum</td>
</tr>
<tr>
<td>blood glucose</td>
<td>low</td>
<td>high initially, low/normal later</td>
</tr>
<tr>
<td>blood insulin</td>
<td>low</td>
<td>high initially, low/normal later</td>
</tr>
<tr>
<td>liver gng</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>liver pathology</td>
<td>none</td>
<td>fatty liver</td>
</tr>
</tbody>
</table>

Glycemia in Dairy Cows

- Hyperglycemia >79 mg/dL
- Normoglycemia 50 to 79 mg/dL
- Hypoglycemia 36 to 50 mg/dL

Herd Level Detection

Example of milk Fat:Protein distribution
Herd Level Detection

Milk Fat:Protein is suggestive but alone is not a strong predictor.

Ketosis Testing

<table>
<thead>
<tr>
<th>Test</th>
<th>Sample</th>
<th>Ketone</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Cost per test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ketostix</td>
<td>urine</td>
<td>Acetoacetate (AcAc)</td>
<td>78%</td>
<td>96%</td>
<td>$0.24</td>
</tr>
<tr>
<td>KetoCheck powder</td>
<td>milk</td>
<td>AcAc</td>
<td>41%</td>
<td>99%</td>
<td>$0.28</td>
</tr>
<tr>
<td>KetoTest</td>
<td>milk</td>
<td>BHBA</td>
<td>27 - 59%</td>
<td>76 - 99%</td>
<td>$2.00</td>
</tr>
<tr>
<td>Precision Xtra Meter</td>
<td>blood</td>
<td>BHBA</td>
<td>91%</td>
<td>94%</td>
<td>$1.30</td>
</tr>
</tbody>
</table>

*compared to serum BHBA diagnostics; Townsend and Eastridge, 2011

Cowside Diagnosis

- Weekly fresh cow testing
  - 5 to 20 DIM
  - cows blood BHBA >1.0 mmol/L previous week
- Takes time and money but pays off

Treatment Strategies

- Goal is to help the cow help herself
- Understanding metabolism sheds light on treatments
  - we want to avoid shutting down liver metabolism
- Lots of choices
Treatment Strategies

- **Recommended treatment**
  - propylene glycol, 300 mL 1x/d, 3 to 4 d
  - recheck
  - reserve dextrose and dexamethasone for clinical cases

---

**Dexamethasone**

**Mobilized Fat**

- NEFA fatty acids $\rightarrow$ ENERGY!
- ketones (ketosis)
- lipids (fatty liver)
- milk fat lactose
- Milch Production $\rightarrow$ Decreases Energy and Glucose

**Global SNP Exploration**

- Prevalence of all SNPs in control vs. ketotic cows
- Identify markers associated with ketosis
  - for use by producers
  - targets for further investigation

**USJersey**

---

**Dextrose**

**Mobilized Fat**

- NEFA fatty acids glycerol $\rightarrow$ ENERGY!
- ketones (ketosis)
- lipids (fatty liver)
- milk fat lactose
- Decrease Liver Function
- Acute Hyperglycemic

**Dextrose**

**Mobilized Fat**

- NEFA fatty acids glycerol $\rightarrow$ ENERGY!
- ketones (ketosis)
- lipids (fatty liver)
- milk fat lactose
- propylene glycol
- Provides a precursor
- Maintains Liver Function

**Global SNP Exploration**

- 54 ketotic or healthy pair matched cows
- Mean parity 2.8
Global SNP Exploration

- 54,609 SNP analyzed
  - 1,685 were different (P ≤ 0.05)
  - 1,862 tended to differ (0.05 < P ≤ 0.01)

Global SNP Exploration

<table>
<thead>
<tr>
<th>SNP Number</th>
<th>Chromosome Number</th>
<th>Name</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2063</td>
<td>19</td>
<td>PRKCA / protein kinase C, alpha</td>
<td>0.05</td>
</tr>
<tr>
<td>3954</td>
<td>2</td>
<td>ALPL / alkaline phosphatase, liver/kidney</td>
<td>0.0447</td>
</tr>
<tr>
<td>6363</td>
<td>15</td>
<td>LOC517402 / pyruvate dehydrogenase complex X</td>
<td>0.0298</td>
</tr>
<tr>
<td>6777</td>
<td>15</td>
<td>NR1H3 / nuclear receptor subfamily 1, group H, member 3</td>
<td>0.0174</td>
</tr>
<tr>
<td>10839</td>
<td>4</td>
<td>IGF2BP3 / insulin-like growth factor 2 messenger RNA binding protein 3</td>
<td>0.0153</td>
</tr>
<tr>
<td>10976</td>
<td>3</td>
<td>ATP1A1 / ATPase, Na+/K+ transporting, alpha 1 polypeptide</td>
<td>0.04</td>
</tr>
<tr>
<td>11750</td>
<td>25</td>
<td>RBFOX1 / RNA binding protein, forkhead box O1</td>
<td>0.0496</td>
</tr>
</tbody>
</table>

Genetic Predisposition to Ketosis

- SNP may be used as markers associated with ketosis
- Council on Dairy Cattle Breeding
  - collecting health data for diseases
- Expanding the data set to include more Holstein and Jersey cattle

What to do with Type II SCK?

- If Type II Ketosis is a persistent herd problem (>50% SCK)
  - dry cow NEFA testing
  - propylene glycol drenches for fresh cows
  - diligent BHBA screening
  - early diagnosis prevents chronic ketosis and fatty liver

Reducing Risk

- Manage negative energy balance
  - prevent over-conditioning in dry period
  - reduce time off feed around calving
  - manage comorbidities
- Manage herd-level prevalence
- Aggressive testing protocols
  - meet glucose and energy needs of lactation with treatment strategies
  - ID by genetic predisposition?

Collaborators

- Producers that participate in the research!
  - Wisconsin Farms, Allenstein Dairy Research Herd, New England Jersey Farms
  - Gary Oetzel, DVM, UW-M School of Veterinary Medicine
  - George Wiggins, Ph. D., USDA Agricultural Research Service Beltsville
  - Kent Weigel, Ph. D., UW-M Dept. Dairy Science
- Students
  - Lisa Dauten, Bethany Sullivan
  - Rob Fugate, James Downey, Ryan Pralle, Tawny Chandler, Kelly Brower

USJersey
Economics of Automatic Calf Feeders

Jennifer Bentley
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jbentley@iastate.edu

Motivation

• Increased trend of technology implementation
• New and growing industry
• New opportunities for producers
• Opportunity for producer and ag. lender/business education
• Interest in localized information

Background of Survey

• Producers in NE Iowa
• Factors affecting financial, economic, feeding, and adoption decisions
• Pre and post installation
• Results at:
  – http://www.extension.iastate.edu/dairyteam
  – Dairy Nutrition – Calves & Heifers
  – Factsheet and presentation

Economics of Automatic Calf Feeders

Jennifer Bentley
Extension Dairy Field Specialist
jbentley@iastate.edu

Calf Inventory and Financial Information

<table>
<thead>
<tr>
<th>Variables</th>
<th>Units</th>
<th>Instructions or Reference Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heifers, Yearly Total</td>
<td>95 no. heifers</td>
<td>Typically 10 to 40 percent of cow herd</td>
</tr>
<tr>
<td>Bulls, Yearly Total</td>
<td>95 no. bulls</td>
<td>Typically 10 to 40 percent of cow herd</td>
</tr>
<tr>
<td>Labor per Cow</td>
<td>$65,000 / 64 hours</td>
<td>Feeders are rented 7.5 to 96 hours</td>
</tr>
<tr>
<td>Feed Cost per Automatic Calf Feeding Device</td>
<td>$80,000 per feeder</td>
<td>Range of $2 to 25,000 per station, $5500</td>
</tr>
<tr>
<td>Feed Cost per Station</td>
<td>$4,000 5 per feeder</td>
<td>Range of $2 to 25,000 per station, $5500</td>
</tr>
<tr>
<td>Feed Cost per Station (10 years)</td>
<td>$35,000 5 per feeder</td>
<td>Typical range of 15% to 30% purchase price of sow or bought money</td>
</tr>
<tr>
<td>Feed Rate of Return</td>
<td>5.5%</td>
<td>Typical rate of return of 5.5% to 7.5% per year</td>
</tr>
<tr>
<td>Insurance Rate per $1,000 Value</td>
<td>0.50%</td>
<td>Total cost of insurance per year is approximately $40 to $50 per feeder</td>
</tr>
</tbody>
</table>

Feed Intake Changes

| Feed Intake Changes | Milk Replacement Cost per Pound of Milk | $3.65 per pound |
| Current Milk Replacement Intake | $3.30 per pound |
| Anticipated Milk Replacement Intake | $3.50 per pound |
| Anticipated Collection/Average Kilogram Intake | $3.00 per pound |
| Current Number of Days in Waning Stage | 60.6% no. days |
| Anticipated Collection/Average Kilogram Intake | $3.00 per pound |
| Anticipated Collection/Average Kilogram Intake | $3.00 per pound |
| Feed Intake Cost per Pound of Milk | $5.30 per pound |
| Anticipated Total Calf Starter Intake, Pounds of Dry Milk | 9.87 pounds per calf |
| Anticipated Total Calf Starter Intake, Pounds of Dry Milk | 9.87 pounds per calf |
| Anticipated Increase of 30% to 40 percent | 1.54% pounds per day |
**Labor Changes**

- Current Feeding Labor Time Per Day: 8.6 minutes per calf
- Anticipated Feeding Labor Time Per Day: 7.6 minutes per calf
- Current Calf Labor Management Per Day: 5.6 minutes per calf
- Anticipated Calf Labor Management Per Day: 7.6 minutes per calf
- Labor Rate for Feeding Cows: $12.08 per hour
- Increased Hours for Record Management: 1.5 hours per day
- Labor Rate for Feeding Cows: $16.86 per hour

**Calf Health Changes**

- Current Calf Treatment Rate: 10% calves
- Anticipated Calf Treatment Rate: 12% calves
- Cost of Treatment per calf: $4.00 per calf

**Utility and Supply Changes**

- Anticipated Change in Electricity and Maintenance: $255 per year
- Anticipated Change in Supplies and Repairs: $288 per year

**Annual Partial Budget Analysis**

<table>
<thead>
<tr>
<th>Positive Impacts</th>
<th>Negative Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased Revenue</td>
<td>Decreased Revenues</td>
</tr>
<tr>
<td>Total Increased Income</td>
<td>Total Decreased Income</td>
</tr>
<tr>
<td>$13,400</td>
<td>$3,330</td>
</tr>
<tr>
<td>Reduced feeding labor</td>
<td>Increased feed cost</td>
</tr>
<tr>
<td>$34,608</td>
<td>$3,198</td>
</tr>
<tr>
<td>Reduced calf management cost</td>
<td>Increased milk production cost</td>
</tr>
<tr>
<td>$3,440</td>
<td>$38,000</td>
</tr>
<tr>
<td>Total decreased expenses</td>
<td>Total increased expenses</td>
</tr>
<tr>
<td>$19,016</td>
<td>$13,330</td>
</tr>
</tbody>
</table>

**Loan Amortization and Net Cash Flow Analysis**

<table>
<thead>
<tr>
<th>Loan Details</th>
<th>Loan Amortization</th>
<th>Net Cash Flow Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sensitivity Analysis**

- Gross Income: $12,000
- Net Income: $3,330
- Net Income Impact per $1 K change in gross income: $0.11

- Capital Recovery Loan Cost: $22,000
- Net Payoff: ($8,300)
- Total Amount of Loan: $22,000
- Yearly Amortization: $8,300
- Interest Cost: $8,300
- Total Payment: $16,600
- Total Cost of Borrowing: $22,000
- Utilization Cost: $8,300
Use of Spreadsheet

- Slight changes in input values can dramatically influence the net financial impact
  - Anticipated days on milk
  - Anticipated milk replacer intake
- Careful review to confidently make decision

Impact on Herd?

- Why are we interested?
  - Farm goals and related impact
  - Direct and indirect changes that affect management and viability
  - Management level
  - Efficiency level
  - Scale
  - Financial advantages
- Long term gains or impacts

Recap

- Partial Budget looks at only changes influenced from Auto Calf Feeder
- Efficiency of labor, improved calf growth and vigor, or long-term gain can be positive impacts on NFI
- Whole farm management of calves and herd to make the feeder successful
Diagnostic Dilemmas
How to Understand Mastitis
Diagnostic Results from Labs, Farms and PCR Tests

Pamela Ruegg, DVM, MPVM
University of Wisconsin – Madison

Mastitis

• Bacterial infection of the udder
• 99% occurs when bacterial exposure at teat end exceeds ability of immune defenses of cow

Subclinical mastitis
– Milk appears normal but contains excessive numbers of inflammatory cells

Clinical mastitis
– Visual abnormalities of milk
– Definition varies among farms

Practical Questions

• When we detect inflammation does that mean that infection is present?
  – Do we need to use an antibiotic?
• When bacteria are identified in a milk sample, does that mean that they are the cause of an infection?
  – Do we need to use an antibiotic?
• What about all these new tests?
  – How do PCR tests compare to traditional culture?

We Detect Mastitis Based on:
Results of the immune response
NOT the moment of INFECTION

We are detecting inflammation NOT INFECTION!

To Control Mastitis The Cause of Mastitis Must be Known

• Mastitis is a bacterial disease
• Different bacteria
  – Infect different parts of the udder
  – Have different reservoirs
  – Require different treatments
  – Have different rates of spontaneous cure

Compare and Contrast Culture Methods versus PCR testing for Control of Mastitis

What are the Options for Detecting Bacteria in Milk?

• Microbiological Culture
  – Submission to a reference laboratory
  – On farm culture
  – In Vet Clinic Culture
• Use of PCR Testing
Practical Aspects of Using Culture Data

- Obtaining a useful sample
- Using the right lab test
- Evaluating the results
- Making management decisions

What Happens in the Lab?

Culturing

- In most culture labs
  - The objective is to rapidly identify likely mastitis pathogens
- Most lab methods are simple
- A small droplet of milk is placed on growth media
- The inoculated plate is allowed time to grow

- The plate is observed for growth
- Different methods are used to identify the bacteria
  - Gram stain
  - Characteristics of the bacteria

It is Easy to Find Bacteria in Milk

But...they Aren't All From Mastitis....

- Mastitis is almost always caused by a single type of bacteria
- When >2 types of bacteria are recovered the milk sample is almost useless
- Proper sampling MUST be performed
  - Train & evaluate
- Take a ¼ sample
  - After prep
  - Before attach

Laboratory Procedures for Milk Samples

- Collecting Milk for Culture
  - Wear gloves or wash hands
  - Use a sterile container
    - Not reused
  - Predip & dry the teat
  - Use alcohol to THROUGHLY scrub the teat end
  - Take the sample without cross contamination

- Laboratory Supplies
- Inoculating Growth Media

Sources & of Bacteria in Milk

- There are multiple ways that bacteria can get into milk
  - Contamination during sampling
  - Poor sample handling
  - Teat skin microflora
  - Streak canal microflora
  - Etc., Etc..
- Sampling procedures are even MORE important when PCR testing is done

Incubation & Identification

- Incubate 24-48 hours
- Look at Colonies & apply Gram Stain
- Examine using a microscope

At least 20% of Milk samples will be Culture Negative (They are Farmers & Sub-clinical)
if nothing grows from all 4 samples...sampling was not correct
Perform a Variety of Other Tests

- Phenotypic tests
  - Appearance of bacteria on plates
  - Growth on specific medias
  - Reactions with enzymes (catalase, coagulase etc.)
  - Biochemical reactions
    - Fermentation of sugars
    - Motility etc...
- Compared with “typical” characteristics of the bacteria are known
- A Best guess is made relative to ID
  - Confidence level is assigned
    - 75% confidence is often the cutpoint

What is Different about an OFC or Vet Clinical Culture LAB?

- Goal is different
  - The same level of accuracy is not required
- Want to rapidly arrive at a bacteriological diagnosis of mastitis
- Use of selective medias to make a rapid diagnosis
  - Look at the colonies on the plate
- OFC using selective media cannot identify most bacteria to species level

So...what can we expect from on-farm culture systems???

OFC are about 80% Accurate and Should be Used to Direct Treatment Decisions but Farmers Need a Backup Lab for Diagnosis of Specific Bacteria

Principle of On Farm Culturing

- Use laboratory shortcuts to arrive at a fast, presumptive diagnosis
  - Don’t treat with antibiotics until the diagnosis is made
- Use of selective medias to make a rapid diagnosis
  - Laboratory “shortcuts”

Typical Decisions

- Treat or No Treat (TNT)
  - Gram + versus Gram neg or no growth
  - Chronic
  - Staph aureus
- Treat with Gram negative spectrum drug
- Alter the duration of treatment

PCR Tests Currently Used In Diagnosis of Mastitis

- Commercial or proprietary PCR tests
  - Used to detect bacterial DNA

PCR = Polymerase Chain Reaction

- Based on concept that nucleus of bacterial cells contain DNA with unique sequences of nucleotides
- Nucleotides are building blocks of DNA
  - Adenine, cytosine, guanine, thymine
- PCR tests identify bacteria that
  - Have known nucleotide sequences that are in a master library
    - “Primer”
  - And are in the particular PCR mix
    - You have to know what you are looking for and include the primer in the test mix
How a PCR Test Works

- The cell structure includes a nucleus with DNA
- The DNA of each type of bacteria is unique

DNA from Milk
Bacteria is Purified

Polymerase Chain Reaction: PCR

Cl = cycling threshold indicates how many copies had to be made before diagnosis

DNA Strands (DENATURE)
Target Sequence
Cycling

Strand of bacterial DNA are Multipied until they can be identified

What is a PCR?

Detection of DNA Does NOT Equal Infection

- Finding 1 colony of bacteria does NOT equal infection
  - Usually require 300-500 cfu/ml
- Finding some types of bacteria does NOT equal infection
  - Most Bacillus
- No one knows how to interpret the recovery of DNA from Milk samples

- Possible sources of DNA in milk
  - Contamination
    - Milk meters
    - Teat skin
    - Equipment
    - Hands
    - Teat canal
    - Dirt
  - Part of bacteria killed as part of a successful immune response

How is PCR Used for Mastitis Diagnosis?

- Pathproof©
  - PCR test that can ID DNA in milk from up to 16 potential mastitis pathogens
- Can potentially find DNA from about 90% of the pathogens that cause mastitis in WI herds
- Unable to identify about 10-15% of organisms that cause mastitis in WI
  - Wide diversity of opportunistic organisms
  - Primer not in mix

Use of PCR on Field Collected Milk Samples Koskinen et al., J Dairy Sci, 2010

- Study conducted in Finland & Holland
- 1,000 quarter milk samples collected using ASEPTIC collection methods
  - 780 Clinical cases
  - 220 from Healthy cows
- Bacterial culture performed in labs using standard techniques
  - >3 colony types were considered contaminated
  - Few colonies of Bacillus, etc. were ignored
- PCR performed using Pathproof®

What is the Difference Between Culturing and PCR?

- Culturing detects only living bacteria
- PCR detects pieces of DNA from both live and dead bacteria
  - Can detect the “dead bodies” left over after the immune response kills bacteria
  - A significant proportion of milk samples yield DNA from >1 type of bacteria
    - ???interpretation???????
    - May detect GENUS or SPECIES depending on primer
      - But not strain

Use of PCR on Field Collected Milk Samples Koskinen et al., J Dairy Sci, 2010

- Study conducted in Finland & Holland
- 1,000 quarter milk samples collected using ASEPTIC collection methods
  - 780 Clinical cases
  - 220 from Healthy cows
- Bacterial culture performed in labs using standard techniques
  - >3 colony types were considered contaminated
  - Few colonies of Bacillus, etc. were ignored
- PCR performed using Pathproof®
Bacteria Found in Culture Negative Samples

- Number of bacterial DNA identifications in culture negative samples
  - 1 species: 68%
  - 2 species: 23%
  - >2 species: 9%
- CNS & C Bovis were most common

What About PCR for Bulk Tanks?

- Bulk tank culturing is useful for
  - Detection of contagious pathogens
  - Monitoring hygiene
- Interpretation of bacterial DNA in bulk milk is completely unknown
  - No science to guide decision making

Comparison of PCR and Culture Results in 780 Clinical Cases

<table>
<thead>
<tr>
<th>Culture Positive</th>
<th>Culture Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCR Pos.</td>
<td>PCR Neg.</td>
</tr>
<tr>
<td>A Pyogenes</td>
<td>12</td>
</tr>
<tr>
<td>C bovis</td>
<td>33</td>
</tr>
<tr>
<td>Enterococci</td>
<td>6</td>
</tr>
<tr>
<td>E coli</td>
<td>54</td>
</tr>
<tr>
<td>Klebsiella</td>
<td>11</td>
</tr>
<tr>
<td>Staph aureus</td>
<td>82</td>
</tr>
<tr>
<td>CNS</td>
<td>131</td>
</tr>
<tr>
<td>Strep agalactiae</td>
<td>1</td>
</tr>
<tr>
<td>Strep dysgalatiae</td>
<td>65</td>
</tr>
<tr>
<td>Strep uberis</td>
<td>71</td>
</tr>
</tbody>
</table>

When You Have PCR Results ALWAYS Look at the Cow History

- When PCR indicates Staph aureus, Strept ag or M bovis:
  - Does the cow have a history of high SCC?
  - Does the cow have a history of recurrent clinical cases?
  - There are many sources of environmental bacteria
- Usefulness of PCR testing for these organisms is unknown

Bacteria Found in Culture & not Using PCR

**Clinical Cases**
- Of 780 cases (6%)
  - Bacillus (n = 10)
  - Enterobacter (n = 3)
  - Gram neg. rods (n = 6)
  - Lactococcus (n = 4)
  - Proteus (n = 1)
  - Pseudomoans (n = 2)
  - Strep bovis (n = 3)
  - Strep spp (n = 8)
  - Yeast (n = 7)

**Subclinical Cases**
- Of 46 cases (20%)
  - Bacillus (n = 3)
  - Gram neg rods (n = 2)
  - Strep spp (n = 3)
  - Yeast (n = 1)

Take Home Point

- PCR tests detect bacterial DNA from both dead and live bacteria
- When PCR tests are used for mastitis the milk sample must be collected aseptically
- PCR tests result in a large proportion of multiple bacterial isolations from milk
  - Decision making for treatment, segregation and culling based on PCR tests is unknown

When using PCR testing always refer to the cow history to help make decisions
Culturing or Other Tests

- Diagnostic tests are only cost effective when the result of the test will be used to make a management decision that increases profits
  - Treatment
  - Culling
  - Segregation
  - Disease prevention

Take Home Message

- The use of molecular methods will increase as the methods get cheaper
- Just like other diagnostic tests
  - Value of test is based on the value of the intervention
- Molecular tests give us different information than we have previously used
  - Need to understand
    - how the tests work
    - Strengths & weaknesses

Final Conclusion

- Always:
  - know why you are performing a test
  - Know how to use the results
  - Combine results with medical history of the animal to make an intervention decision

For more information: http://milkquality.wisc.edu or....
Hemorrhagic Bowel Syndrome:
Update and Observations

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Introduction
Hemorrhagic bowel syndrome, characterized medically as Jejunal Hemorrhage Syndrome (JHS) but also known as bloody gut syndrome, is an important, acute enterotoxemic disorder of adult dairy cattle. Sporadic outbreaks of the condition are reported with increasing frequency since 1991. A definitive cause of JHS has not been established and the condition cannot be experimentally reproduced but two agents, the bacteria, Clostridium perfringens type A and a common mold, Aspergillus fumigatus have been incriminated as having some role in this condition. Characterized as an acute, often fatal condition of high producing dairy cattle that are second lactation or greater, in the first 100 days in milk, consuming high energy total mixed ration (TMR) and using bovine somatotropin, the condition is reported all over the world. Although the incidence of JHS in most herds is less than 10%, the economic impact is significant as the target is typically a highly productive dairy cow at peak performance and a disease outcome that is frequently death.

Clinical Signs
The clinical findings most commonly associated with JHS are listed below.

- Depression
- Decreased rumen motility
- Decreased feed intake
- Decreased milk production
- Succissible fluid with ballottement of the right abdomen
- Reduced to scant fecal production
- Colic
- Right-sided abdominal ping during simultaneous percussion and auscultation
- Dehydration
- Elevated heart rate
- Dark, tarry feces (melena)
- Clotted blood in feces

As individual clinical signs, none of these are specific for JHS but, taken together as a cluster of signs, the diagnosis is more conclusive. With the progression of intestinal injury, hemorrhage, peritonitis and toxemia, more severe clinical signs of cold extremities, hypothermia, muscle fasciculations and recumbency are seen. Conclusive tests such as diagnostic ultrasonography to find dilated small intestine (jejunal portion) with thickened walls and echoic luminal contents suggestive of blood, exploratory surgery and/or post mortem examination are needed to confirm the diagnosis of JHS in an individual cow. Severe intestinal distension and segmental dark red to purple discoloration of the serosal surface are characteristic findings. Luminal contents contain blood, blood clots, fibrin and/or casts. Gross lesions are associated with the microscopic findings of segmental hemorrhage, edema, ulceration and necrosis. Without the definitive findings discussed here, there is a danger of over diagnosis in some herds.

Diagnosis of a JHS herd problem is more complex and relies on careful assessment of herd records and accurate case identification to elucidate targeted animals or groups of cattle, seasonality, lactational incidence, nutritional factors, health or other relevant risk factors. Individual cow exams and diagnostic tests such as fecal screening, rumen pH determination, serum ionized calcium and potassium concentrations may be helpful. Bulk tank MUN data is essential. In individual animals and herds, abomasal ulcers, other causes of enteritis (Salmonella, Bovine Virus Diarrhea and Corona virus), indigestion, and poor intestinal motility should be ruled out.

Treatment of JHS
Without surgery, the JHS mortality is extremely high (77-100%). Surgical options include manual massage of the intestine to break down the blood clot, opening the intestine (enterotomy) to remove the blood clot or resection of the abnormal segment of intestine (enterectomy). A 60% survival rate is reported in JHS cattle that underwent surgery. Early diagnosis, followed by surgery with manual massage of the blood clot carries the best prognosis but survivors are at risk of recurrence, especially within the first 12-months of the initial episode. Alone or in com-
bination with surgery, medical treatment must be instituted early and aggressively to enhance intestinal motility. Fluid therapy provided intravenously, orally or in combination should be high volume (40 L or more) and contain essential electrolytes like calcium, potassium and magnesium. Non-steroidal anti-inflammatory drugs are provided to control pain and to minimize the effects of the inflammatory mediators released when \textit{C. perfringens} type A alpha toxin activates the arachidonic acid cascade. Penicillin and \textit{Clostridium perfringens} type C and D antitoxin are frequently added to the treatment protocol for JHS cases.

Prevention of JHS

Without knowledge of a specific cause of JHS, preventive strategies are based on managing known risk factors that can be controlled. Considering that JHS may be the result of an agent like \textit{Clostridium perfringens} type A taking advantage of an opportunity like abomasal or intestinal motility disturbances to utilize appropriate substrate for rapid proliferation and toxin production, prevention strategies should consider the agent, management factors that enhance abomasal and intestinal motility and ration formulation that minimizes the delivery of favorable substrate.

The bacteria most commonly associated with JHS, \textit{Clostridium perfringens} type A, is ubiquitous in the environment and part of the normal intestinal flora of cattle. Experimental infusion of \textit{Clostridium perfringens} type A cultured from clinical cases into the jejunum of non-lactating cows, however, did not reproduce JHS. Yet, alpha and beta 2-toxin producing \textit{Clostridium perfringens} type A are isolated from feces, intestines and tissues and intestinal lumen toxins are found in JHS cases at a higher rate than from unaffected cattle. Vaccines directed against \textit{Clostridium perfringens} type C and D, which do not provide protection against alpha-toxin but which may provide some cross protection through the beta 2-toxoid component, are widely used in dairy herds but vaccinated animals have developed JHS and new cases continue to develop in the face of vaccination. \textit{Clostridium perfringens} type A toxoid has been incorporated into the vaccination protocol of many dairy herds concerned with JHS but controlled studies are not published to evaluate its efficacy. The requirement that \textit{Clostridium perfringens} type A have bioavailable zinc in the intestinal tract for multiplication and for stability, destructive properties and disease induction from its alpha toxin provides additional insight into the pathophysiology of JHS. While a dietary limit on zinc is neither appropriate nor advocated, control of excessive dietary zinc may be indicated in herds with JHS risk.

The potential role for the common mold, \textit{Aspergillus fumigatus} (AF), in JHS is strengthened by knowledge that it can produce a similar enteric hemorrhagic disease in people and that AF DNA has been demonstrated in blood and intestines of JHS cows but not in controls. \textit{A. fumigatus} may act directly or through other toxins, like gliotoxin, to decrease host defenses and cause immune suppression. The mold inhibitor, Omnigen AF (Prince Agri Products, Inc., Quincy, IL) has been included in the diet of many dairy herds with concern for or experience with JHS cases but controlled studies are not published to validate efficacy as a preventive measure.

Maintenance of normal abomasal and intestinal motility should minimize JHS risk. Dietary consistency with regard to components, amount, moisture content, digestibility, access, quality and availability of minerals and buffers are especially important in the high feed intake groups that are most at risk for JHS. High energy total mixed rations (TMR) have been associated with JHS risk but whether this is due to starch overflow to the small intestine, a reduced fiber mat, high volatile fatty acid (VFA) concentrations, pH change, increased osmolality of abomasal contents, or elevated insulin levels is unknown. Change in the quantity, quality or source of dietary protein may also increase the risk of JHS by enhancing \textit{C. perfringens} type A growth and gas production or altering abomasal motility. Limit stress by minimizing group changes and insuring quiet handling of cattle for timed breeding or bST injections, especially in the high feed intake groups that are at most risk for JHS.

Lingering Questions

- What is the relationship between JHS, other abomasal conditions (ulcers, impaction, functional abomasal outflow obstruction, displaced abomasum), intestinal ileus or indigestion? Are these conditions a continuum of an underlying motility disturbance, fermentation disorder, ingredient overflow, luminal content aberration, or metabolic condition?
- To what degree is JHS an infection, a nutritional issue that has its basis in starch or protein amount, quality or source or a metabolic/motility issue?
- Do breed or genetic factors play a role in JHS?
- Are there tools that enhance early detection of JHS?
References


