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Management Practices and Communication Strategies to Improve Milk Fat and Protein Content on Dairy Farms

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MANAGEMENT PRACTICES AND COMMUNICATION STRATEGIES TO IMPROVE MILK FAT AND PROTEIN CONTENT ON DAIRY FARMS

A Thesis Presented

by

Melissa Woolpert

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ABSTRACT

Dairy farmers in the Northeastern United States are paid based on the amount of fat and protein in their cows’ milk, and improving fat and protein production is linked with improved financial sustainability for dairy farms. However, not all farmers are motivated to make changes to increase milk fat and protein production. Previous research has identified a positive correlation between a group of fatty acids, known as the de novo fatty acids, and the fat and protein content of bulk tank milk from commercial dairy farms. Therefore, the first objective of this research was to explore the relationship of farm management, the cow’s diet, and lactation performance with de novo fatty acid content on Northeastern US dairy farms. Results from the first objective were communicated with dairy farmers; therefore, the second objective was to understand how to communicate with farmers to influence their behavior. We hypothesized that farms with high de novo fatty acids in bulk tank milk would manage and feed their cows to optimize rumen fermentation conditions.

The first (Chapter 2) and second (Chapter 3) studies were methodologically very similar. Farms were categorized as either high de novo (HDN) or low de novo (LDN) based on the concentration of de novo fatty acids in their bulk tank milk for the 6 months prior to the farm visit. Farms were then visited once in March or April, 2014 (Chapter 2) or between February and April, 2015 (Chapter 3) to assess management practices and collect samples of the cows’ diet.

There were no differences in days in milk in Chapter 2 or Chapter 3. Yield of milk, fat, and true protein per cow were higher for HDN versus LDN farms in Chapter 2. In both chapters, HDN farms had higher milk fat and true protein content and higher de novo fatty acid yield per day. The HDN farms had lower freestall stocking density in Chapter 2 and provided more feedbunk space per cow in Chapter 3. Additionally, tiestall feeding frequency was higher for HDN than LDN farms. No differences were detected for dietary chemical composition, except ether extract was lower for HDN than LDN farms in both chapters.

Chapter 4 explored how to communicate the results of Chapter 2 and Chapter 3 through eleven qualitative, semi-structured interviews and insight from the 83 farm visits. Farmers identified the cooperative, expert consultants (nutritionist, veterinarian, and agronomists), financial advisers, print publications, and other farmers as principal sources of information. However, barriers to the transfer of information included family dynamics, lack of access to high speed internet, and difficulties evaluating divergent recommendations from experts. Several farmers expressed an incorrect perception of their farms’ fat and protein production compared with cooperative averages which reduced their motivation to incorporate management changes. Recommendations to overcome these barriers include integrating management team meetings and facilitating informal discussion groups between farmers.

This research is correlational in nature, and future research is needed to verify a causal relationship between de novo fatty acids and milk fat and protein content. However, the results of this research can be used to help farmers increase their cows’ milk fat and protein content, improve the transfer of knowledge to dairy farmers, and ultimately support the financial sustainability of dairy farms in the Northeastern US.
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# TABLE OF CONTENTS

CITATIONS ......................................................................................................................... ii

LIST OF TABLES ..................................................................................................................... viii

LIST OF FIGURES .................................................................................................................. x

CHAPTER 1: COMPREHENSIVE LITERATURE REVIEW ...................................................... 1

1.1. INTRODUCTION AND PROJECT BACKGROUND ...................................................... 1

1.1. THE BIOLOGY OF MILK FAT SYNTHESIS ................................................................. 3

1.1.1. Milk Fat Synthesis ......................................................................................... 3

1.1.2. Rumen Fermentation ....................................................................................... 5

1.1.3. Stage of Lactation and Energy Status ............................................................... 8

1.2. EFFECT OF DIET ON MILK COMPOSITION ......................................................... 8

1.2.1. Dietary Lipids ............................................................................................... 8

1.2.2. Fermentable Carbohydrates .......................................................................... 11

1.2.3. Forage Particle Size ..................................................................................... 12

1.2.4. Dietary Supplements and Additives ............................................................... 15

1.3. EFFECT OF MANAGEMENT ON MILK COMPOSITION ................................... 16

1.3.1. Feeding and Resting Behavior of Lactating Dairy Cows .................................. 17

1.3.2. Rumination Behavior of Dairy Cows .............................................................. 18
1.3.3. Stocking Density ................................................................. 18
1.3.4. Feed Restriction ................................................................. 20
1.3.5. Feeding Frequency .............................................................. 21
1.3.6. Facility Design ................................................................. 22
1.3.7. Feeding Strategy ............................................................... 22
1.3.8. Behavior and Rumen Conditions ......................................... 23
1.4. COMMUNICATION FOR INNOVATION WITH DAIRY FARMERS .... 24
  1.4.1. The Complexity of Managing Farms .................................... 24
  1.4.2. Farmer Decision Making Process ....................................... 25
  1.4.3. Motivating Farmers to Make Changes ................................. 26
  1.4.4. How Farmers Learn ........................................................... 27
  1.4.4. Geographic Barriers to Rural Communication ....................... 29
  1.4.6. Moving Beyond the Diffusion of Innovation Theory ................ 30
  1.4.7. Communication for Innovation with Farmers ....................... 31
  1.4.8. Description of Current Farmer Communication Practices ........ 33
1.5. JUSTIFICATION OF OBJECTIVES .............................................. 34
1.6. REFERENCES ............................................................................. 36
CHAPTER 2: MANAGEMENT, NUTRITION, AND LACTATION PERFORMANCE
ARE RELATED TO BULK TANK MILK DE NOVO FATTY ACID
CONCENTRATION ON NORTHEASTERN US DAIRY FARMS

2.1. ABSTRACT

2.2. INTRODUCTION

2.3. MATERIALS AND METHODS

2.3.1. On-Farm Data Collection

2.3.2. Supplemental Feed Products

2.3.3. Milk Yield and Composition

2.3.4. Statistical Analysis

2.4. RESULTS AND DISCUSSION

2.4.1. Farm Characterization

2.4.2. Milk Composition

2.4.3. Management Practices

2.4.4. Dietary Strategies

2.4.5. Supplemental Feed Products

2.5. CONCLUSION

2.6. REFERENCES
CHAPTER 3: COW COMFORT INDICATORS AND PHYSICALLY EFFECTIVE FIBER ARE RELATED TO BULK TANK MILK DE NOVO FATTY ACID CONCENTRATION FOR HOLSTEIN DAIRY FARMS ........................................... 87

3.1. ABSTRACT ........................................................................................................................................ 88

3.2. INTRODUCTION ................................................................................................................................ 89

3.3. MATERIALS AND METHODS ........................................................................................................ 90
  3.3.1. On-Farm Data Collection and Analysis .................................................................................. 90
  3.3.2. Dietary Supplements and Additives ...................................................................................... 92
  3.3.3. Milk Composition and Fatty Acid Analysis .......................................................................... 92
  3.3.4. Statistical Analysis ................................................................................................................... 93

3.4. RESULTS and DISCUSSION ........................................................................................................... 94

3.5. CONCLUSIONS ................................................................................................................................ 99

3.6. REFERENCES ..................................................................................................................................... 101

CHAPTER 4: OVERCOMING PERCEPTION AND COMMUNICATION BARRIERS TO HELP DAIRY FARMERS MAKE BETTER MILK .............. 117

4.1. INTRODUCTION ................................................................................................................................ 118

4.2. LITERATURE REVIEW .................................................................................................................. 119
  4.2.1. Theoretical Framework ......................................................................................................... 121

4.3. METHODS ........................................................................................................................................... 123

4.4. FINDINGS .......................................................................................................................................... 126
4.4.1. Farmer’s Perception of their Cows’ Fat and Protein Production .................. 126
4.4.2. Sources of Information ............................................................................. 127
4.4.3. Decision Making Dynamics on Farms ..................................................... 129
4.4.4. Communication Strategies from the Cooperative .................................... 131
4.5. DISCUSSION AND RECOMMENDATIONS ............................................. 133
4.5.1. Network of Communication ..................................................................... 133
4.5.2. Solution 1: Overcome Incorrect Perceptions of Fat and Protein .......... 134
4.5.3. Solution 2: Encourage Management Meetings ......................................... 136
4.5.4. Solution 3: Support Informal Discussions Between Farmers .............. 137
4.6. CONCLUSIONS ............................................................................................ 139
4.7. REFERENCES ............................................................................................... 140

CHAPTER 5: CONCLUSIONS AND IMPLICATIONS ........................................... 145

5.1. Future Research on Dairy Farm Management .............................................. 145
5.2. Future Research on Farmer Communication ............................................. 148
5.3. Implications for the Dairy Community ........................................................ 148

COMPREHENSIVE BIBLIOGRAPHY ................................................................ 155
APPENDIX I ........................................................................................................ 172
APPENDIX II ....................................................................................................... 174
LIST OF TABLES

Table 1.1. Fatty acid profile of bovine milk fat (adapted from Jensen, 2002) ............... 51

Table 1.2. Time budget of resting and eating behavior for lactating dairy cows (Grant and Albright, 2001). ................................................................. 52

Table 2.1. Milk composition data representing monthly mean milk composition by farm from September, 2013 to February, 2014 that was used to select high de novo (HDN) and low de novo (LDN) farms to participate in the study. ...................... 79

Table 2.2. Descriptive statistics (mean ± standard deviation) characterizing management factors for high de novo (HDN) or low de novo (LDN) farms. ............... 80

Table 2.3. Odds ratio for binary management and dietary data for high de novo (HDN) or low de novo (LDN) farms observed during the farm visit. ................. 81

Table 2.4. Least squares means of milk composition covariately adjusted by breed for high de novo (HDN) and low de novo (LDN) farms for the month of the farm visit .................................................................................. 82

Table 2.5. Effects of feed additives included in TMR on high de novo (HDN; n=15) or low de novo (LDN; n=18) farms sampled during the farm visit. .............. 83

Table 2.6. Least squares means of management factors for high de novo (HDN) or low de novo (LDN) farms observed or recorded during the farm visit. .... 84

Table 2.7. Nutritional characteristics of weighted average of TMR from high de novo (HDN) and low de novo (LDN) farms ........................................................................... 85

Table 2.8. Nutritional characteristics for high de novo (HDN) and low de novo (LDN) farms for hay crop silage (n = 19 HDN; n = 20 LDN) and corn silage (n = 15 HDN; n = 12 LDN) sampled during the farm visit ........................................................................... 86

Table 3.1. Milk composition data for high de novo (HDN) and low de novo (LDN) farms from September, 2014 to February, 2015. Data were used to select farms to participate in the farm visit study. .................................................. 105

Table 3.2. Cut-point and literature used to categorize high de novo (HDN) and low de novo (LDN) management characteristics for analysis using odds ratios .... 106

Table 3.3. Prevalence of management practices and facility design among high de novo (HDN) and low de novo (LDN) commercial dairy farms ...................... 107
Table 3.4. Least squares means of milk composition factors for high de novo (HDN) and low de novo (LDN) farms based on milk composition data for the month of the farm visit.

Table 3.5. Management data for high de novo (HDN) and low de novo (LDN) farms.

Table 3.6. Effects of milking and freestall feeding frequency on bulk tank milk fatty acid composition among high de novo (HDN) or low de novo (LDN) farms.

Table 3.7. Dietary chemical composition for diets from high de novo (HDN) and low de novo (LDN) farms. Data were mathematically composited by the number of cows consuming the diet and analyzed using farm as the experimental unit.

Table 3.8. Particle size distribution using the Penn State Particle Separator for diets from high de novo (HDN) and low de novo (LDN) farms. Data were mathematically composited by the number of cows consuming the diet and analyzed using farm as the experimental unit. Outliers (n = 3) were identified and removed from the dataset when Cooks-D exceeded 0.13.

Table 3.9. Effects of grain ingredients on bulk tank milk fatty acid composition among high de novo (HDN; n=15) or low de novo (LDN; n=18) farms.

Table 3.10. Least squares means of corn silage analysis provided by farm’s nutritionists for high de novo (HDN) and low de novo (LDN) farms.

Table 4.1. The milk fat and protein percentage from the farms that participated in an interview, the average milk fat and protein percentage from the farms that participated in the study reported in Chapter 3, and the farmer’s perception of their milk fat and protein.

Table 5.1. Descriptive statistics for high de novo (HDN) and low de novo (LDN) herds for studies presented in Chapter 2 and Chapter 3.

Table 5.2. Least squares means of milk composition factors for high de novo (HDN) and low de novo (LDN) farms based on milk composition data for the month of the farm visit for studies presented in Chapter 2 and Chapter 3.

Table 5.3. Least squares means of management factors for high de novo (HDN) or low de novo (LDN) farms observed or recorded during the farm visit for studies reported in Chapter 2 and Chapter 3.

Table 5.4. Dietary chemical composition for diets from high de novo (HDN) and low de novo (LDN) farms for Chapter 2 and Chapter 3. Data were mathematically composited by the number of cows consuming the diet and analyzed using farm as the experimental unit.
LIST OF FIGURES

Figure 1.1. Milk fat percentage in bulk tank milk is positively correlated to de novo FA concentration among St. Albans Cooperative Creamery dairy herds.................. 49

Figure 1.2. Milk true protein percentage in bulk tank milk is positively correlated to de novo FA concentration among St. Albans Cooperative Creamery dairy herds........................................................................................................ 50

Figure 1.3. Normal and alternate rumen biohydrogenation pathways (Adapted from Jenkins, 2011). .......................................................................................................................... 53

Figure 3.1. Milk fat content and dietary physically effective NDF (peNDF) from commercial dairy farms (n=32) exhibit a quadratic relationship................................. 115

Figure 3.2. De novo FA (fatty acid; expressed as g/100g of FA) and dietary physically effective NDF (peNDF) as a % of DM from commercial dairy farms (n=32) exhibit a weak quadratic relationship................................................................. 116

Figure 4.1. Information sources (normal font) and barriers to communication (italic font) that are involved with the transfer of knowledge to dairy farmers........... 144
CHAPTER 1: COMPREHENSIVE LITERATURE REVIEW

1.1. INTRODUCTION AND PROJECT BACKGROUND

In 2000, the US Department of Agriculture Federal Milk Marketing System developed a component-based milk pricing strategy where the price that dairy farmers receive is based primarily on the yield of milk fat and protein, and less so on the total volume of milk produced (Vyas et al., 2012). The price of milk is determined by a complicated pricing system with both market and public administration inputs (Manchester and Blayney, 2001). Farm payments are determined using a price differential based on the fat and protein yield, as well as other geographic and market factors (Manchester and Blayney, 2001). Federal milk marketing orders were established to help counter milk market volatility, but the price producers receive can still be highly variable (Jeffords, 2010).

Regardless of the market, high fat and protein yields are important to maintain farm profitability. Bailey et al. (2005) report that increasing milk fat and protein percentages by one standard deviation (3.76 ± 0.30% for fat; 3.05 ± 0.17% or protein) increased income over feed cost by 7.7% or $16,096 for Holstein herds and 9.2% or $16,229 for Jersey herds given the market at the time. Furthermore, Karszes and Howland (2015) found that the total yield of fat and protein per cow per day explains 70% of the variation in net milk income over total feed costs, and income over feed costs is the most consistent predictor of farm probability.
This research aims to identify management practices and dietary strategies that can be used by dairy farmers to improve the amount of fat and protein in their cows’ milk. In addition, this research explores how information is communicated to dairy farmers, and the barriers to successful information transfer.

The commercial dairy farms enrolled in this research study were members of the St. Albans Cooperative Creamery (St. Albans, VT). The St. Albans Cooperative Creamery member farms were located in Vermont, New Hampshire, and Northeastern New York. All of the farms received milk prices calculated for the Federal Milk Marketing Ordinance Federal Order 1, or the Northeast Marketing Area (USDA AMS Federal Milk Marketing Ordinance, 2011), and the prices were adjusted based on individual farm fat and protein yields. The St. Albans Cooperative Creamery began working with Dr. Dave Barbano (Cornell University Department of Food Science, Ithaca, NY) in 2012. Dr. Barbano developed novel mid-infrared spectroscopy models that can measure milk fatty acid (FA) composition. Every bulk tank milk sample sent to the St. Albans Cooperative Creamery payment testing lab has been analyzed for FA profiles since October, 2012. Important correlations between FA composition and milk fat and protein content were discovered due to the FA profile monitoring (Figure 1.1).

Fatty acids in milk fat can be broadly grouped into three categories: de novo, preformed, and mixed. De novo FA are short chain FA that are synthesized in the mammary gland. The bulk tank monitoring of St. Albans Cooperative Creamery herds revealed a strong positive correlation between de novo FA concentration and milk fat (Figure 1.1) and protein content (Figure 1.2).
The relationship between de novo FA concentration and milk fat and protein content is not well understood. Understanding the relationship between de novo FA and milk fat and protein may elucidate strategies to improve fat and protein content on commercial farms. While milk fat and protein percentage can be affected by a number of factors, farm management and nutrition strategies generally have the largest impact (Bauman et al., 2006).

Farm management recommendations can then be made to farmers based the results of this research. However, there is a need to better understand how to communicate with farmers in a way that motivates them to make changes to improve milk fat and protein production. In addition, it is unclear whether farmers have an accurate perception of their current milk fat and protein production, and it is imperative that farmers who are below average perceive that they have room for improvement. Only then will they become interested in learning more about ways to improve milk fat and protein.

1.1. THE BIOLOGY OF MILK FAT SYNTHESIS

1.1.1. Milk Fat Synthesis

Milk from dairy cows varies in fat content and composition. Typically, Jersey cattle have the highest percentage of fat, whereas Holstein cattle have lower fat percentage but a higher total milk yield. Milk fat content and composition vary within breed due to animal factors including genetics, stage of lactation, ruminal fermentation, and mastitis (Palmquist et al., 1993; Jensen, 2002). Milk fat content and composition also
vary due to nutritional factors such as grain intake, dietary fat, energy intake, seasonal and regional effects, and dietary fat supplements (Palmquist et al., 1993; Jensen, 2002).

Approximately 98% of the lipid portion of milk is made up of triacylglycerides (Neville and Picciano, 1997). Triglycerides are composed of three FA and a glycerol backbone. Although over 400 different FA have been identified in bovine milk, about 20 FA make up the majority (Jensen et al., 2002). Fatty acids in milk fat can be broadly grouped into three categories: de novo, preformed, and mixed FA. De novo FA are short and medium chain FA (C4 to C14) and are synthesized in the mammary gland. Preformed FA (≥C18:0) are absorbed from the diet or mobilized from stores of body fat in the cow. Mixed FA (C16:0 and C16:1) can originate from preformed FA or from de novo synthesis, with about 40 to 50% of C16:0 arising from de novo synthesis (Loften et al., 2014). The proportion of the common FA in bovine milk varies, but generally appears as shown in Table 1.1 (adapted from Jensen, 2002). Palmitic (C16:0) and oleic acid (C18:1 cis-9) are the predominant FA found in bovine milk (22-35 and 20-30 wt%, respectively). Between 18 to 28% of FA in bovine milk are synthesized de novo (Jensen, 2002).

Glucose, acetate, and butyrate are the major substrates needed for de novo FA synthesis in the mammary gland. Glucose from propionate is converted into cofactors or reducing agents (Vernon and Flint, 1983). The first and rate-limiting step in FA synthesis is the conversion of acetyl-CoA to malonyl-CoA, catalyzed by acetyl-CoA carboxylase (Ha and Kim, 1994). Next, the FA synthase catalyzes a series of seven reactions, each of which adds a two-carbon unit to the acyl chain (Smith, 1994). Acetate and butyrate originating from ruminal fermentation of feeds are the major building blocks for de novo synthesis.
milk FA synthesis (Morvay et al., 2011; Harvatile et al., 2009). Finally, a thioesterase enzyme cleaves the FA from the FA synthase (Neville and Picciano, 1997).

Long chain FA are derived from nonesterified FA bound to serum albumin or cleaved from circulating chylomicron by the enzyme lipoprotein lipase (Neville and Picciano, 1997). Once preformed and de novo FA enter the cytoplasm of the mammary epithelial cells, they are bound to FA-binding proteins or they are activated for triacylglyceride synthesis by acetyl-CoA. Microlipid droplets are synthesized in the endoplasmic reticulum, fuse to form cytoplasmic lipid droplets, and are enveloped by the apical membrane to form the milk fat globule that is secreted into the milk (Neville and Picciano, 1997).

1.1.2. Rumen Fermentation

The rumen is a carefully regulated environment, and its main purpose is to ferment, or digest, plant material consumed by ruminant animals. Rumen fermentation is carried out by vast populations of rumen microorganisms. Volatile fatty acids (VFA) are end products of rumen microbial fermentation and are the main energy source for ruminants (Bergman, 1990). The primary VFA are acetate, propionate, and butyrate. Generally, acetate is produced through the fermentation of structural carbohydrates such as cellulose and hemicellulose, whereas starch fermentation produces propionate, therefore diets that contain a higher proportion of forage are associated with higher acetate to propionate ratios (Dijkstra, 1994). Propionate is glucogenic and contributes 65-80% of the glucose utilized by the cow (Morvay et al., 2011; Reynolds, 2003). Acetate and butyrate are nonglucogenic VFA and are primarily sources of FA synthesis (Morvay
et al., 2011; Dijkstra, 2011). In an analysis of 20 published research studies, Seymour et al. (2005) demonstrated that milk fat content is positively correlated to rumen acetate ($r = 0.31$) and negatively correlated to propionate ($r = -0.25$) and butyrate ($r = -0.11$).

However, propionate supply was negatively correlated with milk fat content, but positively correlated with milk protein content (Dijkstra, 1994). It was originally believed that increasing the supply of acetate and butyrate increases milk fat content (Dijkstra, 1994). More recent literature has reported that increasing the molar percentage of acetate is correlated with increased milk fat; however, acetate molar percentage does not accurately reflect acetate production on a moles/d basis (Bauman and Griinari, 2003).

When exogenous acetate is supplemented, milk fat does not always increase significantly (Davis and Brown, 1970). Bauman and Griinari (2003) summarized 5 studies that compared low forage to control diets, and found that the molar percentage of acetate decreased significantly on the low forage diets; however, the ruminal production of acetate (moles/d) did not change. The authors concluded that the supply of acetate and butyrate was not different when a low-fiber diet was fed, and that changes in milk fat content are not likely to be a result of a limited supply of acetate and butyrate (Bauman and Griinari, 2003).

Ruminal fermentation and VFA production are largely supported by a vast rumen microbial population. This population consists of bacteria, protozoa, viruses, and fungi. Bacteria in the rumen are as abundant as $10^{10}$ cells per ml of ruminal contents and range in size from 0.5 to 5 μm (Russell, 2002). Approximately 75% of rumen bacteria are loosely or firmly adhered to feed particles and the remainder are free floating, planktonic bacteria (Russell, 2002). Rumen bacteria can be grouped into two subcategories:
cellulolytic and amylolytic. Cellulolytic bacteria primarily ferment fiber and produce acetate and butyrate, whereas amylolytic bacteria primarily ferment starch and produce propionate (Russell, 2002).

Protozoa are much larger in size than bacteria (30 to 135 μm), and although their numbers in the rumen do not often exceed $10^7$ cells per ml, they make up about half of the total microbial biomass (Russell, 2002). Rumen protozoa often associate with feed particles (Russell, 2002). The main VFA end products of feed digestion by protozoa are acetate and butyrate, with trace amounts of propionate (Dijkstra, 1994). Protozoa contribute 16 to 37% of total VFA, depending on the amount of dry matter intake and ratio of dietary forage:concentrate (Dijkstra, 1993). Rumen fungi are difficult to quantify, but are estimated to make up no more than 6% of the total rumen microbial biomass (Russell, 2002).

Lactate is another VFA found in the rumen that is either produced during silage fermentation and is directly consumed by the cow (Allen, 1997), or is the end product of rapid starch fermentation (Russell, 2002). Lactate is a much stronger acid than the other VFA (pK<sub>a</sub> 3.9 versus approximately 4.7, respectively); therefore, its accumulation in the rumen poses a larger risk for rumen acidosis, or periods of decreased and prolonged low rumen pH (Russell, 2002).

Repeated exposure to low ruminal pH is a condition known as sub-acute rumen acidosis (SARA) which is defined as periods of moderately depressed rumen pH ranging from 5.8 to 5.0 (Krause and Oetzel, 2006). Sub-acute rumen acidosis can impair rumen fermentation, decrease milk production, induce laminitis, and in severe cases it can cause liver and lung abscesses (Stone, 2004; Krause and Oetzel, 2006).
1.1.3. **Stage of Lactation and Energy Status**

Milk fat synthesis and uptake is the largest single contributor to the energy demand for milk production in dairy cows (Gross et al., 2011). In early lactation, cows experience negative energy balance which is compensated for by the mobilization of body reserves (Palmquist et al., 1993; Gross et al., 2011). Adipose FA are mobilized and incorporated into milk fat as preformed FA (Palmquist et al., 1993). De novo FA are low in early lactation and increase substantially, reaching > 90% of the maximum proportion by week 8 of lactation (Palmquist et al., 1993). As cows achieve energy balance and adipose mobilization is no longer necessary to support milk production, the proportion of de novo FA increase and preformed FA decrease.

Due to insufficient quality or quantity of feed, cows can experience negative energy balance in mid or late lactation (Leiber et al., 2005). Gross et al. (2011) studied the effect of energy balance on milk FA profiles in cows from week 14 through 16 of lactation. A negative energy balance was induced through a 3-week feed restriction where cows were fed to 49% of energy requirements. Milk fat percentage increased, de novo FA yield decreased, and preformed FA yield increased in feed-restricted cows compared to control cows. Due to considerable adipose tissue mobilization, C18:1 cis-9 increased markedly in feed restricted cows.

1.2. **EFFECT OF DIET ON MILK COMPOSITION**

1.2.1. **Dietary Lipids**

Nutrition is the predominant factor that affects milk fat percentage and milk FA profile (Bauman et al., 2006). The most dramatic example is low milk fat syndrome, or
milk fat depression (MFD). Milk fat depression occurs when the diet and/or management alters the rumen fermentation environment and when the diet contains high levels of unsaturated FA (Baumen et al., 2006), which leads to altered biohydrogenation of unsaturated FA by rumen microbes (Bauman and Griinari, 2003). Rumen microbes must biohydrogenate unsaturated free FA before incorporation into cell membranes in order to maintain appropriate membrane fluidity. Rumen biohydrogenation can occur through the normal or alternate biohydrogenation pathway (Figure 1.3.; adapted from Jenkins, 2011). The alternate rumen biohydrogenation pathway includes the production of trans-10 cis-12 C18:2 which is associated with MFD due to decreased de novo milk FA synthesis (Harvatine and Bauman, 2011; Bauman et al., 2006). It is hypothesized that other trans biohydrogenation intermediates, such as trans-10 C18:1 and trans-11, cis-15 C18:2 play an interactive role in MFD, however trans-10 cis-12 C18:2 is the primary intermediate shown to cause a reduction in milk fat percentage (Bauman et al., 2006). The mechanism by which trans-10 cis-12 C18:2 causes MFD is still an active area of research. However, it is hypothesized to down-regulate the expression of genes related to FA uptake, transport, synthesis, and esterification (Jenkins, 2011).

Saturated FA supplementation in dairy rations is a growing area of interest. Saturated FA do not provide substrate for rumen biohydrogenation and therefore are naturally rumen inert (Lock et al., 2013). Vyas et al. (2012) hypothesized that saturated short- and medium-chain FA, which under normal metabolic conditions originate from de novo synthesis, have the greatest potential for increasing milk fat synthesis. Their research demonstrated an increase in milk fat of 0.17, 0.25, and 0.33 percentage-units when short and medium chain FA (C8-C16) were fed at 200, 400, and 600 g/d,
respectively. However, milk yield decreased when short and medium chain FA were fed at 600g/d, resulting in a peak milk fat yield at 400g/d.

Research by Lock et al. (2013) showed an increase in milk fat concentration from 3.88 to 4.16% and fat yield from 1.23 to 1.32 kg/d with no change in milk yield when cows were fed a diet containing a fat supplement with approximately 85% palmitic acid (C16:0). The supplement was fed at 2% of dry matter intake. This increase in milk fat was accounted for by C16:0 supplementation. Stoffel et al. (2013) fed diets enriched in either linoleic acid (cis-9, cis-12 C18:2), oleic acid (cis-9 C18:1) or palmitic acid (C16:0) at less than 3% of total FA. The diet enriched with C18:2 decreased milk fat yield and percentage, specifically de novo FA yield, and increased the alternate biohydrogenation intermediate C18:2 trans-10 cis-12 isomer. Supplementation of C18:1 slightly increased milk C18:0 and C18:2 trans-10 cis-12 but did not affect fat yield, percentage, or de novo synthesis. Supplementation of C16:0 increased milk C16:0 but did not change other FA yields.

To maintain proper milk fat globule fluidity, the FA esterified into triacylglycerides must be in a combination that results in a melting point less than the body temperature of the cow (39°C; Jensen, 2002). Hansen and Knudsen (1987) reported an increase in de novo synthesis when C16:0 was added to an incubation of bovine mammary epithelial cells, due in part to the short chain fatty acid’s lower melting point. Alternatively, when C18:1 was added to the incubation, de novo synthesis decreased because C18:1 was preferentially incorporated into the sn-3 position to maintain fluidity.
1.2.2. **Fermentable Carbohydrates**

High producing dairy cows require an adequate supply of dietary energy to support the demands of maintenance, milk production, and reproduction. Carbohydrates generally account for 65% or more of the dietary DM consumed by high producing dairy cows, and the extent of carbohydrate fermentation is highly variable (Allen, 1997). In the United States, corn grain is often fed to meet a high producing cow’s energy requirements (Bradford and Allen, 2004). Corn grain is a highly fermentable carbohydrate source, however fermentability varies due to method of preservation and extent of processing (Firkins et al., 2001). The inclusion of a high concentration of rapidly fermentable carbohydrates is a risk factor for MFD (Bradford and Allen, 2004; Longuski et al., 2009). This is generally associated with a decrease in rumen pH (Bauman and Griinari, 2003). However, Oba and Allen (2003b) reported a decrease in milk fat yield as a response to increased starch fermentability in a high starch diet (32 vs 21%) without treatment differences in mean rumen pH. The decrease in milk fat yield may have been due to increases in propionate, as propionate infusions decrease milk fat content and yield independently of rumen pH (Rulquin et al., 2007; Maxin et al., 2011). High-moisture corn increases starch fermentability when compared to ground dry corn by as much as 20% (Knowlton et al., 1998; Oba and Allen, 2003a). Bradford and Allen (2004) reported 0.9 g/100g FA decrease in de novo synthesis of C10:0 to C14:0 when cows were fed high-moisture corn compared with ground dry corn. Mixed origin FA tended to increase, and preformed FA remained unchanged. Milk from cows fed high-moisture corn increased the production of trans-10 C18:1 and cis-9 trans-11 C18:1 by
1.01 and 0.07 g/100g FA, respectively, suggesting an increase in incomplete rumen biohydrogenation. Treatments did affect trans-10 cis-12 C18:2. However, milk fat depression was reported in cows producing less than 40 kg/d of 3.5% fat-corrected milk.

1.2.3. Forage Particle Size

The physical characteristics and chemical composition of the diet affect the time spent chewing during both eating and ruminating (Beauchemin and Buchanan-Smith, 1989). Chewing is associated with increased saliva output, which buffers ruminal fermentation acids as well as supplies enzymes that aid in digestion (Ulyatt et al., 1986). Chewing is also the primary means of particle size reduction, affects transport of digesta from the reticulorumen, and contributes to overall ruminal passage rate and the location of digestion (Ulyatt et al., 1986; Beauchemin and Buchanan-Smith, 1989).

In part, chewing is stimulated by feeding adequate physically effective NDF (peNDF). It was originally believed that feed particles retained on the 1.18-mm sieve contribute to the rumen digesta mat and are an index of peNDF (Mertens, 1997). However, the majority of the original rumen passage research was conducted in sheep, and in cattle, particles ≥ 3 to 4-mm contribute to the rumen mat (Dixon and Milligan, 1981; Cardoza and Mertens, 1986; Yang et al., 2001a; Oshita et al., 2004). Mertens (2002) recommended feeding adequate peNDF to maintain rumen health and avoid MFD. However, diets that exceed the recommended peNDF, or that contain high levels of undigested NDF (uNDF) may slow ruminal passage rates, limiting DMI and reducing milk production (Taylor and Allen, 2005).
Yang et al. (2001b) found that when feeding a forage-to-concentrate ratio of 55:45 on a dry matter basis, milk fat percentage increased. However, at a lower forage to concentrate ratio of 35:65, milk production increased and total tract fiber and starch digestibility was improved. Milk fat, rumination time, and mean rumen pH increased, and time spent below a pH of 5.8 decreased, for cows eating the 60:40 diet compared with 35:65 (Yang and Beauchemin, 2009). Many other studies have documented the inverse relationship between concentrate allocation and rumination time (Robinson and McQueen, 1997; Maekawa et al., 2002; Kononoff and Heinrichs, 2003).

Caccamo et al. (2014) found no changes in milk or milk fat, but an increase in protein percentage, in a field study of commercial dairy herds when peNDF was between 16.0 and 21.9. A peNDF above or below the reported range resulted in a decrease in protein yield. However, peNDF in the study was calculated using the proportion of particles on an as-fed basis retained on the 1.18-mm screen and above, and current recommendations are to measure the proportion of particles retained on a 4-mm screen and above when testing particle size distribution with as fed samples.

Kononoff and Heinrichs (2003) reported a quadratic effect of four alfalfa particle lengths on rumen pH. However, altering the particle size of corn silage did not affect rumen pH. These findings are in conflict with Beaucheman and Yang (2005), who reported an increase in total chewing time (sum of rumination time and eating time) for cows consuming diets that contained higher peNDF. In this case, the peNDF was altered by increasing theoretical length of cut of corn silage in a corn silage-based diet. Despite the differences in peNDF, Beaucheman and Yang (2005) reported no differences in rumen pH.
Grant et al. (1990a) reported a decrease in milk fat percentage, but not milk yield, when cows were fed fine ground (1.0 mm) versus coarse ground (2.1 mm) alfalfa hay at 55% of diet dry matter. Cows fed the fine chopped hay ruminated 2.5 h/d less, experienced a decrease in rumen pH, and increased rumen propionate concentration. Grant et al. (1990b) also found that feeding fine ground alfalfa silage (2.0 mm) versus course ground alfalfa silage (3.1 mm) did not affect milk yield, but decreased milk fat percentage from 3.8% to 3.0%, respectively. Cows consuming the fine ground alfalfa silage ruminated less, chewed less while eating, experienced a decreased rumen pH, and produced less acetate per unit of propionate in the rumen, however the moles/d of acetate produced was not measured.

Recent research has discovered the role of uNDF in characterizing the physical effectiveness of fiber (Cotanch et al., 2014). In addition to physical effectiveness, uNDF influences gut fill and the ruminal passage dynamics of forages (Cotanch et al., 2014). Undigested NDF can be used to estimate the fast and slow pools of NDF digestion (Raffrenato and Van Amburgh, 2010), and the greater the turnover, the more a cow can consume (Cotanch et al., 2014). There is likely a minimum and maximum uNDF that should be included in the ration to avoid limiting feed intake while maintaining rumen health (Cotanch et al., 2014). Further research is needed to understand the interaction of peNDF and uNDF, and the role of uNDF in optimizing rumen health and milk fat composition.
1.2.4. Dietary Supplements and Additives

When milk fat percentage and yield are normal, specific nutritional supplements and additives may affect milk fat content, yield, and composition. Rumen buffers, such as sodium bicarbonate, sodium sesquicarbonate, and magnesium oxide, increase rumen pH (Overton, 2015). In a meta-analysis of 40 publications, Meschy et al. (2004) reported that rumen buffer supplementation increased DMI by 0.5 kg/d, increased milk yield by 0.5 kg/d, increased milk fat by 0.15% units, and increased rumen pH. However, the authors noted that the response to buffers is largely dependent on the extent of SARA, and cows experiencing more severe SARA were more likely to respond. The improvement in milk fat percentage may have been due to a reduction in biohydrogenation intermediates escaping the rumen (Kalscheur et al., 1997). Cabrita et al. (2009) fed wheat- and corn-based diets with or without 6.5 g/kg DM sodium bicarbonate and 4.8 g/kg DM magnesium oxide and found that buffer supplementation resulted in a more complete rumen biohydrogenation, with no effects on milk production or milk fatty acid profile, but with a trend for an increase in plasma urea concentration which suggests that feeding buffers increased rumen pH. In a meta-analysis, Glasser et al. (2006) found no effects of rumen pH on duodenal flow of cis-18:1, trans-18:1, or the sum of C18:2, but a significant interaction of C18:2 cis-9, cis-12 duodenal flow and rumen pH. The effects reported by Cabrita et al. (2009) may be explained by an increase in rumen pH in cows consuming diets with added buffers, which may have protected against the alternate biohydrogenation pathway, but further research is needed to completely understand this mechanism.
Decreasing the dietary cation-anion difference (DCAD) has been researched extensively as a way to improve transition cow health, but there is also an opportunity to improve performance in peak lactation by increasing DCAD. In a meta-analysis by Hu and Murphy (2004), increasing the DCAD resulted in quadratic increases in milk, fat, and protein yield. However, there was no difference in milk fat or protein percentages. Harrison et al. (2012) reported an increase in milk fat and protein content and a trend for increased fat yield in early lactation cows fed a positive DCAD diet compared to the controls.

Most yeast and yeast culture products are marketed with the support of research data that show positive effects on milk composition (Overton, 2015). In a meta-analysis of 110 papers and 157 experiments, Desnoyers et al. (2009) found that Saccharomyces cerevisiae supplementation increased rumen pH, decreased lactic acid concentration, increased total tract organic matter digestibility, increased DMI, increased milk yield, and tended to increase milk fat content with no effect on milk protein content. Studies that reported a higher concentrate level and greater DMI also found a greater positive effect of treatment on rumen pH. Alternatively, studies with higher NDF were negatively correlated with the efficacy of yeast to increase rumen pH, perhaps because the pH was more optimal to begin with if the cows were consuming diets with adequate NDF.

1.3. EFFECT OF MANAGEMENT ON MILK COMPOSITION

Bach et al. (2008) demonstrated the effects of management on lactation performance by surveying 47 commercial dairy farms feeding the same diet with similar genetics. Milk yield varied from 20.6 to 33.8 kg/d, and management factors such as age
at first calving, presence or absence of feed refusals, stall stocking density, and whether feed was pushed-up in the feed bunk explained 56% of the observed variation in milk yield not attributed to nutrition. Management strategies that restrict resting and lying behavior, such as overstocking, can affect rumen fermentation partially due to changes in the time spent eating and ruminating (Batchelder, 2000).

1.3.1. Feeding and Resting Behavior of Lactating Dairy Cows

To maintain health and productivity, cows must be allowed to exhibit normal behavior and adhere to their optimal time budget (Table1.2; Grant and Albright, 2001). Cows exhibit a diurnal pattern of feeding behavior, with the majority of feeding occurring during the day and early evening and less frequent feeding occurring at night and during early morning (DeVries et al., 2003). Feeding occurs on most farms in the early morning, and often time coincides with the return from milking. Interestingly, DeVries and von Keyserlingk (2005) found that cows increase total daily eating time by 12% when fed 6 h after milking compared with immediately after milking. However, this study found no difference in DMI or milk production.

Cows rest while laying down for approximately 50% of their day (Table 1.2). However, the time an individual cow spends lying varies substantially. In a study of 45 British Columbia farms, Ito et al. (2009) found that individual cow’s lying time varied from just 4 h per d to as much as 19.5 h per d (mean lying time was 11 h per d). In addition, lying bouts ranged from just 1 to 28 bouts per day (Ito et al., 2009).
When cows are not provided with adequate resources (bunk space and freestalls) and must choose between time spent resting or eating, cows will give priority to resting time (Metz, 1985; Munksgaard et al., 2005). As a result, the time spent eating will decrease. Management factors that limit cows’ access to resources, or differentially motivate her to eat, can affect eating and resting behavior. These changes in behavior can substantially influence rumen fermentation dynamics and rumen pH (French and Kennelly, 1990), and in turn may affect de novo synthesis (Bauman and Griinari, 2001).

1.3.2. **Rumination Behavior of Dairy Cows**

Rumination is the main form of particle size reduction in ruminants (Ulyatt et al., 1986; Beauchemin and Buchanan-Smith, 1989). Rumination is associated with increased saliva output, which buffers ruminal fermentation acids and supplies enzymes that aid in digestion (Ulyatt et al., 1986). Cows spend between 7 and 10 h per d ruminating (Grant and Albright, 2001; Dado and Allen, 1994). In general, cows ruminate 66 minutes per d for every kg of NDF consumed (Dado and Allen, 1994). The biological effects of rumination are described in more detail in a previous section.

1.3.3. **Stocking Density**

A USDA National Animal Health Monitoring Service (NAHMS) survey of freestall dairy farms found that 58% of farms were overstocked at the feed bunk (defined as less than 0.60 m/cow of bunk space) and 43% provided less than one stall per cow (USDA, 2010). In the Northeast, the average bunkspace stocking density provided just 46cm/cow (von Keyserlingk et al., 2012). Overcrowded freestalls or feed bunks result in abnormal behavior and affect cows’ time budgets (Grant and Albright, 2001). Increasing
stocking density from 75% to 300% incrementally resulted in a curvilinear reduction in eating time and a curvilinear increase in aggressive behaviors at the feed bunk (Huzzey et al., 2006). However, Hill et al. (2009) reported no difference in eating time but a decrease in resting time when cows were stocked at 142 compared with 100%.

Overstocking also increases rate of feed consumption and increases meal size, with less meals consumed throughout the day (Grant and Albright, 2001). When stalls are not available, cows spend more time standing, and this reduction in lying time decreases total daily rumination time (Batchelder, 2000). Hill et al. (2007) reported a 0.2%-unit reduction in milk fat when cows were crowded at 142% compared with 100%. Krawczel et al. (2012) housed cows at a 100, 113, 131, or 142% stocking rate for two-week periods and reported an increase in feed bunk aggression and a decrease in lying time. These behavioral changes were not accompanied by changes in milk yield or composition; however, shorter durations of increased stocking density may not reflect the interactive effects of overstocking in a commercial dairy setting. It is unclear why a change in milk fat content was observed by Hill et al. (2007) but not by Krawczel et al (2012), but may have been due to differences in diets fed in each study. Campbell et al. (2015) compared 100 versus 142% stocking density and diets with and without straw in a 2 x 2 factorial design and found a significant interaction between diet and stocking density on milk fat percentage and a trend for milk fat yield. Mean rumen pH tended to be higher when cows were housed at 100% stocking density, and the time spent below a pH of 5.8 decreased when cows were stocked at 100 versus 142% and when they were fed straw in the diet versus no straw. There was no effect of stocking density on milk fatty acid profiles.
1.3.4. Feed Restriction

The consequences of overstocking can be exacerbated by not allowing physical access to feed during the day. Feeding 5% above predicted feed intake is recommended to ensure that cows have adequate access to feed for 24 h/d (Grant and Albright, 2001; NRC, 2001; NFACC, 2009). A survey of dairy farms in the Western United States found that an increasing number of dairy managers are feeding for 0% feed refusals, presumably in an attempt to reduce feed costs (Silva-del-Rio et al., 2010). Feeding for 0% refusals greatly increases the likelihood that feed will not be available to the cow for extended periods of time throughout the day.

Schutz et al. (2006) found that 3-h of feed restriction per day changed normal feeding behavior and increased motivation to seek out feed. Collings et al. (2011) studied the interaction of feed restriction (10 h/d) and overcrowding (1:1 or 2:1 cows:bin) and found that feed-restricted, overcrowded cows exhibited a 25% increase in feeding rate during the first two h after feeding. In addition, bunk displacements were 3x higher compared to the unrestricted, 100% stocking density group. Furthermore, compared to 6 h of feed restriction, unrestricted cows produced 3.6 kg more milk and spent more time lying in stalls and eating at the feed bunk (Matzke, 2003).

Feed restriction through feeding for zero refusals can also increase sorting behavior (Sova et al., 2013). Cows usually sort against long particles, which reduces the NDF in the portion of the diet they consume (Leonardi and Armentano, 2003). Cows housed and fed individually in tiestall facilities sort throughout the day, but over 24 h the cow consumes a ration that is similar to what was offered (Maulfair and Heinrichs, 2013).
Sova et al. (2013) found that an increase in sorting in a freestall barn is associated with a 1 kg/d reduction in milk yield, due in part to the fact that the nutrient profile of the ration is being altered by the act of sorting and because sorting occurs when cows experience an increase in competition and a lack of access to feed.

1.3.5. Feeding Frequency

Fresh feed delivery promotes normal feeding behavior (longer meal duration, increased meals per day) and feeding more than once per day can promote rumen health (DeVries et al., 2005; Mantysaari et al., 2006) and reduce the risk of SARA (French and Kennelly, 1990). However, a survey in Minnesota found that 70% of farms feed TMR once per day (Endres and Espejo, 2010). Feeding only once per day results in a peak in feeding directly after the delivery of fresh feed, a condition known as slug feeding (DeVries et al., 2005). Cows fed twice per day versus once per day spend more time eating and ruminating, and decrease sorting behavior (Sova et al., 2013). Rottman et al. (2014) demonstrated a 0.22 to 0.45% increase in milk fat percentage when cows were fed four times per day compared with one time per day. However, other studies have reported a decrease in resting time when cows are fed more than twice per day (Mantysaari et al., 2006; Phillips and Rind, 2001). Hart et al. (2014) compared 1x, 2x, and 3x feeding frequency with feed delivery occurring when the cows returned from each of their three milkings. Cows fed 3x had the greatest DMI, but treatments had no effect on lying time or milk production. It is likely that twice per day feed delivery optimizes resting time, rumen conditions, and milk production, and perhaps feeding beyond twice per day is not necessary.
1.3.6. Facility Design

The majority of the recent feeding behavior research has been conducted in freestall facilities with TMR diets. The 2007 USDA NAHMS survey indicated that 50% of dairy operations house lactating cows primarily in tiestall facilities (USDA, 2010). Nearly 60% of the lactating dairy cows in the US are housed in a freestall facility, because larger operations are more likely to house lactating cows in a freestall (USDA, 2010). Presumably the percentage of cows housed in freestall facilities has increased since 2007; nevertheless, in the Northeast tiestall housing systems are still common. In a tiestall or stanchion facility, cows have access to feed up to 24 h/d provided that feed is available in the manger and that the cow is in her stall. By design, tiestall and stanchion barns provide one cow per stall, and the bunk space available to the cow is usually equal to the stall width. The continuous access to feed in a tiestall facility resulted in more meals consumed per day compared to freestall housed cows fed at a manger that provided 0.76 m per cow, although total eating time was not affected (Colenbrander et al., 1991). The difference in meals consumed is likely due to the non-competitive environment of a tiestall versus the more competitive environment of a freestall, even when bunk space exceeds recommendations.

1.3.7. Feeding Strategy

The goal of feeding a TMR is to meet dietary requirements with a consistently mixed and available feed. A TMR consists of a uniform mix of forages and concentrates that are delivered to the cow as one mixture. Component feeding, on the other hand, strives to meet cow’s nutritional requirements by feeding separate ingredients, or
“components” of the diet one or several times per day. Component feeding may include hay crop silage, corn silage, dry hay, and/or topdress grain. Component feeding is more commonly practiced in tiestall facilities where cows are fed individually.

Because component-fed herds are decreasing in number in the United States, very little recent research is available in the literature about best management practices for feeding frequency and sequence. If several forages are available to the cow, the most palatable should be fed directly before or after concentrates to encourage fiber intake and buffer rumen pH (Robinson, 1989). In a component-fed facility, concentrates are often fed in large quantities once or several times per day. The consumption of a large quantity of rapidly fermentable carbohydrates decreases rumen pH and increases a cow’s risk for MFD (Bauman and Griinari, 2003; Bradford and Allen, 2004; Longuski et al., 2009). Yang and Varga (1989) compared concentrate feeding frequency of one, two, and four times daily in component fed cows and reported an increase in milk fat and milk protein in cows fed concentrate four times per day compared with once. Feeding dietary components separately increases a cow’s risk for SARA compared with feeding a TMR (Krause and Oetzel, 2006).

1.3.8. Behavior and Rumen Conditions

Management strategies that affect rumen fermentation are important when explaining variation in milk FA profiles. Overcrowded cows are more likely to increase their feeding rate (Collings et al., 2011), increase idle standing time, and decrease rumination (Batchelder, 2000). Increased eating rate and decreased rumination time increase the risk for SARA, which can cause a shift towards the altered rumen
biohydrogenation of FA, as discussed above (Bauman and Lock, 2006). An increasing rumen pH is positively correlated to milk fat percentage from experiments reported in the literature (Allen, 1997).

1.4. COMMUNICATION FOR INNOVATION WITH DAIRY FARMERS

‘Communication for Innovation’ is a framework for analyzing the flow of communication and complexities of information transfer (Leeuwis, 2004). Leeuwis (2004) defines communication for innovation as “a series of embedded communicative interventions that are meant, among others, to develop and/or induce innovations which supposedly help to resolve (usually multi-actor) problematic situations.” Recommendations intended for dairy farm owners and managers have to be communicated in a way that is engaging, understandable, and motivating in order for them to apply the practices to their farm. Therefore, the final section of the literature review examines the communications literature as it applies to dairy farm management.

1.4.1. The Complexity of Managing Farms

Agricultural businesses operate in a context of continuous change and require managers and farmers to maintain up to date, complex, and variable skill sets (Kilpatrick and Johns, 2003). A survey of 2,500 farmers found that farm businesses with more highly educated managers or with managers who participated in more continuing education trainings were more profitable (Kilpatrick, 1996). However, education at only the secondary or post-secondary level will no longer suffice for managers or workers on farms, but instead they will need access to continuous, accessible sources of information.
to stay up-to-date with a constantly evolving agricultural environment (Kilpatrick and Johns, 2003).

Due to the complexity of managing dairy farms, and all of the information that is needed to successfully operate even a small farm business, farmers must seek information from several different resources. Before understanding the resources that farmers typically rely on, and how they prefer to receive information, it is important to understand how they make decisions.

1.4.2. Farmer Decision Making Process

Dairy farm decision making strategies directly affect farm sustainability (Russell and Bewley, 2013). Understanding decision making behaviors is critical for appropriately disseminating information to dairy farmers and meeting their changing needs (Hutjens et al., 2004).

A decision that results in a productivity decrease could be detrimental to the financial stability of a dairy farmer (Borchers and Bewley, 2015). Russell and Bewley (2013) surveyed 229 Kentucky dairy producers using a 1-5 Likert scale about their criteria for success, decision making dynamics, information sources, and technology adoption. The results showed that the most important sources of information when making decisions were advice from veterinarians, nutritionists, and other consultants (3.70 ± 1.23), consulting with family members (3.68 ± 1.45), and intuition (3.10 ± 1.45). In a qualitative interview study conducted by Kauppinen et al. (2010), the intent to improve animal welfare was associated with an appreciation of the work of researchers and other specialists in agriculture. While this study supports that scientific knowledge
can affect farmer’s attitudes and behavior, it is unclear whether the scientific knowledge inspired the behavior change or if the farmer developed a plan to change their behavior and then pursued the scientific knowledge.

1.4.3. Motivating Farmers to Make Changes

Before a decision is made on the farm, the farmer must feel motivated to evaluate that aspect of his or her farm and seek out the information required to improve it. Dairy farmers should be motivated to improve milk fat yields due to increased gross income. However, people are more motivated to make decisions that avoid losses than they are to make decisions that will promote gains (Rabin, 1998). In terms of mastitis management, dairy farmers are more motivated to make management changes when threatened with a penalty, or price decrease, than they are when enticed with a bonus, or price increase (Valeeva et al., 2007). This concept, known as “frame effect” in psychology research, may affect dairy farmer behavior regarding milk components because they receive component payments as a bonus for being above a threshold, rather than a penalty for being below a threshold.

Few studies have been conducted to measure dairy farmer beliefs, perception, knowledge, and motivation. This may be due to the inconsistency of naming of different theories, making it difficult to completely review (Kristensen and Jakobsen, 2011). Dairy farmers should be highly motivated to implement changes that improve milk fat yield due to financial benefits; however, reasons for their lack of motivation remain unclear. Perhaps dairy farmers would be more motivated to increase fat yield if the payment
structure resulted in a deduction when below a high but achievable threshold instead of the current system which results in a bonus when above a fairly low threshold.

When farmers are faced with solving a complex problem, such as low milk fat and protein yield, they understand that there is not one easy solution. As a result, they may be less motivated to make changes because they are unsure that these changes will result in an improvement. This is a primary reason why measures to solve complex problem are not adopted (Chase et al., 2006; Garforth et al., 2006; Rehman et al., 2007). Farmers who believe that there is no easy solution perceive that the problem is less important, and accept that the problem cannot be solved (Cameron, 2009). Therefore, they are less motivated to seek out a solution.

1.4.4. How Farmers Learn

Several studies have evaluated how farmers prefer to learn new information. It is clear that farmers seek advice from several people about the different aspects of their farm, including advice from management, financial, and industry-related experts, from family members, and other farm workers (Kilpatrick and Johns, 2003). In addition, they report learning in informal settings from other people, the media, and learning on the job (Bamberry et al., 1997). Russell and Bewley (2013) found that as a general demographic, dairy producers prefer traditional in person training programs and print materials over electronic means of communication and education.

Franz et al. (2010) interviewed farmers about their learning preferences and found that farmers prefer hands-on (99%), demonstrations (96%), farm visits (94%), field days (88%), discussions (87%), and one-on-one (85%) learning. Interestingly, the same study
found that extension agents perceive that farmers prefer farm visits (100%), one-on-one (100%), demonstrations (95%), field days (90%), and on-farm (90%) learning. It is clear that the farmer’s preference and the Extension agent’s perception do not always align; however, both groups highlighted the importance of kinesthetic learning.

Many studies show that an effective style of formal learning is farmer-directed learning groups (Kilpatrick and Johns, 2003). This is consistent with the results of Franz et al. (2010) as hands-on, demonstration, and discussion based learning generally includes interaction with other farmers. In addition, Lasley et al. (2001) found that farmers prefer personalized, face-to-face communication over electronic communication, and in fact, as the amount of electronic communications increase, farmers may be in need of more face-to-face communication with their supporters to help them understand and apply the information contained in the electronic communication.

It is likely that the interaction between farmers happens in informal settings, but also needs to be promoted in more formal, discussion group type settings for knowledge to be shared effectively. A study of social networks in Ghana pineapple farmers found that farmers do not learn from all other farmers (Conley and Udry, 2001). The study randomly matched farmers with 10 other farmers within the same village, and found that only 11% of matches had communicated about practices before. In addition, only 30% of farmers said they would feel comfortable approaching the other farmers for advice (Conley and Udry, 2001).

When considering how farmers learn, it is also important to recognize that there are many different types of learners among the farmer population. Jansen et al. (2010a) categorized farmers into four categories based on how they trust and incorporate
information from external sources: proactivists, do-it-yourselfers, wait-and-see-ers, and reclusive traditionalists. Proactivist farmers seek ample information from their environment. They are users of the Internet, share knowledge with groups of other farmers, and seek information from their veterinarian and other farm consultants. Do-it-yourselfers are well informed but are highly critical of outside information. They generally did not share with other farmers and complained that they received conflicting information from different farm consultants. The wait-and-see-ers tend to be a more complacent group, who recognize the benefits of seeking information but are not always motivated to do so. Lastly, the reclusive traditionalists work alone. They do not appreciate help from external sources and went as far as making attempts to keep consultants and other visitors away from their farm because they suspected these people came with a hidden agenda to make money. Identifying the type of learner the farmer is, and tailoring the message to suit their learning style, may increase the effectiveness of communication and information transfer (Noar et al., 2007).

1.4.4. Geographic Barriers to Rural Communication

Many farmers, especially in the Northeastern United States, live in geographically rural areas. This may present a physical barrier to communication. There are many challenges to rural communication, including an absence of information to communicate, conflicting messages, a fragmented market for information, relatively few farmers scattered over large geographic areas, structural transformation leading to constantly changing channels of communication, a lack of information communication technology (i.e. Internet), and a lack of skills to use the technology (FAO, 2006). Internet access may
improve communication in rural areas because it provides a way to overcome the physical distance between farms in rural areas. However, as the Internet becomes the preferred method of communication, those who do not use the Internet will be even more secluded, and these people generally represent the most disadvantaged portion of the population (Warren, 2007).

1.4.6. Moving Beyond the Diffusion of Innovation Theory

Better communication between specialists, extension agents, and farmers are needed to remove the social or logistical barriers to information transfer (Franz et al., 2010). Many frame information transfer to farmers based on the diffusion of innovation theory. The diffusion of innovation theory attempts to understand why innovation disseminates through a culture at different rates (Kaminski, 2011; Figure 1.4.).

Ondersteijn et al. (2003) found that implementation of best management practices is positively affected by education, but the type of educational strategy is not significant for all farms, indicating that different educational techniques targeted to different farmer typologies may improve the diffusion of innovation.

The diffusion of innovation is complicated by the finding that farmers all define their own perception of success differently. Walter (1997) interviewed farmers in Illinois about their definition of success and found success can be attained by sustaining the land, implementing analytical skill, preserving the farm business, or maintaining an agrarian lifestyle. Even with these four broad groups, approximately 40% of the farmers’ views on success did not fit into any category. The varying definition of success presents another challenge for the diffusion of innovation.
We need to move beyond “diffusing” an innovation and instead promote a process that takes place in the context of a complex system, and communicate in such a way that acknowledges all interacting agents (Leeuwis and Aarts, 2011). Research related to communication for innovation provides a better example of how specialists can communicate with farmers in a way that overcomes some of the barriers to information transfer.

1.4.7. Communication for Innovation with Farmers

Communication with farmers must overcome many barriers, and for this reason many innovations are not adopted by farmers. For example, innovations developed by research that did not include the input of the users, intermediaries, and other societal agents are much less likely to be adopted (Leeuwis and Aarts, 2011). In addition, it must be communicated in a clear and understandable way, because farmers who perceive a problem to be too complex may feel that a complex problem is less important, and the information related to that problem may not be considered relevant to the farmer (Griffin et al., 1999; Moore and Payne, 2007).

Traditional communications theory was based on the subjective model of communication, where the communicator formulates ideas and transfers them to the recipient (Leeuwis and Aarts, 2011). In this model of communication, a failure of information transfer was related to physical barriers, such as a person not checking their email. However, the subjective model did not consider the complexity of a person’s life or decision-making process as a barrier to information transfer. The construction model of communication attempts to consider these complex barriers. Leeuwis and Aarts (2011)
describe the construction model of communication “as a phenomenon in which those involved create meaning in interaction.” Differences in the interpretation of information are based on prior relationships, knowledge, and experiences. Meanings are constructed in a complex context, not a neutral context, and failures of information transfer may be due to the information not aligning with the persons values instead of someone simply not receiving the information (Leeuwis and Aarts, 2011).

There are two communication strategies used when the communicator is attempting to influence a person’s behavior. The first is the traditional “central” strategy, which assumes that people’s decisions are rational and science based (Jansen et al., 2010b). The second is a less direct, more unconscious “peripheral” strategy which persuades farmers to change their behavior (or not change their behavior) based on a series of subconscious cues instead of rational thinking (Jansen et al., 2010b). For the central strategy to be effective, farmers must be motivated to make decisions rationally. When farmers are not motivated to think critically and rationally about a problem, they still may be persuaded to change their behavior if the information is communicated using the peripheral strategy.

Communication for innovation is a communication strategy that transfers information to someone in a way that increases their understanding of a new innovation, motivates them to adopt this innovation, and results in an improvement in their farm business (Leeuwis and Aarts, 2011). There are three processes for the communication for innovation according to Leeuwis (2004). They are:

1) Network building, reconfiguration of existing networks, and development of new networks (Engel, 1995; Callon et al., 1986, Latour, 1987),
2) Supporting social learning and acknowledging that learning is a critical process for acceptance of innovations in an environment (Geels, 2002; Smits and Kuhlmann, 2004; Hommels et al., 2007).

3) Dealing with dynamics of power and conflict, as efforts to influence the status quo lead to tension and block innovation (Leeuwis and Aarts, 2011).

Communicating with these processes in mind will increase the likelihood that a farmer will adopt an innovation successfully.

Even though information will not simply diffuse across a population, it is important to recognize that information will reach certain types of farmers more easily. With regards to best management practice adoption, Baumgart-Getz et al. (2012) recommends a two-tier approach. Tier one involves targeting farmers most likely to adopt (also recommended by Llewelyn, 2011), and tier two involves a continuous effort to increase awareness using networks to inform other farmers about the benefits of adoption. Communication needs to be tailored and customized to the type of farmer based on their perception, goals, attitudes, and motivation (Jansen et al., 2010a). A meta-analysis of the human health communication literature indicates that tailoring messages based on the targeted audience improves the effectiveness and results in a higher likelihood of changing a person’s behavior (Noar et al., 2007).

1.4.8. Description of Current Farmer Communication Practices

Farmers routinely gather auditory, olfactory, visual, and physical contact information that is used to evaluate their animal’s health, welfare, and productivity. They also consult with many different advisors to receive information. A survey of dairy farm
management practices in 2000, 2005, and 2010 showed that the percentage of farms consulting with a nutritionist increased numerically (66.9%, 71.6%, and 72.6%, respectively; Gillespie et al., 2014). The percentage of farms using individual cow records in 2005 versus 2010 numerically increased (60.6% versus 63.6%), while the number of farms using regular veterinary service numerically decreased (68.4% vs 65.8%). Understanding what information farmers use to make decisions, how they are motivated, and how to best communicate with them is important for the dissemination of scientific research to occur. However, there is very little research that addresses the United States dairy farmers’ network of communication.

1.5. JUSTIFICATION OF OBJECTIVES

The objective of this research is to understand the effects of management and nutrition on de novo FA synthesis on commercial dairy farms and to better understand strategies to facilitate information transfer to dairy farmers. Among cows with similar genetics and stage of lactation, management and nutrition have the greatest impact on milk fat content, yield, and composition (Bauman et al., 2006). Previous research has focused on the effects of one or two management practices or dietary strategies in a controlled setting. However, there is also a need to understand the interactive effects of many different management and nutritional strategies in a less controlled, commercial farm setting. To our knowledge, this research is the first to relate milk FA profiles to a variety of management practices and dietary factors on commercial farms.

The objective of the study presented in Chapter Two was to understand how management and nutrition affect de novo FA synthesis on commercial farms. This study
included farms with multiple breed and cross-bred herds. Farms of all sizes, production levels, and management and dietary strategies were included in the study.

The objective of the study presented in Chapter Three was to determine the effects of cow comfort indicators and dietary particle size on de novo FA synthesis among Holstein herds milking at least 50 cows and producing an average of 25 kg of milk per cow per d or more. The farms that participated in this study represent more progressive, larger farms. Focusing on one breed allowed for the control of the effect of breed on our results, because breed has a known effect of milk FA (Soyeurt et al., 2006; Maurice-Van Eijndhoven et al., 2011). It is important to note, however, that the results of this study are relevant to all farms, regardless of the breed of cow that they are milking.

The objective of the study in Chapter Four was to understand the dairy farmer’s perception of his or her cows’ milk fat production, and to explore the network of communication through which farmers receive information. A farmer may perceive his or her fat and protein percentage to be above average, when in reality it is below or at average, which would influence their motivation to make changes in the future. In addition, there is little research addressing the communication network that dairy farmers in the U.S. are a part of, and how barriers within this network block the transfer of information. Therefore, the research in Chapter 4 seeks to address the barriers within these networks and provide recommendations to improve communication between farm consultants and dairy farmers.


Figure 1.1. Milk fat percentage in bulk tank milk is positively correlated to de novo FA concentration among St. Albans Cooperative Creamery dairy herds.

\[ y = 0.1678x + 0.1222 \]

\[ R^2 = 0.4547 \]
Figure 1.2. Milk true protein percentage in bulk tank milk is positively correlated to de novo FA concentration among St. Albans Cooperative Creamery dairy herds.

\[ y = 0.123x + 0.2771 \]

\[ R^2 = 0.6842 \]
Table 1.1. Fatty acid profile of bovine milk fat (adapted from Jensen, 2002).

<table>
<thead>
<tr>
<th>FA(^1) carbon number</th>
<th>FA common name</th>
<th>Average range (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4:0</td>
<td>Butyric</td>
<td>2-5</td>
</tr>
<tr>
<td>6:0</td>
<td>Caproic</td>
<td>1-5</td>
</tr>
<tr>
<td>8:0</td>
<td>Caprylic</td>
<td>1-3</td>
</tr>
<tr>
<td>10:0</td>
<td>Capric</td>
<td>2-4</td>
</tr>
<tr>
<td>12:0</td>
<td>Lauric</td>
<td>2-5</td>
</tr>
<tr>
<td>14:0</td>
<td>Myristic</td>
<td>8-14</td>
</tr>
<tr>
<td>15:0</td>
<td>Pentadecanoic</td>
<td>1-2</td>
</tr>
<tr>
<td>16:0</td>
<td>Palmitic</td>
<td>22-35</td>
</tr>
<tr>
<td>16:1 cis-9</td>
<td>Palmitoleic</td>
<td>1-3</td>
</tr>
<tr>
<td>17:0</td>
<td>Margaric</td>
<td>0.5-1.5</td>
</tr>
<tr>
<td>18:0</td>
<td>Stearic</td>
<td>9-14</td>
</tr>
<tr>
<td>18:1 cis-9</td>
<td>Oleic</td>
<td>20-30</td>
</tr>
<tr>
<td>18:2 cis-9, cis-12</td>
<td>Linoleic</td>
<td>1-3</td>
</tr>
<tr>
<td>18:3 cis-9, cis-12, cis-15</td>
<td>(\alpha)-Linolenic</td>
<td>0.5-2</td>
</tr>
</tbody>
</table>

\(^1\)FA = fatty acid
Table 1.2. Time budget of resting and eating behavior for lactating dairy cows (Grant and Albright, 2001).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time per day (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eating</td>
<td>3 to 5 (9 to 14 meals/d)</td>
</tr>
<tr>
<td>Lying/resting</td>
<td>12 to 14</td>
</tr>
<tr>
<td>Social interactions</td>
<td>2 to 3</td>
</tr>
<tr>
<td>Ruminating</td>
<td>7 to 10</td>
</tr>
<tr>
<td>Drinking</td>
<td>0.5</td>
</tr>
<tr>
<td>Management activities (milking, etc.)</td>
<td>2.5 to 3.5</td>
</tr>
</tbody>
</table>
Figure 1.3. Normal and alternate rumen biohydrogenation pathways (Adapted from Jenkins, 2011).
CHAPTER 2: MANAGEMENT, NUTRITION, AND LACTATION PERFORMANCE ARE RELATED TO BULK TANK MILK DE NOVO FATTY ACID CONCENTRATION ON NORTHEASTERN US DAIRY FARMS

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2.1. ABSTRACT

This study investigated the relationship of management practices, dietary characteristics, milk composition, and lactation performance with de novo fatty acid (FA) concentration in bulk tank milk from commercial dairy farms with Holstein, Jersey, and mixed breed cows. It was hypothesized that farms with higher de novo milk FA concentrations would more commonly use management and nutrition practices known to optimize ruminal conditions that enhance de novo synthesis of milk FA. Farms (n = 44) located in Vermont and northeastern New York were selected based on a history of high de novo (HDN; 26.18 ± 0.94 g/100g FA; mean ± SD) or low de novo (LDN; 24.19 ± 1.22 g/100g FA) FA in bulk tank milk. Management practices were assessed during one visit to each farm in March or April, 2014. Total mixed ration samples were collected and analyzed for chemical composition using near infrared spectroscopy. There were no differences in days in milk at the farm level. Yield of milk fat, true protein, and de novo FA per cow per day were higher for HDN versus LDN farms. The HDN farms had lower freestall stocking density (cows/stall) than LDN farms. Additionally, tiestall feeding frequency was higher for HDN than LDN farms. No differences between HDN and LDN farms were detected for dietary dry matter, crude protein, neutral detergent fiber, starch, or percentage of forage in the diet. However, dietary ether extract was lower for HDN than LDN farms. This research indicates that overcrowded freestalls, reduced feeding frequency, and greater dietary ether extract content are associated with lower de novo FA synthesis and reduced milk fat and true protein yields on commercial dairy farms.
2.2. INTRODUCTION

Milk fat and true protein content are primary drivers of income over feed cost on commercial dairy farms (Bailey et al., 2005). In bulk tank milk samples taken 3 to 20 times per month on 430 commercial farms for 15 months, Barbano et al. (2014) identified a positive correlation between de novo milk FA (C4 to C14) concentration and milk fat and true protein content. Consequently, identifying management and dietary factors that are related to milk de novo FA concentration may be useful for making recommendations to dairy producers to increase milk fat and protein content and improve the income over feed cost of dairy farms.

For high producing Holstein cows, de novo FA typically account for 18 to 28% of the total FA in milk fat (Jensen, 2002). Milk FA profiles vary due to animal factors such as breed and genetics (Soyuert et al., 2008) and stage of lactation (Lynch et al., 1992; Stoop et al., 2009). In addition, nutritional and management practices can influence milk FA profiles and are the predominant environmental factors that affect milk de novo FA synthesis among cows of similar breed and stage of lactation (Palmquist et al., 1993; Bauman and Griinari, 2003).

Diets high in fermentable carbohydrates and polyunsaturated FA may result in depressed milk fat through a shift toward the so-called alternate rumen biohydrogenation pathway, leading to the formation of FA isomers, which down regulate the expression of genes related to de novo FA synthesis (Harvatine and Bauman, 2011). In addition, management practices that change feeding behavior, such as overstocking of the feed bunk (Sova et al., 2013), can increase a cow’s risk for low ruminal pH (French and
Kennelly, 1990) and lead to a reduction in milk fat content (Allen, 1997). Consequently, milk de novo FA content may serve as an indicator of ruminal fermentation conditions. Previous research has evaluated the effects of just one, or a small number, of dietary or management factors on milk FA profiles and has been reviewed elsewhere (Grummer, 1991; Palmquist et al., 1993; Neville and Picciano, 1997; Harvatine et al., 2009). These controlled experiments have been crucial to understanding the factors that affect milk de novo FA content. However, to our knowledge there are no studies in the published literature that describe the relationship of management and nutritional practices with de novo FA synthesis at the farm-level on commercial dairy farms.

Therefore, the objective of this study was to understand the relationship of farm management, dietary composition, milk composition, and lactation performance with milk de novo FA content and yield in bulk tank milk from commercial dairy farms in Vermont and northeastern New York. We hypothesized that bulk tank milk from farms that more commonly use management practices and dietary strategies known to optimize ruminal conditions will produce milk with higher de novo FA content.

2.3. MATERIALS AND METHODS

2.3.1. On-Farm Data Collection

Commercial dairy farms (n = 44) located in Vermont and northeastern New York were enrolled in the study. Eligible farms were members of the St. Albans Cooperative Creamery (St. Albans, Vermont). Farms were categorized as high de novo (HDN; 26.18 ± 0.94 g/100g FA; mean ± SD) or low de novo (LDN; 24.19 ± 1.22 g/100g FA) based on the mean bulk tank milk de novo FA concentration from September, 2013 to February,
2014 (Table 1). All farms in the St. Albans Cooperative were ranked from high to low for de novo FA (expressed as FA/100g FA) for the six months prior to the study. Farms were identified by the St. Albans Cooperative as predominantly Holstein or predominantly Jersey farms. The objective was to visit 20 HDN and 20 LDN farms; however, additional farms were contacted because some farms (n = 12) were not interested in participating in the study or were unable to be contacted by phone. Ultimately, 21 HDN farms and 23 LDN farms were visited once between March 21, 2014 and April 30, 2014 and all farms were included in the final dataset.

During each farm visit, trained research personnel worked with a farm owner or manager to complete a questionnaire. Breed of cows on the farm was self-reported by the farm owner or manager and classified as percentage of the farm that was Holsteins. The number of cows milking and average bulk tank milk shipped for the month of the farm visit was used to determine the mean milk yield per cow. Frequency of fresh feed delivery, number of lactating groups housed separately, and number of nutritional groups (defined as the number of lactating groups fed a unique diet) were included in the questionnaire. Farm DIM was sourced from either a test day within one month of the farm visit by the Dairy Herd Improvement Association (Vermont DHIA, White River Junction, VT) or Dairy One (Ithaca, NY) or by computer dairy management software (PC Dart, Dairy Records Management Services, Raleigh, NC; Dairy Comp 305, Valley Ag Software, Tulare, CA). Bunk space (linear feed bunk space per cow in the pen) and stall stocking density (number of cows per freestall in the pen) were determined during each farm visit on a per-pen basis for freestall farms only. Body condition score on a 1 to 5 scale at 0.25 point increments (Fergusson et al., 1994) was determined during each farm visit.
visit on a pen basis. At least 10 animals or 10% of the group were assigned a BCS. A weighted average of each pen’s stocking density, bunk space, and BCS was calculated based on the number of cows in a pen to determine the mean stocking density, bunk space, and BCS on a farm basis.

Forage and TMR samples were collected on each farm and placed into a re-closable plastic bag (30.5 x 38 cm) at the time of the farm visit. Total mixed rations were sampled from 5 to 10 locations along the length of the feed bunk for all lactating groups of cows. Forage samples from bunker silos or silo bags (Ag Bags; Miller-St. Nazianz, Inc., St. Nazianz, Wisconsin) were collected from 5 to 10 locations on the bunk face. Forages stored in upright silos were unloaded into a cart, homogenized manually, and subsampled using the quartering technique: homogeneous samples were divided into 4 equal subsamples. Two subsamples allocated diagonally were re-homogenized and saved. Round bales and square bales were sampled using a core sampler (Star Quality Samplers, Edmonton, Alberta, Canada) with at least two samples taken from opposite sides of a round bale or ends of a square bale.

A 500-g subsample of forage and TMR was taken by placing the sample in a tub, manually homogenizing, and subsampling using the quartering technique as previously described. Subsamples were dried in a forced-air oven at 60°C for 4 h, ground to 1mm using a Udy Cyclone mill (Udy Corporation, Ft Collins, CO), and analyzed for chemical composition using near infrared spectroscopy (NIR) in a commercial laboratory (Dairy One, Ithaca, NY; Shenk and Westerhaus, 1991; FOSS NIR Systems Model 6500 with Win ISI II v1.5 software, Foss-NIR System, Silver Spring, MD). Hay crop silages, corn silages, and TMR were analyzed for DM (method 991.01; AOAC 2012), CP (method
Neutral detergent fiber, ether extract, ash, and starch calibrations were developed for NIR according to AOAC 2012 method 989.03. Near infrared calibrations were based on reference chemistry using traditional procedures for aNDF with α-amylase and sodium sulfite (method 2002.04; AOAC, 2012), ether extract (method 2003.05; AOAC, 2012), and ash (method 942.05; AOAC, 2012). Near infrared calibrations for starch were developed based on methods described by Bach Knudsen (1997) using a YSI 2700 SELECT Biochemistry Analyzer (YSI Incorporated Life Sciences, Yellow Springs, OH). In short, samples for reference chemistry starch analysis were pre-extracted for sugar by incubation in a 40°C water bath and filtered on Whatman 41 filter paper (Sigma-Aldrich, St Louis, MO). Residues were thermally solubilized using an autoclave and then incubated with glucoamylase to hydrolyze starch and produce dextrose. Prepared samples were then injected into a sample chamber of the YSI Analyzer and dextrose concentration was determined. Starch was determined by multiplying dextrose by 0.9 and these values were used to calibrate the NIR.

In the case of a farm with more than one lactating cow diet, TMR analysis results were mathematically composited by the number of cows consuming the diet. All farms that fed corn silage were only feeding one source of corn silage at the day of the visit. When available, diet information from farms feeding multiple hay crop silage sources (n = 6 farms) was used to calculate a weighted average based on the number of cows consuming the diets and the proportion of each hay crop silage source (on a DM basis) in each diet. When diet information was not available (n = 9 farms), hay crop silage analyses were averaged for each farm. Five farms did not feed hay crop silage.
2.3.2. Supplemental Feed Products

Feed supply companies provided the ingredients for concentrate feeds included in all diets fed to lactating cows on each farm. One farm did not feed any concentrates, and concentrate ingredient information was not available for 10 farms, therefore supplemental feeds were analyzed for 33 farms. Feed products analyzed were selected because of their association with changes in milk fat content or composition and categorized as: distillers grains (Schingoethe et al., 2009), monensin (Rumensin, Elanco Animal Health, Indianapolis, IN; Duffield et al., 2008), rumen inert fat (Loften et al., 2014), animal derived fat (Onetti et al., 2003), yeast (Desnoyers et al., 2009), and essential amino acid sources (Zanton et al., 2014) such as animal-derived protein and commercial amino acids (rumen protected lysine or methionine). If a farm fed a product to at least one dietary group it was included in the analysis. Forage-to-concentrate ratios on a DM basis were calculated based on dietary specifications reported by the farm’s nutrition consultant.

2.3.3. Milk Yield and Composition

Milk yield was calculated using the number of cows milking during the farm visit and the average bulk tank milk shipped during the month of the farm visit. Milk composition data were averaged for the month of the farm visit (March or April, 2014). Milk fat, true protein, and anhydrous lactose content were determined using a Fourier transform mid-infrared (FTIR) spectrophotometer (Lactoscope FTA, Delta Instruments, Drachten, The Netherlands) at the St. Albans Cooperative Creamery payment testing laboratory (St. Albans, VT). Calibration of the FTIR for measurement of fat, true protein, and anhydrous lactose was done using modified milk calibration samples (Kaylegian et
al., 2006) produced monthly with all laboratory mean reference chemistry values produced by a network of 10 to 12 laboratories. The reference methods for fat, true protein, and anhydrous lactose measurement were determined in duplicate in each laboratory using the following validated methods (AOAC, 2000): fat by modified Mojonnier ether extraction (method 989.05), true protein by Kjeldahl analysis (method 991.22), and lactose by enzymatic analysis (method 2006.06). The slopes and intercepts were checked and adjusted every 2 weeks.

Milk FA analyses were conducted at the St. Albans Cooperative payment testing laboratory simultaneously with the component milk testing using partial least squares chemometric prediction models based on the mid-IR spectra (Barbano et al., 2014). These models allowed individual FA (data not reported) as well as FA groups (de novo, C4 to C14; mixed origin, C16:0, C16:1, C17:0; and preformed, ≥ C18:0) to be measured with the FTIR spectrophotometer. Groups of FA measured and used in the analysis include de novo FA, mixed origin FA, and preformed FA expressed as g of FA/100g of milk and as g of FA/100 g of FA. The slopes and intercepts of the calibration for all milk FA parameters were adjusted with the same 14-sample set of milk calibration samples that was used for calibration of the other milk components. Reference individual and groups of milk FA for the 14-sample calibration set were determined by gas liquid chromatography as described by Lynch et al. (2005) and Kaylegian et al. (2009a,b).

2.3.4. Statistical Analysis

Statistical analyses were conducted with SAS (version 9.2, SAS Institute Inc., Cary, NC). Data were summarized by HDN or LDN group and checked for normality
using the UNIVARIATE procedure. Data were considered to be normally distributed when the Shapiro-Wilks W was greater than 0.85. Because breed is known to affect milk FA composition (Soyeurt et al., 2006), the data were adjusted covariately by the proportion of Holsteins in the farm. The Akaike information criterion (AIC; Akaike, 1973) was used for model comparison with and without covariate adjustment. The AIC was more highly conserved in the covariate adjusted model; therefore, the adjusted model was used for all milk composition variables and when significant \( P \leq 0.05 \) for management variables. The covariate was not significant \( P > 0.10 \) for dietary variables; therefore, the covariate was not included in the model.

Differences in management, TMR, and milk composition for HDN versus LDN farms were determined using the GLIMMIX procedure of SAS with de novo group as the fixed effect and farm as the random effect with the following model equation:

\[
Y_{ijk} = \mu + \alpha_i + \beta_j + R_k + E_{ijk}
\]

Where \( Y_{ijk} \) is the dependent variable, \( \mu \) is the overall mean, \( \alpha_i \) is the fixed effect of de novo group, \( \beta_j \) is the fixed effect of the covariate, \( R_k \) is the random effect of farm, and \( E_{ijk} \) is the residual error.

A Poisson distribution with a log link function was used to test the number of cows milking on each farm and the number of times feed was pushed up at the feed bunk. The best fit distribution was identified using the chi-square/degrees freedom ratio (Gbur et al., 2012). Optimal model fit results in a chi-square/degrees of freedom ratio close to 1.0. Freestall feeding frequency (1 or 2 times per day), milking frequency (2 or 3 times per day), freestall barn design (4 or 6 rows of stalls), and inclusion of ingredients of interest in the concentrate mix were analyzed with a binary distribution and a logit link
function to generate odds ratios and 95% confidence intervals, using a similar approach as Silva et al. (2014). All other dietary and management variables were normally distributed and were tested with a Gaussian distribution with an identity link function. Differences were declared significant at $P \leq 0.05$ and trends at $0.05 < P \leq 0.10$.

Two farms had extremely low starch values, either due to sampling error or due to rations that were not balanced to meet the nutrient requirements of lactation. These farms were identified as outliers according to Cook’s Distance (Cody, 2011) and therefore were removed from the dietary composition analysis dataset.

2.4. RESULTS AND DISCUSSION

2.4.1. Farm Characterization

There were similar numbers of tiestall and freestall farms within the HDN and LDN groups (Table 2). On average, there was a higher percentage of Holstein cows on farms in the LDN group. Breed has a strong effect on milk fat and protein content (Soyeurt et al., 2006). For this reason it was especially important to include breed as a covariate in the models. Although there were both conventional and certified organic farms on the study, each of the farms were visited before the grazing season began. Therefore, all of the cows were consuming an indoor diet on the day of each farm visit.

The number of milking cows was not different ($P = 0.93$) between HDN and LDN farms, suggesting that farm size was not a significant factor in HDN versus LDN farms, despite the large variation in farm sizes within the HDN and LDN groups (Table 3). Days in milk were not different ($P = 0.88$) between HDN and LDN farms. The FA profile of bovine milk changes substantially throughout a cow’s lactation (Lynch et al., 1992);
however, because DIM were not different between groups, the stage of lactation of individual cows was not likely to affect the comparison of HDN versus LDN milk composition in the current study. In addition, no difference was observed in milking frequency between HDN and LDN farms, which was either 2 or 3 times per d ($P = 0.19$; Table 3).

### 2.4.2. Milk Composition

Milk yield tended to be higher for HDN farms ($P = 0.06$; Table 4). Milk fat yield, true protein yield, and true protein content were higher ($P < 0.01$) on HDN farms, while milk fat content tended to be higher ($P = 0.10$). The higher milk fat and protein yields per cow per day for HDN farms would indicate that gross milk income per cow was higher on HDN farms during the period of the study.

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

These results are consistent with previous research that found that de novo FA content is correlated positively with milk fat and true protein content (Barbano et al.,
De novo FA, expressed as g/100g of FA, g/100 g of milk, and g/d were higher ($P < 0.05$) on HDN farms. This result was by design as farms were selected to participate in the study based on de novo FA content.

Mixed FA were higher ($P \leq 0.03$) in HDN farms (Table 4). About half of the mixed FA originate from de novo synthesis when cows are in positive energy balance (Loften et al., 2014). It is possible that the same mechanism that was driving de novo synthesis for FA shorter than 14 carbons was also driving de novo synthesis of palmitic acid. An alternate explanation may be that HDN farms were feeding more palmitic acid through rumen inert feed product supplementation. Dietary palmitic acid has been found to increase milk fat content without down regulating de novo synthesis (Loften et al., 2014). There was no difference detected in the proportion of farms feeding a rumen inert fat product ($P > 0.10$; Table 5). However, the composition of the rumen inert fat products fed on farms was not provided to the researchers in the current study. In addition, using the analytical procedures in the present study, it was not possible to differentiate whether the additional mixed FA on HDN farms was of dietary origin or from de novo synthesis.

Preformed FA expressed as g/100 g FA and as g/100 g milk were lower ($P \leq 0.04$; Table 4) on HDN farms, but there was no detectable difference ($P = 0.12$) in preformed FA yield per day (Table 4). These results suggest that changes in preformed FA expressed as g/100g of FA were a result of increased de novo FA yield, and not because cows on LDN farms were yielding more preformed FA per day.
2.4.3. Management Practices

Stall stocking density was lower ($P = 0.05$; Table 6) on HDN farms, and bunk space was numerically higher on HDN farms but no significant difference was detected ($P = 0.13$; Table 6). Stall stocking density above one cow per stall reduces the time cows spend lying and ruminating (Batchelder, 2000). Cows give preference to lying over eating (Grant and Albright, 2001). Therefore, when stall stocking density exceeds 1 cow per stall, cows may reduce eating time, increase rate of feed consumption, and increase meal size with less meals consumed throughout the day in order maximize time spent lying down (Grant and Albright, 2001). Therefore, the higher stall stocking density observed on LDN farms may have resulted in changes in both resting and eating behavior.

Campbell et al. (2015) reported that mean ruminal pH tended to decrease and the time below a pH of 5.8 increased when cows were stocked at 1.42 compared with 1.00 stalls and headlocks per cow. Hill et al. (2007) did not measure ruminal pH, but reported a 0.2%-unit reduction in milk fat when cows were housed at 1.42 cows per stall and headlock compared to 1.00 ($P = 0.03$), presumably due to changes in rumen conditions. However, Krawczel et al. (2012) reported no change in milk composition but an increase in feed bunk aggression and a decrease in lying time when cows were housed at 1.42 compared to 1.00 stall and headlock per cow.

The current study did not detect a difference in bunk space per cow between HDN and LDN farms; however, Sova et al. (2013) reported that a 10 cm/cow increase in feed bunk space was associated with a 0.06%-unit increase in milk fat content. Compared with access to freestalls, bunk space is the first limiting resource in 3-row pens. However, in
the current study there was no difference detected in the odds for HDN farms to have pens that contain 3 rows versus 2 rows of freestalls ($P = 0.28$; Table 3), so the pen design was not likely to confound these results.

High de novo tiestall farms fed their cows more frequently compared to the LDN farms ($P = 0.05$; Table 6). Fourteen of the 21 tiestall farms fed a component-based diet (grain and forages fed separately). When grain is fed separately, it is often consumed rapidly (Robinson, 1989) which has been found to decrease ruminal pH (Bauman and Griinari, 2003; Bradford and Allen, 2004) which is correlated with a decrease in milk fat content (Allen, 1997). However, more frequent delivery of concentrate feeds, as was observed on HDN farms in the current study, can help to prevent postprandial decreases in ruminal pH (French and Kennelly, 1990).

All freestall farms on this study fed a TMR either once or twice a day. No difference was detected in feed delivery frequency between HDN and LDN freestall farms ($P > 0.10$; Table 3). Previous research supports that feeding cows more frequently promotes more natural feeding behavior (DeVries et al., 2005), decreases sorting (DeVries et al., 2008), and is associated with an increased milk fat content (Rottman et al., 2014; Sova et al., 2013). Sorting against long particles can result in a reduced ruminal pH (DeVries et al., 2008), potentially increasing the cow’s risk for milk fat depression (Allen et al., 1997; Bauman et al., 2006). To our knowledge, the current study is the first to evaluate the effects of feed delivery on milk FA profiles.

Interestingly, LDN tiestall and freestall farms tended ($P = 0.06$ and 0.10, respectively) to push up the feed more frequently than HDN farms (Table 6). This unexpected result may have been a function of reduced feeding frequency (Table 6) for
LDN tiestall farms, because when feed is delivered less often it must be pushed up more frequently in order to provide the cow with physical access to the feed. Practices that increase feed availability, such as feed delivery or feed push up, increase feed bunk attendance (DeVries et al., 2003). However, DeVries and von Keyserlingk (2005) found that cows are more motivated to eat by fresh feed delivery than they are by simply pushing up previously delivered feed.

Body condition score was lower on LDN farms \((P = 0.002; \text{Table } 6)\). In addition, LDN farms had higher preformed FA expressed as g/100g of FA and as g/100 g milk and lower milk yield compared with HDN farms (Table 4), suggesting perhaps that LDN farms were mobilizing more adipose tissue due to insufficient energy intake. There were many LDN farms with extremely under conditioned cows (the range in BCS by farm was 2.65 to 3.12 for LDN farms). Cows should begin their lactation between a 3.0 and 3.5 on a 5-point scale, and should not drop below 2.5 in peak lactation to maintain optimal health (Roche et al., 2009). Due to insufficient quality or quantity of feed, cows can experience negative energy balance in mid or late lactation (Leiber et al., 2005). Gross et al. (2011a) found that restricting feed intake in mid-lactation cows increased milk fat content, decreased de novo FA, and increased preformed FA with a considerable increase in C18:1 cis-9, which originates primarily from adipose tissue mobilization. In addition, Gross et al. (2011b) reported a decrease in body weight, BCS, milk yield, and milk protein content during feed restriction in mid-lactation, which is consistent with the results of the current study.
2.4.4. Dietary Strategies

There was no difference detected in DM, CP, NDF, ADF, starch, ash, or percentage of forage in the diets from HDN and LDN farms (\(P > 0.10\); Table 7). However, previous research has reported an influence of starch (Oba and Allen, 2003), NDF (Allen, 1997), and percentage of forage on milk FA profiles (Yang et al., 2001). Oba and Allen (2003) observed a decrease in milk fat yield in response to increased starch content in a high starch diet (32 versus 21% of DM). However, in the present study dietary starch was 23.1 and 20.2% of DM (\(P = 0.15\)) for HDN and LDN farms, respectively. These starch levels reflect the low starch treatment tested by Oba and Allen (2003), and so a difference in milk fat content or composition would not be expected.

Yang et al. (2001) reported an increase in milk fat content when cows consumed a diet with 55:45 forage-to-concentrate compared to a ratio of 35:65. Yang and Beauchemin (2009) reported an increase in mean ruminal pH and a decrease in the time spent below a pH of 5.8 for cows consuming a 60:40 diet compared with 35:65 (forage:concentrate). The forage percentage of the diets in the current study was 58.1 and 57.8% of DM (\(P = 0.51\); Table 7) for HDN and LDN farms, respectively, which is consistent with the high forage diets fed by Yang and Beauchemin (2009) and Yang et al. (2001). Therefore an effect of forage percentage on de novo synthesis was not expected at the level of forage observed on these farms.

Dietary NDF content alone does not completely capture how the NDF will affect the rumen and milk fat composition. For example, partial replacement of corn grain and silage with a non-forage fiber source decreased ruminal pH and milk fat content despite
the lower starch and greater NDF in the diet (Fredin et al., 2015). Optimizing NDF in the
diet is often related to the physically effective NDF (peNDF) and undigested NDF
(uNDF) component of the ration. These were not measured in the current study. Future
research should consider the effects of peNDF and uNDF on milk fat content, yield, and
composition on commercial dairy farms.

Ether extract (EE) was lower in diets from HDN farms ($P < 0.01$; Table 7). The
relationship between dietary fat and milk fat composition has been reviewed previously
(Bauman and Griinari, 2003; Bauman et al., 2006; Harvatine et al., 2009), and excessive
levels of dietary fat are a risk factor for milk fat depression. However, a typical EE
content for a high producing dairy cow diet is around 4 to 5% of DM (NRC, 2001) and
the EE for HDN and LDN farms was 3.7 and 4.4% of DM, respectively ($P < 0.01$; Table
7). It was not expected that this level of EE would have an effect on de novo FA
synthesis. Further analysis would be needed to understand the composition of the FA that
are measured using EE, and whether it contained polyunsaturated FA that, combined with
other dietary and management factors, may have caused a shift in the biohydrogenation
pathway that reduced de novo FA synthesis on LDN farms (Bauman and Griinari, 2003).

No differences in the chemical composition of forages from HDN and LDN farms
were detected ($P > 0.10$), with the exception of a higher ash content of hay crop silages
on LDN farms (Table 8). This may have been as a result of harvesting equipment used on
LDN farms; however, the ash content of the TMR was not different between HDN and
LDN farms. Therefore, it was unlikely that the higher ash content of hay crop silages for
LDN farms was affecting de novo FA synthesis. However, higher ash content may cause
a poor fermentation in hay crop silage (Kung et al., 2014) which will affect rumen
conditions.

2.4.5. Supplemental Feed Products

Feed additives and supplements such as distillers grains (Schingoethe et al.,
2009), monensin (Duffield et al., 2008), rumen inert fat (Loften et al., 2014), animal
derived fat (Onetti et al., 2003), yeast (Desnoyers et al., 2009), and essential amino acids
(Zanton et al., 2014) may affect milk fat content, yield, and composition. However, the
current study found no relationship of milk de novo FA with feed additives ($P > 0.10$;
Table 5). The percentage of LDN farms feeding commercial, rumen inert fat products
was numerically higher but no significant difference was detected (6.6 versus 33.2% of
farms for HDN vs LDN, respectively; $P = 0.11$).

2.5. CONCLUSION

To our knowledge, the current study is the first in the literature to evaluate the
relationship of management, dietary composition, and lactation performance with de
novo milk FA content and yield on commercial dairies with high and low de novo milk
FA content. The current study identified management practices, such as higher stall
stocking density and lower feeding frequency, that were related to lower de novo FA
content in bulk tank milk. Farms with lower de novo FA on average produced less milk
fat and protein per cow per day. In addition, higher dietary EE was related to lower de
novo FA content of milk. High de novo farms also had higher milk yield and fat and true
protein content and yield. However, the current study was conducted on primarily small
and medium sized farms with a relatively low milk production average. Therefore, there
is a need for future research on larger, higher producing commercial farms to verify the relationships between diet and management, de novo FA synthesis, and lactation performance.
2.6. REFERENCES


### TABLES AND FIGURES

Table 2.1. Milk composition data representing monthly mean milk composition by farm from September, 2013 to February, 2014 that was used to select high de novo (HDN) and low de novo (LDN) farms to participate in the study.

<table>
<thead>
<tr>
<th>Milk component</th>
<th>HDN</th>
<th>LDN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Min</td>
</tr>
<tr>
<td>Fat, %</td>
<td>4.55 ± 0.51</td>
<td>3.75</td>
</tr>
<tr>
<td>True protein, %</td>
<td>3.50 ± 0.29</td>
<td>3.11</td>
</tr>
<tr>
<td>De novo FA&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1.13 ± 0.16</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>26.18 ± 0.94</td>
<td>24.20</td>
</tr>
<tr>
<td>Mixed FA&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.65 ± 0.21</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>38.24 ± 0.98</td>
<td>35.65</td>
</tr>
<tr>
<td>Preformed FA&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.52 ± 0.14</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>35.58 ± 1.41</td>
<td>33.24</td>
</tr>
</tbody>
</table>

<sup>1</sup> C4 to C14.

<sup>2</sup> C16, C16:1, C:17.

<sup>3</sup> Greater than or equal to C18.
Table 2.2. Descriptive statistics (mean ± standard deviation) characterizing management factors for high de novo (HDN) or low de novo (LDN) farms.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN</th>
<th>LDN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farms, n</td>
<td>21</td>
<td>23</td>
</tr>
<tr>
<td>Holstein, % of farm</td>
<td>33.7 ± 38.5</td>
<td>61.4 ± 41.2</td>
</tr>
<tr>
<td>Cows milking, n</td>
<td>120 ± 108</td>
<td>224 ± 274</td>
</tr>
<tr>
<td>Lactating groups, n(^1)</td>
<td>1.8 ± 1.3</td>
<td>2.1 ± 1.7</td>
</tr>
<tr>
<td>Nutritional groups, n(^2)</td>
<td>1.5 ± 0.8</td>
<td>1.8 ± 1.3</td>
</tr>
<tr>
<td>Housing type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freestall, n</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>2 rows per pen, n(^3)</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>3 rows per pen, n(^3)</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Tiestall, n</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>Conventional, n</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Certified organic, n</td>
<td>9</td>
<td>4</td>
</tr>
</tbody>
</table>

\(^1\)Separately housed groups of lactating cows per farm.

\(^2\)Rations fed to lactating cows per farm.

\(^3\)Indicates the number of rows of stalls per feed bunk in the pen.
Table 2.3. Odds ratio for binary management and dietary data for high de novo (HDN) or low de novo (LDN) farms observed during the farm visit.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN, %</th>
<th>LDN, %</th>
<th>OR(^6) (95% CI)</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freestall feeding frequency</td>
<td>50.0(^1)</td>
<td>80.2(^1)</td>
<td>0.25 (0.03-2.11)</td>
<td>0.19</td>
</tr>
<tr>
<td>Milking frequency</td>
<td>81.0(^2)</td>
<td>74.0(^2)</td>
<td>1.50 (0.33-6.79)</td>
<td>0.59</td>
</tr>
<tr>
<td>Freestall barn design</td>
<td>69.4(^3)</td>
<td>90.0(^3)</td>
<td>0.25 (0.02-3.39)</td>
<td>0.28</td>
</tr>
<tr>
<td>Component vs TMR fed</td>
<td>33.3(^4)</td>
<td>43.5(^4)</td>
<td>0.65 (0.18-2.37)</td>
<td>0.50</td>
</tr>
<tr>
<td>One vs multiple lactating TMR fed</td>
<td>50.0(^5)</td>
<td>38.4(^5)</td>
<td>1.60 (0.30-8.63)</td>
<td>0.57</td>
</tr>
</tbody>
</table>

\(^1\) Percentage of farms feeding once per day.

\(^2\) Percentage of farms milking twice per day.

\(^3\) Percentage of farms with 3 rows of stalls per row of feed bunk in the pen.

\(^4\) Percentage of component-fed farms (forages and grain fed separately).

\(^5\) Percentage of TMR-fed farms feeding only one diet to lactating cows.

\(^6\) OR = odds ratio. The HDN group was set as referent.
Table 2.4. Least squares means of milk composition covariately adjusted by breed for high de novo (HDN) and low de novo (LDN) farms for the month of the farm visit.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN</th>
<th>LDN</th>
<th>SEM</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk kg/d</td>
<td>26.3</td>
<td>22.7</td>
<td>1.3</td>
<td>0.06</td>
</tr>
<tr>
<td>Fat, kg/d</td>
<td>1.1</td>
<td>0.9</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>Fat, %</td>
<td>4.33</td>
<td>4.14</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>True protein, kg/d</td>
<td>0.89</td>
<td>0.73</td>
<td>0.04</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>True protein, %</td>
<td>3.41</td>
<td>3.22</td>
<td>0.04</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>De novo FA (^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g/100 g milk</td>
<td>1.06</td>
<td>0.94</td>
<td>0.02</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>g/100 g FA</td>
<td>25.61</td>
<td>23.71</td>
<td>0.19</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>g/d</td>
<td>269.8</td>
<td>207.3</td>
<td>12.9</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Mixed FA (^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g/100 g milk</td>
<td>1.60</td>
<td>1.50</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>g/100 g FA</td>
<td>38.86</td>
<td>37.98</td>
<td>0.26</td>
<td>0.02</td>
</tr>
<tr>
<td>g/d</td>
<td>411.9</td>
<td>329.7</td>
<td>20.0</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Preformed FA (^3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g/100 g milk</td>
<td>1.45</td>
<td>1.51</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>g/100 g FA</td>
<td>35.53</td>
<td>38.31</td>
<td>0.31</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>g/d</td>
<td>376.4</td>
<td>333.4</td>
<td>19.2</td>
<td>0.12</td>
</tr>
<tr>
<td>MUN, mg/dL</td>
<td>11.4</td>
<td>11.3</td>
<td>0.5</td>
<td>0.89</td>
</tr>
<tr>
<td>Anhydrous lactose, %</td>
<td>4.60</td>
<td>4.59</td>
<td>0.02</td>
<td>0.66</td>
</tr>
<tr>
<td>Anhydrous lactose, kg/d</td>
<td>2.68</td>
<td>2.31</td>
<td>0.14</td>
<td>0.07</td>
</tr>
</tbody>
</table>

\(^1\) C4 to C14.
\(^2\) C16, C16:1, C:17.
\(^3\) Greater than or equal to C18.
Table 2.5. Effects of feed additives included in TMR on high de novo (HDN; n=15) or low de novo (LDN; n=18) farms sampled during the farm visit.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN, %</th>
<th>LDN, %</th>
<th>OR(^1) (95% CI)</th>
<th>P- Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal-derived fat</td>
<td>19.93(^2)</td>
<td>38.84(^2)</td>
<td>0.39 (0.07-2.14)</td>
<td>0.27</td>
</tr>
<tr>
<td>Rumen inert fat</td>
<td>6.64</td>
<td>33.26</td>
<td>0.13 (0.01-1.55)</td>
<td>0.11</td>
</tr>
<tr>
<td>Monensin(^3)</td>
<td>46.65</td>
<td>44.42</td>
<td>1.09 (0.25-4.82)</td>
<td>0.90</td>
</tr>
<tr>
<td>Yeast(^4)</td>
<td>6.66</td>
<td>10.99</td>
<td>0.57 (0.04-8.28)</td>
<td>0.67</td>
</tr>
<tr>
<td>Animal derived protein</td>
<td>33.27</td>
<td>38.84</td>
<td>0.79 (0.17-3.67)</td>
<td>0.75</td>
</tr>
<tr>
<td>Commercial amino acid</td>
<td>13.28</td>
<td>33.26</td>
<td>0.31 (0.05-2.06)</td>
<td>0.22</td>
</tr>
<tr>
<td>Dried distillers grain</td>
<td>26.57</td>
<td>22.13</td>
<td>1.27 (0.23-7.09)</td>
<td>0.78</td>
</tr>
</tbody>
</table>

\(^1\) OR = odds ratio. The HDN group was set as referent.

\(^2\) Percentage of farms feeding product.

\(^3\) Rumensin, Elanco Animal Health, Indianapolis, IN.

\(^4\) Live and cultured yeast products
Table 2.6. Least squares means of management factors for high de novo (HDN) or low de novo (LDN) farms observed or recorded during the farm visit.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN</th>
<th>LDN</th>
<th>SEM</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cows milking, n</td>
<td>105</td>
<td>108</td>
<td>19</td>
<td>0.93</td>
</tr>
<tr>
<td>DIM</td>
<td>165</td>
<td>179</td>
<td>36.4</td>
<td>0.88</td>
</tr>
<tr>
<td>Bunkspace, cm/cow (^1)</td>
<td>50.6</td>
<td>42.4</td>
<td>3.6</td>
<td>0.13</td>
</tr>
<tr>
<td>Stall stocking density, cow/stall (^1)</td>
<td>1.05</td>
<td>1.20</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Tiestall feeding frequency per d</td>
<td>4.6</td>
<td>2.9</td>
<td>0.7</td>
<td>0.05</td>
</tr>
<tr>
<td>Feed push-up frequency per d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tiestall</td>
<td>1.3</td>
<td>3.5</td>
<td>0.9</td>
<td>0.06</td>
</tr>
<tr>
<td>Freestall</td>
<td>2.7</td>
<td>4.8</td>
<td>0.9</td>
<td>0.10</td>
</tr>
<tr>
<td>BCS</td>
<td>3.08</td>
<td>2.96</td>
<td>0.03</td>
<td>0.002</td>
</tr>
</tbody>
</table>

\(^1\)Only applicable to farms with freestall-housed lactating cows (n = 23).
Table 2.7. Nutritional characteristics of weighted average of TMR from high de novo (HDN) and low de novo (LDN) farms.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN</th>
<th>LDN</th>
<th>SEM</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter, %</td>
<td>42.2</td>
<td>38.9</td>
<td>2.1</td>
<td>0.24</td>
</tr>
<tr>
<td>CP, % of DM</td>
<td>15.1</td>
<td>16.0</td>
<td>0.6</td>
<td>0.24</td>
</tr>
<tr>
<td>ADF, % of DM</td>
<td>22.7</td>
<td>23.7</td>
<td>1.1</td>
<td>0.50</td>
</tr>
<tr>
<td>NDF, % of DM</td>
<td>37.4</td>
<td>38.7</td>
<td>1.4</td>
<td>0.48</td>
</tr>
<tr>
<td>Starch, % of DM</td>
<td>23.1</td>
<td>20.2</td>
<td>1.5</td>
<td>0.15</td>
</tr>
<tr>
<td>Ether extract, % of DM</td>
<td>3.7</td>
<td>4.4</td>
<td>0.1</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ash, % of DM</td>
<td>8.3</td>
<td>8.9</td>
<td>0.4</td>
<td>0.24</td>
</tr>
<tr>
<td>Forage, % DM</td>
<td>58.1</td>
<td>57.8</td>
<td>0.1</td>
<td>0.51</td>
</tr>
</tbody>
</table>
Table 2.8. Nutritional characteristics for high de novo (HDN) and low de novo (LDN) farms for hay crop silage (n = 19 HDN; n = 20 LDN) and corn silage (n = 15 HDN; n = 12 LDN) sampled during the farm visit.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN</th>
<th>LDN</th>
<th>SEM</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hay crop silage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM, % of as fed</td>
<td>43.7</td>
<td>37.8</td>
<td>3.4</td>
<td>0.21</td>
</tr>
<tr>
<td>CP, % of DM</td>
<td>16.1</td>
<td>16.5</td>
<td>0.7</td>
<td>0.75</td>
</tr>
<tr>
<td>ADF, % of DM</td>
<td>35.4</td>
<td>36.5</td>
<td>0.8</td>
<td>0.35</td>
</tr>
<tr>
<td>NDF, % of DM</td>
<td>55.5</td>
<td>55.7</td>
<td>1.3</td>
<td>0.91</td>
</tr>
<tr>
<td>ESC(^1), % of DM</td>
<td>6.0</td>
<td>5.9</td>
<td>1.0</td>
<td>0.96</td>
</tr>
<tr>
<td>Ether extract, % of DM</td>
<td>4.4</td>
<td>4.3</td>
<td>0.2</td>
<td>0.83</td>
</tr>
<tr>
<td>Ash, % of DM</td>
<td>9.1</td>
<td>10.3</td>
<td>0.3</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>Corn silage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM, % of as fed</td>
<td>32.6</td>
<td>29.8</td>
<td>1.2</td>
<td>0.10</td>
</tr>
<tr>
<td>CP, % of DM</td>
<td>7.9</td>
<td>8.2</td>
<td>0.2</td>
<td>0.25</td>
</tr>
<tr>
<td>ADF, % of DM</td>
<td>25.2</td>
<td>25.7</td>
<td>0.8</td>
<td>0.62</td>
</tr>
<tr>
<td>NDF, % of DM</td>
<td>42.9</td>
<td>43.2</td>
<td>1.1</td>
<td>0.86</td>
</tr>
<tr>
<td>ESC(^1), % of DM</td>
<td>1.7</td>
<td>1.9</td>
<td>0.1</td>
<td>0.36</td>
</tr>
<tr>
<td>Ether extract, % of DM</td>
<td>3.2</td>
<td>3.4</td>
<td>0.1</td>
<td>0.31</td>
</tr>
<tr>
<td>Starch, % of DM</td>
<td>32.5</td>
<td>31.4</td>
<td>1.4</td>
<td>0.55</td>
</tr>
<tr>
<td>Ash, % of DM</td>
<td>3.7</td>
<td>4.0</td>
<td>0.2</td>
<td>0.41</td>
</tr>
</tbody>
</table>

\(^1\) Ethanol soluble carbohydrates.
CHAPTER 3: COW COMFORT INDICATORS AND PHYSICALLY EFFECTIVE FIBER ARE RELATED TO BULK TANK MILK DE NOVO FATTY ACID CONCENTRATION FOR HOLSTEIN DAIRY FARMS

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3.1. ABSTRACT

The objective of this study was to evaluate the relationship of cow comfort indicators and dietary factors with de novo fatty acid concentration in bulk tank milk from commercial dairy farms milking Holstein cows. Farms were selected based de novo fatty acid concentration during the 6 months previous to the farm visit and were categorized as high de novo (HDN; 24.53 ± 0.81 g/100g of FA, mean ± standard deviation; n = 19) or low de novo (LDN; 22.99 ± 0.85 g/100g of FA; n = 20). Farms were visited once in February, March, or April, 2015 and evaluated based on management and facility design previously shown to affect cow comfort, physical and chemical characteristics of the diet, forage quality, and the ration formulation obtained from the farm’s nutritionist. There were no differences detected in farm size, time away from the pen for milking, days in milk, or body condition score for HDN versus LDN farms. There were no differences between HDN and LDN farms in milk, fat, or protein yield; however, milk fat and protein content and de novo fatty acid yield per day were higher for HDN farms. High de novo farms tended to be more likely to deliver fresh feed twice versus once per day, have a freestall stocking density less than or equal to 110%, and provide greater than or equal to 46 cm of feed bunk space per cow. There were no detectable differences in forage quality or ration dry matter, crude protein, or starch; however, ether extract was lower and physically effective neutral detergent fiber was higher for HDN compared with LDN farms. The results of this study indicate that cow comfort indicators such as feeding management and stocking density, as well as the physical characteristics of the diet, are related to de novo fatty acid concentration in bulk tank milk from high-producing, Holstein dairy farms.
3.2. INTRODUCTION

De novo fatty acids (FA) are short- and medium-chain (C4 to C14) FA synthesized in the cow’s mammary gland using acetate and butyrate, which are volatile fatty acids that originate from the fermentation of feeds in the rumen (Palmquist et al., 1993). There is a systematic and large change in FA composition of milk fat with stage of lactation (Lynch et al., 1992), with de novo FA as a proportion of total FA starting out low in early lactation and increasing to a relatively steady concentration when cows are in positive energy balance. In high producing Holstein cows, de novo FA typically account for 18.2 to 28.4% of the total FA in milk fat (Jensen, 2002). Environmental factors that affect ruminal conditions, such as nutrition and management, can influence milk FA profiles and are the predominant factors that affect milk de novo FA synthesis among cows of similar breed and stage of lactation (Palmquist et al., 1993; Bauman and Griinari, 2003).

Feeding adequate physically effective NDF (peNDF) has been associated with an increase in ruminal pH (Allen, 1997; Kononoff and Heinrichs, 2003) or no change in ruminal pH (Beaucheman and Yang, 2005). Feeding adequate peNDF increases milk fat (Grant et al., 1990) and milk protein content (Caccamo et al., 2014). However, to our knowledge there are no studies that have evaluated the relationship between the physical characteristics of the diet and bulk tank de novo FA concentration on commercial Holstein dairy farms.

Feed management, stocking density, and facility design are important components of cow comfort on commercial dairy farms (von Keyserlingk et al., 2012). Cow comfort
factors that affect behavior, such as increased feeding rate (Collings et al., 2012), or sorting against long particles (Sova et al., 2013), can increase a cow’s risk for low ruminal pH (French and Kennelly, 1990). Management practices and dietary characteristics that result in a low ruminal pH are associated with a reduction in milk fat content (Allen, 1997) through a shift in the so-called ruminal biohydrogenation pathway, leading to the formation of FA isomers that downregulate the expression of genes related to de novo FA synthesis (Harvatine and Bauman, 2011).

Previous research has evaluated the relationship between management practices and milk de novo FA content for lower producing, smaller dairy farms containing a variety of breeds (Chapter 2). However, there is a need to better understand the relationship between cow comfort indicators and peNDF with de novo FA concentration for high-producing Holstein dairy farms. Therefore, the objectives of this study were to evaluate cow comfort indicators, peNDF, and lactation performance for high-producing, Holstein dairy farms with high or low de novo FA concentrations in bulk tank milk. We hypothesized that Holstein dairy farms that optimize cow comfort and feed adequate peNDF will have higher de novo FA concentrations and higher milk fat and protein content in bulk tank milk.

3.3. MATERIALS AND METHODS

3.3.1. On-Farm Data Collection and Analysis

Farms were enrolled based on their willingness to participate in the study and the concentration of de novo FA in bulk tank milk samples taken between 2 and 20 times per month for each farm. Farms were categorized as either high de novo (HDN) or low de
novo (LDN) based on their average de novo FA concentration (g/100g of FA) for the six month prior to the farm visit (September, 2014 to February, 2015; Table 3.1). To be eligible to participate in the study, farms needed to average at least 25 kg milk per cow per d, have 90% or more Holstein cattle, milk at least 50 cows, and calve year round. Farms were visited once between February 25 and April 24, 2015.

Management practices were recorded and diets were sampled for chemical analysis as described in Chapter 2. Previous research found no detectable differences in the chemical composition of corn silage or hay crop silage for HDN versus LDN herds (Chapter 2); therefore, sampling and chemical analysis of hay crop silage and corn silage were omitted in the current study. However, the most recent hay crop silage and corn silage analyses were obtained from the farm’s nutrition consultant and evaluated for DM and for CP, ADF, NDF with α-amylase and sodium sulfite, organic matter-corrected NDF with α-amylase and sodium sulfite, ether extract, starch (for corn silage only), and ash as a percentage of DM.

Total mixed ration samples were homogenized manually and subsampled using the quartering technique: homogeneous samples were divided into 4 equal subsamples. Two subsamples allocated diagonally were re-homogenized and sent to a commercial laboratory for analysis (Dairy One, Ithaca, NY) as described in Chapter 2. The remaining two subsamples were analyzed separately for particle size distribution on an as-fed basis using the Penn State Particle Separator as described by Heinrichs and Kononoff (2002) using a 19-, 8-, and 4-mm sieve, and a pan. Residues on the three sieves and the pan were weighed and duplicate results were averaged. The peNDF was calculated by multiplying the proportion of TMR retained on and above the 4-mm screen times the NDF content of
the ration as described by Kmicikewycz et al. (2015). A weighted average based on the number of cows consuming each diet was calculated and data were analyzed with farm as the experimental unit.

3.3.2. Dietary Supplements and Additives

Ingredients for concentrate feeds included in all diets fed to lactating cows on each farm were requested from the feed companies. Diets were provided by participating nutritionists from 33 farms (n = 15 HDN; n = 18 LDN). Feed products were categorized and analyzed as described in Chapter 2.

3.3.3. Milk Composition and Fatty Acid Analysis

Milk yield was determined using the number of cows milking during the farm visit and the average bulk tank milked shipped during the month of the farm visit. Milk composition data was averaged for the month of the farm visit (February, March, or April, 2015) and analyzed as reported in Chapter 2. In short, milk fat, true protein, and anhydrous lactose percentages were determined using a Fourier transform mid-infrared (FTIR) spectrophotometer (Lactoscope FTA, Delta Instruments, Drachten, The Netherlands) at the St. Albans Cooperative Creamery payment testing laboratory (St. Albans, VT, USA). Calibration of the FTIR for measurement of fat, true protein, and anhydrous lactose was done using modified milk calibration samples (Kaylegian et al., 2006) produced monthly with all lab mean reference chemistry values produced by a network of 10 to 12 laboratories (Wojciechowski et al., 2016).

Milk FA analysis was conducted at the St. Albans Cooperative payment testing laboratory simultaneously with the component milk testing as described in Chapter 2.
using partial least squares chemometric prediction models based on the mid-IR spectra (Barbano et al., 2014).

3.3.4. Statistical Analysis

Statistical analyses were conducted with SAS (version 9.2, SAS Institute Inc., Cary, North Carolina). Data were summarized by HDN and LDN group and checked for normality using the UNIVARIATE procedure. Data were considered to be normally distributed when the Shapiro-Wilks W was greater than 0.85. Differences in management, milk composition, and diet for HDN versus LDN farms were determined using the GLIMMIX procedure with de novo group as the fixed effect and farm as the random effect with the following model equation:

$$Y_{ij} = \mu + \alpha_i + R_j + E_{ij}$$

where $Y_{ijk}$ is the dependent variable, $\mu$ is the overall mean, $\alpha_i$ is the fixed effect of de novo group, $R_j$ is the random effect of farm, and $E_{ij}$ is the residual error.

Data that were not normally distributed were analyzed using an alternative distribution and the model was checked for over dispersion using the chi-square/degrees of freedom ratio. Models with a chi-square/degrees of freedom ratio close to 1.0 were considered to be a good model fit (Gbur et al., 2012). A Poisson distribution with a log link function was used to test the number of cows milking on each farm and the number of times feed was pushed up at the feed bunk. A negative binomial distribution with a log link function was used to test linear feed bunk space available per cow. Freestall feed delivery frequency (1 or 2 times per d), milking frequency (2 or 3 times per d), and inclusion of supplements or additives in the concentrate mix were analyzed with a binary
distribution and were expressed as the percentage of farms in each category, the odds ratio, and the 95% confidence limit with the HDN group set as the referent. All other dietary and management variables were normally distributed and were tested with a Gaussian distribution with an identity link function.

Additional analysis was conducted for dietary and management factors by converting interval data into nominal data surrounding a common or industry recommended cut-point (Table 3.2). The data were then analyzed using the GLIMMIX procedure using a binary distribution and a logit link function and were expressed as the percentage of farms in each category, the odds ratio, and the 95% confidence limit with the HDN group set as the referent. Differences were declared significant at \( P < 0.05 \) and trends at \( 0.05 < P \leq 0.10 \).

### 3.4. RESULTS and DISCUSSION

A total of 40 farms were visited (\( n = 20 \) HDN; \( n = 20 \) LDN). One HDN farm was removed from the dataset due to missing milk composition data because their milk was shipped to a different processing plant during the month of the farm visit. Therefore, 39 farms (\( n = 19 \) HDN; \( n = 20 \) LDN) were included in the final analysis. Milk composition data from the 6 months prior to the farm visit are presented in Table 3.1. Descriptive statistics, including the frequency of management practices, feeding strategies, and facility designs among HDN and LDN farms are presented in Table 3.3.

No differences in milk, fat, and protein yields were detected between HDN and LDN farms, although milk fat and protein content were higher \( (P < 0.01) \) on HDN farms (Table 3.4). De novo FA expressed as g/100 g of FA and as g/100 g milk were higher \( (P \)}
< 0.01) on HDN farms, and preformed FA expressed as g/100 g of FA and as g/100 g milk were lower ($P < 0.01$ and $P = 0.02$, respectively) on HDN farms. These results are consistent with previous research (Barbano et al., 2014; Chapter 2) that indicates that HDN farms have higher milk fat and protein content in bulk tank milk. De novo FA yield, expressed as g/d, was higher ($P < 0.01$) for HDN farms with no difference detected in milk yield ($P = 0.91$) suggesting that cows on HDN farms are synthesizing more de novo FA. However, milk weights per cow were not measured directly, but estimated indirectly based on the number of cows milking on the day of the farm visit and the average bulk tank milk shipped per day during the month of the farm visit. Thus, the uncertainty in milk weight data was probably higher than the uncertainty in milk composition data.

The difference in income per cow would depend on the actual milk price at any point in time. However, the average fat and protein price for the Federal Milk Order No. 1 for February through April, 2015 was $4.19 and $5.74 per kg, respectively. Therefore, at 30 kg of milk per cow per day, the average HDN farm earned a gross of $5.00 and $5.49 per cow for fat and protein, respectively. The average LDN farm at 30 kg milk per cow per day earned a gross of $4.75 and $5.30 per cow for fat and protein, respectively. These differences for fat and protein between HDN and LDN herds at 30 kg of milk would result in a gross income difference of $9,125 for fat and $6,935 for protein per 100 milking cows per year.

No differences were detected in the number of cows milking or the average DIM between HDN and LDN farms (Table 3.5; $P = 0.74$ and 0.61, respectively). An individual cow’s FA profile varies throughout her lactation (Palmquist et al., 1993); however, there
was no difference in the DIM between HDN and LDN farms, suggesting that the
differences in de novo synthesis are not likely to be caused by differences in stage of
lactation between HDN and LDN farms.

Bunk space (measured in linear centimeters per cow) tended to be higher on HDN
farms (Table 3.5; \( P = 0.06 \)). When categorized as above or below 46 cm of bunkspace per
cow, which is the treatment reported by Krawczel et al. (2012) to result in decreased
lying time, HDN herds tended (\( P = 0.06 \)) to be more likely to provide at least 46 cm of
bunk space per cow (Table 3.6). However, despite changes is resting behavior, Krawczel
et al. (2012) reported no difference in daily yield of FA <16C or milk fat content above or
below 46 cm of feedbunk space per cow. It is possible that changes in de novo FA
concentration on the current study are due to changes in behavior other than resting
behavior. In addition, the least squares means for bunkspace on LDN farms for the
current study was 39.8 cm per cow, which is more overcrowded than the highest
feedbunk stocking density treatment in the Krawczel et al. (2012) study. Therefore,
treatments for Karwczel et al. (2012) may not have resulted in severe enough changes in
behavior to affect ruminal conditions and associated de novo FA synthesis.

No difference in overall freestall stall stocking density was detected (\( P = 0.41 \)),
but HDN farms tended to be more likely to have a stocking density less than or equal to
1.10 cows per stall. The majority of freestall facilities in the northeastern US have more
rows of freestalls than the corresponding amount of bunkspace per cow, and have a
stocking density of approximately 1.10 cows per stall (von Keyserlingk et al., 2012).
Limiting access to feed bunk space is associated with a decrease in eating time (Grant
and Albright, 2001), increase in feeding rate (Collings et al., 2011), increase in aggressive
behaviors (Huzzey et al., 2006), and a trend to decrease mean ruminal pH with more time spent below a pH of 5.8 (Campbell et al., 2015), which can reduce milk fat content (Allen, 1997; Enemark et al., 2004, Sova et al., 2013). The results of the current study are consistent with Chapter 2, which found that higher stall stocking density is related to lower de novo FA content.

No difference in tiestall feeding frequency was detected ($P = 0.56$); however, HDN freestall farms tended to be more likely to feed the cows twice versus once per day (Table 3.6; $P = 0.07$). Previous research to evaluate feed management and milk FA found no detectable difference in freestall feeding frequency but an increase in tiestall feeding frequency for HDN compared with LDN herds (Chapter 2). Sova et al. (2013) found that freestall housed cows on commercial farms that fed twice versus once per day decreased sorting against long particles, and increased DMI, milk yield, eating time, and rumination time. Rottman et al. (2014) reported an increase in milk fat content when cows were fed 4x versus 1x per day. Sova et al. (2013) and Rottman et al. (2014) did not report milk FA; however, the results of the current study suggest that the increase in milk fat content observed by Sova et al. (2013) and Rottman et al. (2014) may have been due to an increase in de novo FA.

No differences were detected in the overall mean of feed push-up frequency between HDN and LDN herds (Table 3.5; $P = 0.88$ and $P = 0.32$ for tiestall and freestall herds, respectively). However, HDN farms were less likely to push up the feed when analyzed using the odds of pushing up the feed five or more times per day (Table 3.6; $P = 0.05$). Typically pushing up the feed motivates cows to eat and allows them physical access to the feed, both of which are associated with increased milk yield and feed
efficiency (Armstrong et al., 2008). However, previous research indicates that fresh feed delivery motivates cows to eat more successfully than pushing up the feed alone (DeVries et al., 2003; DeVries and von Keyserlingk, 2005). In addition, perhaps LDN freestall herds pushed up the feed more frequently because they tended to feed the cows less frequently. There is very little research to evaluate the effects of feed push-up frequency on behavior or lactation performance. Armstrong et al (2008) reported an increase in milk yield and feed efficiency when feed was pushed up every 30 minutes for the first 2 hours after feeding, compared with once per hour in the first four hours after feeding, with a total of 22 versus 31 push ups per day, respectively. Without the use of automated feed push up technology, this frequency of feed push up may be impractical on a commercial dairy farm. Miller-Cushon and DeVries (2015) reported no difference in behavior or lactation performance when comparing 3 versus 5 times per day push up frequency. Future research is needed to better understand the effects of feed delivery and feed push up frequency on rumen fermentation dynamics and milk fat composition.

No differences in dietary DM, CP, ADF, NDF, or starch, were detected but ether extract in the ration was lower \((P < 0.01)\) on HDN farms (3.7 vs 4.0% of DM for HDN vs LDN farms, respectively; Table 3.7). These results are consistent with previous research to evaluate dietary chemical composition on HDN and LDN farms (Chapter 2). However, an ether extract of 4 to 5% of DM is common in high producing dairy cow diets (NRC, 2001). These results warrant further research to understand the effects of ether extract, and its specific FA profiles, on de novo FA synthesis on commercial dairy farms.

Physically effective NDF was higher for TMR fed to cows on HDN compared with LDN farms (Table 3.8; \(P = 0.05\)). Caccamo et al. (2014) found no changes in milk
fat or milk yield, but an increase in milk protein content, for commercial dairy farms that fed adequate peNDF. In the current study, there was a moderate quadratic relationship between milk fat content and peNDF (Figure 3.1); however, there was only a very weak relationship between de novo FA and peNDF (Figure 3.2). While Mertens (2002) recommended a peNDF of 21% of DM, peNDF in the current study appears to be optimal at approximately 25% of DM. However, diets that contain excessive peNDF may slow ruminal passage rates, limit dry matter intake, and reduce milk production (Taylor and Allen, 2005). In addition, more than 15% of long particles can result in sorting against long feed particles (Oetzel, 2003) and increases a cows’ risk for low ruminal pH (DeVries et al., 2008; Enemark et al., 2009), thereby reducing milk fat content (Allen, 1997).

No difference in the inclusion of additives and supplements (Table 3.8) or in the chemical composition of hay crop silage or corn silage (Table 3.9) included in the lactating diets was detected ($P > 0.10$).

3.5. CONCLUSIONS

Cow comfort indicators and dietary peNDF were related to de novo FA concentration in bulk tank milk on high-producing, Holstein dairy farms. The management (i.e., frequent feed delivery and increased feedbunk space per cow) and dietary factors (i.e., adequate physically effective fiber and lower ether extract) that differed between HDN and LDN farms have been shown to affect ruminal function. Therefore, de novo FA concentration may be an important tool to monitor cows’ ruminal function on commercial dairy farms. However, the current study is correlational in
nature and does not imply a causal relationship. Future research is needed to evaluate whether a change in one or more of the management or nutritional strategies identified in the current study causes an increase in de novo FA synthesis and milk fat and protein content on commercial dairy farms.
3.6. REFERENCES


**TABLES AND FIGURES**

Table 3.1. Milk composition data for high de novo (HDN) and low de novo (LDN) farms from September, 2014 to February, 2015. Data were used to select farms to participate in the farm visit study.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN</th>
<th>LDN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Min</td>
</tr>
<tr>
<td>Fat, %</td>
<td>3.96 ± 0.15</td>
<td>3.72</td>
</tr>
<tr>
<td>Protein, %</td>
<td>3.19 ± 0.09</td>
<td>2.99</td>
</tr>
<tr>
<td>De novo fatty acids&lt;sup&gt;1&lt;/sup&gt; g/100g milk</td>
<td>0.92 ± 0.05</td>
<td>0.79</td>
</tr>
<tr>
<td>% of total FA</td>
<td>24.61 ± 0.75</td>
<td>22.57</td>
</tr>
<tr>
<td>Mixed fatty acids&lt;sup&gt;2&lt;/sup&gt; g/100 g milk</td>
<td>1.53 ± 0.09</td>
<td>1.37</td>
</tr>
<tr>
<td>% of total FA</td>
<td>41.15 ± 1.04</td>
<td>39.28</td>
</tr>
<tr>
<td>Preformed fatty acids&lt;sup&gt;3&lt;/sup&gt; g/100 g milk</td>
<td>1.27 ± 0.05</td>
<td>1.16</td>
</tr>
<tr>
<td>% of total FA</td>
<td>34.42 ± 1.35</td>
<td>31.99</td>
</tr>
</tbody>
</table>

<sup>1</sup> C4 to C14.
<sup>2</sup> C16, C16:1, and C17.
<sup>3</sup> C18 and greater.
Table 3.2. Cut-point and literature used to categorize high de novo (HDN) and low de novo (LDN) management characteristics for analysis using odds ratios.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cut-point</th>
<th>Reference</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stocking density, cows/stall</td>
<td>≤ 1.10 cows/stall</td>
<td>von Keyserlingk et al., 2012</td>
<td>The average freestall stocking density for the northeast is around 1.10 cows/stall. Treatments of 46 cm/cow or less reduced lying behavior.</td>
</tr>
<tr>
<td>Bunkspace, cm/cow</td>
<td>≥ 46 cm/cow</td>
<td>Krawczel et al., 2012</td>
<td>This study found no effect of feed push up on behavior or performance. their frequent push up treatment was 5x per d. However, this is the only known study in the published literature to compare a reasonable feed push up frequency for commercial farms.</td>
</tr>
<tr>
<td>Feed push-up frequency</td>
<td>≥ 5 times per day</td>
<td>Miller-Cushon and DeVries, 2015</td>
<td></td>
</tr>
<tr>
<td>Freestall feeding frequency</td>
<td>1 vs 2 times per d</td>
<td>DeVries et al., 2005</td>
<td>Twice versus once per day reduced sorting and increased feeding time. All freestall farms on the current study fed once or twice per day.</td>
</tr>
<tr>
<td>Tiestall feeding frequency</td>
<td>≤ 3 times per d</td>
<td>Gibson, 1984</td>
<td>Tiestall housed cows with low milk fat increased milk fat when fed 3 versus 1 time per day.</td>
</tr>
<tr>
<td>Time away from pen for milking</td>
<td>≤ 3 h per d</td>
<td>Charlton et al., 2014</td>
<td>Lying time affected when cows were away from the pen for 3.7 or more h per d.</td>
</tr>
<tr>
<td>Milking frequency</td>
<td>2 versus 3 times per day</td>
<td>Allen et al., 1986</td>
<td>All farms milked two or three times per day. Three versus twice per day milking is associated with increased milk production.</td>
</tr>
</tbody>
</table>
Table 3.3. Prevalence of management practices and facility design among high de novo (HDN) and low de novo (LDN) commercial dairy farms.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN</th>
<th>LDN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farms enrolled, n</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Farms in final dataset, n</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Freestall facility, n</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>2 rows per pen, n</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>3 rows per pen, n</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>Tiestall facility, n</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Certified organic, n</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Component feeding, n</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>TMR feeding, n</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Uses test day program¹, n</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Computer management, n</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Fans over stalls, n</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Fans over feed bunk, n</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Freestall feeding system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post and rail, n</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>H-Bunk, n</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Headlocks, n</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Combination, n</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

¹ Dairy Herd Improvement Association (Vermont DHIA, White River Junction, VT; Dairy One, Ithaca, NY).
Table 3.4. Least squares means of milk composition factors for high de novo (HDN) and low de novo (LDN) farms based on milk composition data for the month of the farm visit.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN</th>
<th>LDN</th>
<th>SEM</th>
<th>P – value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk yield, kg/d(^1)</td>
<td>31.9</td>
<td>32.1</td>
<td>0.9</td>
<td>0.91</td>
</tr>
<tr>
<td>Fat, %</td>
<td>3.98</td>
<td>3.78</td>
<td>0.04</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Fat, kg</td>
<td>1.27</td>
<td>1.21</td>
<td>0.03</td>
<td>0.25</td>
</tr>
<tr>
<td>De novo fatty acids(^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g/100g milk</td>
<td>0.99</td>
<td>0.86</td>
<td>0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>g/100g FA</td>
<td>25.99</td>
<td>23.78</td>
<td>0.22</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>g/d</td>
<td>315.6</td>
<td>276.2</td>
<td>9.5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Mixed fatty acids(^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g/100g milk</td>
<td>1.48</td>
<td>1.35</td>
<td>0.02</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>g/100g FA</td>
<td>38.86</td>
<td>37.36</td>
<td>0.37</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>g/d</td>
<td>472.0</td>
<td>434.2</td>
<td>15.2</td>
<td>0.08</td>
</tr>
<tr>
<td>Preformed fatty acids(^3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g/100g milk</td>
<td>1.32</td>
<td>1.38</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>g/100g FA</td>
<td>34.60</td>
<td>38.21</td>
<td>0.50</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>g/d</td>
<td>419.0</td>
<td>439.3</td>
<td>10.4</td>
<td>0.17</td>
</tr>
<tr>
<td>Protein, %</td>
<td>3.19</td>
<td>3.08</td>
<td>0.02</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Protein yield, kg</td>
<td>1.02</td>
<td>0.99</td>
<td>0.03</td>
<td>0.44</td>
</tr>
<tr>
<td>MUN, mg/dL</td>
<td>12.1</td>
<td>12.9</td>
<td>0.5</td>
<td>0.25</td>
</tr>
<tr>
<td>Anhydrous lactose, %</td>
<td>4.79</td>
<td>4.80</td>
<td>0.02</td>
<td>0.63</td>
</tr>
<tr>
<td>Anhydrous lactose, kg</td>
<td>1.53</td>
<td>1.54</td>
<td>0.05</td>
<td>0.85</td>
</tr>
</tbody>
</table>

\(^1\) C4 to C14.
\(^2\) C16, C16:1, and C17.
\(^3\) C18 and greater.
Only includes freestall farms with a designated holding area

Freestall bunks include post and rail, head locks, and H-bunks. For push-up frequency, farms with H-bunks are not included in the analysis because feed cannot be pushed up in an H-bunk.

Freestall only

Table 3.5. Management data for high de novo (HDN) and low de novo (LDN) farms.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN</th>
<th>LDN</th>
<th>SEM</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cows milking, n</td>
<td>190</td>
<td>211</td>
<td>46</td>
<td>0.74</td>
</tr>
<tr>
<td>Time away from pen, h¹</td>
<td>3.5</td>
<td>3.3</td>
<td>0.4</td>
<td>0.71</td>
</tr>
<tr>
<td>Tiestall feeding frequency</td>
<td>3.3</td>
<td>4.1</td>
<td>1.1</td>
<td>0.57</td>
</tr>
<tr>
<td>Push-up frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tiestall</td>
<td>4.9</td>
<td>6.1</td>
<td>1.4</td>
<td>0.88</td>
</tr>
<tr>
<td>Freestall²</td>
<td>1.6</td>
<td>1.8</td>
<td>0.9</td>
<td>0.32</td>
</tr>
<tr>
<td>DIM</td>
<td>170</td>
<td>176</td>
<td>8</td>
<td>0.61</td>
</tr>
<tr>
<td>Bunkspace, cm/cow³</td>
<td>50.0</td>
<td>39.8</td>
<td>3.7</td>
<td>0.06</td>
</tr>
<tr>
<td>Stocking density, cows/stall³</td>
<td>1.11</td>
<td>1.16</td>
<td>0.04</td>
<td>0.41</td>
</tr>
<tr>
<td>BCS</td>
<td>3.05</td>
<td>3.03</td>
<td>0.02</td>
<td>0.65</td>
</tr>
</tbody>
</table>

¹ Only includes freestall farms with a designated holding area
² Freestall bunks include post and rail, head locks, and H-bunks. For push-up frequency, farms with H-bunks are not included in the analysis because feed cannot be pushed up in an H-bunk.
³ Freestall only
### Table 3.6. Effects of milking and freestall feeding frequency on bulk tank milk fatty acid composition among high de novo (HDN) or low de novo (LDN) farms.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN, %</th>
<th>LDN, %</th>
<th>OR¹ (95% CI)</th>
<th>P- Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milking frequency</td>
<td>63.19²</td>
<td>50.00²</td>
<td>1.71 (0.44-6.70)</td>
<td>0.59</td>
</tr>
<tr>
<td>Time away from pen ≤ 3 h/d</td>
<td>78.72³</td>
<td>75.15³</td>
<td>1.22 (0.16-9.12)</td>
<td>0.84</td>
</tr>
<tr>
<td>Freestall feeding frequency</td>
<td>68.84⁴</td>
<td>30.68⁴</td>
<td>4.99 (0.89-27.99)</td>
<td>0.07</td>
</tr>
<tr>
<td>Freestall push-up frequency ≥ 5</td>
<td>29.82⁵</td>
<td>77.10⁵</td>
<td>0.12 (0.02-1.02)</td>
<td>0.05</td>
</tr>
<tr>
<td>Stall stocking density ≤ 1.10 cows/stall</td>
<td>65.29⁶</td>
<td>21.35⁶</td>
<td>4.74 (0.83-27.21)</td>
<td>0.08</td>
</tr>
<tr>
<td>Bunkspace ≥ 46 cm per cow</td>
<td>43.71⁷</td>
<td>7.12⁷</td>
<td>10.13 (0.91-112.41)</td>
<td>0.06</td>
</tr>
<tr>
<td>Tiestall feeding frequency</td>
<td>67.38⁸</td>
<td>42.51⁸</td>
<td>2.79 (0.06-134.62)</td>
<td>0.56</td>
</tr>
</tbody>
</table>

¹ OR = odds ratio. The HDN group is set as the referent.
²Percent of farms milking twice per day.
³Percent of freestall farms that remove the cows for 3 or more hours per day for milking. Farms that allow access to the freestall pen during milking were excluded from the analysis.
⁴Percent of farms feeding twice per day.
⁵Percent of freestall farms pushing up the feed 5 or more times per day. Farms with H-bunk mangers excluded from the analysis.
⁶Percent of freestall farms with freestall stocking density at 1.10 cows per stall or less.
⁷Percent of freestall farms with less than 46 cm of bunkspace per cow.
⁸Percent of tiestall farms feeding three or less times per day.
Table 3.7. Dietary chemical composition for diets from high de novo (HDN) and low de novo (LDN) farms. Data were mathematically composited by the number of cows consuming the diet and analyzed using farm as the experimental unit.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN</th>
<th>LDN</th>
<th>SEM</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter, %</td>
<td>41.7</td>
<td>43.7</td>
<td>1.3</td>
<td>0.23</td>
</tr>
<tr>
<td>Crude protein, % of DM</td>
<td>15.6</td>
<td>16.2</td>
<td>0.4</td>
<td>0.29</td>
</tr>
<tr>
<td>ADF, % of DM</td>
<td>23.2</td>
<td>21.5</td>
<td>0.8</td>
<td>0.14</td>
</tr>
<tr>
<td>NDF, % of DM</td>
<td>37.8</td>
<td>35.4</td>
<td>1.0</td>
<td>0.20</td>
</tr>
<tr>
<td>Ether extract, % of DM</td>
<td>3.7</td>
<td>4.0</td>
<td>0.1</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Starch, % of DM</td>
<td>22.6</td>
<td>24.3</td>
<td>1.2</td>
<td>0.29</td>
</tr>
</tbody>
</table>
Table 3.8. Particle size distribution using the Penn State Particle Separator for diets from high de novo (HDN) and low de novo (LDN) farms. Data were mathematically composited by the number of cows consuming the diet and analyzed using farm as the experimental unit. Outliers (n = 3) were identified and removed from the dataset when Cooks-D exceeded 0.13.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN</th>
<th>LDN</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDF, % of DM</td>
<td>37.3</td>
<td>34.6</td>
<td>1.0</td>
<td>0.05</td>
</tr>
<tr>
<td>pef</td>
<td>0.72</td>
<td>0.62</td>
<td>0.02</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>peNDF, % of DM</td>
<td>26.8</td>
<td>21.4</td>
<td>1.1</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>19 mm screen, % as fed</td>
<td>16.5</td>
<td>11.5</td>
<td>2.4</td>
<td>0.18</td>
</tr>
<tr>
<td>8 mm screen, % as fed</td>
<td>38.6</td>
<td>37.8</td>
<td>1.9</td>
<td>0.75</td>
</tr>
<tr>
<td>4 mm screen, % as fed</td>
<td>16.4</td>
<td>11.8</td>
<td>1.4</td>
<td>0.02</td>
</tr>
<tr>
<td>Pan, % as fed</td>
<td>28.5</td>
<td>37.5</td>
<td>2.2</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>
Table 3.9. Effects of grain ingredients on bulk tank milk fatty acid composition among high de novo (HDN; n=15) or low de novo (LDN; n=18) farms.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN, %</th>
<th>LDN, %</th>
<th>OR (95% CI)</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tallow</td>
<td>24.91²</td>
<td>35.22²</td>
<td>0.61 (0.10-3.63)</td>
<td>0.57</td>
</tr>
<tr>
<td>Rumen inert fat</td>
<td>50.00</td>
<td>70.68</td>
<td>0.41 (0.08-2.23)</td>
<td>0.29</td>
</tr>
<tr>
<td>Monensin³</td>
<td>75.09</td>
<td>58.87</td>
<td>2.11 (0.36-12.29)</td>
<td>0.39</td>
</tr>
<tr>
<td>Yeast</td>
<td>33.25</td>
<td>29.32</td>
<td>1.20 (0.21-6.80)</td>
<td>0.83</td>
</tr>
<tr>
<td>Animal derived protein</td>
<td>33.23</td>
<td>23.42</td>
<td>1.63 (0.27-9.75)</td>
<td>0.58</td>
</tr>
<tr>
<td>Rumen protected amino acid</td>
<td>41.61</td>
<td>23.43</td>
<td>2.33 (0.41-13.40)</td>
<td>0.33</td>
</tr>
<tr>
<td>Dried distillers grain</td>
<td>58.38</td>
<td>70.68</td>
<td>0.58 (0.11-3.16)</td>
<td>0.52</td>
</tr>
</tbody>
</table>

¹OR = odds ratio. The HDN group was set as referent.
²Percent of farms feeding product
³Rumensin, Elanco Animal Health, Indianapolis, Indiana.
Table 3.10. Least squares means of corn silage analysis provided by farm’s nutritionists for high de novo (HDN) and low de novo (LDN) farms.

<table>
<thead>
<tr>
<th>Item</th>
<th></th>
<th>HDN</th>
<th>LDN</th>
<th>SEM</th>
<th>P - value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Corn silage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry matter</td>
<td>23</td>
<td>29.5</td>
<td>32.3</td>
<td>1.3</td>
<td>0.11</td>
</tr>
<tr>
<td>CP, % of DM</td>
<td>22</td>
<td>8.5</td>
<td>8.0</td>
<td>0.2</td>
<td>0.10</td>
</tr>
<tr>
<td>ADF, % of DM</td>
<td>22</td>
<td>28.1</td>
<td>25.8</td>
<td>1.2</td>
<td>0.15</td>
</tr>
<tr>
<td>aNDF(^1), % of DM</td>
<td>22</td>
<td>46.1</td>
<td>43.4</td>
<td>1.6</td>
<td>0.22</td>
</tr>
<tr>
<td>aNDFom(^2), % of DM</td>
<td>10</td>
<td>43.2</td>
<td>42.6</td>
<td>1.9</td>
<td>0.83</td>
</tr>
<tr>
<td>Ether extract, % of DM</td>
<td>20</td>
<td>3.1</td>
<td>3.1</td>
<td>0.1</td>
<td>0.88</td>
</tr>
<tr>
<td>Starch, % of DM</td>
<td>20</td>
<td>27.7</td>
<td>31.9</td>
<td>1.9</td>
<td>0.11</td>
</tr>
<tr>
<td>Ash, % of DM</td>
<td>20</td>
<td>3.7</td>
<td>3.6</td>
<td>0.2</td>
<td>0.57</td>
</tr>
<tr>
<td><strong>Hay crop silage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry matter</td>
<td>24</td>
<td>33.3</td>
<td>42.8</td>
<td>2.8</td>
<td>0.02</td>
</tr>
<tr>
<td>CP, % of DM</td>
<td>23</td>
<td>17.3</td>
<td>16.5</td>
<td>0.7</td>
<td>0.37</td>
</tr>
<tr>
<td>ADF, % of DM</td>
<td>23</td>
<td>37.0</td>
<td>34.7</td>
<td>1.0</td>
<td>0.09</td>
</tr>
<tr>
<td>aNDF(^1), % of DM</td>
<td>23</td>
<td>55.5</td>
<td>52.8</td>
<td>1.8</td>
<td>0.28</td>
</tr>
<tr>
<td>aNDFom(^2), % of DM</td>
<td>12</td>
<td>50.2</td>
<td>48.4</td>
<td>3.3</td>
<td>0.69</td>
</tr>
<tr>
<td>Ether extract, % of DM</td>
<td>21</td>
<td>4.1</td>
<td>3.7</td>
<td>0.2</td>
<td>0.12</td>
</tr>
<tr>
<td>Starch, % of DM</td>
<td>18</td>
<td>1.7</td>
<td>1.7</td>
<td>0.3</td>
<td>0.99</td>
</tr>
<tr>
<td>Ash, % of DM</td>
<td>21</td>
<td>10.5</td>
<td>9.6</td>
<td>0.7</td>
<td>0.32</td>
</tr>
</tbody>
</table>

\(^1\)NDF with α-amalyase and sodium sulfite
\(^2\)organic matter-corrected NDF with α-amalyase and sodium sulfite
Figure 3.1. Milk fat content and dietary physically effective NDF (peNDF) from commercial dairy farms (n=32) exhibit a quadratic relationship.

\[ y = -0.0026x^2 + 0.1461x + 1.9056 \]

\[ R^2 = 0.2502 \]
Figure 3.2. De novo FA (fatty acid; expressed as g/100g of FA) and dietary physically effective NDF (peNDF) as a % of DM from commercial dairy farms (n=32) exhibit a weak quadratic relationship.

\[ y = -0.0083x^2 + 0.5035x + 16.726 \]

\[ R^2 = 0.1731 \]
CHAPTER 4: OVERCOMING PERCEPTION AND COMMUNICATION BARRIERS TO HELP DAIRY FARMERS MAKE BETTER MILK

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4.1. INTRODUCTION

Dairy farmers in the Northeastern US who are members of milk marketing cooperatives are paid primarily on the amount of fat and protein in their cows’ milk, and not based on the total volume of milk their cows produce (Vyas et al., 2012). In order to make the high quality milk that yields a higher income, dairy farmers must have access to the latest research in dairy nutrition and farm management best practices. They must also have a clear understanding of the potential fat and protein levels that their cows can achieve which allows them to make “better milk.”

This research was part of a larger project to help farmers increase the amount of fat and protein in their cows’ milk, in order to improve the economic viability of the dairy community in the Northeastern US (Chapter 2; Chapter 3). The current study focused on whether dairy farmers have an accurate perception of their cows’ fat and protein production, and explored how information is communicated from knowledge producers to dairy farmers.

Dairy cooperatives were established to help counter milk market volatility (Jeffords, 2010) and to market milk that is purchased from the farmers. The farmers in this research belonged to a dairy cooperative in the Northeastern US. The cooperative’s primary customers maintain a high demand for cream; therefore, the cooperative was motivated to help farmers increase fat and protein production on their farms.

Previous research conducted with this cooperative’s farmer members indicates that there was a large range in milk fat and protein content, from 3.4 to 4.2% for fat and from 2.9 to 3.4% for protein (Chapter 3). At a milk yield of 30 kg per cow per day (the
average milk yield found in Chapter 3), this difference between the minimum and maximum milk fat and protein content at the milk price at the time of the study (February to April, 2015; USDA AMS, 2015) would relate to a difference in gross income of $36,704 for fat and $31,426 for protein per 100 cows per year.

This large range in milk fat, protein, and gross income provides evidence that not all farmers are motivated to make changes, or that the necessary information is not communicated to them effectively. Therefore, the objectives of this research were to identify barriers to information transfer and explore communication strategies preferred by farmers. In addition, we offered solutions to the communication barriers identified in this research. The findings of this research can be used to improve how recommendations are communicated to dairy farmers and to ultimately encourage farmers to make better milk.

4.2. LITERATURE REVIEW

Agricultural businesses operate in a context of continuous change and require managers and farmers to maintain up-to-date, complex, and variable skill sets (Kilpatrick and Johns, 2003). Understanding decision-making behaviors is critical for appropriately disseminating information to dairy farmers and meeting their changing needs (Hutjens et al., 2004). Russell and Bewley (2013) surveyed 229 Kentucky dairy producers using a 1-5 Likert scale about their criteria for success, decision making dynamics, information sources, and technology adoption. The results showed that the most important sources of information when making decisions were advice from veterinarians, nutritionists, and
other consultants (3.70 ± 1.23), consulting with family members (3.68 ± 1.45), and educational institutions (3.10 ± 1.45).

Before a decision is made, a farmer must feel motivated to evaluate that aspect of their farm and seek out the information required to improve it. However, people are more motivated to make decisions to avoid losses than they are to make decisions that will promote gains (Rabin, 1998). Valeeva et al. (2007) found that dairy farmers are more motivated to make management changes when threatened with a penalty, or price decrease, than they are when coerced with a bonus, or price increase. This concept, known as “frame effect” in psychology research, may affect dairy farmer behavior regarding milk fat and protein because they receive payments as a bonus, rather than a penalty for milk with low fat and protein content. In addition, improving fat and protein on dairy farms is a multifactorial, complex problem and there usually is no single easy solution. When farmers are faced with a complex problem, and are unsure whether the changes they make will result in the desired result, they may be less motivated to address the problem and instead accept that the problem cannot be solved (Cameron, 2009). Therefore, it is imperative that information is communicated to farmers in a way that is not only understandable, but also allows them to comprehend the potential solutions and the financial implications of making changes to their farm operations.

Jansen et al. (2010) categorized farmers into four categories based on how they trust and incorporate information from external sources: proactivists, do-it-yourselfers, wait-and-see-ers, and reclusive traditionalists. Proactivist farmers seek ample information from their environment. They are users of the Internet, share knowledge with groups of other farmers, and seek information from their veterinarian and other farm consultants.
Do-it-yourselfers are well informed but are highly critical of outside information. They generally did not share with other farmers and complained that they received conflicting information from different farm consultants. The wait-and-see-ers tend to be a more complacent group, who recognize the benefits of seeking information but are not always motivated to do so. Lastly, the reclusive traditionalists work alone. They do not appreciate help from external sources and went as far as making attempts to keep consultants and other visitors away from their farm because they suspected these people came with a hidden agenda to make money. Identifying the type of learner the farmer is, and tailoring the message to suit their learning style, may increase the effectiveness of communication and information transfer (Noar et al., 2007).

4.2.1. Theoretical Framework

Better communication between specialists, extension agents, and farmers is needed to remove the social or logistical barriers to information transfer (Franz et al., 2010). Recommendations intended to help farmers succeed often are not adopted by all farmers who receive the information. In addition, some farmers adopt more quickly than others. The ‘Diffusion of Innovation Theory’ attempts to explain why information or a practice diffuses into a farming system at different rates, but primarily focuses on the farmers and whether they are receptive to this information (Rogers, 2003). The diffusion of innovation theory fails to recognize barriers to information communication, and how this may affect whether the innovation ‘diffuses’ successfully. Furthermore, by definition diffusion is the movement from high concentration (presumably those who have already adopted) to low concentration (those who are resistant to adoption) within a system and is
a process that does not require additional energy or input into the system. Effective communication, on the other hand, requires energy in order for the information to be transferred successfully. Therefore, when considering communication best practices for farm consultants who are interested in motivating change on the farm, we must move beyond the diffusion of innovation theory and consider a more active method of information transfer.

An alternative theory of information transfer is ‘Communication for Innovation,’ which considers the role of the communicator, the person that the information is intended for, and the past, present, and future complexities that may interfere with the successful transfer of information (Leeuwis, 2004). Leeuwis (2004) defines communication for innovation as “a series of embedded communicative interventions that are meant, among others, to develop and/or induce innovations which supposedly help to resolve (usually multi-actor) problematic situations.” On the individual farm management level, Leeuwis (2004) offers strategies for successful communication. The first is advisory communication, which includes direct problem solving as well as enhancing the farmer’s general problem solving abilities. This strategy views the communicator as a consultant, and farmer as an active problem owner, which means that both the farmer and the communicator must perceive that they have a problem to solve in order for this strategy to be successful. The second strategy is supporting horizontal knowledge exchange, which is when knowledge is shared between farmers. In this strategy, the communicator acts as a facilitator and the farmer is both an active learner as well as a source of experience for peers. It is possible for a farmer to learn new information through horizontal knowledge exchange without first identifying a particular problem that needs
to be solved. Because the communication for innovation theory includes the complexities of information transfer, and provides solutions to overcome those barriers that consider both the communicator and the farmer as actors within the system, it can be adopted as the theoretical framework for the current study.

4.3. METHODS

This research is part of a larger project that considers farm management practices that are related to higher milk fat and protein production on dairy farms (Chapter 2; Chapter 3). This research engaged the leadership and the farmer members of a single dairy cooperative. The leadership of the cooperative was interested in identifying strategies for farmers to increase the amount of fat and protein in the milk their cows produce. This was because the cooperative’s major customers buy cream, and the cooperative would like the farmers to manage their cows in a way that increases the fat and protein content of milk in order to meet the customers’ cream demand.

Methods for the larger project included one visit to each farm, which was conducted between March and April, 2014 (Chapter 2), or between February and April, 2015 (Chapter 3). We visited 44 dairy farms in 2014 and 39 dairy farms in 2015. During the farm visit, the lead researcher filled out a questionnaire of management practices with the owner or manager of the farm. We considered: cow comfort, feed delivery frequency, milking frequency, the structural design of the barn, use of electronic recordkeeping, the number of animals and resources available in the pen, and the cows’ body condition. In addition, the researcher sampled the cows’ feed and the samples were later analyzed for nutrient composition.
Several of the farm visits were followed up by semi-structured interviews that focused on how farmers and farm managers perceive their milk’s fat and protein content, how they make farm management decisions, and where they access information. A total of nine farm owners and managers were interviewed. To better understand how the cooperative motivates farmers to produce high quality milk, and its involvement in knowledge transfer, we interviewed two employees of the cooperative. Interviews were conducted in 2015 and 2016. Such qualitative research methods allow for a deeper understanding of a participant’s experience with complex issues (Creswell, 2007), which makes it especially applicable for communications research. Semi-structured interviews are a qualitative method that allows participants to share illustrative examples of their experiences or opinions (Valentine, 1997). These interviews explore the issues under investigation directly and tap into participant’s perspectives (Johnson and Onwuegbuzie, 2004). Interviews are frequently used for data collection because participants are more likely to share in depth information about their viewpoints (Flick, 2009) and have been used in communications research (Stebner et al., 2015).

This research was authorized by the University of Vermont Institutional Review Board. Interview questions were designed to stimulate open ended answers to allow farmers or the dairy cooperative’s representatives to share their thoughts on the question. Main questions were asked explicitly in every interview, but the sub questions were only asked if they hadn’t been addressed in the answer to the main question. Interviews were audio recorded with permission. The interviews were conducted individually and confidentially.
A heterogeneous subsample of farms were selected for interviews based on their fat and protein production, the design of their farm facilities, farm size, and whether they were certified organic or conventionally managed. The person selected to participate in the interview on each farm was an owner or manager who was involved with the management and decision making on the farm. Questions one and two were designed to stimulate conversation and allow the farmers to become more comfortable with the interview process (Appendix 1). Question three was designed to explore the sources of information that farmers use, including who or what they trust as a credible source of information. Questions four through seven were designed to understand the producer’s perception of their fat and protein. Question seven transitions into their decision making strategies, which was the main objective for question eight and nine.

For the interviews with the dairy cooperative’s representatives (Appendix 2), question one was designed to explore the methods of communication the cooperative currently uses. Questions two through four were to understand how the representatives cope with barriers to communication and information transfer. Question five sought to understand whether the cooperative’s representatives feel that the farmers have an accurate perception of their fat and protein production, and question six examined how farmers make decisions from the cooperative representative’s opinion. Two representatives from the cooperative who are primary communicators with farmers were interviewed.

Each interview was transcribed into a Microsoft word document. Transcripts were coded by hand to identify common statements or feelings expressed by the farmers or cooperative representatives. Codes were identified based on their frequency (occurring
repeatedly within and across interviews), omission (something that the researchers feel should occur, but never does), and declaration (when the participant tells you that something happens and that it is significant, even if it is not repeated as frequently) (LeCompte, 2000). Codes were categorized into themes and inform the findings of this study.

4.4. FINDINGS

4.4.1. Farmer’s Perception of their Cows’ Fat and Protein Production

Not all farmers in our study had an accurate perception of their cows’ milk fat and protein production. Farmers’ perceptions were compared to the average milk fat and protein content for the month of the farm visit for all farms visited in the larger research study (Chapter 3). The average milk fat and protein content for all farms, each farm we interviewed, and the farmer’s perception of their milk fat and protein content are reported in Table 4.1.

Milk fat typically has a larger range and fluctuates more than milk protein, therefore we considered milk fat to be approximately equal if it was within 0.1 percentage units of the average, and protein to be approximately equal if it was within 0.05 percentage units. For fat, 3 farms were above average, 1 was approximately equal, and 4 were below average. For protein, 3 were above average, 1 was approximately equal, and 4 were below average.

All but one farmer was satisfied with their cows’ fat and protein production. The only farmer who wasn’t satisfied said that their milk fat “is lower than it should be” and that is a correct observation as they were 0.53 and 0.19 percentage units below average.
for fat and protein, respectively. The perceptions of the farmers interviewed matched the reality (whether they were equal to or above average) for 5 farms for fat, and for 5 farms for protein. The remaining three farms perceived that they were above average when really they were below average. For example, when asked about their perception of their cows’ fat and protein production, one of these farmers said “it’s higher than most people” even though they were 0.19 percentage units lower for fat and 0.28 percentage units lower for protein compared with the average from Chapter 3. Assuming a constant milk yield, this difference in milk fat and protein yield on this farm compared to the average would amount to $21,900 per 100 cows in gross income annually (based on the February through March milk prices for Federal Order One; USDA AMS, 2015). Given the potential difference in gross income, it is necessary to communicate recommendations to farmers in ways that are both understandable and motivating. However, the findings presented here indicate that not all farmers recognize that there is an opportunity to improve milk fat and protein on their farms, even when they are below average.

4.4.2. Sources of Information

Farmers draw on many different sources of information to make decisions. Sources used by the farmers in this study can be broadly categorized into print publications, digital sources, farm consultants, financial advisors, formal education, other farmers, and management team meetings. All of the farmers reported that they obtain information from their cows’ nutritionist. A nutritionist typically has expertise in dairy cow health and production, and is responsible for balancing a diet for the cows.
All but one of the farmers mentioned that they source information from their peers, either as part of a young cooperator’s network, from their younger farm employees, or from other farmers in general. When explaining communication with other farmers, one farmer stated, “I get gossip from other farmers.” Two additional farmers specifically mentioned “gossip” when referring to sourcing information from other farmers. A fourth farmer explained further, “there is a lot of farmer to farmer chit chat and interaction on the little things, like ‘what are you doing for your foot baths?’” Another farmer did not mention that they share information with other farmers initially, so when probed about the topic, they said, “Um, not so much. I mean some, when you’re at the store or at a meeting or something. See how everybody is doing.” Perhaps these statements indicate these farmers are more comfortable sourcing information about smaller decisions or new ideas from other farmers, but source the more complex information elsewhere.

Three of the farmers mentioned that they discuss more complex information during routine management meetings. Typically, management meetings on farms involve all owners and manager-level employees, as well as the consultants the farm works with, such as the nutritionist, the veterinarian, and the agronomist. A younger farm owner states,

“In the last year we have started doing a monthly management team meeting. Other than the day to day conversations, those meetings are very helpful for moving forward planning. At the management team meeting pretty much everything is on the table. It’s my brothers, me, dad, grandpa, the vet, the nutritionist, and the banker.”
Another farmer adds, “We have meetings every 6 to 8 weeks to decide where we are going in the future…so we base management on that…and how we can make things better.”

4.4.3. Decision Making Dynamics on Farms

One of the research questions developed at the onset of this study was to address how dairy farmers make decisions that relate to farm management. The original assumption the researchers made was that dairy farmers’ decision making strategies, or the dynamics of the decision, would be somewhat consistent across different types of decisions made on the farm. This assumption was incorrect. When asked to describe how they make decisions, most farmers struggled to answer the question. They responded with, “As far as…uh…that’s kinda a wide span so…” and, “As much [information] as we can. I guess it depends on the decision.”

In addition, farmers highlighted the complexities of decision making on farms. One farmer noted,

“My dad was more of a…if he had something on his mind, that’s how he made a decision. I’m more open to asking questions, what’s going to be best five years down the road. Last year we started an LLC where me and my brother are now part owners. Before that a lot of [the decisions] were just my dad. We had no idea how financial decisions were made. Now that I do that, I try to bring everyone together…to get all of us involved in what decisions need to be made and how they’re made.”

This quotation highlights the difficulty of multiple generations managing a family business together. However, other farmers shared the advantages of multiple generations on the farm. One farmer explained, “My help, being younger and just getting out of school, they have new ideas.” Another farmer added in reference to hiring a younger
employee a few years prior “We’re pretty mellow as far as most people go…and he likes to analyze every little bit of information. He keeps us on our toes, and pushes us to be better.” Therefore, these findings suggest that even though multiple generations on one farm can be challenging, it can also benefit the farm as the younger generations bring new ideas and energy to the business.

On the other hand, two farmers responded quickly that decision making is easy, they just “use common sense.” However, these two farms had some of the lowest fat and protein production of all of the farms interviewed for this study. Jansen et al. (2010) categorized farmers into types, one of which was ‘reclusive traditionalists.’ Jansen et al. (2010) describe these farmers as distrusting of external information sources, and closed off from information from the external world. These two farmers would both fit into this category. One farmer mentioned an extreme distrust in the cooperative, and felt that their low fat and protein production was because the cooperative was cheating, not because their cows were not producing well. The other perceived that their fat and protein was high, but in reference to making changes to improving it further, they said, “It’s not worth it. It’s like saying ‘do you want to make more money but you’ve gotta work 100 hours per week.’” The first farmer was not interested in making changes either. They said, “I never give it much thought really. I just keep doing the same thing every day. I’ve been here milking cows for 43 years.” Some farmers are not interested in incorporating complex information into their farm businesses, and instead choose to make less complex decisions where they can rely on common sense alone to guide them. Communicating with these farmers in a way that will change their behavior is very challenging.
4.4.4. Communication Strategies from the Cooperative

The cooperative has different ways to communicate with their farmer members. These include face-to-face events such as quality awards events, fall informational meetings, and a winter annual gathering and business meeting. In addition, they have a young cooperator’s group for younger farmers. The committee meets monthly, and they plan two annual events for young farmers. In addition, they send a bimonthly newsletter that is included with the farm’s milk check, which contains market information as well as the average milk fat and protein content of the milk from the producer members for the pay period. The cooperative staff believes that approximately 40 to 50% of the membership takes a close look at their newsletter, but if they have something really important, they put it on the back page of the newsletter. “That way if the newsletter is sitting on the counter upside down it will at least have that standing out.”

For digital communication, the cooperative has an active Facebook page, and the young cooperator’s group has a private Facebook group where they share information. In addition, they have email addresses for approximately 70% of their farmer members and they use email to send routine updates on their milk fat and protein levels, as well as additional information that needs to be communicated quickly and efficiently. In fact, one person who regularly communicates with farmers from the cooperative stated that

“If I had a magic wand, all of our producers would have high speed internet and I would have all of their emails…being able to email somebody something and know that they will be able to get it within a 24-hour period is definitely the quickest and most cost effective way.”

A cooperative staff member also mentioned another idea to aid in information transfer,
“An area for potential improvement would be to carve out the time to have more informal barn meetings...more frequent informal group discussions with members in a comfortable farm setting. So for example, if I was going to be in [a particular region] for a day, and I was going to be at Farmer Bob’s farm for a couple hours, to be able to get that information out efficiently and effectively so that members in that area that have questions could stop by...nothing formal like a PowerPoint, but just three or four discussion topics. And then really let the producers who are there dictate where the conversation goes.”

A cooperative staff member also mentioned that farmer attendance at informational meetings is often times tied to the milk price.

“When the price is high are things are going well...I don’t think they’re as concerned about some of the other stuff...maybe they feel a greater need to have all of the information possible for them to make as good of decisions as they can when times are tough and they have to watch every dollar.”

The cooperative wants the farmers to have higher milk fat and protein content, because it leads to more economically viable farms (Bailey et al., 2005) and it supports the demand of the cooperative’s customers. However, when asked about their role as a communicator of information, a cooperative employee stated,

“I think that our philosophy has been that for on farm stuff, we really try to stay out of the producer’s way. Let them run their business as long as they’re meeting certain standards. I think where our role really comes in is as a cooperative and trying to give market information. A producer will call and say ‘Hey, I’ve got my monthly meeting with the vet and the nutritionist, can you give me the latest update with what’s going on with markets and values for milk and milk components?’”

The cooperative recognizes the importance of management team meetings, but doesn’t feel that they need to play an active role as a farm consultant. Instead, they communicate market information that can be used by the other farm consultants and the farmers to make management decisions. Perhaps that is because they feel that the other consultants have the expertise. Another cooperative employee adds to this point,
“I think the nutritionists are going to have a good handle on [fat and protein]. It used to be that these grain companies would just hire an old retired farmer to come around and be a salesman, and I don’t think that’s going to be the case going forward. They are going to have a masters [degree] in animal nutrition or they are not going to be selling grain.”

The cooperative staff members recognize the complexity in producing milk with higher fat and protein, but like many farmers, do not have an easy solution.

4.5. DISCUSSION AND RECOMMENDATIONS

4.5.1. Network of Communication

The farmers interviewed in this study exist in a complicated network of information and communication (Figure 4.1.). This supports the Leeuwis’ (2004) contention that communication networks are embodied and complex and refutes a notion of the diffusion of innovation, which assumes that innovation flows from knowledge producers to farmers. The transfer of information can be slowed, blocked, or complicated by a series of barriers. The barriers mentioned in the interviews for this research are highlighted in Figure 4.1. These barriers include the farmer’s perception of their fat and protein, and whether or not they believe that they need to improve. In addition, improving milk fat and protein content is a complex problem, and farmers are less motivated to solve complex compared with simple problems (Cameron, 2009). All of the farms on the current study have a labor force that is at least partly comprised of family members, and family dynamics introduce an additional barrier. In addition, financial implications, both positive (more fat and protein is related to profitability) and negative (some changes require a financial investment) can be barriers to communication. Financial barriers act in two ways: first, the expert consultants may suggest changes to improve fat and protein
that require a financial investment, and the farm may not have the financial recourses to make the investment. Second, while the financial advisor acts as a consultant, they may also limit the changes that farmers can make because they will not allow the farmer to incur additional debt. Aside from financial barriers, additional barriers include whether consultants and technicians are trained in communication, whether farmers have access to or choose to use the Internet to source information or to receive emails, and whether they read and understand the print publications that they receive in the mail.

Understanding the barriers that emerged from this research allows us to propose solutions based on the communication for innovation’s theory. Communication for innovation’s theory is based on three principals of communication, which includes the development of networks, supporting social learning, and dealing with power conflicts that may block innovation. Therefore, three solutions can be proposed. The first is to help farmers overcome the barrier of perception by allowing them to view their numbers compared with other farmers. The second is to promote the use of management team meetings, which were not only recommended by the farmers that use them, but also can help dissolve barriers between the generations, and barriers related to farm finances, both of which are related to power dynamics. The third is based on a recommendation by one of the cooperative’s employees, and that is to promote more informal discussion groups where farmers can share ideas, contributing to social learning.

4.5.2. Solution 1: Overcome Incorrect Perceptions of Fat and Protein

In order to be motivated to make changes on the farm, a farmer first needs to understand that there is room for improvement. Despite the financial implications of
improving fat and protein, some farmers do not have an accurate perception of their cows’ fat and protein production level and whether there is room for improvement. Farmers can be motivated through the ‘peripheral’ strategy of communication, which is recommended by Jansen et al. (2010) when a communicator is attempting to influence a person’s behavior. The peripheral strategy acknowledges that farmers, and humans in general, are not motivated to think rationally about a problem. However, they still may be persuaded to change their behavior using a series of subconscious cues. One of these cues could be seeing their own farm’s fat and protein content compared with their neighbors, on one piece of paper. This would give farmers a clear understanding of where they stand relative to the average, or relative to farms similar to theirs. In addition, using the current market information, this communication could include the difference in gross income between the current farm, an average farm, and an above average farm. Recognizing the financial implications for higher fat and protein may help motivate a farmer to make changes as well.

Logistically, this recommendation may be the most challenging, but could also result in the highest return. It would first require a very active database that could be used to categorize the farms. At the least, the database would need to identify the predominant breed of cows at the farm. Breed affects milk fat and protein content (Soyeurt et al., 2006); therefore, farms could only be compared to other farms with the same breed. Next, the information would need to be communicated to the farmer, either by letter or through email. If sent by mail, it would ideally accompany the milk check, as this is a piece of information that is likely to be noticed by the farmer. If included in an email, it could be
done more rapidly. However the farmers who do not have access to the Internet or who do not use email would be excluded.

4.5.3. Solution 2: Encourage Management Meetings

Two farmers interviewed for the current study reported that management meetings were an important source of information. Based on the themes reported in this study, management meetings may be a successful way to overcome two barriers: financial barriers, and generational barriers. This recommendation is in agreement with the communication for innovation theory, which supports the building of new networks and restructuring of old networks (Leeuwis, 2004). A management team should include all generations of farm owners, the banker or financial advisor for the farm, as well as the farms consultants who have expertise in fat and protein production, such as the veterinarian and the nutritionist. This network of individuals can serve to promote communication for innovation in a farm setting (Leeuwis, 2004). The financial implications of improving fat and protein can be discussed while in the presence of both the banker, who is the gatekeeper for future farm investments, and the nutritionist, who has the knowledge to make management recommendations that may result in an increased fat and protein.

Management meetings may also support another aspect of the communication for innovation theory, which deals with dynamics of power and conflict (Leeuwis, 2004). A barrier to communication theme that was prominent in the interviews was the conflicts between older and younger generations of farm owners, especially those who are family. The management team may provide a safe network where all farm stakeholders have a
seat at the table and can share ideas openly. This open communication may help promote the adoption of new innovation on dairy farms, especially because younger generations may be more likely to adopt new innovations (Pierpaoli et al., 2013). Previous research has evaluated the efficacy of instating management team meetings that include expert consultants compared to farms with no formal management meetings, and reported a tendency for farm size growth and improved milk production cow (Weinand and Conlin, 2003). In addition, project herds that developed more focused goals were more likely to have a larger impact on herd size, productivity, and cow health. This research supports the importance of management team meetings and highlights the importance of goal setting when implementing farm management changes.

4.5.4. Solution 3: Support Informal Discussions Between Farmers

The value of informal discussions with other farmers emerged as prominent theme in this research. This supports the communication for innovation theory, which supports social learning and acknowledging that learning is a critical process of acceptance of innovations in an environment (Leeuwis, 2004). Based on the experiences of the cooperative’s employee, informal group discussions are an excellent place for farmers to share ideas and learn from each other. Previous research agrees that farmers learn well in informal settings (Kilpatrick and Johns, 2003). In addition, Franz et al. (2010) interviewed farmers about their learning preferences and found that farmers prefer hands on learning, demonstrations, farm visits, field days, and discussions best. All of these activities can take place in a farm setting, where the cooperative employee stated that farmers regard as a “safe place.”
The cooperative has expressed that they feel that their role is not as a consultant, but as a facilitator. Organizing or facilitating informal discussion groups among farmers may be an effective way for the cooperative to be more involved with transferring new information and innovations to farmers without taking a top-down approach. Because farmers have expressed that they are more comfortable sharing information related to simple decisions with other farmers, the best approach may be to facilitate discussions on smaller, more tangible goals rather than opening a broad and complex conversation about difficult problems, such as increasing fat and protein. For example, reducing stocking density (decreasing the number of cows per freestall or increasing feed bunk space per cow) is associated with higher fat and protein content on dairy farms (Chapter 2 and Chapter 3). Therefore, a discussion group could meet and discuss reducing stocking density (a simpler, easier problem) rather than discussing fat and protein in general. This recommendation meets both the farmer’s desire to discuss ideas with other farmers that are less complex, while also meeting the farmer’s desire to participate in more informal discussion meetings to share information.

The young cooperator’s private Facebook group is another example of a safe place for informal discussion, although to belong to the group a farmer has to be less than 40 years old, therefore not all farmers are included. Promoting discussion among the young farmer group may help to improve fat and protein in the future, as these farmers will eventually be the senior owners of the farm. Additional discussion could be stimulated by the cooperative by posing questions to the group, and allowing members to share their experiences or ideas with a particular topic. Both in person and online informal discussion groups should include a moderator with expertise in the subject area.
The moderator’s role is not to lead the discussion, but instead to provide technical information when needed and to ensure that the conversation remains productive.

4.6. CONCLUSIONS

In depth interviews found that knowledge about how to improve milk fat and protein does not easily find its way to individual dairy farmers. The communication network identified includes several barriers that need to be overcome by using effective communication techniques to transfer information. Farmers use a diverse set of methods to make decisions and use different sources of information depending on the complexity and the “weight” of the decision to be made. This research suggests that there are several ways that communication between an agricultural organization and individual farms can be improved. The communication for innovations theory, which recognizes that the role of the communicator, the farmer, and past, present, and future complexities may interfere with communication transfer, should be considered when developing new communication techniques. From this research, we recommend that agricultural organizations correct any misperceptions the farmer may have about their fat and protein level and whether there is room for improvement, encourage management team meetings with farm consultants to discuss complex problems and set farm goals, and to support informal discussion groups where farmers can share ideas in a comfortable setting. Communicating information from knowledge producers to dairy farmers is a critical step in the agricultural research process and is necessary to support innovation and sustainability on today’s dairy farms.
4.7. REFERENCES


### TABLES AND FIGURES

Table 4.1. The milk fat and protein percentage from the farms that participated in an interview, the average milk fat and protein percentage from the farms that participated in the study reported in Chapter 3, and the farmer’s perception of their milk fat and protein.

<table>
<thead>
<tr>
<th></th>
<th>Milk fat, %</th>
<th>Milk protein, %</th>
<th>Perception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average of all farms</td>
<td>3.88</td>
<td>3.13</td>
<td>-</td>
</tr>
<tr>
<td>Average for each farm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.31</td>
<td>3.25</td>
<td>“I’m very satisfied… extremely proud”</td>
</tr>
<tr>
<td>2</td>
<td>3.35</td>
<td>2.94</td>
<td>“It’s lower than it should be”</td>
</tr>
<tr>
<td>3&lt;sup&gt;+&lt;/sup&gt;</td>
<td>3.78</td>
<td>3.16</td>
<td>“Right now we’ve seen a little dip in both but we’re above the co-op average”</td>
</tr>
<tr>
<td>4</td>
<td>4.13</td>
<td>3.22</td>
<td>“Yeah, it’s pretty good”</td>
</tr>
<tr>
<td>5</td>
<td>3.69</td>
<td>2.85</td>
<td>“It’s higher than most people”</td>
</tr>
<tr>
<td>6</td>
<td>3.89</td>
<td>3.19</td>
<td>“I would obviously like to see both higher, but I can’t complain”</td>
</tr>
<tr>
<td>7</td>
<td>4.02</td>
<td>3.07</td>
<td>“We always want it to be higher. Doesn’t everybody”</td>
</tr>
<tr>
<td>8</td>
<td>3.66</td>
<td>3.07</td>
<td>“Yeah. Yep”</td>
</tr>
</tbody>
</table>

<sup>1</sup> Response to the questions “Are you satisfied with you herd’s fat and protein production?”

<sup>2</sup> Average milk fat and protein content of all farms visited (n = 39) and reported in Chapter 3.

<sup>3</sup> Average milk fat and protein content for each individual farm during the month of the farm visit.

<sup>4</sup> Two interviews were conducted on this farm. The farm owner and the employee shared a similar perception of their cows’ fat and protein production level.
Figure 4.1. Information sources (normal font) and barriers to communication (italic font) that are involved with the transfer of knowledge to dairy farmers.
CHAPTER 5: CONCLUSIONS AND IMPLICATIONS

5.1. Future Research on Dairy Farm Management

The biological link between high de novo FA and high milk fat and protein content is not well understood and is a potential area for future research. The relationship between de novo FA and milk fat and protein content is likely due to differences in rumen conditions. Severe and prolonged decreases in rumen pH cause changes in rumen metabolism that downregulate de novo FA synthesis. In addition, adequate fiber fermentation is necessary to supply acetate and butyrate for de novo FA synthesis. Management and diet that protect against low rumen pH and allow for adequate acetate and butyrate production also support microbial protein production, which provides amino acids needed for milk protein synthesis. The relationship between de novo fatty acids and milk fat and protein content identified in the current study is correlational in nature. Future research to investigate a causal relationship should focus on influencing the above rumen metabolic states to change de novo FA content, and measure its effect on milk fat and protein content and yield.

The results of the studies in Chapter 2 and Chapter 3 vary slightly, but the overall interpretation and implications of the results are similar. Milk yield was higher on HDN compared with LDN farms in Chapter 2, and was the same between groups in Chapter 3 (Table 5.2.) De novo and mixed origin fatty acids were higher and preformed fatty acids were lower on HDN farms in both chapters. This indicates that increasing de novo is associated with an increase in milk fat and protein content, with an increase or no change
in milk yield, all of which are related to an increase in gross income on a commercial dairy farm.

No difference was detected in body condition score in Chapter 3, but there was a difference in Chapter 2, which may be due to the inclusion of farms with extremely low milk yield feeding poor quality feed in the LDN group (Table 5.3.). It is critical that dairy cow rations meet their energy demands, and both dairy farmers and nutritionists are responsible for monitoring the cows’ body condition during lactation. Regular body condition scoring on commercial farms may be a practical and low cost way to monitor and prevent excessive body condition loss.

Tiestall feeding frequency was higher on HDN farms in Chapter 2 (Table 5.3.), but there were only nine tiestall farms included in Chapter 3; therefore, we may have lacked statistical power to detect differences in tiestall feeding frequency. No difference in freestall feeding frequency was detected in Chapter 2, but HDN farms were more likely to feed their cows twice per day in Chapter 3. In addition, HDN farms pushed up the feed less frequently in Chapter 2 and were less likely to push up the feed at least 5 times per day in Chapter 3. This was an unexpected result but could be related to delivering fresh feed less frequently on the LDN farms. Very little research has evaluated the effects of feed push up frequency on cow behavior and lactation performance. Future research should compare different levels of feeding frequency and feed push up frequency to identify the appropriate frequency of both practices on commercial farms.

Bunkspace tended to be higher on HDN farms in Chapter 3, but in Chapter 2 no difference was detected. This may be due to the dataset in Chapter 3 which contained more farms across both groups that housed their animals in barns with three rows of stalls.
for every row of freestalls (i.e. six row barns; Table 5.1.), which results in the bunkspace being the most limiting resource. In Chapter 2, there were fewer farms with six-row barns and more farms with 2-row barns, in which case the freestalls would be more limiting or equally as limiting. Therefore, the significant difference in freestall stocking density observed in Chapter 2 but not in Chapter 3 is consistent with the facilities design of the farms included in each dataset. Future management recommendations should be tailored to the design of the freestall barn on individual farms, since stall stocking density may be more critical in 2-row pens, while feedbunk space may be more critical in 3-row pens.

In both Chapter 2 and Chapter 3, ether extract was higher in TMR from LDN farms. Furthermore, no difference was detected between HDN and LDN herds in dietary DM, CP, ADF, NDF, or starch in either study. A larger proportion of LDN farms fed rumen inert fat products in Chapter 2 ($P = 0.11$) but there was no difference detected in the inclusion of other feed additives or supplements in either study. Future research is needed to evaluate the effects of specific fatty acids in the diet of lactating dairy cow feeds on commercial dairy farms.

The specific results sometimes varied, but the overall messages from both studies are similar. Both studies demonstrated that management practices such as overcrowding and feed frequency influenced bulk tank de novo FA content. In addition, both studies indicate that ether extract levels in the ration may play a role in the level of de novo milk FA synthesis.
5.2. Future Research on Farmer Communication

The research in Chapter 4 found that not all farmers have an accurate perception of their cows’ milk fat and protein production level, and whether there is room for improvement. In addition, we found that farmers make decisions using different information, and the information source depends on the complexity of the decision. Farmers look to other farmers for new ideas, recommendations, and information regarding simple decisions. However, they look to farm consultants with expertise, such as their nutritionist, for information regarding complex problems and decisions.

From this research, we developed three recommendations: 1) to help farmers understand when there is room to improve their cows’ fat and protein production, 2) to encourage that the farm begins regular management team meetings with all upper level employees and farm consultants, and 3) for the cooperative to support informal discussion groups where farmers can share ideas. However, future research is needed to evaluate the efficacy of these recommendations. For example, a group of farms could be selected and half of them could begin using these recommendations, and half could serve as controls. Farmers could be interviewed before, during, and after the study to understand whether they believe these recommendations are effective. In addition, their milk fat and protein levels could be monitored throughout and after the study to identify whether instating the recommendations resulted in higher milk fat and protein production.

5.3. Implications for the Dairy Community

On February 13, 2016 the St. Albans Cooperative Creamery began sharing de novo, mixed, and preformed fatty acid information with the dairy producers. This
information is another tool in the farmer’s toolbox that indicates whether their cow’s rumens are functioning properly. The results of the farm visit studies presented in Chapter 2 and Chapter 3 can provide insight as to the best management practices dairy farmers use to increase de novo fatty acids. As de novo fatty acids increase, milk fat and protein content typically increase. A higher milk fat and protein yield may improve the gross income of the farm at a time when low milk prices are tightening farm budgets.

Dairy nutritionists are typically given access to the farms bulk tank milk fat and protein test, which will now include milk fatty acid information. The nutritionists can use this information to evaluate the diets they are feeding to the cows, and also use it to make recommendations to farmers about their farm management practices.

In Chapter 4, the St. Albans Cooperative expressed that they would prefer let the nutritionists make the specific recommendations that pertain to increasing de novo fatty acids, as they believe the nutritionists have the expertise. However, this research might have a larger impact if the St. Albans Cooperative Creamery continues to organize educational outreach initiatives that help farmers and nutritionists better understand and apply fatty acid information to their farms.

Fatty acid information can be used by farmers to evaluate their management practices, with the ultimate goal of increasing milk fat and protein content. The results of Chapter 2 and 3 provide recommendations that farmers can use to increase de novo fatty acids in bulk tank milk. Chapter 4 highlights the importance of using best communication practices when interacting with farmers, and provides three recommendations that farm consultants can use to motivate farmers to change their behavior, and their management practices. Innovative, economically viable farms are critical for the future of the dairy
industry in the Northeast, and this research provides recommendations that farmers can use to position themselves for a successful future in dairy farming.
Table 5.1. Descriptive statistics for high de novo (HDN) and low de novo (LDN) herds for studies presented in Chapter 2 and Chapter 3.

<table>
<thead>
<tr>
<th>Item</th>
<th>Chapter 2</th>
<th></th>
<th></th>
<th>Chapter 3</th>
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<tbody>
<tr>
<td>Farms enrolled, n</td>
<td>21</td>
<td>23</td>
<td></td>
<td>20</td>
<td>20</td>
<td></td>
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<tr>
<td>Farms in final dataset, n</td>
<td>21</td>
<td>23</td>
<td></td>
<td>19</td>
<td>20</td>
<td></td>
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<tr>
<td>Freestall facility, n</td>
<td>13</td>
<td>10</td>
<td></td>
<td>16</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>2 rows per pen, n</td>
<td>4</td>
<td>1</td>
<td></td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3 rows per pen, n</td>
<td>9</td>
<td>9</td>
<td></td>
<td>11</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Tiestall facility, n</td>
<td>8</td>
<td>13</td>
<td></td>
<td>3</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Certified organic, n</td>
<td>9</td>
<td>4</td>
<td></td>
<td>0</td>
<td>1</td>
<td></td>
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<tr>
<td>Component feeding, n</td>
<td>7</td>
<td>10</td>
<td></td>
<td>1</td>
<td>5</td>
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<tr>
<td>TMR feeding, n</td>
<td>14</td>
<td>13</td>
<td></td>
<td>18</td>
<td>15</td>
<td></td>
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<tr>
<td>Uses test day program¹, n</td>
<td>12</td>
<td>13</td>
<td></td>
<td>8</td>
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<td>Computer management, n</td>
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<td>13</td>
<td></td>
<td>12</td>
<td>14</td>
<td></td>
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<tr>
<td>Fans over stalls, n</td>
<td>9</td>
<td>9</td>
<td></td>
<td>14</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Fans over feed bunk, n</td>
<td>7</td>
<td>4</td>
<td></td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Freestall feeding system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post and rail, n</td>
<td>7</td>
<td>4</td>
<td></td>
<td>7</td>
<td>5</td>
<td></td>
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<tr>
<td>H-Bunk, n</td>
<td>5</td>
<td>1</td>
<td></td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Headlocks, n</td>
<td>1</td>
<td>5</td>
<td></td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Combination, n</td>
<td>0</td>
<td>0</td>
<td></td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

¹ Dairy Herd Improvement Association (Vermont DHIA, White River Junction, VT; Dairy One, Ithaca, NY).
Table 5.2. Least squares means of milk composition factors for high de novo (HDN) and low de novo (LDN) farms based on milk composition data for the month of the farm visit for studies presented in Chapter 2 and Chapter 3.

<table>
<thead>
<tr>
<th>Item</th>
<th>Chapter 2</th>
<th></th>
<th>Chapter 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk yield, kg/d</td>
<td>26.3**</td>
<td>22.7**</td>
<td>31.9</td>
<td>32.1</td>
</tr>
<tr>
<td>Fat, %</td>
<td>4.33*</td>
<td>4.14*</td>
<td>3.98***</td>
<td>3.78***</td>
</tr>
<tr>
<td>Fat, kg</td>
<td>1.1**</td>
<td>0.9**</td>
<td>1.27</td>
<td>1.21</td>
</tr>
<tr>
<td>De novo fatty acids(^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g/100g milk</td>
<td>1.06***</td>
<td>0.94***</td>
<td>0.99***</td>
<td>0.86***</td>
</tr>
<tr>
<td>g/100g FA</td>
<td>25.61***</td>
<td>23.71***</td>
<td>25.99***</td>
<td>23.78***</td>
</tr>
<tr>
<td>g/d</td>
<td>269.8***</td>
<td>207.3***</td>
<td>315.6***</td>
<td>276.2***</td>
</tr>
<tr>
<td>Mixed fatty acids(^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g/100g milk</td>
<td>1.60**</td>
<td>1.50**</td>
<td>1.48***</td>
<td>1.35***</td>
</tr>
<tr>
<td>g/100g FA</td>
<td>38.86**</td>
<td>37.98**</td>
<td>38.86***</td>
<td>37.36***</td>
</tr>
<tr>
<td>g/d</td>
<td>411.9***</td>
<td>329.7***</td>
<td>472.0*</td>
<td>434.2*</td>
</tr>
<tr>
<td>Preformed fatty acids(^3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g/100g milk</td>
<td>1.45**</td>
<td>1.51**</td>
<td>1.32**</td>
<td>1.38**</td>
</tr>
<tr>
<td>g/100g FA</td>
<td>35.53***</td>
<td>38.31***</td>
<td>34.60***</td>
<td>38.21***</td>
</tr>
<tr>
<td>g/d</td>
<td>376.4</td>
<td>333.4</td>
<td>419.0</td>
<td>439.3</td>
</tr>
<tr>
<td>Protein, %</td>
<td>3.41***</td>
<td>3.22***</td>
<td>3.19***</td>
<td>3.08***</td>
</tr>
<tr>
<td>Protein yield, kg</td>
<td>0.89***</td>
<td>0.73***</td>
<td>1.02</td>
<td>0.99</td>
</tr>
<tr>
<td>MUN, mg/dL</td>
<td>11.4</td>
<td>11.3</td>
<td>12.1</td>
<td>12.9</td>
</tr>
<tr>
<td>Anhydrous lactose, %</td>
<td>4.60</td>
<td>4.59</td>
<td>4.79</td>
<td>4.80</td>
</tr>
<tr>
<td>Anhydrous lactose, kg</td>
<td>2.68*</td>
<td>2.31*</td>
<td>1.53</td>
<td>1.54</td>
</tr>
</tbody>
</table>

\(^1\) C4 to C14.
\(^2\) C16, C16:1, and C17.
\(^3\) C18 and greater.
Table 5.3. Least squares means of management factors for high de novo (HDN) or low de novo (LDN) farms observed or recorded during the farm visit for studies reported in Chapter 2 and Chapter 3.

<table>
<thead>
<tr>
<th>Item</th>
<th>Chapter 2 HDN</th>
<th>Chapter 2 LDN</th>
<th>Chapter 3 HDN</th>
<th>Chapter 3 LDN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cows milking, n</td>
<td>105</td>
<td>108</td>
<td>190</td>
<td>211</td>
</tr>
<tr>
<td>DIM</td>
<td>165</td>
<td>179</td>
<td>170</td>
<td>176</td>
</tr>
<tr>
<td>Bunkspace, cm/cow(^1)</td>
<td>50.6</td>
<td>42.4</td>
<td>50.0(^*)</td>
<td>39.8(^*)</td>
</tr>
<tr>
<td>Stall stocking density, cow/stall(^1)</td>
<td>1.05(^**)</td>
<td>1.20(^**)</td>
<td>1.11</td>
<td>1.16</td>
</tr>
<tr>
<td>Tiestall feeding frequency per d</td>
<td>4.6(^**)</td>
<td>2.9(^**)</td>
<td>3.3</td>
<td>4.1</td>
</tr>
<tr>
<td>Feed push-up frequency per d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tiestall</td>
<td>1.3(^*)</td>
<td>3.5(^*)</td>
<td>4.9</td>
<td>6.1</td>
</tr>
<tr>
<td>Freestall</td>
<td>2.7(^*)</td>
<td>4.8(^*)</td>
<td>1.6</td>
<td>1.8</td>
</tr>
<tr>
<td>BCS</td>
<td>3.08(^***)</td>
<td>2.96(^***)</td>
<td>3.05</td>
<td>3.03</td>
</tr>
</tbody>
</table>

\(^*\) 0.05 < \(P\) ≤ 0.10  
\(^**\) 0.01 < \(P\) ≤ 0.05  
\(^***\) \(P\) < 0.01
Table 5.4. Dietary chemical composition for diets from high de novo (HDN) and low de novo (LDN) farms for Chapter 2 and Chapter 3. Data were mathematically composited by the number of cows consuming the diet and analyzed using farm as the experimental unit.

<table>
<thead>
<tr>
<th>Item</th>
<th>HDN</th>
<th>LDN</th>
<th>HDN</th>
<th>LDN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter, %</td>
<td>42.2</td>
<td>38.9</td>
<td>41.7</td>
<td>43.7</td>
</tr>
<tr>
<td>CP, % of DM</td>
<td>15.1</td>
<td>16.0</td>
<td>15.6</td>
<td>16.2</td>
</tr>
<tr>
<td>ADF, % of DM</td>
<td>22.7</td>
<td>23.7</td>
<td>23.2</td>
<td>21.5</td>
</tr>
<tr>
<td>NDF, % of DM</td>
<td>37.4</td>
<td>38.7</td>
<td>37.8</td>
<td>35.4</td>
</tr>
<tr>
<td>Starch, % of DM</td>
<td>23.1</td>
<td>20.2</td>
<td>22.6</td>
<td>24.3</td>
</tr>
<tr>
<td>Ether extract, % of DM</td>
<td>3.7***</td>
<td>4.4***</td>
<td>3.7***</td>
<td>4.0***</td>
</tr>
</tbody>
</table>

*** P < 0.01


APPENDIX I

Semi-structured Interview questions for farmer interviews, Chapter 4

1) How did you become a dairy farmer?
   a. Did you grow up on a farm?
   b. Did you learn about farming in school?

2) How would you describe your main role on the farm?
   a. Do you work more with the cows or with crops?
   b. Are you a full time employee on the farm?

3) When you are looking for information on cow management or running the farm in general, where do you go?
   a. Examples would be a veterinarian, nutritionist, conferences, etc?
   b. Are there any other sources that we haven’t talked about that you use to help make management decisions?
   c. Do you take to other farmers in your area to help make management decisions?
   d. Do you use different sources for different kinds of problems or decisions?

4) Who is involved in making decisions on your farm?
   a. Family nutritionist veterinarian etc?

5) Are you satisfied with your herd’s fat and protein production?
   a. Can you tell me what steps you might take to support your herd’s fat and protein production?
   b. Are there seasonal differences? How do you respond to them?

6) What do you think is the biggest challenge relative to improving your fat and protein yield?

7) If you could make one change and cost wasn’t a factor, what might you change to improve fat and protein yield?

8) What was the most recent change you made on your farm to improve your facilities, management, nutrition, or feeding strategies?
   a. When did you do this?
   b. Did you consult with anyone off of the farm to help you make this decision?
c. Did you see the response that you hoped after making this change? Why or why not?

9) Where do you see your farm business going in the next 10 years,
   a. Expansions, generational transfer, or staying the same?

Thank you very much for your time. Is there anything else you would like to add about your farm or your fat and protein production?
APPENDIX II

Semi-structured Interview questions for cooperative employee interviews, Chapter 4

1) What does the co-op do to communicate with farmers in general?
   a. Send out technicians to the farms
   b. Newsletter – do they think its effective and how do they know
   c. YC program
   d. Annual meetings?
   e. Social media?
   f. Do you have any other ideas?

2) When you get to a farm, how do you get a reluctant farmer to open up to you?

3) What’s the most effective way to get information back and forth?
   a. Does it depend on the farmer?
   b. Do you tailor to individual farmers or farmer types? If not currently, how would you envision doing so in the future?

4) Are there any gaps or problems? Problems where you are finding it hard to communicate?
   a. How does a technician get to make an impact with a farmer that might be difficult
   b. How do you develop trust? Are there times where the farmers don’t trust you, or other consultants (eg veterinarian, nutritionist)
   c. Do you have any examples or stories that illustrate this?

5) In your minds, do farmers have an accurate perception of their fat and protein production?
   a. Does it depend on the farmer?

6) How do you think that farmers make decisions?
   a. What resources do they use
   b. Who do they talk to with
   c. Do you wish they consulted with certain people more?
   d. Do you think these relationships ever hinder, rather than support, management improvements?

7) In an ideal world, what do you think would be the best way to get the farms to increase fat and protein?