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FARM-LEVEL EVALUATION OF IMPLEMENTING FEEDING BEST MANAGEMENT PRACTICES ON PENNSYLVANIA DAIRY FARMS

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ABSTRACT

Feeding best management practices (BMP) can have a significant impact on the environmental footprint of dairy farms. The objective of this thesis was to evaluate the environmental and productive effects of implementing feeding BMP on commercial dairy farms in Pennsylvania. Fifteen farms (124.8 ± 20.5 ha, 169 ± 39 cows, and 31.4 ± 0.2 kg/d of milk yield) in central and southeast Pennsylvania participated in this study. A set of four background total mixed ration (TMR), forage, milk, feces, and urine samples, as well as feed intake and production data, were collected from each cooperator farm biweekly between January and March of 2013 **(PreBMP period)**. Feeding BMP were chosen by the producer, including reduction of dietary crude protein (CP; n = 7) and phosphorus (P; n = 3) concentrations, adjusting rations for changes in forage dry matter (DM; n = 10), and group feeding of the lactating herd (n = 2). Following the implementation of applicable feeding BMP, another set of four sampling and data collection events took place between June and August of 2013 **(PostBMP period)**. Data were analyzed using the MIXED procedure of SAS with farm as a random effect. Seven farms reduced dietary CP (from 17.2 to 15.8%; $P < 0.001$), which resulted in decreased total urinary N (0.75 vs. 0.57%; $P < 0.001$), urinary urea-N (544 vs. 461 mg/dL; $P = 0.007$), and milk urea-N (MUN; 16.8 vs. 13.7 mg/dL $P < 0.001$) from PreBMP to PostBMP, respectively. Three farms lowered dietary P (from 0.42 to 0.40; $P = 0.06$), which resulted in decreased fecal P concentration (0.83 vs. 0.69%; $P = 0.001$). Group feeding was implemented on 2 farms and average CP of the lactating rations decreased (from 15.7 to 14.7% (high) or 14.3% (low); $P = 0.03$ and $P = 0.02$), which resulted in decreased total urinary N (0.81 to 0.51% (high) or 0.51% (low); $P < 0.001$ and $P < 0.001$), urinary urea-N (594 to 398 mg/dL (high) or 384 (low) mg/dL; $P < 0.001$, respectively), and MUN (17.4 to 13.7 mg/dL; $P = 0.03$). Dry matter intake (DMI; 23.3 vs. 22.7 ± 0.46 kg/d; $P = 0.05$), milk yield (32.7 vs. 31.9 ± 0.76 kg/d; $P < 0.001$), bulk tank milk fat (3.91 vs. 3.56%; $P <$

0.001), and milk protein (3.13 vs. 2.98%; $P < 0.001$) decreased on all farms from PreBMP to PostBMP period, due to seasonal effects.

Environmental effects of implementing feeding BMP were evaluated using the Integrated Farm System Model (IFSM). On farms that reduced dietary CP, nitrogen (N) imported onto the farm (313 vs. 293 kg/ha; $P = 0.02$), N lost by leaching (53 vs. 49 kg/ha; $P = 0.01$), N lost by denitrification (15.3 vs. 14.7 kg/ha; $P = 0.008$), N lost in runoff (1.69 vs. 1.61 kg/ha; $P = 0.008$), and N concentrate in leachate (22.5 vs. 20.4 ppm; $P = 0.01$) decreased from PreBMP to PostBMP period. Greenhouse gasses (GHG) emitted by manure (196,083 vs. 191,960 kg/yr; $P = 0.003$) and feed production (201,207 vs. 195,256 kg/yr; $P = 0.02$) decreased for farms that reduced dietary CP. On farms that reduced dietary P, P imported onto the farm (24.6 vs. 22.1 kg/ha; $P = 0.19$), P lost in runoff leachate (1.67 vs. 1.53 kg/ha; $P = 0.42$), and P buildup in soil (4.43 vs. 2.47 kg/ha; $P = 0.22$) numerically decreased when evaluated using IFSM from PreBMP to PostBMP period. Environmental effects of implementing group feeding or monitoring forage DM when evaluated using IFSM were minimal from PreBMP to PostBMP period.

Milk urea-N is a useful measurement to monitor dietary CP intake and N utilization in lactating dairy cattle. Two experiments were conducted to explore discrepancies in MUN results between three laboratories, one experiment to compare the effect of two preservatives (bronopol and Broad Spectrum Microtabs® II; BSM) on MUN, and one experiment to evaluate MUN with increasing levels of bronopol. In experiment 1, 10 milk samples, collected over five consecutive days, were sent to three milk processing laboratories. Average MUN differed ($P < 0.001$ to $P = 0.05$) between Laboratory A (14.9 ± 0.40 mg/dL), Laboratory B (6.5 ± 0.17 mg/dL), and Laboratory C (7.4 ± 0.36 mg/dL). In experiment 2, milk samples were spiked with urea at 0, 17.2, 34.2, and 51.5 mg urea/dL of milk. Two 35-mL samples from each urea level were sent to three laboratories. Average analyzed MUN was higher than expected for Laboratory A (23.2 vs. 21.0 mg/dL; $P = 0.001$), Laboratory B (18.0 vs. 13.3 mg/dL; $P < 0.001$), and Laboratory C (20.6 vs.

15.2 mg/dL; $P < 0.001$). In experiment 3, three samples of control (without preservative), milk preserved with bronopol, and milk preserved with BSM were sent to Laboratory A and two samples of both bronopol and BSM were sent to Laboratory B. Milk urea-N results from Laboratory A differed ($P < 0.01$) between control (9.2 mg/dL), BSM (9.7 mg/dL), and bronopol (11.2 mg/dL), however, no difference ($P = 0.60$) in MUN was observed between bronopol and BSM at Laboratory B. In experiment 4, milk samples contained 0 to 0.30 g of bronopol and ranged in MUN concentration from 7.7 to 11.9 ± 0.27 mg/dL on Foss 4000 and from 9.0 to 9.3 ± 0.05 mg/dL on CL10, respectively.

In summary, implementing one or more feeding BMP did not affect average DMI or milk yield of the cows, but reduced N and P excretions on commercial dairy farms in Pennsylvania, and consequently had a positive impact on the environment. Milk urea-N concentrations may vary depending on type and amount of preservative, analytical procedures, laboratory, and equipment used to measure MUN concentrations.

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ABBREVIATIONS

AA	Amino acids
ADF	Acid detergent fiber
ADG	Average daily gain
BMP	Best management practices
BMR	Brown mid-rib
BSM	Broad Spectrum Microtabs® II
BUN	Blood urea nitrogen
BW	Body weight
C	Carbon
CP	Crude protein
DFM	Direct fed microbials
DIM	Days in milk
DM	Dry matter
DMI	Dry matter intake
ECM	Energy corrected milk
FCM	Fat corrected milk
FPC	Fat and protein corrected (milk)
GHG	Greenhouse gas
IFSM	Integrated farm system model
IOFC	Income over feed costs
MP	Metabolizable protein
MPS	Microbial protein synthesis
MUN	Milk urea nitrogen
N	Nitrogen
NDF	Neutral detergent fiber
NE_L	Net energy of lactation
NFC	Non-fiber carbohydrates
NPN	Non-protein nitrogen
NMP	Nutrient management plan
P	Phosphorus
peNDF	Physically effective fiber
PSPS	Penn State Particle Separator
PF	Precision feeding
SARA	Sub-acute ruminal acidosis
TDS	Total dissolved solids
TLC	Theoretical length of cut
VOC	Volatile organic compounds

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Chapter 1

INTRODUCTION

Over time, the modern dairy cow has been selected to produce greater amounts of milk, and in turn, requires more energy and nutrients to do so (VandeHaar and St-Pierre, 2006; Hutjens, 2011). Excess nutrients fed and not utilized for milk production are primarily excreted, which results in nutrient pollution of air and water (NRC, 2001; Colmenero and Broderick, 2006). Proper diet formulation, feed management, and manure disposal on-farm are essential to protect the environment (James and Cox, 2008). Hence, it is important to mitigate negative effects on the environment through on-farm management and planning such as implementation of feeding best management practices (BMP).

Feeding BMP are feed management techniques and conservation practices used for environmental protection (Jackson-Smith et al., 2010). A short-term transition to reduce immediate impact on the environment is through diet formulation and precision feeding (PF). Dietary crude protein (CP) and phosphorus (P) concentrations in dairy cattle rations have a direct effect on N and P excretion (NRC, 2001; Cerosaletti et al., 2004). Reducing CP to within 16.0 to 16.5% of DM for high producing dairy cows reduces urinary N, urinary urea-N, milk urea-N (MUN), and ammonia (NH_3) emissions (NRC, 2001; Broderick, 2003; Colmenero and Broderick, 2006; Lee et al., 2012b; Sinclair et al., 2014). Reducing P content in the diet to within 0.36 and 0.38% DM reduces P excretion in feces (Wu and Satter, 2000; Satter et al., 2005). Some long-term feeding BMP include maximizing homegrown or locally sourced feeds, improving forage quality, use of various feed additives, group feeding, and maximizing feed efficiency (Jonker et al., 2002b; Ipharraguerre and Clark, 2003; Huhtanen et al., 2009).

Implementation of feeding BMP can have a significant impact on the environmental footprint of dairy farms. Reducing P in dairy cow diets, and therefore amount excreted in manure, can prevent additional P from being spread onto fields, which may not be completely used by crops and build up on cropland or runoff into nearby waterways (Sharpley et al., 1994). Additionally, with reduced CP, less N will be available to volatilize into NH_3 (Lauer et al., 1976).

Milk urea-N is used to monitor dietary CP and N utilization in lactating cows and is linearly correlated with urinary N (Broderick and Clayton, 1997; Hof et al., 1997; Kauffman and St-Pierre, 2001; Jonker et al., 2002a). High MUN concentrations can indicate excess feeding of CP, which can have negative effects including increased energy requirements, increased purchased feed costs, and excess N excretion and secretion (Broderick and Clayton, 1997; Jonker et al., 2002b). There are multiple methods used to analyze MUN, which can cause varying results in MUN concentration reported to producers (Arunvipas et al., 2003). This discrepancy can cause confusion on how a farm's MUN ranks relative to the generally accepted benchmark values of 10 to 12 mg/dL (Powell et al., 2014).

Numerous studies explored diet adjustments for the purpose of reduced nutrient excretions (Holter et al., 1982; Howard et al., 1987; Morse et al., 1992; Kalscheur et al., 1999; Wu et al., 2000; Wu and Satter, 2000; Knowlton et al., 2001; Knowlton and Herbein, 2002; Wu et al., 2003; Kincaid et al., 2005; Wu, 2005; Colmenero and Broderick, 2006; Bjelland et al., 2011; Lee et al., 2011; Lee et al., 2012a; Lee et al., 2012c; Ray et al., 2013). The present study will investigate combinations of feeding BMP in order to evaluate whole farm impact. It is important to quantify effects of multiple feeding BMP in the field to reflect desired implementation of several feeding BMP in the dairy industry. The objectives of this research were to evaluate the environmental and productive effects of implementing feeding BMP, selected by the producers, on 15 commercial dairy farms in central and southeast Pennsylvania and to explore discrepancies in on-farm MUN testing.

Chapter 2

LITERATURE REVIEW

Feeding BMP can have a significant impact on the environmental footprint of dairy farms. Some of these management techniques include TMR preparation and delivery, diet formulation, herd management, and grain and forage harvest, processing, and storage (full list presented in the Appendix). Implementing feeding BMP on-farm can help mitigate the dairy industry's impact on the environment.

Feed Preparation Standard Operating Procedure

Day-to-day TMR variably (precision) and the difference between the formulated ration and the ration fed to the cow (accuracy) are two terms used to describe on-farm variability when mixing feed (James and Cox, 2008). Consistency of TMR mixing over time and accuracy of ingredients added are important factors when feeding dairy cattle in order to maximize production, reduce wasted feed and nutrients, and reduce greenhouse gas (GHG) emissions (Barmore, 2002; Hutjens, 2011: Hristov et al., 2013). Having a TMR standard operating procedure (SOP) can help to maintain uniformity at the feed bunk.

Monitoring DM. One component of PF is to routinely measure DM of wet ingredients and make ration adjustments in order to ensure that the proper amount of each ingredient is incorporated into the TMR (Sova et al., 2014). Although rations on paper may be formulated well, variation in forage DM, when not properly adjusted for, can cause inconsistencies in the physical and chemical composition of the TMR delivered to the feed bunk (Barmore, 2002). Barmore (2002) reported two reasons why farms do not monitor DM: 1) farms lack a protocol for

testing their forages; and 2) farms lack the correct equipment to test DM. Adjusting for changes in forage DM will have small effects on rumen health, DMI, and milk production, which can in turn, indirectly effect the environment. Diet composition largely contributes to CH_4 production; diets with lower forage to concentrate ratio will result in lower CH_4 emissions per unit of DMI (Hristov et al., 2013).

The National Research Council (NRC, 2001) suggests dry matter intake (DMI) and high-moisture TMR (>50% moisture) share a negative correlation. For every one-unit decrease in TMR DM (>50% moisture), DMI will decrease 0.02% of body weight (BW) (NRC, 2001). A common practice on dairy farms is to add water to TMR to decrease DM content and reduce sorting (Lahr et al., 1983). Lahr et al. (1983) observed that DMI increased (19.4, 19.4, 20.5, and 22.3 kg/d) when identically formulated diets increased in DM (40, 52, 64, and 78% DM, respectively) while milk production remained unaffected (Lahr et al., 1983). On the other hand, Leonardi et al. (2004) found that adding water to a 80.8% DM diet (dry) to make it 64.4% DM (wet) did not affect DMI or milk yield but reduced sorting and increased neutral detergent fiber (NDF) intake (6.15 vs. 6.42 kg/d) and milk fat percentage (3.31 vs. 3.41%) when feeding dry vs. wet, respectively (Leonardi et al., 2004). It is also important to note that feed will heat up and spoil more quickly when water is added (Felton and DeVries, 2010). Felton and DeVries (2010) observed reduced DMI (28.4, 26.1, and 24.2 kg/d) with reduced TMR DM of the diet (56.3, 50.8, and 44.1% DM) and attributed the drop in DMI to unpalatable, spoiled feed. Milk yield was unaffected in this study, but due to decreased DMI, production efficiency increased (Felton and DeVries, 2010).

Access to feed. Lactating dairy cattle require sufficient access to feed in order to maintain adequate DMI and high milk production. Shabi et al. (2005) reported that time spent at the feed bunk and milk production have a positive correlation. Martinsson and Burstedt (1991) found that increasing dairy cows' access to feed from 8 to 24 h/d increased DMI, which increased energy

corrected milk (ECM). Conversely, Erdman et al. (1988) concluded that dairy cattle require no more than 8 h/d at the feed bunk when comparing 8 vs. 20 h/d.

Feeding frequency. Ideal feeding frequency, or number of times throughout the day fresh feed is delivered to cattle, has been debated. Increased feeding frequency from one to two times per day reduced sorting and increased time at the feed bunk (DeVries et al., 2005). The thought is that constant eating allows for optimal ruminal fermentation, and therefore more stable rumen pH (Gibson, 1984; Krause and Oetzel, 2006). Gibson (1984) examined 35 experiments on feeding frequency in dairy cattle to find that milk fat percent and milk yield increased when feeding frequency increased from one or two times per day to four or more times per day, although not all studies reviewed experienced increased milk yield. Adequate feeding frequency can provide constant nutrient availability in the rumen; however there is little support that increased feeding frequency mitigates CH_4 production (Hristov et al., 2013). Although pushing up feed has not been observed to increase DMI, it is an important part of feed management SOP to ensure cattle can reach feed so that DMI is not reduced (NRC, 2001; Barmore, 2002).

Particle size. Proper handling of forages, and all feeds, from time of harvest until in the feed bunk can affect properties of feedstuffs. Multiple factors affect particle size during TMR preparation including DM of ingredients, mixing time, knife condition, order of ingredients added, and how full to capacity the mixer is (Heinrichs et al., 1998; Barmore, 2002). In a study by Heinrichs et al. (1998), four min of mixing time reduced >18 mm particles by 31%. Barmore (2002) concluded that the optimum mix time for a TMR is between three and six min. In addition, dull knives reduced particle size less than knives that have been recently sharpened (Barmore, 2002). Ingredients added at the beginning of mixing will have more time on knives and therefore will have reduced particles on the top screen (>18 mm) compared with ingredients added at the end of the batch (Barmore, 2002).

Another crucial area for a feeding SOP is silage management. Forage silos should be harvested, filled, and tightly sealed quickly in order to minimize oxygen incorporation and heating (Jones et al., 2004). Additionally, forages should be ensiled at least two to three wk before feed out to allow for proper fermentation (Jones et al., 2004). An adequate amount of silage must be removed from a bunker silo face in order to minimize heating, using eight to 12 inches per day as a rule of thumb, however more should be removed in the summer (Barmore, 2002). Keeping the silo face as flat as possible and avoid lifting the pile with the loader bucket is important to prevent the incorporation of oxygen into the silage (Barmore, 2002; Borreani and Tabacco, 2010). Feeding moldy silage should be avoided by discarding spoiled feed (Barmore, 2002).

It is important to standardize TMR preparation procedures to reduce variation and keep the feed mixing as accurate and consistent as possible for lactating dairy cows. A customized on-farm SOP can encourage a uniform end product. It is important to customize an SOP to each individual farm due to differences in forage source, theoretical length of cut (TLC), mixer size, mixer type, and facilities.

Monitoring DMI and Feed Efficiency

Feed is the largest cost associated with milk production and has prompted dairies to focus on DMI, amount of feed refused, and feed efficiency; all of which contribute to environmental impact (Britt et al., 2003; Connor et al., 2012). Although debated, it is believed that DMI is driven by milk production (Etherton and Bauman, 1998; NRC, 2001) and underfeeding of nutrients limits milk production in dairy cattle (Allen, 2000).

Dry matter intake is a function of many factors including gut fill, rate of digestion, body size, and stage of lactation (Allison, 1985; Allen, 2000). Hence the importance of tracking DMI

and feed refusals to ensure dairy cattle have adequate feed available for consumption. At the same time, wasted feed (greater than 3 to 5% of DMI) not only cost money, but has a negative impact on the environment due to excess nutrients that will not be utilized by the animal for production, and therefore will not leave the farm (NRC, 2001; Barmore, 2002; Hutjens, 2011). Phosphorus and N are the two nutrients of primary environmental concern in animal agriculture (Carpenter et al., 1998).

Feed efficiency is defined as the conversion of one unit of milk per unit of DMI. A cow with low intake producing the same amount of milk as a cow with high intake will more efficiently utilize feed, excrete fewer nutrients in manure, produce less GHG (methane and nitrous oxide) per unit of intake, and be a more profitable animal (Hutjens, 2005; Vallimont et al., 2010; Yan et al., 2010; Hristov et al., 2013). A 2010 study found that feed efficiency is the primary reason for variation in the GHG emissions that fluid milk production contributes to carbon (C) footprint (Thoma et al., 2010). A number of factors influence feed efficiency including stage of lactation, lactation number, ration composition, feed digestibility, pregnancy requirements, and heat or cold stress (Britt, 2003; Hutjens, 2005; Casper, 2008; Hutjens 2011). It is documented that gross feed efficiency, residual feed intake, DMI efficiency, and net energy of lactation (NE_L) efficiency are heritable traits (Vallimont et al., 2010; Connor et al., 2012). In 2011, it was estimated that a 0.1 increase in feed efficiency equates to $0.30 to $0.38/cow/d (Hutjens, 2011).

Many technological and management advances over time have contributed to greater production efficiency on dairy farms. A study by Capper et al. (2009) compared modern dairy systems from 2007 with those in 1944; not only were there fewer dairy cows in 2007 compared to 1944 (9.2 vs. 25.6 million) but cows produced more milk (9,193 vs. 2,074 kg/cow/yr) and were more efficient. In addition, methane (CH_4) and nitrous oxide (N_2O) per unit of milk produced

were reduced. This all contributed to a reduced C footprint per unit of milk produced in 2007 compared to 1944 (Capper et al., 2009).

Monitoring DMI, feed efficiency, and amount of feed refused should be a standard practice on-farm. These practices have the potential to reduce feed and nutrient waste, increase profitability, and reduce the environmental impact due to reduced nutrient excretions and GHG emission per unit of milk produced.

Group Feeding of Lactating Herd

Grouping dairy cattle with similarities such as milk yield, parity, or reproductive status can more specifically cater to their nutrient requirements and decrease the variation in nutrient intake and production within a group. Feeding a single lactating diet to a herd can limit a high producing cow because her requirements may not be met. On the other hand, low producing cows on the same diet, although consume less than high producing cows, will not utilize all nutrients and will either store them in adipose tissue or excrete them (St-Pierre and Thraen, 1999; Grant and Albright, 2001). Precision feeding through grouping strategy can reduce the environmental impact and increase efficiency by reducing the amount of excess nutrients being excreted in feces and urine (Grant and Albright, 2001; NRC, 2001).

Because nutrient requirements for select groups of cattle differ, allowing more specifically balanced rations to each group can more closely meet the requirements of each individual cow and minimize nutrient losses (Grant and Albright, 2001). Williams and Oltenacu (1992) looked at multiple grouping strategies in a model and concluded that grouping cattle, in two or three groups, based on energy and protein requirements, maximized income over feed cost (IOFC). St-Pierre and Thraen (1999) found that increasing from one lactating group to three lactating groups reduced N excretions 3.7% and increased N efficiency 5.8%. In addition,

increasing to six groups reduced N excretions 5.8% and increased N efficiency 8.0%, however, no further benefits were concluded when greater than six groups were included in their model (St-Pierre and Thraen, 1999).

Differences in DMI, meal size, meal length, and rumination time were reported when multiparous vs. primiparous cows and high producing cows vs. low producing cows were grouped (Dado and Allen, 1994). However, another study found no significant difference in DMI or milk production when primiparous and multiparous cows were separated (Bach et al., 2006). The NRC (2001) reports that DMI for both primiparous and multiparous cows follow the lactation curve, and because primiparous cows peak later and maintain higher persistency throughout their lactation than multiparous cows, the NRC (2001) recommends separating primiparous cows from multiparous cows due to nutritional requirements and differences in social behavior and dominance of multiparous cows.

Grouping like cows can reduce competition for feed at the feed bunk (Grant and Albright, 2001). High stocking density contributes to competition at the feed bunk, resulting in reduced eating time and increased aggressive behavior (Huzzey et al., 2006). It is especially important to encourage adequate DMI post-calving because cows will be in negative energy balance. Therefore it has been suggested to separate fresh cows from the rest of the lactating herd to reduce competition and promote adequate intakes, especially during periods of stress (Sniffen et al., 1993).

Some limitations of increasing the number of groups in a herd include improper facilities and limited labor. Still, nutrient requirements should be met but not exceeded (NRC, 2001). Grouping like cattle according to parity or milk production is an opportunity to maximize production, increase nutrient efficiency, and reduce excess nutrient losses and GHG emissions.

Particle Size and Physically Effective Fiber

Dairy cattle have been fed increasing amounts of concentrate feeds, however, adequate physically effective fiber (peNDF) is necessary for proper rumen function. If appropriate long particles are not provided, chewing time is reduced which leads to reduced saliva production and decreased ruminal pH which can have adverse health effects. Monitoring and maintaining adequate particle size on-farm is critical to animal health and productivity. A widely used tool to monitor particle size of forages and TMR on-farm is the Penn State Particle Separator (PSPS) (Kononoff et al., 2003a; Kononoff et al., 2003b; Zebeli et al., 2006).

Roughages promote chewing, which stimulate saliva production (NRC, 2001; Plaizier et al., 2008). Salvia contains buffers, including bicarbonates and phosphates, which modify the rumen environment (Sudweeks et al., 1981; Plaizier et al., 2008). Lack of peNDF or excess concentrate in the diet can trigger a drop in rumen pH and result in metabolic disorders like displaced abomasum, acidosis which can lead to laminitis, milk fat depression, rumen parakeratosis, and ketosis (Sudweeks et al., 1981; Heinrichs et al., 1999; Krause and Oetzel, 2006; Plaizier et al., 2008). Ruminal epithelium cells are not coated with mucus and are susceptible to damage caused by acids (Krause and Oetzel, 2006). The four groups of cattle at highest risk for developing acidosis include transition cows, high DMI cows, cows prone to variation in eating patterns, and those with poorly formulated diets (Sudweeks et al., 1981; Stone, 2004).

At the end of a cow's lactation, her diet is switched from high concentrate to high forage. That change alters the bacterial population in the rumen (Krause and Oetzel, 2006). Due to the decrease in highly fermentable carbohydrates, lactate producing bacteria decline which results in a decline in bacteria that convert lactate into acetate and propionate (Krause and Oetzel, 2006). In addition, rumen papillae length and absorptive surface area decrease in the dry period (DeVries et

al., 2008). Fresh cows tend to be more prone to developing acidosis due to the diet change from high forage to lower forage/higher concentrate at freshening coupled with increased DMI due to production demands (Woodford and Murphy, 1988; DeVries et al., 2008). Therefore at calving, the rapid change to a high concentrate diet puts her at risk for acidosis due to rapid increase in lactic acid production (NRC, 2001).

When rumen pH falls below 6.0, growth of fiber digesting rumen microorganisms is decreased which allows for an increase in propionate producing microbes (Grant, 1990; Heinrichs et al., 1998). This change decreases the rumen acetate to propionate ratio, which is associated with milk fat depression (Grant, 1990; Heinrichs et al., 1998; Zebeli et al., 2006; Plaizier et al., 2008). Decreased milk fat percentage can directly impact the profitability of a farm because most producers receive premiums for milk components.

Decreased TMR particle size results in increased passage rate and decreased digestibility (Heinrichs, 1998). Neutral detergent fiber and acid detergent fiber (ADF) have a positive, linear relationship with peNDF (Zebeli et al., 2006). Reduced gut fill because of increased passage rate can also increase DMI but reduce efficiency (Heinrichs et al., 1998; Schroeder et al., 2003). This can cause increased hindgut fermentation resulting in diarrhea (Plaizier et al., 2008).

Sorting is a contributing factor as to why cattle may not be receiving adequate peNDF. Cows tend to sort for small particles, but some studies have observed acidotic cows sorting for longer particles, possibly to meet their fiber needs (Beauchemin and Yang, 2005; Yang and Beauchemin, 2006; DeVries et al., 2008). In a study by DeVries et al. (2008), cows at high risk for developing acidosis (early lactation) sorted against small particles while low risk cows (mid-lactation) sorted for small particles. Rumen pH was positively correlated with sorting for long particles, whereas sorting for medium and short particles were negatively correlated with rumen pH (DeVries et al., 2008). As rumen pH drops, lactic acid producing bacteria are able to proliferate, further contributing to low ruminal pH (Nocek, 1997).

On farms, sub-acute ruminal acidosis (SARA) defined as rumen pH of 5.2 to 5.6, can cause inconsistent appetite, weight loss, diarrhea, and lameness (Nocek, 1997). In a meta-analysis, Zebeli et al. (2006) concluded that the amount of peNDF <1.18 mm is a good predictor of ruminal pH. It is suggested that as rumen pH is reduced, blood flow increases and endotoxins and histamine can be released, which cause vascular constriction and dilation further increasing blood flow. This increase in blood pressure damages vessels, which causes edema and thrombosis on the dermal layer of the hoof (Nocek, 1997; Stone, 2004; Plaizier et al., 2008). Lameness is a major cause of premature and involuntary culling in dairy herds. It is estimated that each case of SARA costs dairy producers $400 to $475/cow/yr due to decreased milk yield and components (Stone, 1999).

It is important to provide lactating dairy cows with adequate peNDF. Monitoring and adjusting for adequate TMR particle size as well as forage particle size at harvest is important to maintain proper rumen health, support production performance, and improve efficiency.

Silage Quality

Many factors contribute to quality and digestibility of silages. Maturity and DM at harvest, mechanical processing, use of inoculants, particle size, and type of storage all contribute to silage quality. Producing high quality forages is important in maintaining rumen health, production, and reducing CH_4 production per unit of DMI.

Ensiling forage is a widely used method of preserving feedstuffs. It is a natural fermentation process that takes place under anaerobic conditions where lactic acid bacteria convert water-soluble carbohydrates to organic acids, usually lactic acid, decreasing the pH of the feedstuff (Weinberg and Muck, 1996). Spoilage is caused when oxygen is introduced to silage which re-activates aerobic microorganisms. This can be due to improper silo filling, inadequate or

delayed silo covering, and poor silage handling during feedout (Woolford, 1990; Weinberg and Muck, 1996). In a study using ruminally cannulated crossbred steers, DMI decreased as three levels of spoiled corn silage increased in the diet. In addition, examination of the forage mat revealed extensive damage in the rumen (Whitlock et al., 2010).

Secondary fermentation or production of butyric acid and NH_3 should be avoided. If the forage at the time of ensiling is too wet or the pH does not decrease rapidly, *Clostridium* bacteria can become active. *Clostridium* convert lactic acid to butyric acid and amino acids (AA) to NH_3, which results in DM losses and decreased quality of the feedstuff (Weinberg and Muck, 1996). On the other hand, forage ensiled at a high DM will delayed lactic acid producing bacteria growth rates and therefore delayed fermentation (Pitt et al., 1985).

The use of silage inoculants is a management option that some producers utilize. Bacterial, mainly lactic acid bacterial, inoculants are safe, not corrosive to equipment, and do not negatively impact the environment (Weinberg and Muck, 1996). The purpose of inoculants is to promote and control proper silage fermentation by quickly and efficiently utilizing water soluble carbohydrates to produce lactic acid for a rapid drop in silage pH (Weinberg and Muck, 1996). Dry matter losses decreased in corn silage that had been inoculated and kernel processed compared to a control, which was unprocessed and not treated with inoculant (Johnson et al., 1999). However, silage inoculants come with a cost to the producer and may not always be successful at dominating the fermentation process and inhibiting adverse microbial activity (Weinberg and Muck, 1996).

Mechanical processing (kernel processing) of corn silage increases starch, ruminal, intestinal, and total tract digestibility and reduces DM losses (Johnson et al., 1999; Bal et al., 2000; Weiss and Wyatt, 2000; NRC, 2001). Total tract starch digestibility of kernel processed corn silage increased about 5 to 6% compared to unprocessed corn silage (Bal et al., 2000; Weiss and Wyatt, 2000; NRC, 2001). Some trials reported improved DMI, milk yield, milk fat yield,

and milk protein yield (Johnson et al., 1999; Bal et al., 2000). Conversely, Dhiman et al. (2000) reported no effect on milk yield or DMI when kernel processed silage was fed. Maturity of corn silage is thought to play a role in how effective and beneficial kernel processing is on digestion (Dhiman et al., 2000; Firkins et al., 2006). Due to lack of data, the NRC (2001) does not recommend a specific adjustment for the energy value of kernel processed corn silage versus unprocessed corn silage.

Kernel processed corn silage alters particle size compared to unprocessed corn silage (Johnson et al., 1999). Kernel processing reduced particle size 15 to 30% and average length of cut was about 25% smaller than TLC (Johnson et al., 1999). Average length of cut and amount of corn kernels found in feces have a positive correlation (Buck et al., 1969). Processing reduced the number of whole kernels from 20 to 5% (Johnson et al., 1999). Kernel processing reduced DM losses during ensiling for multiple maturity levels compared to unprocessed corn silage (Johnson et al., 1999). In addition, kernel processing reduced the amount of corn grain that is undigested and therefore lost in feces (Johnson et al., 1999).

Increased forage digestibility decreases the amount of CH_4 produced per unit of DMI (Hristov et al., 2013). Digestibility of forages decreases with increasing maturity due to decreased nonstructural carbohydrates and increased lignin concentration (Bal et al., 1997; Johnson et al., 1999). However, because grain formation increases with maturity, yet NDF and ADF concentrations decline, whole plant corn silage digestibility can be hard to interpret (Bal et al., 1997; Johnson et al., 1999). As corn becomes more mature, DM and starch contents increase but become less digestible (Bal et al., 1997; Johnson et al., 1999). Corn silage harvested at two-thirds and one-half milk line are 5 and 9% more digestible than corn silage harvested at black line, respectively (Johnson et al., 1999). However, to maximize DM yield at harvest, corn should be harvested at two-thirds milk line to black layer (Ganoe and Roth, 1992). Optimum milk

production and DMI are usually obtained with good quality corn silage harvested at optimum maturity, between 33 and 36% DM (Johnson et al., 1999; Bal et al., 2000).

Another important factor to consider in forage quality is NDF digestibility. Neutral detergent fiber is an indicator of DMI and a large amount of dietary NDF should come from forage sources (Kendall et al., 2009). However, excess NDF in the diet can limit voluntary feed intake due to rumen fill (Oba and Allen, 1999). Studies feeding rations with similar NDF and CP levels but varying NDF digestibly from forage reported increased DMI and milk yield with increasing NDF digestibility (Dado and Allen, 1996; Oba and Allen, 1999). Different forage varieties, including brown mid-rib (BMR), have higher NDF digestibility due to reduced lignin content (Jung and Allen, 1995).

Silage quality can be controlled on-farm through management decisions including time of harvest, use of inoculants, mechanical processing, and proper feed-out management. These all contribute to cow health, production, feed efficiency, and energetic CH_4 production of dairy cows.

Grain Processing

High-energy components are added to lactating diets in order to fulfill the demands of milk production. Grains, including corn, sorghum, and barley, should be processed to break the seat coat and make nutrients more available for digestion (Firkins et al., 2001; Ferraretto et al., 2013). Increasing the extent of grain processing has been shown to increase production and feed efficiency and reduce GHG emission (Knowlton et al., 1998; Yang et al., 2001; Hristov et al., 2013). Different forms of grain processing change the digestion location and rate of digestion (Nocek and Tamminga, 1991).

The most common types of processing include steam flaked, steam rolled, dry rolled, and ground grains (Theurer et al., 1999). Steam flaked is the most intensive process out of those listed. Grains are steamed for 30 to 60 min before being rolled at a high pressure. As flake density decreases the quality of flaked grain increases; optimum density of steam flaked corn and sorghum is about 28 lbs/bu (Theurer et al., 1999). The cost of steam flaking is about double that of grinding (Dhiman et al., 2002). Steam rolled grains are steamed for 15 min and crushed to produce a thick flake with a high density that is about 34 to 42 lbs/bu for corn (Theurer et al., 1999). Dry-rolled grains are reduced in size with rollers, but without the use of heat or steam (Crocker et al., 1998; Theurer et al., 1999). Dry ground grains are also processed through a roller mill, grains are passed through the mill once for course ground and multiple times for fine ground gains (Yu et al., 1998).

Dry matter intake was not affected by the type of processed grains fed to lactating cattle in some studies (Yu et al., 1998; Dhiman et al., 2002), yet DMI increased with increased grain processing in other studies (Knowlton et al., 1998; Yang et al., 2001). Steam flake has greater starch digestibility than whole, dry rolled, or coarse ground grains (Theurer, 1986; Yu et al., 1998). Steam flaking provides greater ruminal, intestinal, and total tract starch digestion than other forms of processing (Crocker et al., 1998; Yu et al., 1998). Grain processing and starch gelatinization improves ruminal digestion and utilization and decreases postruminal starch digestion, which maximizes total tract digestibility (Hale, 1973; Theurer, 1986; Yu et al., 1998; Firkins et al., 2001). Dhiman et al. (2002) found that starch excreted in feces was reduced with steam flaked corn compared to coarse ground or fine ground corn. Improving starch utilization in dairy cows has the potential to improve lactation performance (Ferraretto et al., 2013).

Ruminal starch digestibility is positively correlated with total tract starch digestibility (Firkins et al., 2001). Increased ruminal degradable starch can promote increased milk performance most likely attributed to increased volatile fatty acid (VFA) production and ruminal

bacterial yields (Yu et al., 1998; Theurer et al., 1999; Firkins et al., 2001; Dhiman et al., 2002). A review concluded that feeding steam flaked corn did not affect milk fat concentrations (Theurer et al., 1999). However, other studies found that feeding steam flaked corn caused milk fat depression, which could be due to a decreased acetate to propionate ratio in the rumen when rate of gluconeogenesis and starch hydrolysis increased (Crocker et al., 1998; Yu et al., 1998; Firkins et al., 2001; Dhiman et al., 2002; Ferraretto et al., 2013).

It has been reported that steam flaking corn or sorghum grain improved milk protein yield compared to steam rolled or dry rolled grains (Theurer et al., 1999; Dhiman et al., 2002). However, others report no difference in milk protein yield (Yu et al., 1998). Starch digestibility of sorghum and corn increased 26, 10, and 6% when steam flaked or steam rolled were compared to dry-rolled grains, respectively (Huntington, 1997).

When comparing types of processed corn grain, steam flaked is 2.5 and 3.2 times more reactive, or percent of starch digested into glucose, than dry rolled and whole corn, respectively (Crocker et al., 1998). Neutral detergent fiber and ADF digestibility are negatively correlated with starch digestibility, which may be due to lower ruminal pH and excess starch fermentation (Yu et al., 1998). Studies that look into the effect of grain processing can be hard to compare due to the variations in grain source, quality, lack of processing method standardization, and variation in starch analysis (Firkins et al., 2001).

Maximizing and accounting for grain digestibility, along with forage digestibility as previously discussed, are important factors when formulating lactating dairy cow rations. Extent of grain processing influences grain digestibility. The more nutrients available for absorption and utilization by the dairy cow, the less are lost in feces.

Dietary Nitrogen

Protein is a vital component in dairy cattle diets. The goal of protein nutrition in dairy cows is to provide adequate amounts of essential and non-essential AA, metabolizable protein (MP), ruminally undegradable protein (RUP), ruminally degradable protein (RDP), and CP without overfeeding these components. Excess CP intake in dairy cattle is a leading cause of N pollution in the environment (Roy et al., 2011; NRC, 2001).

The NRC (2001) recommends early to mid-lactation dairy cattle diets range between 17.5 and 14.5% CP on a DM basis and mid to late lactation cattle diets contain around 13.5% CP. The NRC (2001) also estimates that a one-percent increase in dietary CP from 15 to 16% will increase milk production 0.75 kg/cow/d on average. However, increasing dietary CP over 16.5% has no effect on milk yield or milk protein yield (Colmenero and Broderick, 2006; Nadeau et al., 2007; Li et al., 2009). There is inconstant data regarding changes in DMI with reduced CP (Broderick, 2003; Colmenero and Broderick, 2006; Lee et al., 2012a).

Balancing rations based on dietary CP content alone gives no information regarding the types of protein fractions or site of digestion (Sinclair et al., 2014). Ruminally degradable protein provides peptides, AA, and NH_3 to the rumen for synthesis of microbial protein and microbial growth (NRC, 2001). However, when RDP requirement is exceeded, ruminal NH_3 concentrations increase and cannot be efficiently used for microbial protein synthesis (MPS) and is excreted as N in urine (Hristov et al., 2004). Non-protein N (NPN) sources, such as urea, are hydrolyzed to NH_3 in the rumen, then used to meet protein requirement by being converted to microbial protein (Roy et al., 2011). Microbial protein and RUP supply AA to the small intestine for absorption (NRC, 2001). Met, Lys, and most recently His, are noted as the three most limiting essential AA in lactating dairy cattle diets (Rogers et al., 1989; Polan et al., 1991; Lee et al., 2012a; Lee et al., 2012c).

Metabolizable protein is positively correlated with milk protein yield (Lee et al., 2012a; Sinclair et al., 2014) Diets that are MP deficient reduce milk yield compared to diets that are adequate in MP (Lee et al., 2011b; Lee et al., 2012a). However, diets deficient in MP have increased efficiency for use of MP for milk synthesis (Sinclair et al., 2014; Lee et al., 2012a). When MP requirements are met, yet RDP is decreased, efficiency of ruminal NH_3-N used for milk synthesis improves (Agle et al., 2010). In addition, total-tract digestibility decreased in diets deficient in MP (Lee et al., 2011b).

Although dietary protein levels relative to reproductive performance are inconsistent, some studies report overfeeding dietary protein can risk reduced fertility (Lean et al., 2012). Some studies reported that feeding excess protein (>19.0% CP) reduced reproductive performance; more specifically, feeding excess RDP decreased conception rates (Canfield et al., 1990; Lean et al., 2012). However, other studies observed no effect of overfeeding protein (20% CP) on days to first estrus, days to first service, services per conception, or pregnancy rate (Howard et al., 1987; Carroll et al., 1988).

Milk urea-N and blood urea-N (BUN) are indicators of the amount of urea produced by the liver, and both MUN and BUN are highly correlated with dietary CP (NRC, 2001; Broderick, 2003; Colmenero and Broderick, 2006). Urea concentration in milk is the end product of protein and NPN and the result of AA catabolism in the mammary gland (Roy et al., 2011). High NH_3 concentration in the rumen is the leading cause of high BUN because NH_3 is converted to urea by the liver (Colmenero and Broderick, 2006; Roy et al., 2011). Blood urea is then filtered out by the kidneys and is eventually excreted in urine (Roy et al., 2011). Milk urea-N is the preferred on-farm test compared to BUN because it is a non-invasive, easy to sample, and cost-friendly approach (Roy et al., 2011). However, MUN varies by season, parity, stage of lactation, and sample analysis (Roy et al., 2011).

Only about 25 to 35% of dietary CP is converted into milk products while the remaining N is excreted through feces and urine (Sinclair et al., 2014). Dietary CP concentration and N intake are highly correlated with manure N output (Yan et al., 2006). Decreasing dietary CP decreased urinary N, urinary urea-N, BUN, MUN, and NH_3 emitting potential of manure without affecting milk protein (Broderick, 2003; Colmenero and Broderick, 2006; Agle et al., 2010; Lee et al., 2012c). Reducing dietary CP concentration increased milk N efficiency and reduced N losses due to increased N recycling and decreased use of protein for energy (Broderick, 2003; Colmenero and Broderick, 2006; Huhtanen and Hristov, 2009). It can be concluded that ideal dietary CP content for lactating dairy cattle that optimizes production and minimizes N excretions is 16.5 to 16.7% CP, when MP, AA, RDP, and RUP are also properly balanced for in the ration (Broderick, 2003; Colmenero and Broderick, 2006).

Excess N excreted via feces and urine has adverse effects on the environment including eutrophication of surface waters, nitrate contamination of ground waters, and air pollution (Colmenero and Broderick, 2006; Roy et al., 2011; Hristov et al., 2011). When manure is spread onto nearby fields, excess nutrients can run off into surface waters causing eutrophication. Eutrophication is a result of algae blooms, loss of oxygen, fish kills, and loss of aquatic biodiversity (Carpenter et al., 1998). Excess dietary CP increases urinary urea-N, which is converted to ammonium and eventually volatized into the air and lost as NH_3 (Colmenero and Broderick, 2006; Hristov et al., 2011). About 25 to 50% of N excreted into manure is lost as NH_3 and the average dairy cow emits 59 g/d of NH_3 (Hristov et al., 2011). Ammonia emitting potential was greater for diets with higher CP concentration (16.7%) vs. a lower CP concentration (14.8%) (Lee et al., 2012b).

In conclusion, balancing for MP, AA, RDP, and RUP in addition to CP is important in order to optimize milk yield and milk protein yield in dairy cows, while limiting excess N

excreted through feces and urine. Excess N on dairy farms contributes negatively to the surrounding environment. Optimizing N efficiency is key to mitigating environmental impact.

Dietary Phosphorus

Phosphorus is an essential nutrient for dairy cattle. However, it is common practice to feed excess P to lactating dairy cattle, which ultimately ends up in feces. Excess P can build up on cropland over time and cause harm to the environment. Formulating dietary P in agreement with NRC (2001) recommendations is the most effective method to mitigate excess P output in manure (Kebreab et al., 2008).

Phosphorus supports many functions including feeding rumen microbes, buffering the rumen through salvia, energy pathways (ATP), and synthesis of cell membranes, nucleotides, and bone. If the P requirements of the rumen microbes are not met, fermentation and MPS are reduced. Phosphorus regulates enzyme activities in rumen microbes and many sources indicate that P needs for rumen microbes may be higher than that of the host animal (Van Soest, 1994; NRC, 2001; Underwood and Suttle, 2001; Pfeffer and Hristov, 2005; Hill et al., 2008). Phosphorus cannot be synthesized in the body and therefore must be acquired through the diet; however, P can be recycled by ruminants through salivary phosphate (Satter et al., 2005). Phytate must be hydrolyzed by phytase in order to be absorbed (Satter et al., 2005). Ruminants have superior ability to break down phytate than do monogastric animals because the ruminal bacteria associated with starch fermentation have phytase activity (Satter et al., 2005). Unlike in non-ruminants, phytase activity of the rumen microorganisms renders nearly all of the phytate P available for absorption (Van Soest, 1994; NRC, 2001; Underwood and Suttle, 2001; Pfeffer and Hristov, 2005; Hill et al., 2008). Phosphorus is acquired through passive absorption in the small intestine (Satter et al., 2005).

Most lactating dairy cattle require 0.36 to 0.38% P on a DM basis to support high milk yield (NRC, 2001). Wu and Satter (2000) found that reducing dietary P from 0.48 to 0.38% on a DM basis did not negatively impact milk production when studied over a two-year period. It is reported that feeding P below requirements (<0.31% P on a DM basis) maintained high production during peak lactation; however, with this constant deficiency, milk yield could not be fully be maintained later in lactation (Wu et al., 2000). Some producers will feed higher amounts of P during the fresh period, however, this is not necessary because cattle mobilize P from bones and restore the supply later in lactation (Wu et al., 2000). For studies looking at P levels in lactating dairy cattle diets, it is important to look at long-term effects (Wu et al., 2000). Long-term P deficiency (<0.30% P on a DM basis) has been shown to have a negative effect on milk production (Satter et al., 2005).

In 1999, a survey of U.S. dairy farmers indicated that the average amount of P being fed was 0.45 to 0.50% on a DM basis (Sansinena et al., 1999). A survey conducted in 2003, found that producers were feeding P in excess due to recommendations by their nutritionist (Dou et al., 2003). Typically, diets without added P contain 0.33 to 0.40% P on a DM basis; therefore, feeding P at 0.45 and 0.50% requires supplemental P (Wu et al., 2000). There are a few reasons for overfeeding P: 1) the belief that P is highly linked to reproductive performance; 2) uncertainty of P content in feedstuffs; 3) cost of replacing high P ingredients (byproducts) with low P ingredients; 4) a lack of information regarding the lowest amounts of P able to be fed while maintaining high milk production; and 5) overfeeding P does not negatively impact cow health (Satter et al., 2005; Harrison et al., 2012). However, a survey conducted in 2010, showed progress being made with nutritionists to feed P at NRC (2001) recommended levels (Harrison et al., 2012).

Some producers and nutritionists believe, due to results in early studies, that increased P will improve reproductive performance (Harrison et al., 2012). However, these studies were

flawed and fed P far below the NRC (1989 and 2001) recommended levels; therefore P was limiting and CP levels were an additional factor in these experiments (Satter et al., 2005). No differences were found in duration of estrus, total mounts, total mounting time, days to first estrus, and average milk production when 0.38 vs. 0.48% P on a DM basis were fed (Lopez et al., 2004). If P levels in lactating cow diets are between 0.36 and 0.38% on a DM basis, reproductive performance will not benefit from additional P (Wu et al., 2000; Wu and Satter, 2000).

Phosphorus is a costly additive and all too often fed in excess to dairy cattle (Satter et al., 2005). Grains, especially byproducts and high protein feeds, tend to have higher P content than forages and low protein feeds (Satter et al., 2005; Stewart et al., 2012). Phosphorus can also be added to diets through mineral supplements such as dicalcium phosphate and monosodium phosphate (Satter et al., 2005; Harrison et al., 2012). Obviously, when eliminating a feed ingredient, such as a P supplement, feed costs will be reduced and P in the diet will decrease. Reducing dietary P fed to lactating dairy cows by eliminating P additives can save $22/cow/yr (Rotz et al., 2011). On the other hand, reformulating diets to reduce P by altering feed ingredients has the potential to increase overall feed costs depending on current feed market conditions because low cost feeds, including byproducts, tend to be high in P (Stewart et al., 2012). Using 2011 feed prices, reducing P from 0.45 to 0.31% DM increased feed price from $5.05 to $5.34/cow/d (Stewart et al., 2012).

Phosphorus, like N, enters farms in feed and fertilizer, and leaves the farm through milk, meat, and manure (Carpenter et al., 1998; Bosch et al., 2006; Harrison et al., 2012). About 95% of P excreted from dairy cattle is through feces and P excretion is a function of P intake through the diet (Satter et al., 2005; Klop et al., 2013). Often, manure is spread on fields to meet the N requirement, which results in excess of P on fields, with the potential to runoff and pollute surface waters (Carpenter et al., 1998; Bosch et al., 2006; Harrison et al., 2012). Phosphorus is a non-

renewable resource; therefore PF of P is important to conserve overall supply (Harrison et al., 2012).

As previously discussed, excess amount of nutrients, including P, contribute to surface water pollution, such as eutrophication (Carpenter et al., 1998; Bosch et al., 2006; Harrison et al., 2012). Animal agriculture, including dairy farms, contributes about 10 to 50% of the total P loads found in surface waters (Harrison et al., 2012). Feed, manure handling, and overall management changes on farms are the key to reducing accumulations of P on dairy farms (Rotz et al., 2011). Excluding P supplements from dairy cow diet, on average, reduce P accumulation by 7 kg/cow/yr (Rotz et al., 2011).

In summary, reducing dietary P is the most effective method to decrease P output in manure, mitigating negative effects excess P has on the environment. Increasing dietary P has no benefits to production or reproductive performance, therefore dairy cattle rations should be formulated to meet, and not exceed, NRC recommendations.

Feed Additives

Many feed additives have been developed to improve production and efficiency in dairy cattle. Some include ionophores, rumen bypass fats, direct fed microbials (DFM), and enzymes. The ionophore approved for use in the U.S. dairy industry is monensin. Monensin functions by shifting the bacterial population in the rumen by reducing gram-positive bacteria allowing gram-negative bacteria to proliferate. This shift can result in increased efficiency and improved N utilization (Duffield et al., 2008b). Monensin improves feed efficiency through increased milk production and/or decreased feed intake (Tedeschi et al., 2003). In a meta-analysis, milk yield increased 0.7 kg/d and DMI decreased 0.3 kg/d, therefore increasing milk production efficiency by 2.5% (Duffield et al., 2008b). Milk fat and milk protein concentrations decreased, however,

milk fat yield was unaffected and milk protein yield increased (Duffield et al., 2008b). Moreover, feeding monensin also provides some health benefits to dairy cattle. In another meta-analysis, monensin decreased the risk of ketosis, displaced abomasums, and mastitis (Duffield et al., 2008c). However, long term feeding of monensin over the dry period increased risk of dystocia and retained placenta (Duffield et al., 2008c).

Feeding monensin to dairy cattle can positively affect the environment. Due to increased feed efficiency with monensin, it takes less feed to produce a unit of gain or milk resulting in reduced manure excretion and therefore amount of nutrients excreted (Tedeschi et al, 2003). Nitrogen excretion in feces was reduced when monensin was fed (Ruiz et al., 2001; Marineau et al., 2007). Agriculture is responsible for 8.1% of all GHG emissions; energetic fermentation and manure management are the main contributors to CH_4 emissions (EPA, 2014). Monensin increases propionic acid production, which changes the VFA proportions in the rumen, posing potential for decreased CH_4 production (NRC, 2001; Tedeschi et al., 2003; Duffield et al., 2008a). In a meta-analysis, Appuhmay at al. (2013) concluded that dairy cows fed monensin at 21 mg/kg produced 6 ± 3 g/d less CH_4.

Direct fed microbials are a "source of live, naturally occurring microorganisms," which include bacteria, fungi, and yeast (Krehbiel et al., 2003). Direct fed microbials are used in the dairy industry to stabilize the rumen and improve milk production and feed efficiency (Krehbiel et al., 2003; Nocek and Kautz, 2006; Beauchemin, 2012). Direct fed microbials provide growth factors for rumen microbes to stimulate lactate utilization in the rumen, reducing incidence of SARA (Martin and Nisbet, 1992; Krehbiel et al., 2003; Nocek and Kautz, 2006). Nocek and Kautz (2006) and Nocek et al. (2003) fed *Enterococcus faecium* to dairy cattle prepartum and postpartum. Results from those studies indicated that cows fed *Enterococcus faecium* had higher DMI and milk yields than untreated cows. Conversely, Raeth-Knight et al. (2007) reported no differences in DMI, lactation performance, apparent digestibility, or ruminal fermentation when

mid-lactation dairy cows were fed *Lactobacillus acidophilus* and *Propionibacteria freudenreichii* (Raeth-Knight et al., 2007). A meta-analysis looked at three different yeast cultures; two active dry yeasts and one yeast culture and concluded that milk yield increased 0.9 kg/d regardless of yeast product and low producing cows showed a greater response than high producing cows (Robinson and Erasmus, 2009). It is estimated that 50% of dairies in the United States use a yeast product (Beauchemin, 2012). The cost of adding yeast to dairy cattle rations ranges from $0.03 to $0.08/cow/d (Beauchemin, 2012).

The addition of fibrolytic enzymes to improve feed digestibility in monogastric diets is a common practice, now research has been conducted to explore use of exogenous enzymes in ruminants (Rode et al., 1999). In lactating dairy cattle, milk production and DM digestibility increased for mid-lactation cows fed xylanase and cellulase with no effect on DMI (Lewis et al., 1999; Yang et al., 1999). Because fibrolytic enzymes affect diet digestibility, it is thought that the greatest benefit would be to cattle in negative energy balance. In a study where xylanase and cellulase was fed to fresh cows, DMI was unaffected, but TDN increased therefore milk yield tended to increase (Rode et al., 1999). Data on enzyme use in ruminants is limited, and effects on digestibility and milk production are minimal with use of enzymes in dairy cows (Hristov et al., 2013).

Maintaining 3 to 5% fat in high producing dairy cow diets through supplementation can help meet energy requirements without the addition of supplemental concentrate (Palmquist and Jenkins, 1980; Grummer and Carroll, 1991; Wu and Huber, 1994). Moderate supplementation of dietary fat in the form of tallow, calcium salts, prilled fat, or oilseeds in dairy cattle rations can promote milk production and depress DMI (Rabiee et al., 2012). This results in increased feed efficiency and therefore decreased production of CH_4 (Hristov et al., 2013). As the amount of unsaturated fatty acids in the diet increases, milk fat decreases (NRC, 2001). Unsaturated fatty acids are detrimental to the rumen and need to be hydrogenated by ruminal microorganisms;

biohydrogenation of calcium salts in the rumen may be as low as 30 to 40% (Klusmeyer and Clark, 1991). Fat supplementation has the potential to reduce milk protein percent due to the lack of AA availability in the mammary gland to support the increased milk yield stimulated by fat supplementation (Wu and Huber, 1994). Fat supplementation has also been shown to promote reproductive performance (Staples et al., 1998).

The addition of various feed additives such as monensin, DFM, and fats to dairy cow diets can be beneficial in improving milk production and feed efficiency. However, little research has been conducted to compare combinations of different feed additives to suggest optimum interaction to maximize production performance.

Heifer Growth

Raising replacement heifers is a large cost to every farm and quality of heifer rearing can influence lifetime milk production and overall profitability of a dairy operation (Heinrichs, 1993; NRC, 2001). Heifer growth standards have evolved over the years due to genetic selection and improved management techniques (Heinrichs and Losinger, 1998). Balancing quality replacement rearing with a cost effective heifer-rearing program is hard to optimize (Heinrichs, 1993).

Management strategies play an important role in optimizing growth in dairy calves (Heinrichs, 1993; Place et al., 1998). Maintaining adequate average daily gain (ADG) is key and highly influenced by DMI, environment, and season (Place et al., 1998). Adequate DMI should be maintained and diets should be balanced for CP and energy to optimize feed efficiency. Place et al. (1998) concluded that for every one-unit increase in DMI, ADG increased 0.26 units.

In a meta-analysis, results indicated that prepubertal ADG explained a significant portion of the variation in lactation performance of first lactation dairy cows (Zanton and Heinrichs, 2005). It was also concluded that optimum prepubertal ADG for Holstein dairy heifers, to

maximize milk yield and components, was around 0.8 kg/d (Zanton and Heinrichs, 2005). However, early calving in heifers fed moderate or accelerated diets during the prepubertal period negatively impacted milk production (Abeni et al., 2000).

A study by Hoffman et al. (1996) assessed postpubertal growth rates on Holstein heifers and effects of accelerated diets and delayed breeding (10 vs. 14 months). Average daily gains for accelerated vs. control diets were 933 g/d and 778 g/d, respectively. Additionally, heifers fed the accelerated diet conceived earlier and therefore calved earlier, 21.7 months vs. 24.6 months, than the control. Although BW at calving was similar for both diets, heifers on the accelerated diet were smaller and had lower BW after calving. Although lactation performance was unaffected by breeding date, delay bred heifers calved 2 months later, had higher BW before and after calving, and were taller at the point of withers than those bred at 10 months. However, delayed calving also had a higher incidence of dystocia (Hoffman et al., 1996). Although accelerated growth programs and decreased age at first calving can reduce replacement rearing costs, results from this study indicate that accelerated feeding programs and early calving reduced first lactation performance in Holstein dairy heifers (Hoffman et al., 1996; Tozer and Heinrichs, 2001).

Height and weight have a strong correlation and are a good indicator of heifer growth (Heinrichs and Losinger, 1998). There is a strong correlation between heifer growth and rolling herd average for milk production (Heinrichs and Losinger, 1998). Achieving adequate growth by first calving is important so lactation and reproductive performance is not limited (Hoffman et al., 1996). On the other hand, excess energy intake not only increases feed costs but also causes excess weight gain in dairy heifers (Heinrichs, 1993; Van Amburgh et al., 1998). Over conditioned heifers at calving have decreased milk production during the first lactation (Heinrichs, 1993; Van Amburgh et al., 1998). At first calving, dairy heifers should be 82% of their mature BW (NRC, 2001). Mature weights of different breeds vary; 400 kg for small breeds and 680 kg for large breeds, therefore breed must be accounted for when estimating growth

requirements (NRC, 2001). The mean weight for U.S. dairy heifers at 23.5 months is 528.9 ± 99.4 kg, which is a good estimate of time at first calving (Heinrichs and Losinger, 1998). As dairy heifers mature, the variability of BW within a herd is greater (Heinrichs and Losinger, 1998).

Heifer rearing accounts for 15 to 20% of the total cost of milk production (Heinrichs, 1993). Age at first calving and replacement rate to maintain milking herd size are the two greatest factors that determine costs of raising dairy replacement heifers (Tozer and Heinrichs, 2001). Tozer and Heinrichs (2001) calculated that it would cost $32,344 to raise replacements for a 100-cow dairy herd with a 25 month age at first calving, 13 month calving interval, 25% herd-culling rate, and 10% calf death loss. In this situation, the most influential variable was herd-culling rate and when reduced from 25 to 20% the cost of replacement rearing decreased 24.6% (Tozer and Heinrichs, 2001). Because heifer rearing is a large cost on dairy farms, it is best to optimize heifer growth in order to set the farm up for future success.

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Chapter 3

FARM-LEVEL EVALUATION OF IMPLEMENTING FEEDING BEST MANAGEMENT PRACTICES ON PENNSYLVANIA DAIRY FARMS

Abstract

Feeding best management practices (BMP) can have a significant impact on the environmental footprint of dairy farms. The objective of this study was to evaluate the environmental and productive effects of implementing feeding BMP on commercial dairy farms in Pennsylvania. Fifteen farms (124.8 ± 20.5 ha, 169 ± 39 cows, and 31.4 ± 0.2 kg/d of milk yield) in central and southeast Pennsylvania participated in this study. A set of four background total mixed ration (TMR), forage, milk, feces, and urine samples, as well as feed intake and production data, were collected from each cooperator farm biweekly between January and March of 2013 **(PreBMP period)**. Feeding BMP were chosen by the producer, including reduction of dietary CP (n = 7) and P (n = 3) concentrations, adjusting rations for changes in forage dry matter (n = 10), and group feeding of the lactating herd (n = 2). Following the implementation of applicable feeding BMP, another set of four sampling and data collection events took place between June and August of 2013 **(PostBMP period)**. Data were analyzed using the MIXED procedure of SAS with farm as a random effect. Seven farms reduced dietary CP (from 17.2 to 15.8%; $P < 0.001$), which resulted in decreased total urinary N (0.75 vs. 0.57%; $P < 0.001$), urinary urea-N (544 vs. 461 mg/dL; $P = 0.007$), and milk urea-N (MUN; 16.8 vs. 13.7 mg/dL $P < 0.001$) from PreBMP to PostBMP, respectively. Three farms lowered dietary P (from 0.42 to 0.40; $P = 0.06$), which resulted in decreased fecal P concentration (0.83 vs. 0.69%; $P = 0.001$). Group feeding was implemented on 2 farms and average CP of the lactating rations decreased

(from 15.7 to 14.7% (high) or 14.3% (low); $P = 0.03$ and $P = 0.02$), which resulted in decreased total urinary N (0.81 to 0.51% (high) or 0.51% (low); $P < 0.001$ and $P < 0.001$), urinary urea-N (594 to 398 mg/dL (high) or 384 (low) mg/dL; $P < 0.001$, respectively), and MUN (17.4 to 13.7 mg/dL; $P = 0.03$). Dry matter intake (23.3 vs. 22.7 ± 0.46 kg/d; $P = 0.05$), milk yield (32.7 vs. 31.9 ± 0.76 kg/d; $P < 0.001$), bulk tank milk fat (3.91 vs. 3.56%; $P < 0.001$), and milk protein (3.13 vs. 2.98%; $P < 0.001$) decreased on all farms from PreBMP to PostBMP period, due to seasonal effects. In conclusion, reduced dietary CP decreased N concentrations in urine, feces, and milk, and reduced dietary P decreased fecal P concentration on commercial dairy farms.

Introduction

Implementing feeding BMP, such as reducing dietary CP, reducing dietary P, grouping cattle according to nutritional requirements, and reducing TMR variation, can reduce N and P excretion without impacting production. Hristov et al. (2006) reported that high-producing western dairies fed diets containing, on average, 17.6% CP; however, it is reported that 16.5 to 16.7% CP is adequate for high producing dairy cows while minimizing N excretions (Broderick, 2003; Colmenero and Broderick, 2006). Likewise, formulating dietary P in agreement with NRC (2001) recommendations is the most effective method to mitigate excess P output in manure (Kebreab et al., 2008). In 2003, a survey of 612 mid-Atlantic producers indicated that P content in lactating diets ranged from 0.36 to 0.70% P on a DM basis with a mean of 0.44% P (Dou et al., 2003). Those producers fed excess P due to recommendations by their nutritionist (Dou et al., 2003). Typically, diets without added P contain 0.33 to 0.40% P; therefore, rations containing 0.45 and 0.50% P require a P supplement, such as dicalcium phosphate (Wu et al., 2000).

Grouping dairy cattle with similarities such as by milk production or parity, can more specifically cater to their nutrient requirements and decrease the variation in DMI within the

group. Feeding a single lactating diet can limit high producing cows because their requirements may not be met, but low producing cows on the same diet may not utilize all of the nutrients and will either store them in adipose tissue or excrete them (St-Pierre and Thraen, 1999; Grant and Albright, 2001). Precision feeding through grouping strategy can reduce the environmental impact by reducing the amount of excess nutrients being excreted in feces and urine (Grant and Albright, 2001; NRC, 2001). Another management practice is to monitor forages for changes in DM and adjusting the TMR accordingly. Consistency of TMR over time and accuracy of ingredients added are important factors when feeding dairy cattle (Barmore, 2002; Hutjens, 2011; McBeth et al., 2013; Sova et al., 2013; Sova et al., 2014). Although rations may be balanced well, variation in forage DM, when not properly adjusted for, can cause inconsistencies in the TMR delivered to the feed bunk (Barmore, 2002). Properly implementing one or more feeding BMP, including those discussed above can reduce nutrient excretions on dairy farms without negatively impacting DMI or production.

Materials and Methods

Animals involved in this study were cared for according to the guidelines of the Pennsylvania State University Animal Care and Use Committee. The committee reviewed and approved the experiment and all procedures performed in the study.

Study design

Initial surveys were conducted on 15 Pennsylvania dairy farms (124.8 ± 20.5 ha, 169 ± 39 cows, and 31.4 ± 0.2 kg/cow/d of milk yield) located in Mifflin County and Lancaster County in 2012 to gather background information on land area, herd size, current management practices, and lactating cow diets from their consulting nutritionist. Farm visits were conducted with each

producer to introduce the personnel involved in the sampling and data collection, explore the full list of BMP, and discuss resources the project team would provide. Four background sampling and data collection events took place every two wks, on each farm, between January and March 2013 **(PreBMP period)**. After background sampling was complete, follow up interviews were conducted with each producer and their consulting nutritionist to review an extensive list of feeding BMP including maximizing forage quality, regularly monitoring rations for nutrient composition and particle size, precision diet formulation, and use of feed additives (complete list in the Appendix). Producers reviewed which feeding BMP and herd management strategies were already in place and which feeding BMP they would implement for the PostBMP period (Table 3-1). A two wk adaptation period was allowed for following BMP implementation. Four additional sampling and data collection events took place every two wk, on each farm, between June and August 2013 **(PostBMP period)**.

Sampling and Measurements

As-is feed intakes from each lactating cow group were recorded during each six wk sampling period. Dry matter intake was calculated (as-is feed intake × TMR DM%). Total milk yield and number of lactating cows were recorded daily to calculate average milk yield per cow (total bulk tank milk yield ÷ number of cows). Calculated DMI and average milk yield were used to estimate feed efficiency (milk yield ÷ DMI). Individual forage and TMR samples were collected (both high and low lactating groups, if applicable) at each sampling event. Samples were stored in coolers during transportation to University Park, PA. Samples were refrigerated for 24 h before being dried in a forced air oven at 55ºC for 48 h to determine DM; the remaining sample was frozen at -20°C. Dried samples were ground in a Wiley Mill (A. H. Thomas Co., Philadelphia, PA) through a 1-mm sieve. Each TMR sample was submitted to Cumberland Valley Analytical Services (Maugansville, MD) for wet chemistry analysis of CP, NDF, ADF, ether

extract, Ca, and P and estimated NE_L. (details at: http://www.foragelaboratory.com/Media/CVAS_Proceedure_References.pdf, accessed October 1, 2014). Total mixed ration samples were analyzed for starch according to Knudsen (1997) and were measured for particle size using PSPS. Forage samples were submitted to Cumberland Valley Analytical Services (Maugansville, MD) for NIR analysis (details at: http://www.foragelaboratory.com/Media/CVAS_Proceedure_References.pdf, accessed October 1, 2014).

Milk samples (35 mL each sample) were collected from the bulk tank after five min of continuous agitation and were preserved with liquid bronopol. Samples were stored in coolers during transport to University Park, PA and were submitted to Dairy One Laboratory (Pennsylvania DHIA, University Park, PA) for analysis of milk fat, true protein, lactose, and MUN using infrared spectroscopy (MilkoScan 4000; Foss Electric, Hillerød, Denmark).

Five to 10 fresh fecal samples (500 mL per sample) were collected from randomly selected cows in each lactating group. Samples were either collected directly from the cow or collected as fresh feces from the barn floor in each lactating group. Wet samples were composited on-farm and stored in coolers during transport to University Park, PA. Samples were refrigerated for 24 h before being dried in a forced air oven at 65 °C for 72 h, the remaining sample was frozen at -20°C. Fecal composite samples were sent to Cumberland Valley Analytical Services in Hagerstown, MD for P analysis according to procedures outlined by Peters (2003). Fecal samples were pulverized using a Mixer Mill MM 200 (Retsch GmbH, Haan, Germany) for N analysis. Nitrogen was analyzed on a Costech ECS 4010 C/N/S elemental analyzer (Costech Analytical Technologies Inc., Valencia, CA).

Spot urine samples (500 mL per sampling) from five to 10 randomly selected cows were collected from each lactating group by massaging the vulva. A composite sample of equal amounts from each cow was filtered through cheesecloth and the composite sample was acidified

with 2M H_2SO_4 at a 10:1 ratio. Samples were stored in coolers during transport to University Park, PA. Samples were refrigerated for 24 h and diluted 10:1 ratio with distilled water, keeping the remaining urine sample in a separate vial. Samples were frozen at -20°C for later analysis of urea-N (Stanbio Urea Nitrogen Kit 580; Stanbio Laboratoryoratory Inc.) and total urinary N concentration, which was analyzed on a Costech ECS 4010 C/N/S elemental analyzer (Costech Analytical Technologies Inc., Valencia, CA).

One water sample was collected from each farm at the beginning of the PostBMP period. A water source was selected, after filtering but before water troughs, as a representative sample of the lactating herd's water source. Water was washed out of the pipes for five min prior to sample collection in order to gather an uncontaminated sample. Samples were stored in coolers during transportation to the Agricultural Analytical Services Laboratory in University Park, PA. Samples were analyzed for total coliform bacteria (SM 9223 B97[1]), *E. coli* (9223-97/ONPGMUG [Colilert][1]), pH (EPA 150.1[2]), total dissolved solids (TDS; SM2540C[3]), nitrate and nitrite (SM450-No3-E[3]) hardness (SM2340B[3]), minerals (Ca; Mg; Na; Fe; Ma; Cu; EPA 200.7[4]), Cl (USGS 1-1187-85[5]), and S (SM4500 S04E[3]).

Income over feed cost (gross milk price, $/cwt – feed costs, $/cow/d) was calculated using the Pennsylvania State Extension Dairy Team IOFC Tool. Inputs were gathered from the producer, cooperating feed company, and the milk check.

All farms that implemented at least one BMP were evaluated for whole farm environmental impact using the USDA ARS Integrated Farm System Model (IFSM) version 4.1

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[1] Details at: http://www.epa.gov/ogwdw/methods/pdfs/methods/methods_tcr.pdf, accessed October 15, 2014.

[2] Details at http://www.epa.gov/region6/qa/qadevtools/mod5_sops/field_measurements/29palms_field_ph.pdf, accessed October 15, 2014.

[3] Details at; http://www.standardmethods.org, accessed October 15, 2014.

[4] Details at: http://water.epa.gov/scitech/methods/cwa/bioindicators/upload/2007_07_10_methods_method_200_7.pdf, accessed October 15, 2014.

[5] Details at: http://www.caslab.com/Test-Methods-Search/PDF/USGS-Method-I-1187-85.pdf, accessed October 15, 2014.

(Rotz, 1999a). With IFSM, whole farm environmental impact was simulated based on crop production, total feed use, and nutrients applied to land through manure and fertilizer. Inputs were gathered from producer surveys, nutrient management plans (NMP), and sample analyses (Table 3-2). For the purpose of the present study, an average of the two most recent years of weather and economic data were used to simulate effects before and after BMP implementation. The PreBMP and PostBMP periods were compared for each BMP category. All inputs remained unchanged for both simulations (PreBMP and PostBMP), except for CP in the diet, P in the diet, and percent of cows in each group for the specified BMP. For the seven farms that implemented reduced dietary CP, dietary CP was adjusted in the model (as of percent of NRC requirements) to achieve the specified CP level in the lactating rations for each farm for both the PreBMP and PostBMP simulations. Likewise, for the three farms that reduced P, dietary P was adjusted in the model using the same methods. For the two farms that implemented group feeding, all lactating cows were listed as one group for the PreBMP period, however were split into a high group and low group for the PostBMP simulation, in which percentages of high and low cows were specific to each farm.

Statistical Analysis

Data were analyzed using PROC MIXED of SAS (SAS Institute, 2003; SAS Inst. Inc., Cary, NC). Class variables were Farm and Phase and the model included Phase. The error term was assumed to be normally distributed with mean = 0 and constant variance. Farm was considered as random effect. All data were analyzed using the following model:

```
proc mixed data = NFWFBMP;
class Farm Phase;
model DependentVariable = Phase;
random Farm / subject = Farm;
```

lsmeans phase / diff;

When the main effect of treatment was significant, means were separated by pairwise t-test (diff option of PROC MIXED). Significant differences were declared at $P \leq 0.05$ and a trend toward significance at $0.05 < P \leq 0.10$. Means are presented as least squares means.

Results

Reduced dietary CP. On-farm effects of reduced dietary CP are presented in Table 3-3. Seven farms reduced dietary CP in their lactating cow rations (from 17.2 to 15.8%; $P < 0.001$) resulting in decreased fecal N ($P = 0.03$), urinary urea-N ($P = 0.007$), total urinary N ($P < 0.001$), and MUN ($P < 0.001$). Dry matter intake ($P = 0.30$), milk yield ($P = 0.97$), feed efficiency (milk yield ÷ DMI; $P = 0.45$), and milk N efficiency (milk protein N yield ÷ N intake; $P = 0.51$), were unaffected with reduced dietary CP. Both milk fat ($P < 0.001$) and milk protein concentrations ($P < 0.001$) decreased from the PreBMP to PostBMP period. Total mixed ration starch increased ($P = 0.007$) and fecal starch tended to increase ($P = 0.10$) when dietary CP was reduced. Income over feed cost (Figure 3-1) was not different for farms that reduced dietary CP compared to the average of all farms for February (PreBMP; $P = 0.28$), March (PreBMP; $P = 0.35$), June (PostBMP; $P = 0.29$), and July (PostBMP; $P = 0.37$). Additionally, feed cost (Figure 3-2) and gross milk price (Figure 3-3) were no different compared to the average for farms that reduced dietary CP.

Whole farm environmental effects for reduced dietary CP calculated using IFSM are presented in Table 3-4. Nitrogen imported onto the farm ($P = 0.02$), N lost by volatilization (0.02), N lost by leaching ($P = 0.01$), N lost by denitrification ($P = 0.008$), N lost in runoff ($P = 0.008$), and N concentrate in leachate ($P = 0.01$) decreased from the PreBMP to PostBMP period

for the farms that reduced dietary CP. Greenhouse gasses emitted by manure ($P = 0.003$), GHG emitted by feed production ($P = 0.02$), and N_2O emissions ($P = 0.01$) decreased and gas emissions including NH_3 ($P = 0.08$), ozone-forming volatile organic compounds (VOC) emissions ($P = 0.09$), and GHG emitted by animal ($P = 0.08$) tended to decrease. Impact on environmental footprint including reactive N footprint ($P = 0.004$), energy footprint ($P = 0.005$), and C footprint without biogenic CO_2 ($P = 0.004$) were reduced from the PreBMP to PostBMP period for the farms that reduced dietary CP. Net total return to farm ($P = 0.004$) increased with reduced CP in the diet.

During the PostBMP period, Farm M received an incorrect grain mix, which was higher in CP than rations were balanced for. Samplings one and two of the PostBMP period were collected while the correct grain mix was fed. However, samplings three and four were collected when cows received the high CP grain mix. Results from the PostBMP period for Farm M are shown in Table 3-5. Total mixed ration CP ($P = 0.008$) and P ($P = 0.02$) increased when the incorrect grain mix was used in the lactating rations. There was no effect on N excretions and secretions, although MUN numerically increased. Fecal P increased ($P = 0.03$) in the third and forth samplings compared to the first and second samplings of the PostBMP period. Total mixed ration starch decreased ($P = 0.004$), as did fecal starch ($P < 0.001$). Although DMI and milk yield were unaffected, milk fat increased ($P = 0.05$) when the incorrect, high CP grain mix was fed.

Reduced dietary P. On-farm effects of reduced dietary P are presented in Table 3-6. Three farms lowered dietary P in their lactating cow diets (from 0.42 to 0.40%; $P = 0.06$) by reducing or eliminating P supplements in diets, which resulted in decreased fecal P ($P = 0.001$). Dry matter intake ($P = 0.44$), milk yield ($P = 0.58$), feed efficiency ($P = 0.50$), and P efficiency (milk yield ÷ P intake; $P = 0.34$) were unaffected by reduced dietary P. Both milk fat ($P < 0.001$) and milk protein concentrations ($P < 0.001$) decreased from the PreBMP to PostBMP period. Milk urea-N decreased ($P = 0.04$) although CP remained unchanged ($P = 0.21$) for farms that

decreased dietary P. Total mixed ration starch was unaffected ($P = 0.46$), yet fecal starch increased ($P = 0.001$). Income over feed cost was not different for farms that reduced dietary P compared to the average of all farms for February (PreBMP; $P = 0.41$), March (PreBMP; $P = 0.39$), June (PostBMP; $P = 0.29$), and July (PostBMP; $P = 0.39$). Additionally, gross milk price was also not different compared to the average for farms that reduced dietary P. Feed price was not different for February (PreBMP; $P = 0.27$), March (PreBMP; $P = 0.33$), and July (PostBMP; $P = 0.36$), however feed price tended to be lower ($P = 0.10$) than the average for June (PostBMP).

Phosphorus imported onto the farm ($P = 0.19$), P exported from the farm ($P = 0.53$), P lost in runoff leachate ($P = 0.42$), and P buildup in soil ($P = 0.22$) numerically decreased for farms that reduced dietary P when evaluated using IFSM (Table 3-7). Whole farm environmental impact and gas emissions when calculated using IFSM were unaffected from the PreBMP to PostBMP period.

Group feeding. On-farm effects of group feeding lactating cattle are presented in Table 3-8. Two farms split their lactating herd into two groups based on production parameters. Data collected from the PreBMP period were from one lactating group and PostBMP data were weighted average from both the high and low lactating groups or split by group. Dry matter intake (high group; $P = 0.19$ and low group; $P = 0.69$), milk yield ($P = 0.72$) and feed efficiency ($P = 0.54$) were unaffected by group feeding of the lactating herd. Farm F formulated for lower CP (17.2 vs. 14.8%; $P < 0.001$), therefore dietary CP was reduced (high group; $P = 0.03$ and low group; $P = 0.02$) for the group feeding BMP as well. Group feeding of lactating cows resulted in decreased urinary urea-N (high group; $P = 0.003$ and low group; $P < 0.001$), total urinary N (high group; $P < 0.001$ and low group; $P < 0.001$), and MUN ($P = 0.03$), while milk N efficiency tended to increase ($P = 0.09$) from the PreBMP to PostBMP period. Although Farm K maintained dietary CP (14.2 vs. 14.2; $P = 0.98$) throughout both sampling periods, urinary urea-N (627 to 390 mg/dL; $P < 0.001$) and total urinary N (0.85 to 0.48%; $P < 0.001$) decreased while MUN

numerically decreased (17.3 to 15.5%; $P = 0.42$). On both farms that implemented group feeding, TMR P unintentionally increased (high group; $P = 0.03$ and low group; $P = 0.05$) and consequently fecal P increased for the high group ($P = 0.006$) and numerically increased for the low group ($P = 0.13$), resulting in a tendency for decreased P efficiency ($P = 0.06$). Total mixed ration starch (high group; $P = 0.89$ and low group; $P = 0.83$) and fecal starch (high group; $P = 0.82$ and low group; $P = 0.17$) were unaffected from the PreBMP to PostBMP period. Income over feed cost was not different for farms that group fed compared to the average of all farms for February (PreBMP; $P = 0.23$), March (PreBMP; $P = 0.49$), June (PostBMP; $P = 0.33$), and July (PostBMP; $P = 0.24$). Additionally, feed cost and gross milk price were not different compared to the average for farms that implemented the group feeding BMP. Effects of group feeding evaluated using IFSM showed reduced N exported from the farm ($P = 0.03$), yet other farm parameters were unaffected (Table 3-9).

Monitoring forage DM. Descriptive statistics of the variability in TMR, corn silage, and haylage DM are presented in Table 3-10 and on-farm effects of monitoring and adjusting for changes in forage DM are presented in Table 3-11. Dry matter intake ($P = 0.18$), milk yield ($P = 0.32$), and feed efficiency ($P = 0.54$) were unaffected. Dietary CP tended to decrease ($P = 0.09$) resulting in decreased urinary urea-N ($P = 0.008$), urinary N ($P < 0.001$), and MUN ($P < 0.001$) from the PreBMP to PostBMP period for farms that monitored forage DM. Total mixed ration starch ($P = 0.39$) was unaffected, yet fecal starch increased ($P = 0.002$) from the PreBMP to PostBMP period. Income over feed cost was not different for farms that monitored and adjusted rations for changes in forage DM compared to the average of all farms for February (PreBMP; $P = 0.11$), June (PostBMP; $P = 0.20$), and July (PostBMP; $P = 0.42$), however tended to be lower in March (PreBMP; $P = 0.10$). Additionally, feed cost and gross milk price were not different compared to the average for farms that monitored forage DM. Effects of monitoring and adjusting

the ration for changes in forage DM was evaluated using IFSM by adjusting CP and P in the diet; however, no significant differences were found (data not shown).

No BMP implementation. Three farms did not implement a new BMP (Table 3-12). Dry matter intake was unaffected ($P = 0.29$), however milk yield ($P = 0.001$), milk fat percent ($P = 0.004$), and milk protein percent ($P = 0.009$) decreased from the PreBMP to PostBMP period for farms that did not implement new feeding BMP. Average DIM increased ($P = 0.004$) from the PreBMP to PostBMP period. No diet formulation adjustments took place on these farms however TMR P ($P = 0.07$) and TMR starch ($P = 0.052$) tended to decrease. Nitrogen secretions and excretions were unaffected with the exception of a tendency for decreased urinary N ($P = 0.08$).

Discussion

The concept of this on-farm study was to summarize the productive and environmental effects of implementing combinations of feeding BMP. We hypothesized that implementing feeding BMP would benefit the environment by reducing N and P excretions without reducing milk production or farm profitability.

Reduced dietary CP. Jonker et al. (2002) reported that dairy producers in the mid-Atlantic overfed N by 6.6% compared to NRC recommendations. In the present study, seven farms formulated their lactating cow diets for reduced dietary CP and did so according to their consulting nutritionist's recommendations; either by reducing CP in the grain mix or by increasing corn silage and decreasing haylage. For the seven farms that reduced CP, diet changes resulted reduced CP by 1.4 units; compared to the three farms that did not implement a new BMP where dietary CP was not affected from the PreBMP to PostBMP period. Urinary urea-N, total urinary N, and MUN results in the present study are consistent with other studies (Table 3-15) that reduced dietary CP (Broderick, 2003; Hristov et al., 2004; Colmenero and Broderick, 2006;

Lee et al., 2011; Lee et al., 2012a; Lee et al., 2012b). Dry matter intake, and therefore feed efficiency, need to be interpreted with caution for all BMP discussed because DMI data were estimated based on as-fed intakes provided to the project team by each producer therefore the accuracy and precision of measurements are difficult to determine. However, DMI calculated according to NRC (2001) was similar to that observed on farms for each BMP category. No difference in DMI was reported in the present study and similar studies reported no difference in DMI for diets between 14.8 and 19.4% CP (Holter et al., 1982; Howard et al., 1987; Kalscheur et al., 1999; Wu and Satter, 2000; Colmenero and Broderick, 2006; Lee et al., 2011; Lee et al., 2012a; Lee et al., 2012b). Others reported decreased DMI with decreased dietary CP (Wu and Satter, 2000; Broderick, 2003; Hristov and Giallongo, 2014). Milk yield was unaffected with reduced dietary CP and is supported by other findings (Holter et al., 1982; Howard et al., 1987; Kalscheur et al., 1999; Hristov et al., 2004; Colmenero and Broderick, 2006). However, data from Kalscheur et al., (1999) and Wu and Satter, (2000) indicated that milk yield and milk protein were reduced with decreased dietary CP in early lactation cows. In the present study, milk fat and milk protein concentrations were reduced, likely due to seasonal effects (Allore et al., 1997; Bailey et al., 2005) and not due to the reduction in dietary CP (Holter et al., 1982; Howard et al., 1987; Kalscheur et al., 1999; Hristov et al., 2004; Colmenero and Broderick, 2006; Lee et al., 2011; Lee et al., 2012a). Milk N efficiency remained unaffected because although dietary CP intake was reduced, so was milk protein concentration, while DMI and milk production were unaffected. Other studies indicate that N efficiency increased with decreased CP in the diet (Broderick, 2003; Colmenero and Broderick, 2006). Total mixed ration starch likely increased due to changes in feed source or grain processing and therefore fecal starch also tended to increase; starch digestibility in ruminants is dependent on starch source (Moharrery et al., 2014). Protein is an expensive feed ingredient and therefore overfeeding CP increases purchased feed costs (Jonker et al., 2002). Reducing CP should decrease purchased feed costs without impacting

production, which should result in increased IOFC (Chase et al., 2009). However feed ingredient costs numerically increased on all farms due to market conditions and gross milk price numerically decreased; therefore, no change was detected in IOFC for farms that reduced dietary CP. In two field trials, Chase et al. (2009) found that reducing dietary CP one unit (17.5 to 16.6 and 17.7 to 16.9) reduced purchased feed cost by $0.59 and $0.31/cow/d, respectively, which in turn increased IOFC $0.75 and $0.21/cow/d.

Whole farm environmental effects of each BMP category were calculated using IFSM (Rotz et al., 1999a). Inputs were gathered through farm surveys, sample analysis and NMP. The IFSM is primarily for evaluating long-term effects (Rotz et al., 1999a); however for the present study, two years were modeled and averaged to obtain values over a short period of time. As expected, reducing dietary CP in lactating cow diets reduced the amount of N on-farm and N lost in the atmosphere (Rotz et al., 1999b; Rotz et al., 2010).

Reduced dietary P. Mitigating P excretion is largely dependent on the reduction of P excretion in feces because P in milk is secreted at a steady rate of 0.9 g/kg of milk (Kebreab et al., 2008). Three farms lowered dietary P in their lactating cow diets by removing supplemental P minerals causing a 0.02 unit decrease in dietary P; compared to the three farms that did not implement new BMP, TMR P tended to be lower due to routine adjustments in ingredients used due to cost. For the reduced dietary P BMP, reduction in dietary P decreased fecal P, which is in agreement with other studies (Table 3-16) that reduced dietary P (Morse et al., 1992; Wu et al., 2000; Knowlton and Herbein, 2002; Wu et al., 2003; Knowlton et al., 2001; Kincaid et al., 2005; Wu, 2005; Bjelland et al., 2011; Ray et al., 2013). As expected, DMI and milk yield were unaffected (Morse et al., 1992; Wu et al., 2000; Knowlton and Herbein, 2002; Wu et al., 2003; Cerosaletti et al., 2004 Kincaid et al., 2005; Bjelland et al., 2011; Ray et al., 2013). Knowlton et al. (2001) and Wu (2005) reported decreased DMI with no effect on milk yield associated with deficient dietary P (≤ 0.34% on a DM basis). In the present study, both milk fat and milk protein

concentrations decreased, which were attributed to seasonal effects as described earlier. Milk urea-N decreased although CP was no different for the PreBMP vs. PostBMP periods. Milk urea-N is above average in winter and summer and below average in spring and fall and therefore we do not conclude that MUN was reduced due to change in season (Wattiaux et al., 2005). Although TMR starch concentration was unchanged, fecal starch increased, likely due to change in feed source (Moharrery et al., 2014). At $4.90/kg of inorganic P supplementation, it was estimated that reducing P from 0.41 to 0.35% could save $20 /cow/yr (Kebreab et al., 2008). Because P was only reduced by 0.02% DM in the present study, P balance and whole farm environmental impact evaluated using IFSM was statistically unaffected but numerically reduced.

Group feeding. Grouping like dairy cattle, such as similar milk production or parity, can more specifically meet nutrient requirements of cattle and decrease the variation in DMI within the group. Feeding a single lactating diet to a herd can limit high producing dairy cows and overfeed low producing cows (St-Pierre and Thraen, 1999; Grant and Albright, 2001). Implementing a grouping strategy can reduce the environmental impact and increase efficiency by reducing the amount of excess nutrients being excreted in feces and urine (Grant and Albright, 2001; NRC, 2001). Two farms split their lactating herd into two groups based on milk production; there were no changes to the facilities used at these farms. Dry matter intake and milk yield were unaffected by the change. One of the two farms reformulated for lower CP as well (17.2 to 14.8% CP), therefore dietary CP was also reduced for the group feeding BMP even though the second farm maintained dietary CP levels. This resulted in decreased urinary urea-N, urinary N, and MUN and increased fecal N and milk N efficiency on both farms. Although Farm K did not reduce dietary CP, the decrease in urinary urea-N, urinary N, and MUN, as well as increased milk N efficiency, could be because both groups (high and low) received a more customized diet and fewer excess nutrients when in late lactation. Total mixed ration P was unintentionally increased on both farms due to changes in ingredients incorporated into the

rations and consequently, fecal P increased; however, P efficiency increased as well. Total mixed ration and fecal starch were unaffected by the change. Limited whole farm environmental effects were observed with IFSM with group feeding of the lactating herd.

Monitoring forage DM. It is accepted that there are three rations on a dairy farm; TMR formulated by the nutritionist, TMR mixed and delivery to the cow, and the TMR that the cow consumes (Sova et al., 2014). There is limited research looking into variations in on-farm TMR mixing, however, one study reported that day-to-day variability in ration mixing (precision) is more constant than the difference between the formulated ration and that fed to the cow (accuracy) (James and Cox, 2008; Sova et al., 2014). In attempt to increase precision and accuracy, 10 farms monitored forages and adjusted the TMR for changes in DM on a weekly basis. Jonker et al. (2002) found that higher fat corrected milk (FCM) was associated with farms that adjusted rations for changes in forage DM on a weekly or monthly basis compared to a quarterly basis. In the present study, DMI and milk production were unaffected, however, another study associated less variability in ration composition with greater DMI, milk yield, and feed efficiency (Sova et al., 2013; Sova et al., 2014). McBeth et al. (2013) looked at feeding unbalanced TMR due to wetted silage and observed lower DMI for the first day when wetted silage was fed. In the present study, dietary CP remained unchanged, but urinary urea-N, total urinary N, and MUN decreased possibly due to a more accurate and consistent diet being fed and possibly because protein source of the TMR was altered between the two periods. Total mixed ration starch did not change, but fecal starch increased; likely due to differences in grain processing and change in forage source (Moharrery et al., 2014). Like with previous BMP discussed, changes observed in milk components may be due to seasonal effects. Feed cost was unchanged, but the decrease in gross milk price most likely contributed to reduced IOFC between the PreBMP and PostBMP period. Minimal whole farm environmental effects were observed with IFSM with monitoring forages for changes in DM and adjusting the lactating cow rations.

No BMP implementation. Three farms did not implement a new BMP between the two sampling periods. Dry matter intake, milk yield, and milk components decreased on these farms, most likely due to increased days in milk (DIM) and heat stress caused by seasonal effects (Allore et al., 1997; NRC, 2001; Bailey et al., 2005). It is possible that BMP implementation and attention to record keeping on the other farms may have mitigated severity of seasonal effects for DMI and milk yield. For farms that did not implement new feeding BMP, gross milk price was unaffected, but an increase in feed cost contributed to reduced IOFC from the PreBMP to PostBMP period.

All Farms. Water is the most important nutrient supplied to dairy cattle and is required for proper digestion, maintenance, and production (Adams and Sharpe, 2001; Beede, 2006). There are five main factors when considering water quality: organoleptic properties (odor and taste), physical and chemical properties (pH, TDS, and hardness), presence of toxic compounds, minerals content, and presence of bacteria (Adams and Sharpe, 2001; NRC, 2001; Beede, 2006). Poor water quality or limited water availability can reduce free water intake and therefore limit DMI and milk production (NRC, 2001; Beede, 2006). Results from water samples collected on each farm are presented in Table 3-14. Farm A had a small amount of coliform bacteria but no *E. coli*, so there were no likely issues with bacteria. Additionally, nitrate was high and should be monitored so it does not exceed 20 mg/L. Farm B initially tested for very high bacteria with *E. coli* present, but these data were considered unreliable due to sample contamination. An additional sample was taken by the producer (analyzed at Agri Analysis Inc.), which resulted in 95 colonies per 100 mL of water for coliform and 2 colonies per 100 mL of water for *E.coli*, which are still considered high, therefore Farm B decided to implement new technology in order to fix their bacteria problem after receiving results from the water analysis. In addition, nitrate also tested high on Farm B, E, and K and should be monitored so it does not exceed 20 mg/L. Additionally, sodium was high on Farm E and may need to be accounted for in the ration and is

possibly due to the use of water softener, based on hardness value. Farm G tested high for iron, which could limit water intake due to poor palatability and also had high sodium content and should be accounted for in the ration. Farm J had *E. coli* present, with potential health issues for the herd, and the nitrate level is nearly 20 mg/L and should be monitored. Farms C, F, and H also had *E. coli* present, with potential health issues for herd. Farm L had high levels of both *E. coli* and coliform and low TDS, causing potential herd health problems. Farms D, I, M, N, and O did not have any water quality concerns (B. R. Swistock, 2012).

Descriptive statistics from particle size analysis of TMR using PSPS are presented in Table 3-13. The top sieve (19mm) should contain 2 to 8% of as-is weight and is representative of the long forage particles that form the rumen forage mat and stimulate cud chewing (Heinrichs, 2013). The middle sieve (8mm) should contain 30 to 50% of as-is weight and form the majority of the forage mat (Heinrichs, 2013). The particles caught on the bottom sieve (4mm) should be between 10 to 20% of as-is weight and remain in the rumen for a short period of time. The amount of particles in these three sieves is used to calculate peNDF (Heinrichs, 2013). During the PostBMP period, particle size analysis was sent to each farm's nutritionist following each sampling event. General observations indicate lower SEM for particle size analysis in the PostBMP compared to the PreBMP period, suggesting more consistency with the particle size of the ration. Most TMR particle size analyses were within recommendations, and therefore did not require any major adjustments.

Conclusion

Reduced dietary CP decreased N concentrations in urine and feces and reduced dietary P decreased fecal P concentration on commercial dairy farms. Feeding dairy cattle more precisely through monitoring forage DM and grouping cows of similar nutrient requirements reduced N

output. The amount of N on-farm and N lost in the atmosphere was reduced with decreased dietary CP and the amount of P on-farm was numerically reduced with decreased dietary P when evaluated using IFSM. In this experiment, implementing one or more feeding BMP did not affect DMI or milk yield, but reduced nutrient excretions on commercial dairy farms in Pennsylvania, and consequently had a positive impact on the environment.

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Table 3-1. List of farms and BMP implemented

Farm	Total Ha	No. Cows	Milk Yield, kg/d	BMP Implemented
A	304	607	32.2	No BMP
B	95	182	36.0	No BMP
C	87	71	29.8	Reduced dietary P Adjusted for DM
D	121	87	30.7	Reduced dietary CP Adjusted for DM
E	81	106	32.9	Adjusted for DM
F	16	46	28.9	Reduced dietary CP Adjusted for DM Group feeding of lactating herd
G	132	167	35.6	No BMP
H	32	167	32.6	Reduced dietary CP Reduced dietary P Adjusted for DM
I	93	118	33.0	Reduced dietary CP Adjusted for DM
J	243	389	37.1	Reduced dietary CP
K	138	265	34.0	Group feeding of lactating herd
L	243	108	31.6	Reduced dietary P Adjusted for DM
M	89	130	31.2	Reduced dietary CP Adjusted for DM
N	92	76	28.6	Adjusted for DM
O	107	132	29.4	Reduced dietary CP Adjusted for DM

Table 3-2. Summary of input data for each farm evaluated using IFSM

Farm	Alfalfa area, ha	Grass area, ha	Corn area, ha	Small grain area, ha	Soybean area, ha	No-till, % of ha	Types of forage storage	Liquid manure storage capacity, tons
C	34.6	11.0	38.8	28.9	0	100	Upright silos Pressed bag	1384
D	19.1	14.2	59.8	21.1	24.4	75	Upright silos	1378
E	15.5	6.4	41.6	16.1	0	35	Upright silos	1251
F	7.7	4.6	7.7	7.7	0	100	Upright silos	807
H	10.3	6.3	21.3	19.2	0	33	Upright silos	1308
I	26.7	4.3	48.5	29.8	0	60	Upright silos	1624
J	117.6	18.6	113.9	49.0	11.8	50	Bunker silo Pressed bag	4373
K	11.9	11.8	107.5	107.5	11.2	100	Upright silos Pressed bag	3759
L	23.9	27.7	57.5	25.4	17.4	100	Upright silos	1081
M	31.4	5.1	49.1	9.1	0	100	Upright silos	807
N	26.9	9.1	35.3	4.5	19	21	Upright silos	1624
O	39.7	11.5	53.3	2.7	0	17	Upright silos	1624

Input data for IFSM were gathered from farm surveys, sample analysis, and NMP.

Table 3-3. On-farm effects of reduced dietary CP[1]

	PreBMP	PostBMP	SEM	*P* - value
DIM	182	183	5.0	0.85
DM intake[2], kg/d	23.3	22.4	0.86	0.30
Milk yield, kg/d	31.8	31.8	1.08	0.97
Milk ÷ DMI	1.37	1.42	0.057	0.45
4% FCM ÷ DMI	1.36	1.32	0.046	0.50
Milk N efficiency, %	24.7	25.5	1.18	0.51
Milk composition				
Fat, %	3.92	3.55	0.053	<0.001
True protein, %	3.14	2.96	0.020	<0.001
SCC × 1000, cells/mL	169	228	23.5	0.01
MUN, mg/dL	16.8	13.7	0.46	<0.001
TMR composition, % of DM				
CP	17.2	15.8	0.20	<0.001
NDF	31.3	32.1	0.48	0.24
ADF	21.2	21.2	0.39	0.98
Starch	22.6	25.0	0.60	0.007
N excretion				
Fecal N, % of DM	2.76	2.64	0.040	0.03
UUN[3], mg/dL	544	461	21.2	0.007
Urinary N, % as-is	0.75	0.57	0.028	<0.001
Fecal starch, %	4.03	4.73	0.293	0.10

[1]n = 7 farms.
[2]DMI was determined by the producer therefore accuracy could not be confirmed.
[3]Urinary urea-N.

Table 3-4. Effects of reduced dietary CP[1] quantified using IFSM

	PreBMP	PostBMP	SEM	*P* - value
N balance				
N Imported to farm, kg/ha	313	293	32.6	0.02
N exported from farm, kg/ha	144	142	24.8	0.34
N lost by volatilization, kg/ha	103	93	12.0	0.02
N lost by leaching, kg/ha	53.0	49.0	5.47	0.01
N lost by denitrification, kg/ha	15.3	14.7	1.63	0.008
N lost in runoff, kg/ha	1.69	1.61	0.371	0.008
N concentration in leachate, ppm	22.5	20.4	1.96	0.01
Net total return, $/cow/yr	2230	2286	248.7	0.004
Return to management, $/yr	173,459	184,060	69,444.0	0.12
Gas emissions				
NH_3, kg/yr	11,640	10,520	3,135.2	0.08
Hydrogen sulfide, kg/yr	316	315	86.2	0.11
Ozone forming VOC, kg/yr	2,946	2,936	1,236.0	0.09
CH_4, kg/yr	28,197	30,920	8,214.6	0.45
N_2O, kg/yr	943	910	215	0.01
Net biogenic CO_2, ton/yr	-476.6	-477.5	123.4	0.48
Anthropogenic CO_2, ton/yr	45.2	45.2	14.6	0.52
GHG by animal, kg/yr	636,314	623,726	177,955.0	0.08
GHG by manure, kg/yr	196,083	191,960	21,225.0	0.003
GHG by feed production, kg/yr	201,207	195,256	47,500.0	0.02
Environmental Footprint				
Water footprint without rain, kg/kg FPC[2] milk	285.2	285.8	46.96	0.79
Reactive N footprint, g/kg FPC[2] milk	10.57	9.75	0.879	0.004
Energy footprint MJ/kg FPC[2] milk	1.97	1.96	0.133	0.005
C footprint without biogenic CO_2 kg/kg FPC[2] milk	0.89	0.87	0.039	0.004

[1]n = 7 farms.
[2]4% fat and 3.3% true protein corrected milk.

Table 3-5. Effects of Farm M receiving incorrect, high CP grain mix[1]

	PostBMP[2]	PostBMP[3]	SEM	*P* - value
DM intake[4], kg/d	23.7	23.2	1.63	0.85
Milk yield, kg/d	31.3	31.9	1.44	0.69
Milk Composition				
Milk Fat, %	3.47	3.60	0.049	0.051
Milk Protein, %	2.95	2.91	0.034	0.30
Milk SCC × 1000, cells/mL	224	206	22.3	0.46
MUN, mg/dL	16.6	18.3	2.02	0.44
TMR Composition, % of DM				
CP	16.6	20.9	0.98	0.008
P	0.43	0.52	0.027	0.02
NDF	35.4	37.9	2.04	0.40
ADF	23.0	25.6	1.70	0.30
Starch	18.5	11.0	1.47	0.004
N Excretion				
Fecal N, %	2.80	2.62	0.085	0.15
UUN[5], mg/dL	677	676	50.0	0.99
Urinary N, %	0.78	0.82	0.096	0.74
Fecal Composition, % of DM				
Starch	5.35	1.21	0.437	<0.001
P	0.83	1.01	0.053	0.03

[1]Halfway through the PostBMP sampling period, Farm M received an incorrect, high CP grain mix from the feed mill and this mistake was not corrected until after the conclusion of the PostBMP period. Due to the high CP grain mix, the nutrient composition of the TMR was likewise affected during sampling events three and four in the PostBMP period.
[2]Sampling events one and two in PostBMP period.
[3]Sampling events three and four in PostBMP period.
[4]DMI was determined by the producer therefore accuracy could not be confirmed.
[5]Urinary urea-N.

Table 3-6. On-farm effects of reduced dietary P[1]

	PreBMP	PostBMP	SEM	*P* - value
DIM	179	181	7.0	0.81
DM intake[2], kg/d	22.2	21.3	1.60	0.44
Milk yield, kg/d	31.1	31.6	0.88	0.58
Milk ÷ DMI	1.40	1.51	0.141	0.50
4% FCM ÷ DMI	1.39	1.39	0.114	0.98
P efficiency, %	29.6	33.8	3.03	0.34
Milk composition				
Fat, %	3.89	3.50	0.061	<0.001
True protein, %	3.11	2.97	0.025	<0.001
SCC × 1000, cells/mL	157	202	80.6	0.42
MUN, mg/dL	16.5	14.2	0.97	0.04
TMR composition, % of DM				
P	0.42	0.40	0.008	0.06
NDF	30.3	32.1	0.73	0.09
ADF	20.4	21.1	0.63	0.46
Starch	24.3	25.7	1.34	0.46
Fecal composition, % of DM				
P	0.83	0.69	0.028	0.001
Starch	3.06	5.74	0.490	0.001

[1]n = 3 farms.
[2]DMI was determined by the producer therefore accuracy could not be confirmed.

Table 3-7. Effects of reduced dietary P[1] quantified using IFSM

	PreBMP	PostBMP	SEM	*P* - value
P balance				
P Imported to farm, kg/ha	24.6	22.1	5.82	0.19
P exported from farm, kg/ha	18.4	18.0	3.93	0.53
P lost in runoff leachate, kg/ha	1.67	1.53	0.167	0.42
P buildup in soil, kg/ha	4.43	2.47	3.789	0.22
Feed cost, $/yr	165,264	169,185	31,003.0	0.42
IOFC, $/yr	222,360	218,438	53,666.0	0.42
Net total return, $/cow/yr	2485	2457	41.3	0.54
Return to management, $/yr	101,406	97,486	33,313.0	0.42
Gas emissions				
NH_3, kg/yr	6,192	6,779	1,812.8	0.37
Hydrogen sulfide, kg/yr	180	180	21.3	1.00
Ozone forming VOC, kg/yr	2,493	2,631	1,028.6	0.43
CH_4, kg/yr	22,298	22,678	3,493.3	0.42
N_2O, kg/yr	548	561	219.9	0.54
Net biogenic CO_2, ton/yr	-296.1	-297.2	58.7	0.42
Anthropogenic CO_2, ton/yr	28.4	28.9	10.9	0.51
GHG by animal, kg/yr	401,480	410,612	88,510.0	0.41
GHG by manure, kg/yr	177,809	177,622	14,039.0	0.95
GHG by feed production, kg/yr	120,767	128,224	82,580.0	0.44
Environmental footprint				
Water footprint without rain, kg/kg FPC[2] milk	322.5	202.7	62.22	0.31
Reactive N footprint, g/kg FPC[2] milk	9.36	9.90	1.102	0.44
Energy footprint MJ/kg FPC[2] milk	1.93	1.94	0.122	0.46
C footprint without biogenic CO_2 kg/kg FPC[2] milk	0.89	0.90	0.023	0.62

[1]n = 3 farms.
[2]4% fat and 3.3% true protein corrected milk.

Table 3-8. On-farm effects group feeding lactating dairy cattle[1]

	PreBMP	PostBMP	SEM	*P* - value
DIM	183	189	8.1	0.68
DM intake[2] (high[3]), kg/d	23.2	24.4	0.61	0.19
DM intake[2] (low[4]), kg/d	23.2	22.9	0.76	0.69
Milk yield, kg/d	31.7	31.2	2.59	0.72
Milk ÷ DMI	1.36	1.40	0.107	0.54
4% FCM ÷ DMI	1.34	1.31	0.100	0.73
Milk N efficiency, %	26.4	28.6	3.70	0.09
P efficiency, %	32.3	31.7	4.49	0.06
Milk composition				
Fat, %	3.89	3.57	0.650	0.001
True protein, %	3.08	2.92	0.041	0.001
SCC × 1000, cells/mL	101	110	12.8	0.64
MUN, mg/dL	17.4	13.7	1.15	0.03
TMR (high[3]), % of DM				
CP	15.7	14.7	1.00	0.03
P	0.38	0.41	0.020	0.03
NDF	31.4	32.5	0.70	0.30
ADF	20.8	20.9	1.09	0.89
Starch	24.9	24.7	1.09	0.89
TMR (low[4]), % of DM				
CP	15.7	14.3	0.91	0.02
P	0.38	0.41	0.020	0.05
NDF	31.4	33.4	1.04	0.06
ADF	20.8	21.2	0.60	0.66
Starch	24.9	24.5	1.24	0.83
N excretion (high[3])				
Fecal N, % of DM	2.40	2.78	0.227	<0.001
UUN[5], mg/dL	594	398	37.6	0.003
Urinary N, % as-is	0.81	0.51	0.034	<0.001
N excretion (low[4])				
Fecal N, % of DM	2.40	2.60	0.167	0.06
UUN[5], mg/dL	594	385	32.6	<0.001
Urinary N, % as-is	0.81	0.51	0.030	<0.001
Fecal composition (high[3])				
Starch, % of DM	4.12	4.26	0.406	0.82
P, % of DM	0.70	0.80	0.050	0.006
Fecal composition (low[4])				
Starch, % of DM	4.12	5.14	0.809	0.17
P, % of DM	0.70	0.77	0.030	0.13

[1]n = 2 farms.
[2] DMI was determined by the producer therefore accuracy could not be confirmed.
[3]PreBMP DMI was collected from one lactating group, PostBMP DMI was collected from the high group.
[4]PreBMP DMI was collected from one lactating group, PostBMP DMI was collected from the low group.
[5]Urinary urea-N.

Table 3-9. Effects of group feeding lactating dairy cattle[1] quantified using IFSM

	PreBMP	PostBMP	SEM	*P* - value
N balance				
N Imported to farm, kg/ha	429	400	54.2	0.48
N exported from farm, kg/ha	246	231	44.0	0.03
N lost by volatilization, kg/ha	139	129	28.8	0.70
N lost by leaching, kg/ha	39.9	37.5	15.23	0.72
N lost by denitrification, kg/ha	10.1	9.5	3.50	0.58
N lost in runoff, kg/ha	0.85	0.80	0.128	0.50
N concentration in leachate, ppm	16.7	14.9	1.53	0.56
P balance				
P Imported to farm, kg/ha	53.7	58.5	10.86	0.21
P exported from farm, kg/ha	39.5	39.2	5.6543	0.86
P buildup in soil, kg/ha	9.30	14.40	8.122	0.32
C balance				
C imported to farm, kg/ha	14,398	14,298	1,016.7	0.51
C exported from farm, kg/ha	3,020	2,960	150.8	0.50
C lost at CO_2, kg/ha	10,962	10,927	1,075.5	0.64
C lost as CH4, kg/ha	413	408	86.4	0.74
Feed cost, $/yr	327,582	331,498	181,294.0	0.71
IOFC, $/yr	535,999	511,884	463,972.0	0.55
Net total return, $/cow/yr	2,329	2282	1079.3	0.78
Return to management, $/yr	333,491	306,463	322,002.0	0.55
Gas emissions				
NH_3, kg/yr	10,971	11,389	7,283.8	0.76
Hydrogen sulfide, kg/yr	489	481	387.8	0.50
Ozone forming VOC, kg/yr	8,108	8,077	7,594.5	0.42
CH_4, kg/yr	37,167	37,592	24,173.0	0.72
N_2O, kg/yr	378	374	206.2	0.84
Net biogenic CO_2, ton/yr	-654.9	-642.9	404.3	0.46
Anthropogenic CO_2, ton/yr	35.2	35.2	20.4	0.70
GHG by animal, kg/yr	596,358	614,674	355,956.0	0.63
GHG by manure, kg/yr	357,939	349,909	256,674.0	0.30
GHG by feed production, kg/yr	68,680	68,611	3,4931.0	0.99
Environmental Footprint				
Water footprint without rain, kg/kg FPC[2] milk	461.5	440.1	90.37	0.49
Reactive N footprint, g/kg FPC[2] milk	7.79	7.31	0.459	0.59
Energy footprint MJ/kg FPC[2] milk	2.23	2.23	0.333	0.80
C footprint without biogenic CO_2 kg/kg FPC[2] milk	0.82	0.80	0.143	0.66

[1]n = 2 farms.

[2]4% fat and 3.3% true protein corrected milk.

Table 3-10. Variability in TMR, corn silage, and haylage DM

	PreBMP[1]	SEM[2]	PostBMP[3]	SEM[4]
TMR				
Farm C	43.3	0.79	54.8	2.46
Farm D (high)	52.2	2.11	58.6	0.57
Farm D (low)	52.3	0.73	56.8	0.17
Farm E (high)	57.5	0.57	61.2	2.43
Farm E (low)	53.9	0.83	59.8	1.73
Farm F (high)	56.5	0.90	56.5	0.60
Farm F (low)	56.5	0.90	56.3	0.78
Farm H	55.5	1.35	50.9	1.56
Farm I	44.3	0.65	48.3	2.15
Farm L	48.1	0.60	45.2	0.52
Farm M (high)	46.2	2.61	48.8	0.89
Farm M (low)	41.0	3.58	49.8	1.80
Farm N	50.8	1.00	57.1	0.63
Farm O	50.8	0.84	52.2	1.66
Corn Silage				
Farm C	30.8	0.55	64.2	2.30
Farm D	37.0	0.57	40.8	0.27
Farm E	37.6	1.40	33.9	1.25
Farm F	44.8	0.18	44.6	1.30
Farm H	42.7	0.48	43.5	1.20
Farm I	34.7	0.59	40.3	0.74
Farm L	42.0	0.57	37.6	0.89
Farm M	36.4	0.86	39.5	3.29
Farm N	36.7	0.80	37.6	0.82
Farm O	38.2	0.81	36.7	2.15
Haylage				
Farm C	38.6	1.40	45.0	5.72
Farm D	50.9	2.33	57.8	0.68
Farm E[5]	43.7	1.98	40.3	7.78
Farm F	53.2	0.87	49.5	1.81
Farm H	57.1	8.77	39.1	3.76
Farm I	35.7	4.29	40.9	4.34
Farm L	30.6	0.42	36.4	1.56
Farm M	45.6	9.62	46.4	3.52
Farm N	44.1	1.57	57.8	1.46
Farm O	46.9	0.63	51.2	6.30

[1]Mean DM percent for PreBMP period.
[2]SEM for PreBMP period.
[3]Mean DM percent for PostBMP period.
[4]SEM for PostBMP period.
[5]Farm E fed new crop haylage during the PostBMP period.

Table 3-11. On-farm effects of monitoring and adjusting for changes in forage DM[1]

	PreBMP	PostBMP	SEM	*P* - value
DIM	178	184	4.7	0.40
DM intake[2], kg/d	23.2	22.3	0.60	0.18
Milk yield, kg/d	31.2	30.7	0.55	0.32
Milk ÷ DMI	1.35	1.38	0.050	0.54
4% FCM ÷ DMI	1.34	1.29	0.041	0.23
Milk N efficiency, %	24.9	24.4	1.12	0.68
P efficiency, %	28.6	29.5	1.43	0.44
Milk composition				
Fat, %	3.94	3.61	0.531	<0.001
True protein, %	3.14	2.99	0.018	<0.001
SCC × 1000, cells/mL	166	294	57.1	0.07
MUN, mg/dL	17.0	14.3	0.47	<0.001
TMR composition, % of DM				
CP	16.6	16.2	0.18	0.09
P	0.43	0.43	0.009	0.90
NDF	31.9	33.1	0.35	0.02
ADF	21.7	22.0	0.30	0.53
Starch	22.8	23.4	0.52	0.39
N excretion				
Fecal N, %	2.62	2.61	0.034	0.81
UUN[3], mg/dL	549	483	17.2	0.008
Urinary N, %	0.75	0.61	0.022	<0.001
Fecal composition, % of DM				
Starch	4.10	5.15	0.232	0.002
P	0.81	0.78	0.024	0.39

[1]n = 10 farms.
[2]DMI was determined by the producer therefore accuracy could not be confirmed.
[3]Urinary urea-N.

Table 3-12. Farms that did not implement new feeding BMP[1]

	PreBMP	PostBMP	SEM	*P* - value
DIM	181	221	4.6	0.004
DM intake[2], kg/d	23.6	22.6	0.36	0.29
Milk yield, kg/d	37.3	31.5	1.37	0.001
Milk ÷ DMI	1.61	1.45	0.067	0.28
4% FCM ÷ DMI	1.56	1.34	1.449	0.19
Milk N efficiency, %	33.1	29.3	1.09	0.25
P efficiency, %	35.7	35.1	2.95	0.82
Milk composition				
Fat, %	3.78	3.46	0.107	<0.001
True protein, %	3.11	3.03	0.037	0.01
SCC × 1000, cells/mL	113	151	28.4	0.10
MUN, mg/dL	14.6	14.2	0.76	0.58
TMR composition, % of DM				
CP	14.2	14.5	0.17	0.16
P	0.40	0.37	0.009	0.07
NDF	31.7	32.4	0.44	0.25
ADF	20.7	20.8	0.30	0.78
Starch	26.7	25.3	0.49	0.05
N Excretion				
Fecal N, %	2.57	2.64	0.039	0.20
UUN[3], mg/dL	473	450	16.7	0.34
Urinary N, %	0.65	0.57	0.029	0.08
Fecal composition, % of DM				
Starch	2.55	2.30	0.212	0.39
P	0.68	0.71	0.026	0.49

[1]n = 3 farms.
[2]DMI was determined by the producer therefore accuracy could not be confirmed.
[3]Urinary urea-N.

Table 3-13. Particle size distribution of lactating cow TMR

Farm	Sieve	PreBMP[1]	SEM[2]	PostBMP[3]	SEM[4]
A (high)	Top[7]	11.1	2.93	4.4	0.55
	Middle[8]	32.2	7.56	44.8	0.85
	Bottom[9]	13.5	1.32	13.7	0.58
	Pan[10]	43.3	4.29	37.2	1.33
A (low)	Top[7]	9.3	2.83	4.6	0.79
	Middle[8]	32.4	9.62	47.3	1.02
	Bottom[9]	14.3	0.86	12.9	0.59
	Pan[10]	44.1	6.36	35.2	1.14
B (high)	Top[7]	12.0	3.20	7.6	1.54
	Middle[8]	30.9	4.57	35.6	1.48
	Bottom[9]	19.5	3.92	17.9	0.73
	Pan[10]	37.5	1.03	38.9	1.31
B (low)	Top[7]	11.9	3.83	10.3	2.18
	Middle[8]	32.3	5.18	37.8	1.19
	Bottom[9]	16.2	1.15	16.8	1.00
	Pan[10]	39.6	0.46	35.1	1.31
C	Top[7]	4.7	1.59	24.1	3.32
	Middle[8]	36.4	5.09	26.6	1.52
	Bottom[9]	24.7	2.13	19.0	1.74
	Pan[10]	34.2	2.47	30.3	3.07
D (high)	Top[7]	11.9	4.21	5.1	1.13
	Middle[8]	31.3	4.61	35.6	1.65
	Bottom[9]	23.1	5.19	27.6	0.55
	Pan[10]	33.8	1.46	31.6	1.95
D (low)	Top[7]	8.8	2.48	4.9	1.24
	Middle[8]	26.5	5.93	35.2	2.30
	Bottom[9]	27.2	1.09	26.7	0.85
	Pan[10]	37.5	2.83	33.2	2.50
E (high)	Top[7]	13.9	5.81	4.3	0.17
	Middle[8]	30.6	1.38	28.6	3.46
	Bottom[9]	12.4	1.20	14.5	0.96
	Pan[10]	43.0	4.30	52.6	4.15
E (low)	Top[7]	15.7	4.47	4.5	0.36
	Middle[8]	33.2	2.71	33.5	1.93
	Bottom[9]	13.7	1.29	13.7	0.64
	Pan[10]	37.5	3.25	48.4	1.86
F (high[5])	Top[7]	7.1	3.40	5.2	1.18
	Middle[8]	31.4	4.53	36.8	2.32
	Bottom[9]	25.7	1.01	27.7	1.36
	Pan[10]	35.8	0.33	30.3	2.13
F (low[6])	Top[7]	7.1	3.40	7.0	3.77
	Middle[8]	31.4	4.53	36.0	2.90
	Bottom[9]	25.7	1.01	28.2	3.18
	Pan[10]	35.8	0.33	28.8	3.48

G (high)	Top[7]	12.9	4.65	3.2	0.54
	Middle[8]	36.0	6.97	41.5	1.44
	Bottom[9]	12.7	0.90	13.2	0.27
	Pan[10]	38.3	4.76	42.0	1.08
G (low)	Top[7]	9.5	2.36	3.8	0.77
	Middle[8]	32.8	8.03	45.5	1.80
	Bottom[9]	13.1	0.90	13.0	0.47
	Pan[10]	44.6	4.80	37.6	2.04
H	Top[7]	6.6	3.78	4.8	2.45
	Middle[8]	27.2	0.72	32.8	3.28
	Bottom[9]	25.1	1.08	24.6	1.20
	Pan[10]	41.1	3.82	37.8	4.95
I	Top[7]	4.8	1.14	3.2	0.42
	Middle[8]	32.7	1.91	30.6	1.68
	Bottom[9]	27.4	1.42	29.6	2.07
	Pan[10]	35.1	0.78	36.5	1.67
J (high)	Top[7]	3.6	0.99	6.6	0.95
	Middle[8]	38.9	5.54	49.8	11.14
	Bottom[9]	20.6	0.22	16.1	1.23
	Pan[10]	36.9	4.64	27.6	2.55
J (low)	Top[7]	4.3	1.06	6.5	0.62
	Middle[8]	39.1	5.89	48.9	1.33
	Bottom[9]	20.7	1.19	15.4	0.82
	Pan[10]	35.8	4.86	29.2	2.16
K (high[5])	Top[7]	13.3	1.62	6.9	1.30
	Middle[8]	34.6	3.29	35.6	0.80
	Bottom[9]	16.1	0.80	18.1	1.40
	Pan[10]	36.0	0.90	39.4	3.50
K (low[6])	Top[7]	13.3	1.62	4.7	1.24
	Middle[8]	34.6	3.29	40.1	1.48
	Bottom[9]	16.1	0.80	18.1	1.17
	Pan[10]	36.0	0.90	37.1	1.75
L	Top[7]	5.7	2.68	5.7	0.35
	Middle[8]	32.3	2.24	41.3	0.89
	Bottom[9]	27.6	0.65	23.4	1.82
	Pan[10]	34.4	2.26	29.6	1.23
M (high)	Top[7]	7.2	2.74	6.4	3.32
	Middle[8]	39.9	4.15	37.5	1.93
	Bottom[9]	21.3	1.67	23.3	2.48
	Pan[10]	31.6	2.97	32.8	2.78
M (low)	Top[7]	7.2	2.18	5.3	2.39
	Middle[8]	43.1	5.84	29.8	8.71
	Bottom[9]	19.4	1.40	24.8	2.33
	Pan[10]	30.3	4.42	40.1	8.78
N	Top[7]	5.4	2.77	2.3	0.35
	Middle[8]	29.0	2.95	26.7	0.79
	Bottom[9]	26.9	0.99	25.7	0.83
	Pan[10]	38.7	3.50	45.4	0.19

O	Top[7]	9.5	3.22	5.9	1.16
	Middle[8]	33.8	1.77	34.5	0.91
	Bottom[9]	16.5	0.54	17.1	0.38
	Pan[10]	40.2	2.28	42.4	1.91

[1]Mean particle size percent of as-is for PreBMP period.
[2]SEM for PreBMP period.
[3]Mean particle size percent of as-is for PostBMP period.
[4]SEM for PostBMP period.
[5]One lactating cow diet reported in PreBMP period, high cow diet reported in PostBMP period.
[6]One lactating cow diet reported in PreBMP period, low cow diet reported in PostBMP period.
[7]Recommended range of top sieve (19mm) for TMR: 2 to 8%.
[8]Recommended range of middle sieve (8mm) for TMR: 30 to 50%.
[9]Recommended range of bottom sieve (4mm) for TMR: 10 to 20%.
[10]Recommended range of pan for TMR: 30 to 40%.

Table 3-14. Water analysis from participating farms

Farm	Coliform[1]	*E. coli*[1]	pH	TDS, mg/L	Nitrate+ Nitrite, mg/L	$CaCO_3$[2], mg/L	Ca, Mg/L	Mg Mg,L	Na, Mg/L	Fe, Mg/L	Mn, Mg/L	Cl, Mg/L	SO_4, Mg/L	Cu, Mg/L
A	29	<1	7.5	433	9.4	327	107	14.5	13.5	<0.1	<0.01	32.9	48.1	0.01
B	1553	39	7.5	383	11.2	291	97.3	11.6	7.6	<0.1	<0.01	19.8	31.9	<0.01
C	345	4	6.9	21	<0.5	10	1.7	1.4	0.5	<0.1	<0.01	2	5.9	0.05
D	<1	<1	8.1	337	6.0	263	59.3	27.8	7.9	<0.1	<0.01	18.5	26.2	<0.01
E	15	<1	7.4	515	16.8	1	<0.3	<0.1	144.2	<0.1	<0.01	40.2	35.8	0.01
F	228	1	7.5	52	<0.5	29	7.9	2.3	2.0	<0.1	0.04	2.8	7.3	0.03
G	17	<1	7.3	657	4.2	513	103.7	61.7	30.1	0.6	0.01	34.7	156.9	<0.01
H	387	10	7.1	26	<0.5	13	2.6	1.5	0.7	0.1	0.01	2	7.6	<0.01
I	1	<1	7.5	553	11.1	372	88.6	36.5	19.5	0.3	<0.01	49	38	0.01
J	41	3	7.7	570	18.6	450	100.6	48.3	10.0	0.3	<0.01	35.1	21.2	0.01
K	<1	<1	7.7	448	11.7	316	103.8	13.8	19.5	<0.1	<0.01	28.8	41	0.01
L	1986	16	7.2	19	<0.5	9	1.4	1.3	0.7	<0.1	0.01	<5	3.4	0.01
N	<1	<1	7.6	423	13.1	309	73.5	30.5	11.2	<0.1	<0.01	24.2	17.6	<0.01
M	<1	<1	7.1	27	<0.5	12	1.9	1.8	1.1	<0.1	<0.01	2	7.8	0.01
O	<1	<1	6.8	19	<0.5	9	1.4	1.3	0.6	<0.1	<0.01	2	3.8	0.03
Level of conern[3]	-	>1	<6.0 or >8.0	>1000	>20	-	>500	>500	>20	>0.3	>0.05	>250	>1000	>1

[1]Probably number of colonies per 100 mL of water.
[2]Measure of water hardness.
[3]Level of concern as indicated by the Agricultural Analytical Services Laboratory.

Table 3-15. Literature summary of the effects of dietary CP on DMI, milk yield, milk protein, and N excretions and secretions

Author	No. Cows	Diet	Dietary CP, %	DMI kg/d	Milk Yield, kg	Milk True Protein, %	Milk Protein, %	MUN mg/dL	Fecal N, g/d	Urinary urea-N, g/d	Urinary N, g/d
Holter et al., 1982 (Trial 1)	32 (152 d postpartum)	A	11.0	18.6	27.7[b]		2.85				
		B	13.6	19.8	31.8[a]		3.18				
		C	15.9	19.7	32.8[a]		3.02				
		D	19.4	19.4	32.6[a]		3.13				
Holter et al., 1982 (Trial 1)	46 (159 d postpartum)	A	11.0	17.5	27.2[e]		2.65[d]				
		B	13.6	18.3	30.6[d]		3.00[c]				
		C	15.9	18.7	34.0[c]		3.04[c]				
		D	19.4	18.9	33.3[cd]		3.09[c]				
Holter et al., 1982 (Trial 2)	32 (152 d postpartum)	A	13.8	20.4	40.4		2.77				
		B	16.3	21.4	41.3		2.81				
		C	18.8	21.2	40.3		2.83				
		D	20.9	21.7	42.2		2.91				
Holter et al., 1982 (Trial 2)	46 (159 d postpartum)	A	13.8	20.3[d]	40.3		2.68				
		B	16.3	20.8[cd]	38.6		2.80				
		C	18.8	22.0[cd]	38.6		2.88				
		D	20.9	23.1[c]	41.3		2.88				
Howard et al., 1987	146	A	14.5	21.6	25.9[a]		3.21				
		B	19.4	21.8	26.4[b]		3.25				
Kalscheur et al., 1999 (Trial 1)	39 (4-14 wks postpartum)	A	17.4	22.2	37.6[a]		2.93[y]				
		B	15.4	21.3	32.7[b]		2.83[z]				
		C	15.0	22.3	35.9[b]		2.87[z]				
		D	15.2	21.5	36.1[b]		2.78[z]				
Kalscheur et al., 1999 (Trial 2)	40 (19-29 wks postpartum)	A	15.3	21.4	25.7		3.25				
		B	13.2	20.8	24.5		3.16				
		C	13.3	20.4	25.5		3.26				
		D	13.6	21.3	26.0		3.14				
Kalscheur et al., 1999 (Trial 3)	39 (34-44 wks postpartum)	A	14.2	19.5[a]	16.8		3.52				
		B	12.4	18.7[b]	15.1		3.63				
		C	12.5	18.3[b]	16.2		3.56				
		D	12.9	19.0[b]	16.4		3.47				

Wu and Satter, 2000	58 (1-16 wks postpartum)	A	15.4	21.2	36.9 [b]		2.92 [a]				
		B	17.4	22.3	39.5 [a]		2.84 [b]				
		C	17.4	22.3	39.5 [a]		2.84 [b]				
		D	19.3	21.8	40.8 [a]		2.86 [ab]				
Wu and Satter, 2000	58 (17-44 wks postpartum)	A	16.0	24.0[b]	30.1 [b]		3.36 [a]				
		B	16.0	24.2 [b]	32.9 [ab]		3.19 [b]				
		C	17.9	25.4[a]	33.8 [a]		3.12 [b]				
		D	17.9	24.7[ab]	33.5 [a]		3.23 [b]				
Broderick, 2003	63	A	15.1	21.2[c]	33.0 [b]	2.80	2.99 [b]	9.2 [c]	236[b]	119[c]	140[c]
		B	16.7	22.1[b]	34.1 [a]	2.82	3.03 [a]	12.4 [b]	264[a]	172[b]	193[b]
		C	18.4	22.6[a]	34.1 [a]	2.79	3.02 [a]	15.9 [a]	273[a]	216[a]	236[a]
Hristov et al., 2004	4	A	15.8	23.5[y]	22.7	3.08		13.1 [a]	185		252[y]
		B	18.3	23.8 [z]	23.2	3.01		15.8 [b]	188		321[z]
Groff and Wu, 2005 (Trial 1)	16	A	15.0	22.9	31.5		3.16	9.8 [a]	269[a]		229[a]
		B	16.3	23.3	32.0		3.12	10.2 [b]	270[b]		256[b]
		C	17.5	22.6	32.2		3.17	11.8 [c]	285[c]		252[c]
		D	18.8	23.2	32.5		3.10	13.3 [d]	323[d]		310[d]
Groff and Wu, 2005 (Trial 2)	16	A	15.0	28.7 [c]	34.7 [w]		3.06	6.2[a]	369[a]		127[a]
		B	16.3	27.9 [d]	34.9 [x]		3.01	6.8[b]	370[b]		139[b]
		C	17.5	30.2 [a]	35.8 [y]		3.03	8.5[c]	386[c]		177[c]
		D	18.8	29.3 [b]	36.5 [z]		3.03	9.9[d]	382[d]		204[d]
Groff and Wu, 2005 (Trial 3)	16	A	15.0	24.2	36.4		2.78	12.4[a]	229[a]		204[a]
		B	16.3	24.7	36.8		2.86	13.1[b]	259[b]		225[b]
		C	17.5	23.9	35.8		2.81	12.7[c]	273[c]		246[c]
		D	18.8	24.9	36.8		2.82	13.6[d]	264[d]		288[d]
Groff and Wu, 2005 (Trial 4)	16	A	15.0	25.8	39.2 [a]		2.98	10.8[a]	283[a]		236[a]
		B	16.3	26.4	38.5 [b]		3.00	13.2[b]	238[b]		231[b]
		C	17.5	25.9	39.1 [c]		2.98	14.4[c]	240[c]		247[c]
		D	18.8	25.7	39.3 [d]		2.93	14.9[d]	224[d]		276[d]
Colmenero and Broderick, 2006	40	A	13.5	22.3	36.3	3.09		7.7[d]	196[a]	63[e]	113[c]
		B	15.0	22.2	37.2	3.15		8.5[d]	176[b]	91[d]	140[d]
		C	16.5	23.0	38.3	3.09		11.2[c]	196[a]	128[c]	180[c]
		D	17.9	22.3	36.6	3.18		13.0[b]	197[a]	174[b]	213[b]
		E	19.4	22.9	37.0	3.16		15.6[a]	210[a]	208[a]	257[a]

Lee et al., 2011	36	A	16.7	24.7 [a]	39.3[a]	2.97	12.5[a]	213[a]	153[a]	194[a]
		B	14.8	23.8 [a]	36.2[b]	3.03	8.3[b]	207[a]	69[b]	122[b]
		C	14.7	21.6 [b]	34.4[b]	3.04	9.5[b]	175[b]	80[b]	123[b]
Lee et al., 2012a	48	A	15.6	24.9	38.8[a]	2.98	13.0[a]	233	104[a]	143[a]
		B	13.6	22.9	35.2[b]	2.94	10.3[bc]	213	47[b]	92[b]
		C	13.6	23.6	36.9[ab]	2.99	10.1[c]	224	41[b]	87[b]
		D	13.6	24.2	38.5[a]	3.03	11.1[b]	241	49[b]	97[b]
Lee et al., 2012b (Trial 1)	36	A	15.6	24.9	39.2	3.04[a]	10.0	259	85[a]	155[a]
		B	14.0	24.6	38.1	2.92[b]	8.4	253	41[b]	107[b]
		C	14.0	24.8	38.1	2.95[ab]	8.5	250	42[b]	106[b]

[a,b,c,d] unlike superscripts indicate significant difference ($P \leq 0.05$).
[y,z] unlike superscripts indicate trend ($P \leq 0.10$).

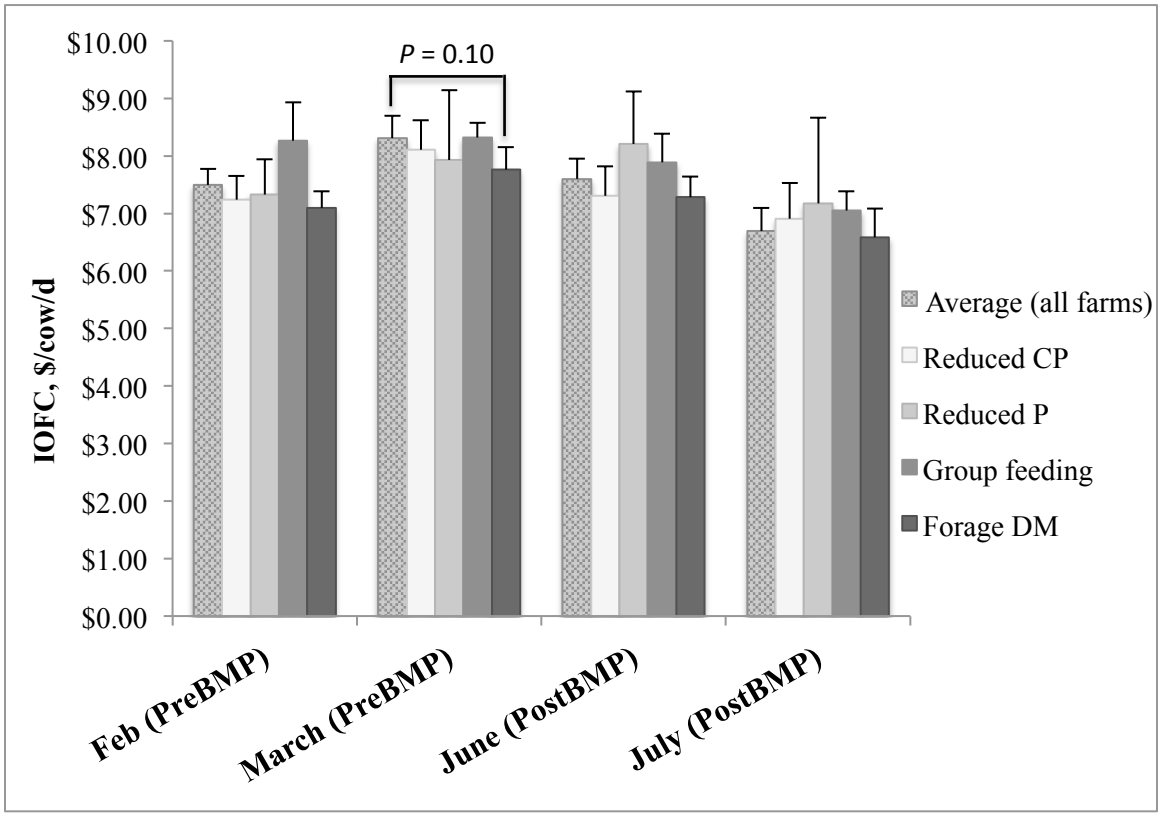
Table 3-16. Literature summary of the effects of dietary P on DMI, milk yield, milk protein, and P excretions

Author	No. Cows	Diet	Dietary P, %	DMI, kg/d	Milk Yield kg/d	Fecal P, g/d	Urinary P, g/d	Total P Excretion, g/d
Morse et al., 1992	12	A	0.30			40.3	0.66	58.9
		B	0.41		22.2	45.1	1.26	66.7
		C	0.56		22.4	62.9	3.36	87.7
Wu et al., 2000	26	A	0.31	23.0	35.0	37.2		
		B	0.40	22.4	36.5	52.5		
		C	0.49	23.4	36.2	67.6		
Knowlton et al., 2001	36	A	0.38	23.5^{y}	36.3	46.3^{a}	0.86	47.2^{a}
		B	0.34	20.9^{z}	33.3	40.3^{b}	0.74	41.1^{b}
		C	0.36	22.5^{y}	33.8	45.8^{a}	0.61	46.4^{a}
		D	0.34	20.6^{z}	32.4	39.0^{b}	0.54	39.5^{b}
Knowlton and Herbein, 2002	13 (3-11 wk postpartum)	A	0.34	25.3	49.5	42.3^{a}	0.32^{a}	42.6^{a}
		B	0.51	26.6	48.4	87.5^{b}	1.28^{b}	88.8^{b}
		C	0.67	24.1	45.8	108.6^{c}	5.12^{c}	112.5^{c}
Wu et al., 2003	44	A	0.33	23.1	36.4	45.2^{a}		
		B	0.33	24.0	33.8	52.2^{a}		
		C	0.42	23.2	36.5	63.7^{b}		
		D	0.42	23.9	34.2	66.0^{b}		
Kincaid et al., 2005 (Trial 1)	8	A	0.58	19.2	19.5	34.9^{a}		
		B	0.55	19.5	20.1	19.5^{cd}		
		C	0.50	19.4	21.2	11.4^{d}		
		D	0.57	19.4	20.6	28.3^{ab}		
		E	0.54	18.6	21.0	21.2^{cb}		
Wu, 2005	32	A	0.33	25.8^{a}	42.5	57.5^{a}		
		B	0.32	24.2^{a}	41.7	45.6^{a}		
		C	0.44	26.9^{b}	43.4	96.8^{b}		
		D	0.43	26.1^{b}	44.5	82.4^{b}		
Bjelland et al., 2011	365	A	0.40	8.7	28.6	29.2^{y}		
		B	0.30	9.4	28.5	24.2^{z}		

Ray et al., 2013	6	A	0.43	17.9	33.0	41.5[a]	0.20
		B	0.48	18.6	32.6	58.2[b]	0.26
		C	0.54	18.1	32.8	64.6[s]	0.31
		D	0.53	17.8	34.0	50.5[d]	0.61

[a,b,c,d] unlike superscripts indicate significant difference ($P \leq 0.05$).
[y,z] unlike superscripts indicate trend ($P \leq 0.10$)

Figure 3-1. Income over feed cost for each BMP category compared to the average IOFC for all farms



Income over feed cost (gross milk price, $/cwt – feed costs, $/cow/d) was calculated using the Pennsylvania State Extension Dairy Team IOFC Tool.

Figure 3-2. Feed cost for each BMP category compared to the average feed cost for all farms

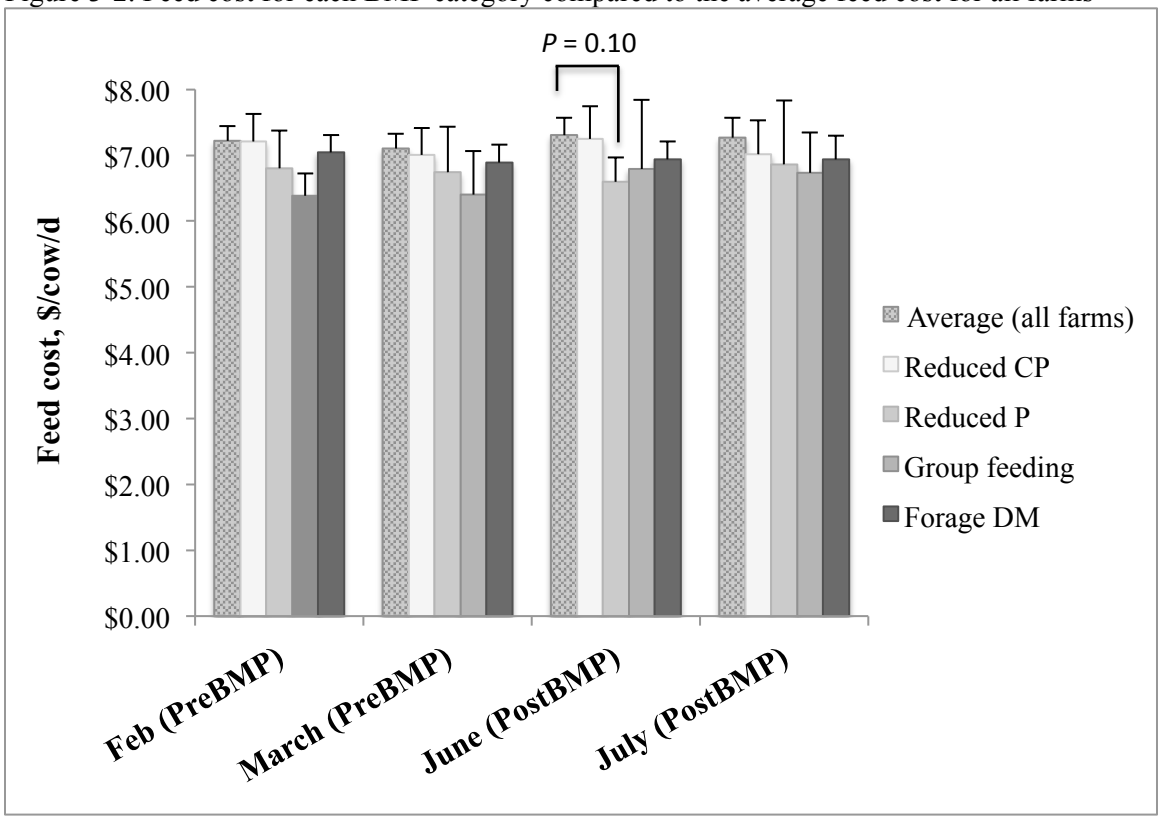
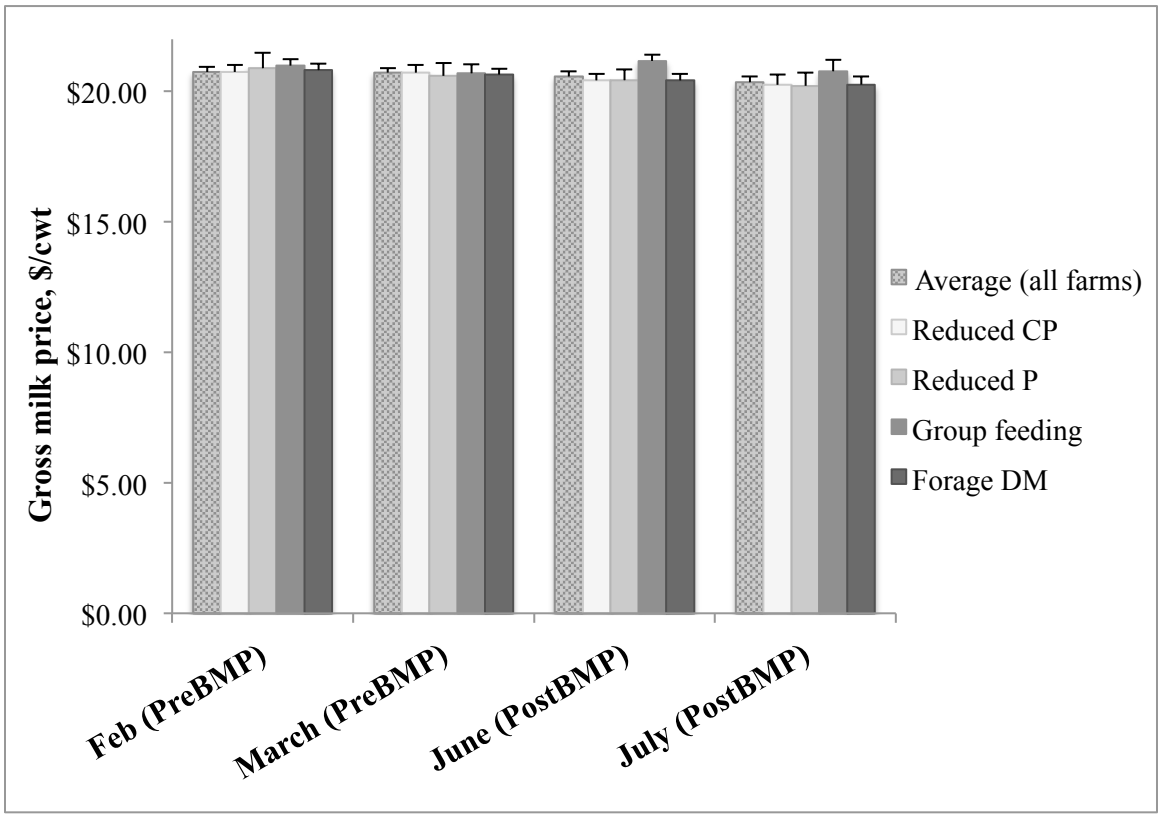


Figure 3-3.Gross milk price for each BMP category compared to the average gross milk price for all farms



Gross milk price did not contribute to any difference observed in IOFC between any BMP category and the average.

Chapter 4

DISCREPANCIES IN MILK UREA NITROGEN CONCENTRATION AMONG MILK LABORATORIES IN PENNSYLVANIA

Abstract

Milk urea-N is a useful measurement to monitor dietary CP intake and N utilization in lactating dairy cattle. Two experiments were conducted to explore discrepancies in MUN results among three laboratories, one experiment to compare the effect of two preservatives (bronopol and Broad Spectrum Microtabs® II; BSM) on MUN, and one experiment to evaluate MUN with increasing levels of bronopol. In experiment 1, 10 milk samples, collected over five consecutive days, were sent to three milk processing laboratories. Average MUN differed ($P < 0.001$ to $P = 0.05$) between Laboratory A (14.9 ± 0.40 mg/dL), Laboratory B (6.5 ± 0.17 mg/dL), and Laboratory C (7.4 ± 0.36 mg/dL). In experiment 2, milk samples were spiked with urea at 0, 17.2, 34.2, and 51.5 mg urea/dL of milk. Two 35-mL samples from each urea level were sent to three laboratories. Average analyzed MUN was higher than expected for Laboratory A (23.2 vs. 21.0 mg/dL; $P = 0.001$), Laboratory B (18.0 vs. 13.3 mg/dL; $P < 0.001$), and Laboratory C (20.6 vs. 15.2 mg/dL; $P < 0.001$). In experiment 3, three samples of control (without preservative), milk preserved with bronopol, and milk preserved with BSM were sent to Laboratory A and two samples of both bronopol and BSM were sent to Laboratory B. Milk urea-N results from Laboratory A differed ($P < 0.01$) between control (9.2 mg/dL), BSM (9.7 mg/dL), and bronopol (11.2 mg/dL), however, no difference ($P = 0.60$) in MUN was observed between bronopol and BSM at Laboratory B. In experiment 4, milk samples contained 0 to 0.30 g of bronopol and ranged in MUN concentration from 7.7 to 11.9 ± 0.27 mg/dL on Foss 4000 and from 9.0 to 9.3 ±

0.05 mg/dL on CL10, respectively. In summary, MUN concentrations vary depending on preservative and analytical procedures used and it is important to maintain consistency in milk sample preservation and analysis in order to ensure precision and accuracy of MUN results.

Introduction

There are many ways to monitor N levels in dairy cattle including BUN, urinary urea-N, and MUN. Milk urea-N is the most practiced analysis that dairy producers utilize due to ease of sample collection (Roy et al., 2011). Milk urea-N is used to monitor dietary CP and N utilization in lactating cows and is linearly correlated with urinary N (Broderick and Clayton, 1997; Hof et al., 1997; Kauffman and St-Pierre, 2001; Burgos et al., 2007). High MUN levels can indicate excess feeding of CP, which can have negative effects including increased energy requirements, increased purchased feed costs, excess N excretion in manure, and excess NH_3 emissions into the environment (Broderick and Clayton, 1997; Jonker et al., 2002b; Burgos et al., 2007). Milk urea-N of bulk tank milk is a more reliable value than MUN of individual cows to evaluate surplus N available for MPS in the rumen (Hof et al., 1997). Jonker et al. (2002a) concluded that when farms were regularly provided MUN results, MUN decreased 0.52 mg/dL over the course of the study, which resulted from 11 g/d decrease in N intake. There are multiple methods and equipment to analyze for MUN, which can cause varying results (Arunvipas et al., 2003; Kohn et al., 2004). This discrepancy can cause confusion on how MUN for a particular farm ranks relative to optimum MUN values of 10 to 12 mg/dL (Powell et al., 2014). The objective of the following experiments was to investigate differences in MUN results from multiple laboratories in Pennsylvania. The hypothesis tested in the first experiment was that identical milk samples sent to three laboratories would differ and Laboratory A would report higher MUN than Laboratories B and C. The hypothesis for experiment 2 was that the difference between analyzed and expected

MUN would be smallest for Laboratory A compared to Laboratories B and C for milk samples spiked with urea. The hypothesis for experiment 3 was that both milk preserved with bronopol and BSM would result in higher MUN than the control without preservative. Finally, the hypothesis for experiment 4 was that MUN would increase linearly with increasing amounts of bronopol added to milk, regardless of type of equipment used to analyze MUN.

Materials and Methods

Experiment 1. Milk samples were collected from The Pennsylvania State University's Dairy Center bulk tank over five consecutive days. After five min of continuous agitation, 6, 35-mL milk samples were taken at 2:00 p.m. daily. Two samples from each day were shipped to three milk processing laboratories (Laboratory A, Laboratory B, and Laboratory C) to be analyzed for MUN. Milk samples were analyzed using infrared spectroscopy at Laboratory A (MilkoScan 4000; Foss Electric, Hillerød, Denmark[6]), at Laboratory B using MilkoScan FT+ 600 (Foss North America Inc., Eden Prairie, MN[7]), and at Laboratory C using Milkoscan 6000 (Foss North America Inc., Eden Prairie, MN[6]). Milk samples sent to Laboratory A and Laboratory B were preserved with bronopol (Janssen Pharmacauticalaan, Beerse, Belgium). Milk samples sent to Laboratory C were shipped refrigerated and without preservative due to the inability of Laboratory C's equipment to analyze milk preserved bronopol.

Experiment 2. Two liters of milk were collected from The Pennsylvania State University's Dairy Center bulk tank at 2:00 p.m. on a single day after five min of continuous agitation. The two liters of milk was divided into four, 500-mL samples. Samples were spiked with urea at 0, 17.2, 34.2, and 51.5 mg urea/dL of milk. The projected MUN concentration for each urea level was 8.0, 12.0, 16.0, 20.0 mg/dL, respectively. Two, 35-mL samples from each

[6] Details at http://www.foss.us/industry-solution/products/milkoscan-ft1, accessed October 30, 2014
[7] Details at: http://www.foss.us/industry-solution/products/milkoscan-ft-plus, accessed October 30, 2014

urea level were sent to the three laboratories and preserved and analyzed according to methods listed in experiment 1. Based on the urea level and MUN of the control samples from each laboratory, expected MUN was calculated for each Laboratory at each urea level.

Experiment 3. Five hundred mL of milk was collected from The Pennsylvania State University's Dairy Center bulk tank according to procedures listed in experiment 2. Three milk vials were prepared as control (without preservative), five with liquid bronopol (Janssen Pharmacauticalaan, Beerse, Belgium), and five with BSM (Advanced Instruments, Inc., Norwood, MA). Thirty-five mL of milk was added to each milk vial. Three samples of each the control, milk preserved with bronopol, and milk preserved with BSM were sent to Laboratory A and analyzed using methods in experiment 1. Two samples of milk preserved with bronopol and milk preserved with BSM were shipped to Laboratory B and analyzed using the methods listed in experiment 1. Laboratory B did not receive control vials because the samples were not refrigerated during shipment.

Experiment 4. Forty-eight milk vials were prepared with 0 to 0.30 g of liquid bronopol (Janssen Pharmacauticalaan, Beerse, Belgium), increasing at 0.02 g increments. Each bronopol level was replicated three times. Two liters of milk were collected from The Pennsylvania State University's Dairy Center bulk tank by the same procedure listed in experiment 2. Thirty-five mL of milk was added to each milk vial. All milk vials were sent to Laboratory A for both a standard analysis using infrared spectroscopy on a MilkoScan 4000 (Foss Electric, Hillerød, Denmark; details at http://www.foss.us/industry-solution/products/milkoscan-ft1) and for supplemental analysis on a CL10 (EuroChem, Moscow, Russia) according to procedures outline by Luzzana and Giardino (1999).

Statistical Analysis

Data in experiment 1 were analyzed as repeated measures assuming an AR(1) covariance structure using PROC GLM of SAS (SAS Institute, 2003; SAS Inst. Inc., Cary, NC). Class variables were Day and Lab and the model included Day, Lab, and Day × Lab interaction. The error term was assumed to be normally distributed with mean = 0 and constant variance. Milk urea-N data were analyzed using the following model:

```
proc glm data = MUNExp1;
        class Day Lab;
        model MUN = Day Lab Day*Lab;
        repeated Day;
        lsmeans Lab / diff;
```

Data in experiment 2 and were analyzed using PROC MIXED of SAS. Class variables were Lab, MUN type (expected or analyzed), and Urea level and the model included Lab, MUN type, Urea level, MUN type × Urea Level interaction, and MUN type × Lab interaction. The error term was assumed to be normally distributed with mean = 0 and constant variance. Milk urea-N data were analyzed using the following model:

```
proc mixed data = MUNExp2;
        class Lab MUNtype UreaLevel;
        model MUN = Lab MUNtype UreaLevel MUNtype*UreaLevel MUNtype*Lab;
        lsmeans Lab MUNtype UreaLevel MUNtype*UreaLevel MUNtype*Lab / diff;
```

Data in experiment 3 were analyzed using PROC GLM of SAS. Class variables were Lab and Preservative and the model included Lab, Preservative, and Lab × Preservative interaction. The error term was assumed to be normally distributed with mean = 0 and constant variance.

Milk urea-N data were analyzed using the following model:

```
proc glm data = MUNExp3;
        class Lab Preservative;
        model MUN = Lab Preservative Lab*Preservative;
        random Lab;
        lsmeans Preservative / diff;
```

Data in experiment 4 and were analyzed using PROC MIXED of SAS. Class variable was Bronopol level and the model included Bronopol level. The error term was assumed to be normally distributed with mean = 0 and constant variance. Data were analyzed to evaluate the effect of bronopol level on MUN using the following model:

```
proc mixed data = MUNexp4;
        class BronopolLevel;
        model MUN = BronopolLevel;
        lsmeans BronopolLevel / diff;
        ods output LSMeans=lsmeans;
        contrast 'linear' BronopolLevel -15 -13 -11 -9 -7 -5 -3 -1 1 3 5 7 9 11 13 15;
        contrast 'quadratic' BronopolLevel 7 5 3 1 -1 -3 -5 -7 -7 -5 -3 -1 1 3 5 7;
```

When the main effect of treatment was significant, means were separated by pairwise t-test (diff option of PROC MIXED). Significant differences were declared at $P \leq 0.05$ and a trend toward significance at $0.05 < P \leq 0.10$. Means are presented as least squares means.

Results

Experiment 1. Average MUN for Laboratory A, B, and C were 14.9 ± 0.40, 6.5 ± 0.17, and 7.4 ± 0.36 mg/dL, respectively (Figure 4-1). Average MUN concentration analyzed at Laboratory A was higher than Laboratory B ($P < 0.001$) and Laboratory C ($P < 0.001$). In addition, average MUN concentration at Laboratory C was higher ($P = 0.05$) than Laboratory B. There was no effect of day sampled ($P = 0.82$) or day × lab interaction ($P = 0.23$).

Experiment 2. The difference between the analyzed and expected MUN was measured for each laboratory (Figure 4-2). Expected MUN (calculated from amount of urea added and MUN of the control samples from each laboratory) was lower than analyzed MUN for Laboratory A (21.0 vs. 23.2 mg/dL; $P = 0.001$), Laboratory B (13.3 vs. 18.0 mg/dL; $P < 0.001$), and Laboratory C (15.2 vs. 20.6 mg/dL; $P < 0.001$). Average difference between expected MUN and analyzed MUN were 2.2, 4.6, and 5.4 mg/dL for Laboratory A, B, and C, respectively.

Experiment 3. The effect of laboratory × preservative interaction ($P < 0.001$) was significant; therefore results from Laboratory A (Figure 4-3) and Laboratory B (Figure 4-4) are presented in separate figures. At Laboratory A, milk preserved with bronopol resulted in higher MUN than the control (11.2 vs. 9.2 mg/dL; $P < 0.001$) and higher than milk preserved with BSM (11.2 vs. 9.7 mg/dL; $P < 0.001$). Additionally, milk preserved with BSM resulted in higher ($P = 0.003$) MUN than the control as analyzed at Laboratory A. At Laboratory B, no difference ($P = 0.60$) was observed between preservatives.

Experiment 4. Results of MUN analysis for differing levels of bronopol are shown in Figure 4-5. Those sent for analysis on the Milkoscan 4000 ranged from 7.7 to 11.9 ± 0.27 mg/dL and linearly increased ($P < 0.001$) with no quadratic effect ($P = 0.19$). Those analyzed on the CL10 ranged from 9.0 to 9.3 ± 0.05 mg/dL and showed a linear trend ($P = 0.06$) with no quadratic effect ($P = 0.22$).

Discussion

As part of the on-farm study discussed in Chapter 3, MUN concentration data from the bulk tank milk samples collected on-farm were almost double that of the producers' milk cooperatives. Although previous studies reported that MUN concentrations differ between laboratories due to variation in analytical procedures (Arunvipas et al., 2003; Kohn et al., 2004), we made an effort to assess the difference in MUN concentrations between three laboratories in Pennsylvania. The objectives of this study were to achieve a baseline for MUN concentration at each laboratory, test accuracy with milk samples at differing levels of added urea, compare two preservatives (bronopol and BSM), and test effects of increasing levels of bronopol on MUN concentrations.

Experiment 1. The concept of this experiment was to establish a baseline MUN for three Pennsylvania laboratories. In a study using bulk tank milk, Kohl et al. (2004) concluded that 33.8% of the variation in MUN concentration for Foss 4000 was attributed to laboratory. Additionally, milk samples analyzed on Foss 4000 resulted in the largest standard deviation (± 2.51 mg/dL) from the CL10 when compared to samples analyzed on Bentley (± 0.45 mg/dL), Foss 6000 (± 0.62 mg/dL), and Skalar (± 0.55 mg/dL) (Kohl et al., 2004). Peterson et al. (2004) also concluded that the highest variation among methods occurred with the Foss 4000 and the lowest variation with CL10. In the present study, average MUN concentrations differed ($P <$ 0.001 to $P = 0$ 0.05) between Laboratories A (Foss Milkoscan 4000), B (Foss Milkocan FT + 6000), and C (Foss Milkoscan 6000), most likely due to variation in analytical procedure and equipment (Arunvipas et al., 2003; Kohn et al., 2004). The Foss Milkoscan FT + 6000 is a newer, more improved model than the Foss Milkoscan machines. Milk urea-N has been an accepted benchmark of 10 to 12 mg/dL (Powell et al., 2014), and results from the present study indicate Laboratory A is above the benchmark and Laboratories B and C are below the benchmark for

identical milk samples. Even with such a large difference between laboratories, laboratory and analytical procedures are not considered variables that affect MUN like other factors including dietary CP, milk production, and BW (Broderick and Clayton, 1997; Jonker et al., 1999; Jonker et al., 2002a).

Experiment 2. Based on the MUN concentration of the control (without urea) for each laboratory, MUN was calculated for each urea level (0, 17.2, 34.2, and 51.5 mg urea/dL of milk). A study by Peterson et al. (2004) compared recovery of urea-N among five analytical methods: Bentley, CL10, Foss 4000, Foss 6000, and Skalar using milk samples from 100 individual cows. Each milk sample was divided into two (control or treated with 4 mg/dL of urea) and sent to 14 independent laboratories. Recovery fraction was calculated and reported as a percent recovery ([treated MUN mg/dL – control MUN mg/dL] ÷ 4 mg/dL). Bentley (92.1 ± 2.76%), Foss 6000 (95.4 ± 10.1%), and Skalar (95.1 ± 7.61%) were not different ($P > 0.10$) in recovery of urea-N. Recovery by CL10 (85.0 ± 2.76%) was lower ($P < 0.05$) than the Bentley, Foss 6000, and Skalar, but higher ($P < 0.05$) than the Foss 4000 (47.1 ± 9.88%). Furthermore, no differences ($P > 0.05$) were detected for the Bentley and CL10 between laboratories, however, the Foss 4000 ($P < 0.001$), Foss 6000 ($P < 0.001$), and Skalar ($P < 0.001$) varied among laboratories. In the present study, all three laboratories overestimated MUN compared to what was calculated based on the MUN of each control. Although the average difference between expected and analyzed MUN were all significantly different, Laboratory A numerically had the least difference compared to Laboratories B and C.

Experiment 3. Efforts were made to look into how preservative type effects MUN. Liquid bronopol and BSM are the milk preservatives most widely used for on-farm sampling. Godden et al. (2000) also observed that milk samples preserved with a bronopol tablet (2-bromo-2-nitro-pro- pane-1,3 diol: 6 mg/tablet: D & F Control, San Ramone, CA) resulted in higher MUN concentration than unpreserved milk (mean difference 1.6 ± 0.65 mg/dL; $P < 0.05$) as

analyzed on a Foss 4000; however, this study concluded that the difference in MUN was numerically not a cause for concern. In the present study, milk samples analyzed at Laboratory A differed ($P < 0.01$) in MUN concentrations and tested highest to lowest for bronopol, BSM, and the control, respectively. At Laboratory B, although BSM resulted in numerically higher MUN than bronopol, no difference ($P = 0.60$) was detected, however, there was no data on how the preserved samples measure relative to a control for Laboratory B. Bronopol (2-bromo-2-nitro-1, 3-propanediol; $C_3H_6NO_4Br$) and BSM (8 mg bronopol [$C_3H_6NO_4Br$] plus 0.30 mg Natamycin [$C_{33}H_{47}NO_{13}$]) both contain bronopol, which interferes with the light wavelengths in infrared spectrometry and both contain N components that could contribute to increased MUN concentration when added to milk; this hypothesis is discussed further using bronopol in experiment 4.

Experiment 4. We hypothesized that higher MUN is detected at ≥ 0.12 g bronopol per 35 mL milk sample. Milk samples were analyzed on both the Milkoscan 4000 and CL10. Milkoscan 4000 uses infrared spectroscopy, in which a beam of light at specified wavelength for the component being measured is passed through milk and the amount of light absorbed is measured; bronopol can interfere with the measurement of light absorbed using this method (Arunvipas et al., 2003). On the CL10, the amount of NH_3 formed from urea after urease is added is used to calculate MUN (Arunvipas et al., 2003; Kohn et al., 2004). Previous studies indicate greater variability with Foss 4000 compared to the CL10 for multiple laboratories (Kohn et al., 2004; Peterson et al., 2004). Conversely, Arunvipas et al. (2003), reported high reliability and repeatability for both Foss 4000 and CL10 when analyzed at a single laboratory. In the present experiment, although measurements on the CL10 were more precise, most levels of bronopol tested were still different ($P < 0.05$) than the control (without bronopol). The use of the CL10 is widely accepted as the most accurate measurement of MUN; however, due to cost and additional labor needed to analyze samples, it is not practical for commercial use of milk analysis

(Arunvipas et al., 2003). In the present study, results from 19 milk vials indicated that the average bronopol added to milk vials was 0.21 ± 0.003 g (data not shown). The addition of 0.20 g of bronopol to 35 mL of milk resulted in higher ($P < 0.001$) MUN than the control (11.2 vs. 8.5 mg/dL, respectively). In this experiment, bronopol contributed 7.9% of the total N in milk for the 0.21g bronopol per 35 mL milk sample when milk protein was 3.01% and MUN (in control) was 8.5 mg/dL. Therefore, bronopol used to preserve milk samples in Chapter 3 may have contributed to high MUN concentrations.

In research, the difference in MUN concentration between treatments is usually the measure of interest rather than the actual MUN concentration itself. However, MUN is also widely used on-farm as an indicator of dietary CP levels and N utilization (Broderick and Clayton, 1997; Hof et al., 1997; Kauffman and St-Pierre, 2001; Jonker et al., 2002a). On-farm, MUN is often compared to a benchmark, however, that benchmark may need to be adjusted depending on the laboratory methods and preservative used. Consistently using the same laboratory and sampling procedure is an appropriate method to monitor changes observed in MUN concentrations.

Conclusion

Milk urea-N concentrations vary depending on analytical procedures, laboratory, and equipment used to measure MUN. Type of preservative (bronopol or BSM) and amount of bronopol used to preserve milk samples can alter MUN concentration. It is important to maintain consistency in methods of milk sample preparation and analysis in order to ensure precision and accuracy of results. Establishing a threshold relative to the laboratory used maybe helpful to for on-farm management purposes.

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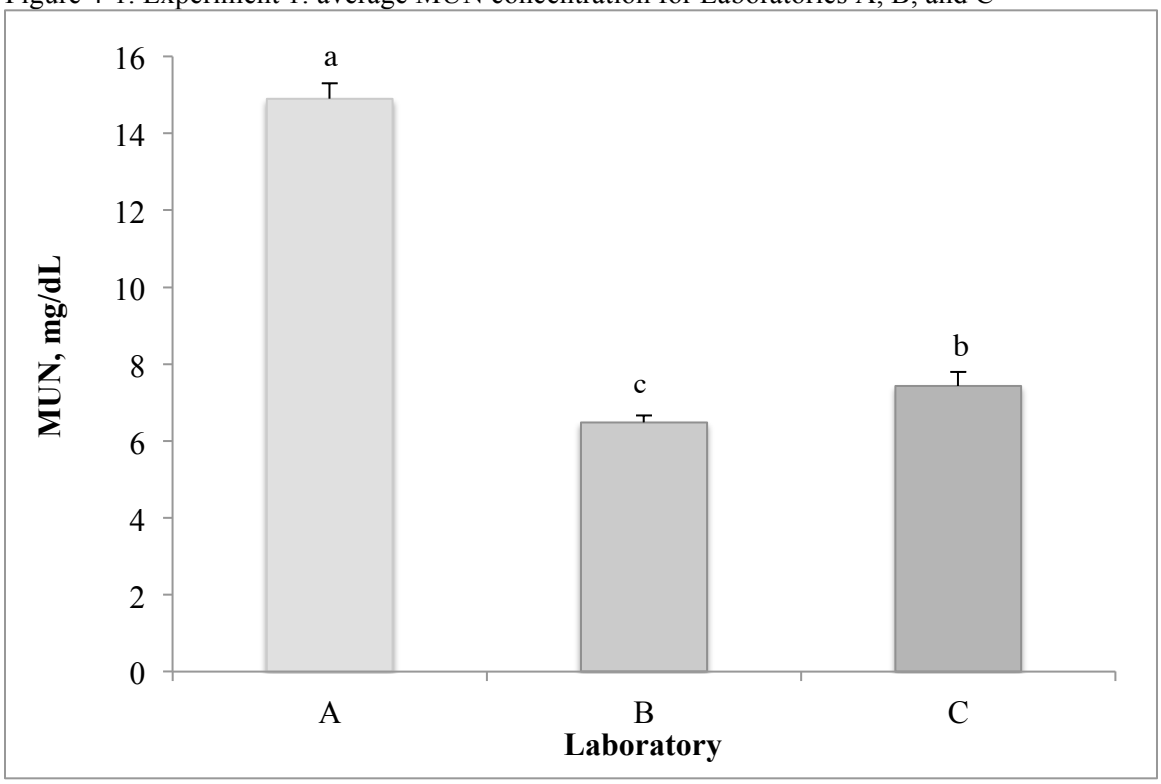
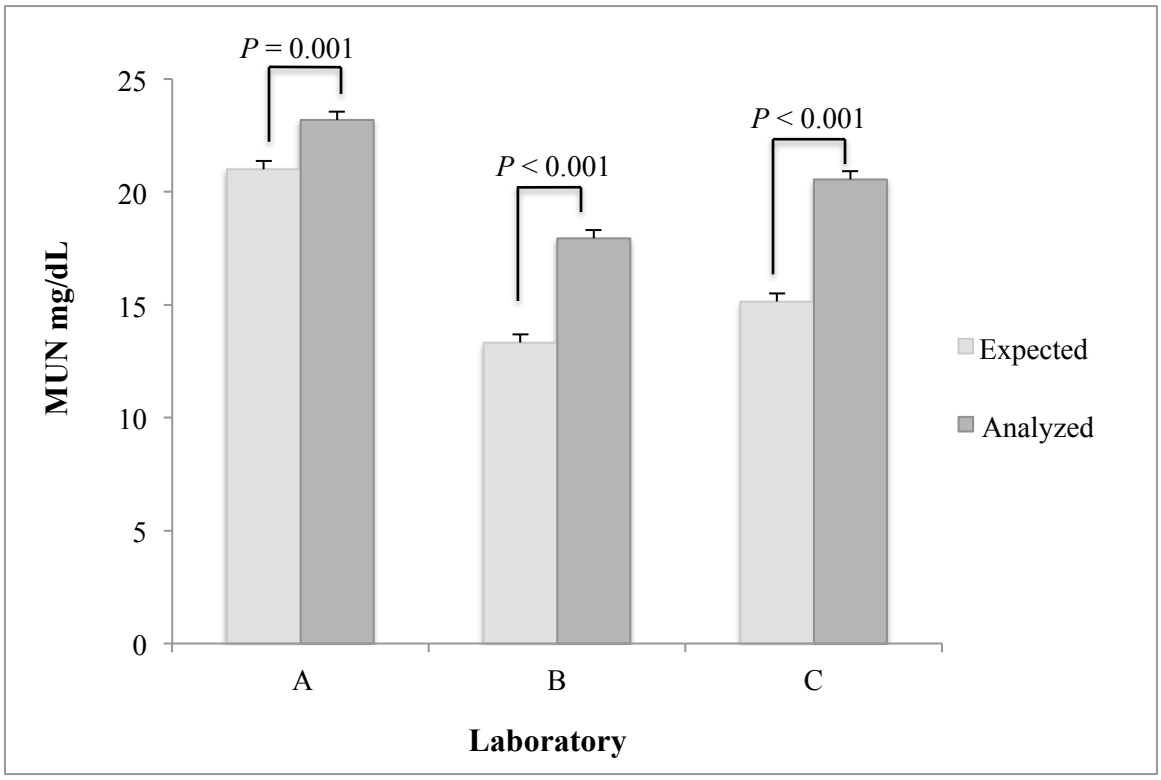
Figure 4-1. Experiment 1: average MUN concentration for Laboratories A, B, and C



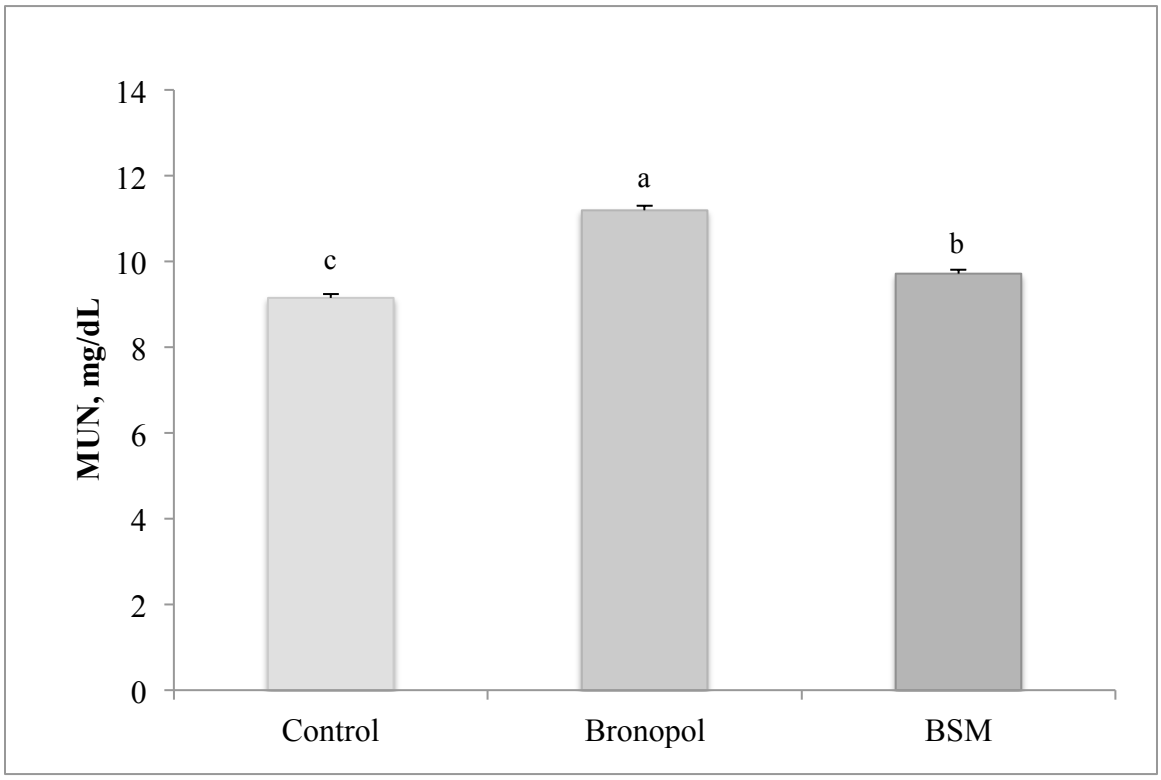
Means labeled with different letters (a, b, and c) differ at $P < 0.05$; bars represent SE.

Figure 4-2. Experiment 2: average expected and analyzed MUN concentrations of milk with added urea for Laboratories A, B, and C.



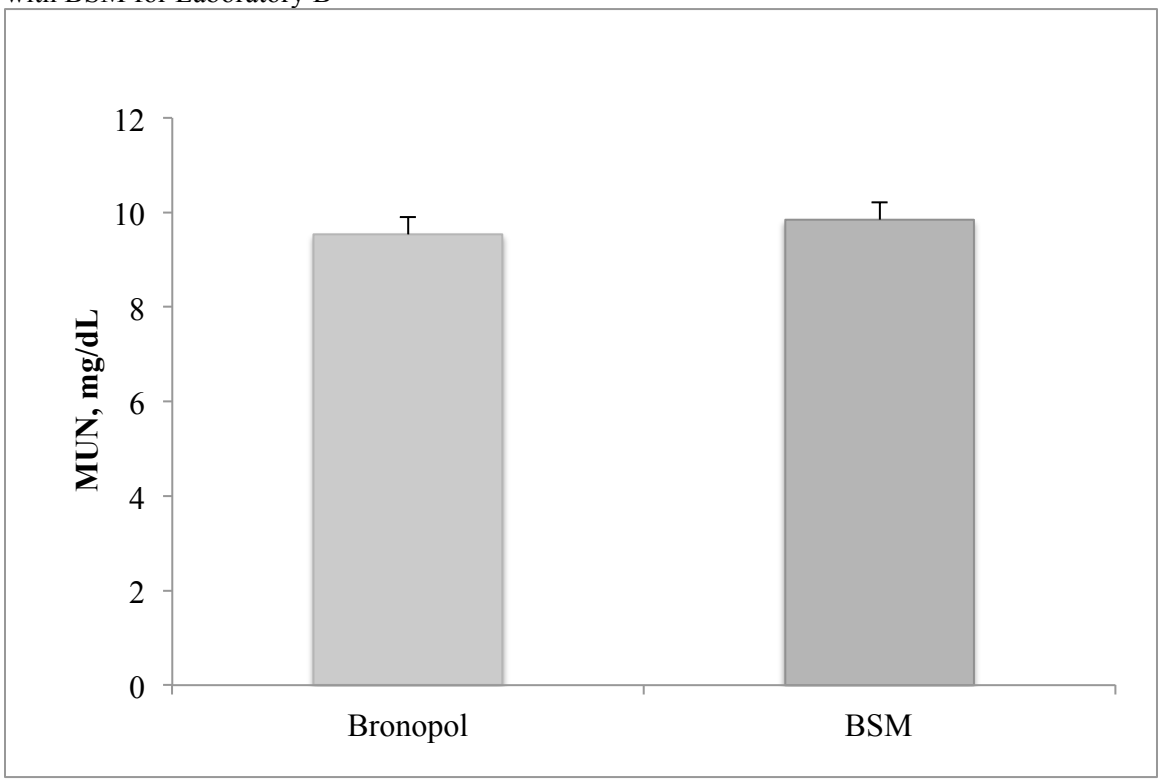
Means of expected (calculated from amount of urea added and MUN of the control samples from each laboratory) and analyzed MUN concentrations for Laboratories A, B, and C. *P*-values represent difference between average expected and analyzed MUN concentrations for each Laboratory (A, B, and C); bars represent SE.

Figure 4-3. Experiment 3: average MUN of control, milk preserved with bronopol, and milk preserved with BSM for Laboratory A



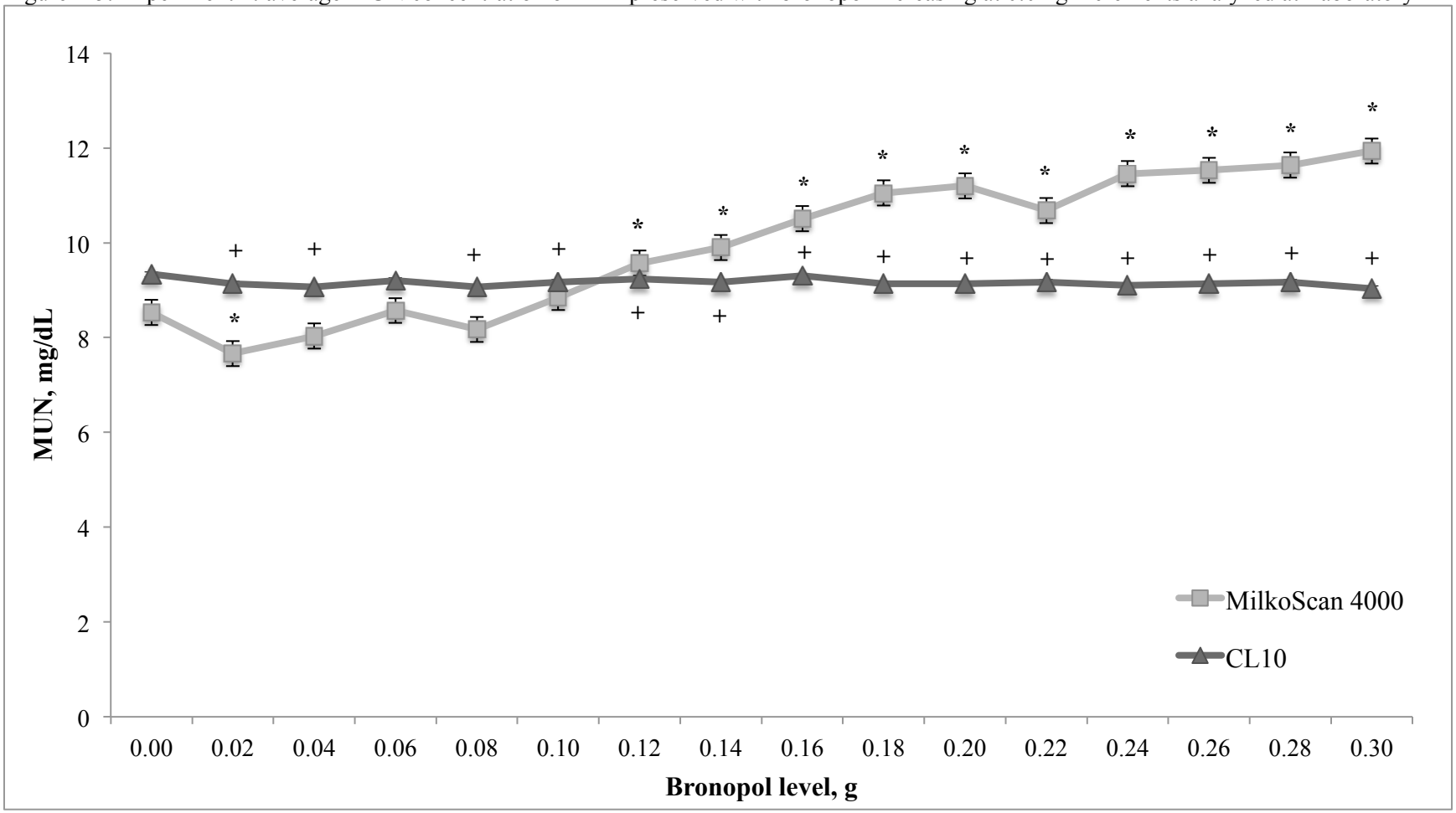
Means labeled with different letters (a, b, and c) differ at $P < 0.01$ when analyzed on MilkoScan 4000; bars represent SE.

Figure 4-4. Experiment 3: average MUN of milk preserved with bronopol and milk preserved with BSM for Laboratory B



No difference was detected ($P = 0.60$) between milk preserved with bronopol and milk preserved with BSM for Laboratory B when analyzed on Milkoscan FT+ 600; bars represent SE.

Figure 4-5. Experiment 4: average MUN concentration of milk preserved with bronopol increasing at 0.02 g increments analyzed at Laboratory A



*Indicates significant difference ($P < 0.05$) between control (0 g bronopol) and specified level of bronopol when analyzed on MilkoScan 4000. +Indicates significant difference ($P < 0.05$) between control (0 g bronopol) and specified level of bronopol when analyzed on CL10. Error bars represent SE; where not visible, error bars fall within symbols.

Appendix

Table 0-1. List of forage quality BMP presented to participating producers

Feed Management BMP	Inputs and Required Information	Process Changes (Cost and Benefits, On-farm Impacts)
Maximize home-grown or locally-sourced feeds in the rations	• Locally purchased or homegrown	• Save on feed costs • Carbon footprint (transportation costs) • Farm profitability (IOFC and others)
Maximize quality (protein, fiber digestibility, starch) of home-grown forages	• Forage analysis • DM, starch, 30 h NDF digestibility • Timeliness of harvest; maturity of crop • Weather • Laboratory	• DMI • Milk yield • Milk components • Farm profitability (IOFC and others)
Harvest, store, and follow BMP forages (silages, haylage, hay) to maximize digestibility (quick filling, tight packing, cover, silage additive)	• Laboratory • Facilities • Packing density • Quickness of harvest and storage • Total digestible nutrients, forage analyses, 30 h NDF digestibility • Cost of inoculants	• Milk yield • $ lost in waste (mold, aerobic fermentation) • Digestibility, increased milk yield, farm profitability (IOFC and others) • Carbon footprint
Minimize silage feed-out losses (remove 6 in/d or greater for corn silage)	• Equipment, • Cost • Laboratory	• Loss in shrink due to aerobic fermentation • Digestibility, increased milk yield, farm profitability (IOFC and others) • Carbon footprint
Store different quality forages separately to match forage nutrients with nutrient requirements	• Cost of building and maintaining facilities	• On paper compared to what cows actually receive • Rumen health • Digestibility, milk production, farm profitability (IOFC and others)

Use kernel processor for corn silage	• Fuel for chopper • Routinely sharpening and adjusting rollers • Increased starch digestibility	• Digestibility • Milk yield • Milk fat • Farm profitability (IOFC and others)
Regularly analyze and monitor silages for pH and fermentation profile, fiber digestibility	• Cost of sample analyses • pH • Acids produced during fermentation • Variability in DM of silage • 30 h NDF digestibility	• Reformulating ration • DMI • Milk yield and components • Rumen health

Table 0-2. List of feed analysis BMP presented to participating producers

Feed Management BMP	Inputs and Required Information	Process Changes (Cost and Benefits, On-farm Impacts)
Regularly analyze forages for nutrients, specifically protein fractions and major minerals (P & K)	• CP • Soluble Protein • Ca • P • K • 30 h NDF digestibility • Laboratory	• Cost of NIR or wet chemistry test • Environmental effect; excess P and N in manure and urine • Cost of supplements to make up for any mineral deficiencies • Farm profitability (IOFC and others)
Regularly analyze rations for nutrient composition	• CP • NFC, starch • NDF • ADF • 30 h NDF digestibility • Laboratory	• Cost of wet chemistry test • If overfeeding compared to requirements; possible lowered feed costs with correct adjustment • If underfeeding compared to requirements; lowered production and components • Milk yield, farm profitability (IOFC and others) • Carbon footprint
Regularly monitor moisture of silages and correct diet formulations	• Cost of Koster tester or microwave • Laboratory • DM% of silage • Ration costs	• Adjusting DM% of ration to ensure correct DM to AF conversion when mixing. • DMI • Milk yield and components • Farm profitability (IOFC and others)

Table 0-3. List of diet formulation BMP presented to participating producers

Feed Management BMP	Inputs and Required Information	Process Changes (Cost and Benefits, On-farm Impacts)
Group feeding of animals: formulate multiple rations to meet requirements of high and low-producers, dry, transition cows	• Formulating rations specifically for factor like DIM, pregnancy, production, etc. • Limited by facilities • Laboratory • Equipment	• Feed cost savings due to cow specific as nutrient requirements change. • Transition cows; reducing health problems (milk fever, ketosis, RP, etc.) that can delay or reduce peak production. • Milk yield, farm profitability (IOFC and others), animal health and productive life.
Regularly monitor DMI	• Laboratory: feeder recording weights or using TMR tracker or Feed Watch • DM% of ration • Amount fed • No. cows fed • Changes due to temperature and weather • Refusals	• Adjust rations for actual intake as it changes • Cost of overfeeding nutrients & potential environmental effect of excesses nutrients in manure • Production lost in underfeeding nutrients • Milk yield, farm profitability (IOFC and others)
Restrict energy input to about 15% over average group requirements	• NE_L requirement of lactating dairy cow • NE_L of TMR • TDN of feeds • 30 h NDF digestibility	• Cost of overfeeding energy & potential environmental effect of excesses nutrients in manure • Production lost in underfeeding energy & health issues • Milk yield, farm profitability (IOFC and others)
Formulate diets to meet or slightly exceed MP requirements (< 110%)	• MP requirement of lactating dairy cow • CP, RUP, RDP, MP of TMR	• Cost of in overfeeding protein (most expensive nutrient) & potential environmental effect of excess N in manure and urine – NH_3 and N_2O emissions, N leaching • Production lost in underfeeding protein • Milk yield, farm profitability (IOFC and others)

Monitor CP, soluble protein, RDP, and RUP of the diets	• Requirements of soluble protein, CP, RDP, & RUP • Soluble protein, CP, RUP, & RDP of TMR • Laboratory	• Cost of overfeeding protein (most expensive nutrient) & potential environmental effect of excess N in manure • Production lost in underfeeding protein • Milk yield, farm profitability (IOFC and others)
Formulate diets for limiting AA	• Essential AA requirements of lactating dairy cow (Lys and Met) • Laboratory • Feed cost	• Production lost because of a limiting AA • Milk yield, milk fat and protein • ADG of heifers • Farm profitability (IOFC and others) • Carbon footprint
Formulate diets to meet but not exceed P requirements (0.36 to 0.38% TMR DM)	• P requirement of a lactating dairy cow • P content of TMR • P content of soil test • P content of feeds/forages • Laboratory	• Save on P supplements in the ration • Environment effect; manure spreading on soil • Efficiency of absorption of P decreased as intake increased • P content of TMR • Farm profitability (IOFC and others)
Regularly monitor and reformulate diets, if forage quality changes (DM, protein fractions, fiber, energy, starch, P)	• DM, protein, NDF, ADF, energy starch, digestibility • NIR tests of forages; laboratory fee • DM tests of forages; laboratory	• Cost of overfeeding nutrients & potential environmental effect of excesses nutrients in manure • Production lost in underfeeding nutrients and inconstant ration • Milk yield, farm profitability (IOFC and others)
Formulate for dietary cation/anion difference	• Weekly monitoring urine pH; laboratory • Separating close ups; facility limitation • K, Na, Cl, S in the diet	• Adjusting anionic salts as needed • Urine pH too high > 6.8; milk fever, ketosis • Urine pH too acidic < 6.2; waster $ in supplementing too much anionic salts, makes cows more vulnerable to heat stress • Milk production, Farm profitability (IOFC and others)

Feed ionophores	• Cost of ionophores • Effect to milk production, milk composition (fat test), and DMI • Laboratory	• Feed efficiency (maintain or increase in milk production and decrease in feed cost, and increased in ADG of heifers) • Possible drop in milk fat • Animal health: prevention and control of coccidiossis, prevention of ketosis and acidosis • Possible decrease in CH_4 production; carbon footprint • Milk production, Farm profitability (IOFC and others)
Feed DFM (yeast culture)	• Cost of yeast culture • Effect to milk yield, milk composition, DMI • Laboratory	• Feed efficiency • Milk yield • Improve nutrient utilization • Stabilization of rumen pH • Animal health • Farm profitability (IOFC and others)
Feed supplemental lipids (total lipids < 6 to 7% of dietary DM)	• Cost of supplemental lipids • Effect to milk production • Feed efficiency • Laboratory	• Overfeeding: reduced DMI (palatability), possible decrease in milk protein and milk fat • Possible increase in milk production • Better repro performance
Feed concentrate to forage diets to increase FE	• Feed costs • Laboratory	• DMI; reducing fill • Milk production and components
Process grain to maximize digestion	• Cost of processing • Constancy of product • Digestibility • Starch availability and digestibility • Milk yield and composition (fat) • Laboratory	• Milk production and components

Table 0-4. List of feed management BMP presented to participating producers

Feed Management BMP	Inputs and Required Information	Process Changes (Cost and Benefits, On-farm Impacts)
Monitor feed efficiency (i.e., milk yield /feed DMI; should >1.50)	• Pounds of milk produced per lb. of DM • DMI, milk yield, milk composition • Laboratory	• Increasing feed efficiency increased IOFC • Milk yield
Monitor N efficiency (i.e. milk protein N/ feed N intake; should be > 0.27)	• Protein of ration • NPN • MPN • MUN • Milk yield and composition • Laboratory	• Environment; Excess N coming out in manure and urine (water contaminant) • Air pollution- NH_3, N_2O • As milk production increases, excretion of N in feces and urine decreases • As protein inputs increase, excretion of N in feces and urine increases • Milk production, farm profitability (IOFC and others)
Control total mixed rations (TMR) for ingredient mixing accuracy, consistency of mixing	• Particle size analysis • Mixing time • Laboratory; constancy • Feed equipment; accuracy of mixer scale	• Milk production • Rumen health • Milk fat and protein • Farm profitability (IOFC and others)
Regularly monitor and adjust ration particle size (using PSPS)	• Initial cost of PSPS • Laboratory: five min per sample or done by the nutritionist • Results indicate: mixer wagon knife maintenance needed and/or adjusting length of chop needed and/or ration adjustment is needed; time of mixing	• Animal Health • Too fine: Possible health issues including; fat cow syndrome, abomasal ulcers, rumen parakeratosis, DA, cortical necrosis, laminitis, ketosis, milk fat depression. (Sudweeks et al., 1981) • Too course: reduced intake; fill • Milk production, farm profitability (IOFC and others)
If component feeding, consider feeding TMR	• Cost of mixer wagon, fuel • Storage location, cost of custom harvest or purchasing equipment • Laboratory	• Constancy of ration • Rumen health – better nutrient utilization • Animal health • Milk yield • Milk components • Farm profitability (IOFC and others)

Keep refusal in lactating rations to a minimum	• Actual amount fed and amount of orts • Laboratory • Feed costs • Milk production	• Money wasted in excess refusals • Old TMR either recycled in dry cow or heifer rations or spread on fields with manure (environment) • Milk production, farm profitability (IOFC and others)
Have TMR preparation SOP	• Laboratory • Mixing equipment	• Consistency of ration; particle size, completely mixed • Milk production and components • Rumen health • Farm profitability (IOFC and others)
Regularly check feed mixer scale, knives	• Laboratory • Cost of maintenance • Particle size analysis • Milk fat test • DMI, milk production	• Particle size; sorting and waste in refusals • DMI • Milk production and composition • Farm profitability (IOFC and others)
Clean water bowls at least weekly	• Laboratory • Animal health	• Water intake: DMI • Animal health • Milk yield • Farm profitability (IOFC and others)
Clean feed bunks regularly (at least 3X/wk)	• Laboratory • Feed cost • Rumen and animal health	• If not cleaned; molded, smelly, hot feed (reduced DMI and production) • Fresh feed encouraged DMI • Cost of excess refusals • Milk yield, farm profitability (IOFC and others)
Monitor water quality (TDS, coliforms, minerals)	• Water test cost • Laboratory	• Water intake: DMI • Milk production, farm profitability (IOFC and others)

Table 0-5. List of farm management BMP presented to participating producers

Feed Management BMP	Inputs and Required Information	Process Changes (Cost and Benefits, On-farm Impacts)
Monitor MUN and use correct dietary protein	• Cost of milk test or DHIA • Feed cost • Feed analysis • Laboratory (sample collection, reformulating, control)	• MUN is an indicator of protein fed • If overfeeding protein; cost of protein ingrediencts, environmental effects in manure and urine • Milk production, farm profitability (IFOC and others)
Monitor IOFC	• Total pounds of milk shipped per month • Feed costs • Laboratory	• Feed efficiency • Feed cost • Farm profitability (IOFC and others)
Strive to maximize cow health, reproduction, and productive life	• Repro: 21-day pregnancy rate, cost of days open, days to 1st service, • Cow health: transition cow problems, feet, udder health • PL: longevity, cost of replacements • Laboratory	• Vet bills • Reducing excess costs due to health problems; AI-semen, medicine, laboratory • Milk production (lifetime production), farm profitability (IOFC and others) • Cost of raising heifers • Carbon footprint • Water and air pollution
Use PCDART, DC305, or another cow record system	• Initial Cost of program • Cost of upkeep • Laboratory	• Monitor improvements over time; increased efficiency, reduced health issues, increased repro performance • Milk production, farm profitability (IOFC and others)
Monitor heifers for ADG (0.80 kg/d; 636 kg mature weight)	• ADG • Feed cost • Average age at 1st calving • Laboratory	• Feed efficiency; cost/unit of gain
Use rBST	• Cost of injection • Laboratory • Increased feed cost (feed intake)	• Increased milk yield • Farm profitability (IOFC and others)