Evaluating and improving the nutritional management of Canadian dairy farms

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ABSTRACT

EVALUATING AND IMPROVING THE NUTRITIONAL MANAGEMENT OF CANADIAN DAIRY FARMS

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In order to continue to advance nutritional management practices in Canada, more knowledge is needed regarding farm demographics, feeds utilized, and attitudes towards feeding practices. An online survey was sent to dairy producers. 230 responses were received from Ontario and Western Canada. They showed similar demographics to known numbers. Feeds more commonly grown within that region were used more often in diets. Farmers valued performance greatest when formulating rations. One potential way to improve nutritional management on farms is to feed a rumen-protected amino acid such as lysine to stop the reduction in milk resulting from feeding low protein diets. Lactating dairy cattle (n=12) were fed 15 or 17% dietary CP diets with or without lysine top-dressed. Lysine supplementation in low protein diets improved milk yields to a level similar to high protein diets, while decreasing N waste. The results reported here demonstrate potential routes for improvement on Canadian dairies.

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1 Overall Introduction

Within the Canadian dairy industry, feeds for cattle are the number one cost on farms in Ontario (Ontario Dairy Farm Accounting Project, 2017). Therefore, it is expected for dairy producers to treat the feed they feed to their cattle with the utmost importance. In spite of this importance, little is known within Canada the popularity of feedstuffs. Numbers regarding herd size, barn type and milk production can be found for farms across Canada (Statistics Canada, 2017; Valacta, 2018). However, knowledge into feeds used on Canadian dairy farms is relatively limited. This knowledge could be used to look for common potential bottlenecks on dairy farms and drawing attention to these. This data could also uncover some less commonly used feeds on diets, allowing further research to investigate their benefits and weaknesses.

Canada uses a supply management system which could lead to different producer motivations compared to other countries (Dairy Farmers of Canada, 2019). Whereas these countries may be more focused on cost, with each farm producing a quota in Canada, it is likely that other factors such as performance or health may be considered more important. Likewise, with the increasing interest into nutrient management to prevent N runoff and waste from polluting the environment, it could be demonstrated if producers themselves are actually being more interested in nutrient management (Van Amburgh et al., 2018).

Nitrogen waste is a result of the low N efficiency in dairy cattle, as large amounts of N waste is expelled by the cow in urine which is then released into the environment (Huhtanen and Hristov, 2009). To reduce the environmental impact of cattle waste, lower amounts of CP can be fed within the cattle's diet; however, the reason dairy producers feed high levels of CP within their diets is to maximize milk production. Alternatively, there have been studies that have shown that lower CP diets can have similar milk yields to high CP diets (Mutsvangwa et al., 2016). Lowering CP in diets also results in increased N efficiency (Broderick et al., 2008). The decreased milk production is likely the result of a low amount of a certain limiting essential amino acid (AA), such as Lys or Met. If not enough of a certain AA is available, it will stop further protein production and results in the remaining AA being expelled as waste in urine or feces. The addition of rumen-protected supplements of both Met and Lys together to 15% CP diets have shown similar results to unsupplemented 17% CP diets (Arriola Apelo et al., 2014). This shows that dairy cows can produce similar milk yields with greater N efficiency if these rumen-protected EAA supplements are fed, under some circumstances. With increasing interest in nutrient management and reducing N waste by the public, more research into this feeding strategy should be taken to determine its effectiveness.

The first part of this thesis will determine the type of rations fed in Canadian dairy farms and their reasons behind using these rations. The second part will focus on determining whether supplemental rumen-protected Lys can be used to improve the milk production of low CP diets effectively and its impact on N waste.

2 Literature Review

2.1 INTRODUCTION

Feed costs are a major expense to dairy cattle operations everywhere. In 2017, feed costs and crop expenses averaged 40% of expenses, and feed costs were the number one cost on Ontario dairy farms (Ontario Dairy Farm Accounting Project, 2017). Additionally, growing feed for animal production utilizes considerable land that could be used for other purposes, such as food for human consumption. Cattle do not convert human edible feed to animal products to 100% effectiveness, as they consume more feed for their own growth than they produce for human consumption, leading to a net loss in potential food for humans (Cassidy et al., 2003). However, ruminants can convert human inedible, low-cost feed products to animal products (Ertl et al., 2015). Therefore, there are considerable benefits to investigating these feeds, such as byproduct and coproduct feeds, compared to traditional feeds such as grain corn and soybean meal. Byproducts are left over materials from other processes such as cooking oil or citrus production, whereas coproducts are produced alongside a main product such as in biofuel production. These materials can potentially be fed to animals instead of being thrown away as most still have nutritional value for ruminants. Byproducts and coproducts often are higher in starch and lower in fiber compared to traditional feeds (Ertl et al., 2015), and they are often more variable in nutrient composition between different feed sources (Kleinschmit et al., 2006). These differences in composition can have an impact on the digestibility of the feed and may affect productivity if not carefully managed. If these cheaper byproducts lead to similar milk production when carefully substituted into the diet, this can lower costs and thus improve profits. There have been many studies evaluating a variety of byproducts and coproducts to test if they can be used effectively in the diets of dairy cattle without negative effects.

2.2 Distiller's Grains with Solubles (DGS)

A major coproduct used in dairy cattle rations is distiller's grains with solubles (DGS). DGS is a coproduct produced from ethanol production (Schingoethe et al., 2009). They are an excellent protein source (approximately 30% CP), with high amounts of ruminal undegradable protein (approximately 55% of CP). There are many different types of DGS, as they can be wet (WDGS) or dry (DDGS), high (HPDDGS) or low protein, or sourced from different types of grains, including corn and wheat. Production and utilization of DGS has increased with greater ethanol production, leading to more research into this feed. In their review, Schingoethe et al. (2009) concluded that DGS could effectively replace some of the grain in dairy cattle diets with minimal changes in milk production, as DGS is a good protein source that is high in NE_l and is digestible by dairy cattle. Dairy cows fed diets containing 10% to 20% of either WDGS or DDGS had similar milk yields to a control diet containing corn grain and soybean meal (Anderson et al., 2006). Cows fed diets with 10, 20, or 30% DDGS replacing corn and soybean meal demonstrated a slight increase in their milk production for all diets (Janicek et al., 2008). DDGS replacing barley silage in one diet and barley grain in another diet resulted in similar milk yields across all diets with little change in the rumen pH (Zhang et al., 2010). When DGS is produced, Maillard reactions from heating can result in differing digestibility, and this effect may vary within and between sources. To test if DDGS vary by source, cows were fed DDGS from different sources at 20% diet DM by replacing ground corn and soybean meal from a control diet (Kleinschmit et al., 2006). Milk production was similar for cows across all experimental diets, with milk production slightly increased versus the control diet. Wheat DDGS replacing canola meal and other protein sources at up to 20% of the diet had no detrimental effects to the rumen of the cow or on milk production (Chibisa et al., 2012). Three different diets with varying types of

DGS (wheat or corn DDGS alone or a combination of wheat and corn WDGS) replacing different ration components were compared to a control diet by Penner et al. (2009). They found that although the WDGS mix resulted in decreased rumination time, it could replace barley silage and not affect milk production, while corn and wheat DDGS could effectively replace canola and soybean meal with no detrimental effects on milk production. Replacing barley grain with wheat DDGS at 17% of the diet resulted in similar milk yields (Sun and Oba, 2014). Comparing HPDDGS (12% of diet DM) to soybean meal (12% of diet DM), canola meal (12% of diet), and conventional DDGS (21% of diet DM) resulted in similar milk production levels across the different diets (Christen et al., 2009). Similar levels of milk production were found in cows fed three different types of corn byproducts (DDGS, HPDDGS, and corn germ) fed at 15% of diet DM compared to milk yields of cows fed a control diet (Kelzer et al., 2009). When comparing wheat DDGS, HPDDGS, canola meal, and soybean meal, rumen degradability was lowest for HPDDGS and greatest for wheat DDGS (Maxin et al., 2013a). Feeding of these four protein sources resulted in similar milk production. There were some differences in blood amino acid profiles, as soybean meal was deficient in methionine and HPDDGS was deficient in lysine, with wheat DDGS having an insignificant deficiency in histidine and canola meal having no deficiencies (Maxin et al., 2013b). Mjoun et al. (2010) fed cows increasing amounts of reduced fat DDGS to replace corn and soybean meal and found there was no effect on milk production when DDGS were fed at levels up to 30% of diet DM. Comparing the reduced fat DDGS to regular DDGS resulted in similar milk yields. Cows fed wet brewer's grain at 16% DM in hot weather led to a slight increase in milk production over a control diet (Belibasakis and Tsirgogianni, 1994). Overall, the literature shows that DGS is an effective coproduct to be used in dairy rations. Across different amounts and types of DGS, research indicates that DGS can be used as an effective replacement for traditional feedstuffs up to 30% of the diet (Janicek et al., 2008). If this can be achieved with no change in milk production with cheaper costs than traditional feeds, then DGS are an effective and worthwhile feed to use in dairy cattle rations.

2.3 Soy Hulls

Another well-researched byproduct feed is soy hulls, a byproduct of soybean processing. Soy hulls are a feed with high NDF content so they have a lower digestibility than traditional grains such as corn (Ipharraguerre and Clark, 2003). The use of soy hulls as a replacement for traditional grains in dairy cattle diets was reviewed by Ipharraguerre and Clark (2003). They found in reviewing related research that soy hulls could replace up to 30% of the concentrate or 25% of the forage in cattle diets without affecting milk production by dairy cattle. Iphaarraguerre et al. (2002) fed soy hulls as a replacement to concentrate up to 40% of the diet. They found similar milk production feeding up to 30% soy hulls in the diet, but feeding the 40% soy hull diet resulted in a significant decrease in milk yields and dry matter intake. They also measured the ruminal effects on these cattle and found soy hulls to be less digestible in the rumen, likely due to their high NDF content. When soy hulls were fed as a replacement to forage in two different diets or as a replacement to concentrate in two different diets, similar intake and milk production was found in the four experimental diets when compared to the control (Sarwar et al. 1991). When wheat was replaced in the diet by soy hulls at varying levels, the best response was found when soy hulls replaced 33% of wheat in the diet (Aikman et al., 2006). Replacing grain corn with increasing amounts of a 50:50 mix of soy and cottonseed hulls at 5 and 10% of the TMR resulted in similar milk yields across different diets (Beckman and Weiss, 2005). Cows fed a reduced starch diet by replacing grain corn with soy hulls and exogenous amylase had similar milk production compared to feeding a control diet (Gencoglu et al., 2010). In an experiment where soy hulls were compared to corn silage in different diets, there was similar milk production between the two diets when oat hay was added to the soy hull diet to balance for equal NDF content across diets (Miron et al., 2003). Feeding cattle a diet with soy hulls replacing corn and SBM at 22% of diet DM resulted in similar milk production (Bernard and McNeill, 1991). Replacing forage with soy hulls in early lactation cattle reduced NDF content of the diet and resulted in an increase in intake and milk production (Miron et al. 2010). Overall, soy hulls have been shown to be an acceptable replacement to either forage or concentrate, depending on the ration. The NDF content of the diet must be balanced appropriately, since soy hulls are high in fiber content, making them less easily digestible to dairy cattle than traditional feeds like grain corn (Ipharraguerre and Clark, 2003).

2.4 Corn Milling Byproducts

Corn gluten feed is another heavily researched coproduct that is produced from wet milling of corn. When cattle were fed wet corn gluten feed in the diet at up to 36% of diet DM by replacing corn grain and soybean meal, all diets resulted in similar milk production compared to cows fed the control diet (Armentano and Dentine, 1988). Both wet corn gluten feed and dry corn gluten feed were fed at 27% of diet DM, replacing some corn silage, corn grain, and concentrate in the control diet (Bernard et al., 1991). Results showed similar milk yields to the control diet.

Allen and Grant (2000) evaluated 2 rations containing wet corn gluten feed (NDF = 32% of diet DM), with one feeding alfalfa silage as the forage and the other containing a mix of alfalfa silage and alfalfa hay for forages; these diets were compared to both high (32% NDF) and a low (23% NDF) fiber control diets. Cows fed either wet corn gluten feed ration had increased

DMI compared to the high fiber control with similar milk production, while the diet containing a mix of silage and hay primarily increased rumination time versus feeding the silage diet. Feeding cows a diet with corn gluten feed replacing corn and SBM at 22% of diet DM led to similar milk production (Bernard and McNeill, 1991). Cows fed wet corn gluten feed at 20, 30, and 40% of diet DM showed similar growth and milk production up to 30% of diet DM, while feeding wet corn gluten feed at 40% of diet DM diet resulted in weight loss for cows (Staples et al., 1983). Boddugari et al. (2001) fed wet corn gluten feed in three different experiments. They used it as a concentrate replacement for corn grain and SBM (at 50, 75 and 100% of the diet DM) in experiment one, a fiber replacement for alfalfa and corn silage at (15, 30 and 45% of the diet DM) in experiment 2, and a partial replacement to both in the diet of cattle for four different diets at 40% of the diet DM in experiment 3. They reported similar milk production across all treatments in the three experiments, showing it could be an effective replacement of both some forage and concentrate. Shepherd et al. (2014) used a variant of wet corn gluten feed with increased CP and decreased NDF at 20 and 30% DM with different forage sources. They found similar milk production with an increased rumen rate of passage with greater inclusion of wet corn gluten feed. There can be other coproducts produced as a result of corn milling as well, such as corn bran. Feeding corn bran in dairy cow diets at varying levels (10-25% of diet DM) resulted in similar milk yields across diets (Janicek et al., 2007). Research shows that corn milling byproducts do not negatively impact milk production in lactating dairy cattle rations when incorporated at up to 30% DM of the diet (Staples et al., 1983).

2.5 Pulp Byproducts

Pulps are another very commonly used byproduct in feeds. The two major types of pulp are citrus pulp, a byproduct of the citrus industry, and beet pulp, which is a byproduct from sugar production from sugar beets. Bampidis and Robinson (2005) reviewed the use of citrus byproducts such as citrus pulp in the diets of several species of ruminants. They found that citrus byproduct is a high-energy feedstuff that leads to similar milk production when replacing grains; however, it should not be used at levels greater than 3-4 kg/d to prevent toxicity from mycotoxins (Bampidis and Robinson, 2005). Cows fed citrus pulp produced similar amounts of milk compared to cows fed corn-based diets (Leiva et al., 2000). There were no differences in milk production between cows fed citrus pulp compared to cows fed beet pulp and grain corn in a control diet (Belibasakis and Tsirgogianni, 1995). Beet pulp research was reviewed by Kelly (1983), who reported that feeding beet pulp resulted in similar milk production when substituted for barley. Bhattacharya and Lubbadah (1971) found that sugar beet pulp could substitute up to 73% of diet concentrate with similar milk production. Beet pulp partially replacing corn grain at 15% DM in a lactating cattle diet resulted in similar milk production to the control diet. However, milk protein levels were reduced, likely due to decreased protein content in the diet (Mansfield et al., 1993). Beet pulp fed as a substitution for high moisture corn at up to 24% of diet DM led to decreased dry matter intake but similar milk production (Voelker and Allen, 2003). Cows fed beet pulp silage at 20% of diet DM as a substitution for corn silage and barley in the control diet had similar levels of milk production (Boguhn et al., 2009). Wheat bran and sugar beet pulp fed as a grain supplement replacement in grass-based dairy cow diets resulted in no change in milk yields for the cattle (Ertl et al., 2016). Substituting beet pulp for corn silage in heat-stressed cattle at 8-12% of the diet DM led to similar milk production. However, at 16% of the diet, feeding beet pulp resulted in milk fat depression (Naderi et al., 2016). Research has shown that both citrus and sugar beet byproducts can be used effectively in dairy cattle diets as a partial replacement of concentrate with little change in milk production; however, care must be taken to not feed in excess to avoid health problems (Bampidis and Robinson, 2005).

2.6 Bacterial Byproducts

There are also many byproducts associated with fermentation processes that could potentially be used as a feedstuff in dairy cattle diets, such as bacterial fermentation proteins. Carpenter et al. (2017) tested a bacterial byproduct from lysine production in continuous culture fermenters to evaluate the potential in dairy cattle diets. They found similar N metabolism, although VFA production decreased. Cows fed yeast derived microbial protein in diets at 2.25% of the diet DM in both high and low forage diets resulted in no impact on dairy cattle performance (Manthey et al., 2016). There was no change in the milk production of the animals when small amounts of SBM in the diet were substituted for yeast microbial protein, at 300-900 g/d per cow (Sabbia et al., 2012). Six different fermentation byproducts were fed as a protein source compared to wheat middlings and soybean meal (Broderick et al., 2000). Milk production showed a similar response with wheat middlings but a slight decrease compared to soybean meal. There are many different kinds of byproducts of fermentation processes that may have use in dairy rations.

2.7 Incorporating multiple byproducts

It is likely that dairy farmers would incorporate multiple byproducts into their diets. This would occur in a situation where a farmer has a choice of numerous feeds and can choose a mix to best account for all the nutritional requirements of a lactating herd, while accounting for cost and milk production. St. Pierre and Weiss (2015) found that byproduct feeds generally have increased variation in nutrient composition between and within farms compared to traditional feeds such as corn and soybean meal. This needs to be taken into account when designing high byproduct diets. One way to lower the impact of this variation impacting diet composition is to blend multiple sources of that feed together as a way to lower variation (St-Pierre and Weiss, 2006). Firkins (1997) compared the NDF digestibility of various byproducts in the rumen, finding significant differences across different byproducts. Clark et al. (1986) compared the protein content of various byproducts showing differences in amino acid content between the different feedstuffs that must be balanced for in dairy cattle diets. When using multiple byproducts, much of the dietary starch can be replaced in the diet due to the byproducts having more digestible NDF, resulting in similar dietary digestible energy concentrations (Weiss et al., 2009). Nutrient content variation between batches of feed is a major issue in using byproduct feeds and must be taken into account when feeding them.

There are many studies in which numerous different byproducts, including some mentioned previously, are combined in a diet to examine the impacts on dairy cattle production compared to feeding more traditional diets. Similar production of rumen microbes occurred *in vitro* in diets substituting grains for byproducts in diets with 75:25 and 50:50 forage:concentrate ratios (Ertl et al., 2015). While the use of byproducts increased propionate production in vitro, milk production was similar across the four diets. Replacing corn and soybean meal at increasing amounts with a byproduct mix containing wheat middlings, brewer's grains, and soy hulls, resulted in similar milk production, despite the byproducts increasing dietary NDF and reducing DMI in cattle (Batajoo and Shaver, 1994). Partially replacing high moisture corn and SBM with cottonseed, distiller's grains, and wheat middlings at both low (16% DM) and high (32% DM) levels led to similar milk production between the control diet and both byproduct diets, with the low byproduct diet showing the greatest milk production (Clark and Armentano, 1997).

Substituting some corn and SBM with either wheat middlings, corn gluten feed, or a mix of DDGS and hominy resulted in similar milk production across diets (Zhu et al., 1997). Byproducts replacing grains and forages in cow diets with the varying amounts of chopped wheat straw (0-9%) and sugar beet pulp (3-12%) showed that the byproduct diets increased DMI but led to similar milk production (Hall and Chase, 2014). Replacing some corn grain in the diet with soy hulls and citrus pulp resulted in no significant differences in milk production, with or without exogenous amylase, although amylase increased NDF digestibility (McCarthy et al., 2013). Replacing increasing amounts of either alfalfa hay or corn and SBM in the diet with a mix of corn gluten feed, soy hulls, and wheat middlings resulted in similar milk production across diets, although there was a milk fat depression when alfalfa hay was replaced with the byproduct mix (Mowrey et al., 1998). Pereira et al. (1999) fed a diet with a byproduct mix of corn gluten feed, brewer's grain, and wheat middlings and compared them to two different control diets, a positive control with increased alfalfa silage and similar NDF content, and a negative control with increased grain corn, and decreased NDF content. They also tested the effects of adding bicarbonate to the experimental diet and the controls, for a total of six diets fed. Adding bicarbonate increased milk production and intake but not digestibility. While the negative control diet had the lowest milk production compared to the byproduct and the high forage diets, there was milk fat depression from the byproduct diets compared to feeding the positive control diet. While total VFA production was similar across all diets, VFA proportions in byproduct diets were similar to proportions found in the negative control diet while being statistically different from the positive control diet. There was increased propionate proportion in the byproduct diet and decreased acetate proportion compared to the positive control diet. In a follow-up study utilizing the same diets, dry matter digestibility decreased with the byproduct diets, likely due to increased NDF content (Pereira and Armentano, 2000). There was a linear decrease in DMI in cows fed diets fed with decreasing amounts of grain corn replaced with DDGS and soy hulls, although both milk production and the VFA profile of the rumen remained similar (Ranathunga et al., 2010). When brewer's grains and bean curd pomace were fed individually or in combination to replace corn, researchers reported similar milk production between treatments (Chiou et al., 1997). Whelan et al. (2017) evaluated DDGS, palm kernel expeller, and soy hulls to replace barley and SBM at 35% to 95% of the concentrate DM to supplement pasture-raised cows. Use of the byproducts did not affect milk production or digestibility across all of the diets. Oba (2010) examined different high sugar byproducts and found they were more digestible in the rumen than starch with greater butyrate production by rumen microbes. These experiments show that an assortment of different byproducts can be used to replace traditional concentrates in cattle diets with minimal changes in milk production. Producers need to ensure diets are properly balanced when feeding byproducts and the cow is receiving all the essential proteins and nutrients, as these experiments show similar milk production when byproducts are used to replace conventional feed ingredients.

2.8 Fat Byproducts

There is also potential to examine fat sources for dairy cattle diets. There are two different major types of fats, unsaturated and saturated fats. Saturated fats are single-bonded fatty acids produced by animals and are found in milk, as well as palm oil. Saturated fats are generally fed as prills to help with digestion and can be sourced from animal products such as grease as well as some plant products such as a byproduct of palm oil production. Unsaturated fats contain more double-bonds and are found in many plant oils. These unsaturated fats are fed as calcium soaps and can be produced as byproducts from various plant oil production, such as canola and soybeans. A major issue that can result from feeding fats is milk fat depression (Harvatine and Allen, 2006). Comparing saturated and unsaturated fatty acid supplements to a control, results in increases unsaturated fat supplements depressed milk fat (Harvatine and Allen, 2006). This is caused by some polyunsaturated fatty acid intermediates created by rumen microbes impairing milk fat synthesis if polyunsaturated fatty acids are fed in excess. Excessive consumption of fat supplements will cause a milk fat depression which decreases milk quality and price. If fat supplementation is to be used, it should be done carefully and regulated well to avoid this problem (Harvatine and Allen, 2006). Supplementation with a vegetable oil byproduct on pastured cattle at either 0.5 or 1 kg a day resulted in similar milk production to the control (Schroeder et al., 2002). Fats must be used sparingly due to the potential for milk fat depression, which can limit their usage compared to fiber or protein sources.

2.9 Glycerol

Glycerol is a coproduct of biofuel production that differs from the previously described byproducts as it is not primarily a protein or fiber source but an alcohol. Glycerol has been fed at 0, 5, 10, or 15% of diet DM as a ground corn replacement in the diet of dairy cattle without affecting milk production (Donkin et al., 2009). Glycerol fed at 11% of DM as a replacement for high moisture corn in the diets of both pre-partum and post-partum dairy cattle resulted in similar milk production for the two diets, although blood glucose levels decreased and blood β-hydroxybutyrate (BHB) levels increased feeding glycerol (Carvalho et al., 2011). Increasing amounts of glycerol fed in cattle diets as a replacement for barley meal led to similar milk production (Harzia et al., 2012). Continuous culture studies found that glycerol tested up to 8% of the diet altered VFA profiles, with a lower acetate proportion and a larger propionate proportion, as well as increased digestibility (Rico et al., 2012). Shin et al. (2012) fed glycerin fed at 0, 5, and 10% of the diet for replacing ground corn with two different test diets, a traditional diet based on corn silage and alfalfa hay diet and a diet other with bermudagrass hay, cottonseed hulls, and more ground corn. Feeding glycerin at 5% of the diet did not affect milk production but 10% glycerin in the diet depressed milk fat (Shin et al., 2012). Glycerol supplemented at 100-300 g/d led to similar milk production with no significant difference in fat versus the control diet without supplementation (Wang et al., 2008). Research also has found that glycerol supplementation changes the rumen gut composition due to greater propionate and lower acetate being produced without changing total VFA production (Rico et al., 2012). Research has shown that glycerol is another potential coproduct that can be used in dairy cattle rations effectively.

2.10 Stover

Stover is the leaves and stalks left over from the harvesting of corn and may be a potential byproduct used in cattle feeds. Cows were fed increasing amounts of stover treated with calcium oxide from 4.4% to 13% of diet DM as a substitution for corn grain, resulting in decreased performance in the animals as the amount of stover in the diet increased (Cook et al., 2016). The digestibility of the diet decreased due to increasing NDF content provided by the added corn stover. In another study, cows were fed stover in 3 different diets replacing rye, corn silage, or corn grain (Shi et al., 2015). They found similar milk production to the control diet. Replacing all alfalfa hay in the diet with stover or rice straw led to a large decrease in milk yields compared to the alfalfa hay control diet (Wang et al., 2014). Diets in which a portion of alfalfa hay was replaced with either stover or ryegrass resulted in a slight decrease in the performance of the cows fed stover and ryegrass diets compared to the alfalfa hay diet (Zhu et al., 2013). Stover is a poor-quality feedstuff that has lower digestibility in cattle and thus will reduce available energy content of cattle diets when used to replace higher quality feedstuffs. If producers use corn stover in cow diets, they must be careful to properly balance the diet to account for the low energy supply. Stover is also high in NDF content and is susceptible to toxins and molding, which should be further watched for by the producer. Stover could be used as an effective feedstuff for animals with lower energy requirements compared to high producing dairy cows, but more research should be done beyond replacing alfalfa hay.

2.11 Unique Feeds

So far many of the feedstuffs previously mentioned have been quite common byproducts or coproducts, such as DGS, corn gluten feed or soy hulls. However, there is potential for evaluating novel feedstuffs that are perhaps not as closely related to traditional agriculture like corn and wheat. Cassinerio et al. (2015) tested tomato seeds against cottonseeds as a supplement in cow diets, finding similar milk production and intake between the diets, although milk fat decreased slightly. Van Horn et al. (1983) compared a control diet of 30% DM cottonseed hulls to two different experimental diets of either 30% DM sunflower hulls, or a mix of 10% DM peanut hulls and 10% DM ground corrugated boxes. They found significantly decreased milk production in the unique diets compared to feeding the control cottonseed hulls. Compared to byproducts of traditional feeds such as corn and wheat products, it is difficult to find studies for more novel feedstuffs similar to the one mentioned above. More research into unconventional feeds should be done to find more byproduct feeds that could partially or fully replace more expensive, traditional feeds in dairy cattle diets. Perhaps there are farms that currently use novel feedstuffs successfully in their dairy cattle diets. However, there have not been many surveys that examine the types of feedstuffs used by dairy farmers. Mowrey and Spain (1998) distributed a survey for dairy nutritionists at American universities to determine the usage of different feeds on dairy farms in their state. As expected, usage of feeds depended on what region they were in, as certain crops grow better and are cheaper in certain regions. In the approximately 20 years since that study, there has been no research to determine feed usage on dairy farms, and cattle diets have potentially changed in that time period. There have never been any studies done in Canada to determine the usage of feeds on dairy farms. It is possible that certain farms use novel feeds successfully to maintain milk production while reducing feed costs. While there have been many studies evaluating certain byproducts, more information is required to determine what novel feeds are being used by dairy producers. If novel feeds are being used, research should be done to find out if they are adequate to use in dairy rations without significantly impacting milk production.

2.12 Low Crude Protein Diets

Dairy cattle diets generally contain an excess of nitrogen, as farmers want enough microbial protein produced to maximize milk production (Olmos Colmenero and Broderick, 2006). This leads to large amounts of nitrogen being excreted by the cow in urine and feces that are unused and wasted. These inefficiencies actually cost the farmer as this can waste expensive protein supplements, and lead to a significant increase in nitrogen levels within cattle manure (Broderick, 2003). By lowering the crude protein (CP) content in diets, this can lead to increased nitrogen efficiency and a better environmental impact with less wasted nitrogen. Olmos Colmenero and Broderick (2006) fed five different diets to increase dietary CP from 13.5 to 19.4% CP. They found the diet that increased milk production the most while having the greatest N efficiency was the middle diet containing 16.5% CP, with greater amounts of dietary CP leading to increased N waste with no change in milk production.

Certain amino acids are essential, so by supplementing them it can lead to the amino acid requirements being met with less protein being fed and excreted (Arriola Apelo et al., 2014). The amino acids lysine and methionine are generally the two essential amino acids that are most commonly limiting in lactating diets, and therefore can be supplemented to make sure diets meet their requirements for the two amino acids. Many coproducts such as DGS contain high amounts of rumen undegradable protein (RUP). RUP is fed to bypass the rumen microbes so the protein is absorbed directly by the cow in the small intestine, potentially increasing N efficiency (Nichols et al., 1998). Rumen digestible CP is not absorbed directly by the cattle but is used by the rumen microbes to form microbial crude protein (MCP) which are then absorbed by the cattle. If limiting amino acids are fed as ruminally protected supplements, they can be absorbed directly by the cattle so they are easier to control for. There have been many studies comparing differing levels of dietary CP with the supplementation of ruminally protected limiting AA and their impacts on milk production and N efficiency. Broderick et al. (2008) compared four cattle diets with decreasing dietary CP (18.6% to 14.8%) while increasing the amount of ruminally protected methionine supplemented (from 0 to 15 g/d). They found the highest milk production by feeding a 17.3% CP diet providing 5 g/d methionine or a 16.1% CP diet providing 10 g/d methionine, with the latter diet providing increased N efficiency. Broderick et al. (2009) compared two levels of dietary CP (15.8 and 17.1% CP), the inclusion of 5% RUP in the form of expeller SBM, and the inclusion of ruminally protected methionine together for a total of 8 diets. They found increasing dietary CP increased milk production but reduced N efficiency; the increased RUP increased efficiency but was not utilized well due to limited methionine. The provision of additional methionine improved production of milk and milk protein, such that these parameters were similar between cows fed low CP diets with ruminally protected methionine to cows fed high CP diets without ruminally protected methionine. Arriola Apelo et al. (2014) compared a 17% CP diet control to a 15% CP diet with varying rumen-protected amino acid supplements of lysine, leucine and methionine, with 8 diets total. They found similar milk production and efficiency across all diets. Frank and Svensson (2002) fed 5 rations, with 3 at 17% CP (high CP) and two at around 13% CP (low CP), with one of the high CP diets being a control. To lower CP, they increased beet pulp content in the diet. They also tested two protein supplements of similar composition from different sources at each protein level, for a total of four experimental diets. Feeding the low CP diets resulted in lower milk production, while feeding both supplements increased milk protein levels. Leonardi et al. (2003) fed 4 diets with either 16 or 18.8% CP with or without methionine supplementation. They found no significant impact on milk production, although supplemental methionine increased milk protein % in milk levels. Piepenbrink et al., (1996) fed two diets with either 18% CP or 14% CP with rumen-protected methionine and lysine added. They found a slight decrease in milk yield in the 14% diet. Lee et al. (2012) compared a control diet with 15.7% CP content to a metabolizable protein deficient diet with 13.7% CP, supplemented with a mix of ruminally protected lysine, methionine, and histidine. Feeding the low CP diet with supplementation provided similar milk production to the control diet while producing less N waste and being more efficient. Giallongo et al. (2016) compared a control high CP diet in cattle containing 16.8% CP versus a low CP diet containing 14.8% CP with supplementation of either ruminally protected methionine, ruminally protected lysine, ruminally protected histidine, or a combination of all three supplements, for a total of six diets. Feeding the combination of the three supplements improved milk fat, milk protein, and energy corrected milk from the low CP diet, while adding just lysine led to increased milk protein from the low CP diet. Wang et al. (2010) compared a control diet deficient in lysine and methionine to diets with ruminally protected lysine, ruminally protected methionine, or a combination of the two supplements. Feeding both the lysine and methionine supplements improved milk production. Perhaps by lowering CP content in diets along with the usage of byproduct feeds and RUP supplementation of limiting essential AA, this can improve the environmental impact of dairy production by lowering nitrogen waste and decreasing the amount of land required to feed dairy cattle.

2.13 CONCLUSIONS

There have been numerous research studies evaluating the effectiveness of providing byproduct feeds in dairy cattle diets. These studies have found that many byproduct feeds can be incorporated into dairy cattle diets without negative impacts on milk production if fed in moderation. These include commonly used byproduct feeds such as DGS, corn gluten feed and citrus pulp. Generally, many of these feeds can be fed to up to 30% dry matter of the diet without negative effects. Certain fat byproducts and forages have potential to be used in diets as well. However, knowledge about the types of feeds used by dairy farmers is still relatively unknown, as there have been few studies examining the types of feeds that are used in rations by milk producers. In Canada there has never been a nationwide survey into the types of feeds fed in dairy rations before. This lack of knowledge could mean that researchers are missing an opportunity to investigate other potential low-cost feeds to determine if they could potentially be an effective feed in cattle diets. Although many low-cost feeds have been studied to examine their impacts on milk production and rumen performance, there are still more out there that can be evaluated to determine if they potentially could be used to bring more profit to dairy operations. By examining what dairy producers are using in their rations, we can determine which low-cost feeds are most commonly used. The reasons behind ration formulation decisions can also be revealed in a survey.

Another way to improve efficiency in dairy rations is by lowering the dietary CP levels to increase N efficiency and reduce N waste. However an issue with this is that milk production can be negatively impacted if there is not adequate CP provided in diet. Many research studies have shown that supplementing rumen protected, limiting essential AA such as lysine and methionine can help mitigate this reduced milk production. Amino acid supplementation could result in similar milk production but with increased N efficiency and less waste. More studies can be done into these supplements to see if they can significantly improve the milk production of low protein diets, to that of high CP diets without supplements. If these supplements can lead to producers reducing the dietary CP content in their rations in order to improve N efficiency, this could reduce the large amounts of N waste that are produced by cattle when fed high CP diets. Overall these reviewed papers show there are different ways for dairy producers to improve the efficiency if nutrient utilization of their rations while not negatively impacting milk production. By either feeding low-cost feeds and byproducts to reduce the amount of land needed to feed dairy cattle, or by reducing dietary CP content to reduce N waste and improve efficiency, experiments can be done to show how to help farms improve their efficiency and reduce wastefulness in dairy rations.

The objectives of this thesis are to discover the types of feeds used on Canadian dairy farms and the factors that drive their use, as well as to see if feeding a rumen-protected Lys supplement on diets with two different levels of CP content (15% vs. 17% of diet DM) where Lys was the limiting EAA impacted milk production and N utilization and efficiency.

3 Experiment 1: Survey of feeding practices on dairy farms in Ontario and Western Canada

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3.1 ABSTRACT

A feed ingredient and feeding management survey was created and distributed online to Canadian dairy producers in Ontario and western Canada. There were 230 responses from Ontario (n=146) and the four western provinces (British Columbia, Alberta, Saskatchewan and Manitoba; n=84). Responses were split into three categories for the four Western provinces (WP; n=84), Ontario freestall farms (OF; n=75), and Ontario tiestall (OT) farms (n=71). Statistical analysis was done using IBM SPSS Statistics 25. Farm demographics such as herd size were similar to known national numbers. Pasture access was significantly more common in tiestall farms. The most common feeds fed in lactating diets were corn silage along with hay and/or haylage. Regional differences were observed for many feed ingredients, as corn and soybean meal were more commonly used in Ontario ($P \leq 0.01$), while barley and wheat products as well as grass hays were more commonly used in the West ($P \leq 0.01$), consistent with the known local production of those crops. The survey found the most important factors to producers in balancing rations are production and health, cost, simplicity, and nutrient management, although nutrient management was more important in the West for all types of diets ($P \leq 0.01$). The interest in production and health above other options suggests that the supply management system in Canada impacts decisions in the makeup of rations, as farmers focus on meeting their quota allocation as effectively as possible. The majority of farms frequently tested for ration dry matter and nutrient composition, although Ontario tiestall farms tested less often than other groups ($P = 0.09$). Overall, this survey showed that diet composition aligned with the common crops grown within the particular region, and that Canadian farmers have a stated interest for improving milk production and cow health in their herds.

3.2 INTRODUCTION

The dairy industry in Canada is an important part of the country's agricultural sector. The Canadian Dairy Information Centre (2017) reported there are over 10,000 dairy farms in Canada that are shipping milk from approximately 945,000 milking cows. While some descriptions of farm demographics of the Canadian dairy industry are commonly recorded, such as average herd size and the barn types, there is little known regarding feeds and feeding practices being used. There have been surveys of feeding practices in the United States (Mowrey and Spain, 1998). Statistics Canada (2017) calculates the total production and land usage of field crops, but this does not cover how much of field crops are grown for feeding dairy cattle. These numbers cannot be used to assume the grains fed in each region on dairy farms, as these crops can be used for humans and other animal species. In Canada, DHI services are widely used, and cover a majority of dairy farms, with 74% of all Canadian dairy farms in 2017 using them in some capacity (67% in the four Western Provinces, 75% in Ontario, 79% in Quebec, and 59% in Atlantic Canada). Thus, we felt that DHI services would be a good resource to use for distribution of a survey (Valacta, 2018, Western Progress Report, 2018).

The objectives of this survey were to discover which types of feeds dairy producers are feeding their animals and to examine producer strategies and attitudes towards feed management.

3.3 MATERIALS AND METHODS

3.3.1 Survey Distribution

An online survey was created using Qualtrics survey software (Qualtrics International, Inc., Seattle, WA, USA) for distribution by CanWest DHI (Guelph, ON, Canada). The survey was created at the University of Guelph, after approval from the Research Ethics Board (REB# 17-07-008). All producers on test with CanWest DHI received an invitation to complete the survey from May to July 2018. Producers in Quebec received their survey invitation in French through Valacta (Sainte-Anne-de-Bellevue, QC, Canada). The survey was pretested by two dairy producers for feedback, after which the survey was translated into French and distributed to producers. All producers were able to select an English or French version of the survey.

3.3.2 Survey Content

Producers were first asked general information regarding the dairy operation that they run, such as province, whether they used a nutritionist, and the type of milking operation they operated (parlor, tiestall, robot). The next section focused on the milking herd, asking how the cattle were grouped, if the herd was given pasture access, if different rations were fed among the milking herd, and what management considerations were used when assigning cows to different rations if more than one lactation ration was used. Respondents were given a list of common feedstuffs with different forages, byproduct feeds and grains, and asked which feeds were fed in each of their lactation diets. There was an option to write in any feeds that were not included on the list, and they were asked to report the crude protein level of the diet(s), if known. Similar questions were asked in the following sections focusing on dry cows and heifers. In addition, producers indicated dry period length in the dry cow section. The final section was focused on nutrition management. In this section farmers were asked to rate certain factors such as simplicity, cost, performance and health on how they choose the different rations for heifers, dry cows, and lactating cows. They were also asked how often feed was delivered. Next they were asked about how many sources they used for their feed, and how often they test their rations for dry matter and nutrient composition.

3.3.3 Data Analysis

Analysis was done on all survey responses using IBM SPSS Statistics 25 (Armonk, NY). Survey respondents were assigned to one of three categories based on location within Canada and facility type for farms located in Ontario. These categories were western provinces (WP; n = 84) which consisted of all responding farms located in British Columbia, Alberta, Saskatchewan and Manitoba; Ontario tiestalls (OT; n = 71), which consisted of all responding farms in Ontario who used a tiestall barn to house the milking herd; and Ontario freestalls (OF; n = 74), which consisted of the remaining responding Ontario farms that did not use tiestall barns. WP farms included both freestall (n = 75) and tiestall (n = 9) facilities. These three categories were selected for analysis due to the balanced distribution between freestall and tiestall farms in Ontario, with both categories also being close to the number of responding farms in the four western provinces. A total of 9 French responses were received from Valacta herds in Quebec, but these responses were discarded due to being too small of a sample. Chi squared tests were used to determine if there were significant differences in answers among the three categories in "yes" or "no" questions. Tukey's test was used to determine significance of herd size among and between the three categories. For the attitude rating questions, the Kruskal-Wallis test was used to determine significance among the three categories. Significance was declared at $P \leq 0.10$.

3.4 RESULTS

3.4.1 Farm Demographics

There were 230 completed surveys available for analysis, or approximately 3% of milk recorded farms in Canada (Valacta, 2018). Excluding Quebec and the Maritimes, which did not answer the survey in adequate numbers, respondents represented 6% of farms in the remaining provinces (Ontario Progress Report, 2018, Western Progress Report, 2018). Ontario dairy producers represented 63% (n = 146) of responses, followed by Alberta at 15% (n = 34). The remaining responses came from British Columbia (10%, n = 23), Manitoba (7%, n = 15) and Saskatchewan (5%, n = 12). Each province that had completed surveys varied in percentage from 6% of DHI reporting farms completion in Ontario to 13% of DHI reporting farms in Saskatchewan.

The average herd sizes across respondent groups are presented in Table 1. The average herd size was 113 cows, which is larger than the national average of 89 cows, but is very close to the average herd size of DHI reporting farms in both Ontario and the Western Provinces, which is 110 cows per herd (Ontario Progress Report, 2018, Western Progress Report, 2018). The average herd size for Ontario farms was close to the average of the surveyed farms (87 to 91). Comparing the three groups, WP farms had the highest average herd size at 160 cows per herd, which was very close to the reported average herd size of 164 (Western Progress Report, 2018), with OT farms having the lowest average herd size of 57 cows per herd, with OF in between at 113 cows per herd.

General farm information questions showed some differences across the three categories (Table 2). The majority (83%) of respondents used nutritionists to balance their rations, compared to doing it themselves (14%) or having a veterinarian (4%) do it. Eight (3%) of farms were organic, which is similar to the 2% organic dairy farms in Canada, and there were no differences among the categories ($P = 0.93$). Regarding barn design, 61% of farms surveyed were freestall, with 35% of farms being tiestall. In Ontario, 49% of the farms were tiestall, with the majority (89%) of the tiestall farms in the survey located in Ontario. For the responding WP farms, 75 (88%) were freestall. Across responding farms, 17% used a robot to milk cows, with significant differences across the three groups ($P \leq 0.01$). Robots were used by 31% of OF farms, while the OT farms had zero robot farms. Across all farms, 37% of respondents indicated that they provide additional supplements to lactating cattle based on their age or stage of lactation (WP farms = 29%, OF farms = 35%, OT farms = 50%; $P = 0.06$).

Differences in group size are reported in Table 3 while Table 4 reports differences in number of rations by respondent farms. There was no difference in number of groups between WP and OF farms (Table 3), while OF farms were more likely to use one ration ($P < 0.05$) than WP farms (Table 4). Pasture access of any kind was given to lactating cattle for 25% of respondents (Table 4). Pasture access was greater ($P < 0.05$) in OT farms versus OF and WP farms, with 39% of OT farms providing pasture access (Table 4). Average pasture access increased to 53% and 49% for dry cows (Table 5) and heifers (Table 6), respectively. Again, access to pasture was greater ($P < 0.05$) in OT farms for dry cows (76%; Table 5) and heifers (65%; Table 6) versus WP and OF farms.

3.4.2 Feeds

Responses to the types of ingredients used within lactating rations are presented in Table 7 for forages, and Table 8 for concentrates and byproduct feeds. The most common forage used in lactating cattle rations was conventional corn silage, used on 73% of farms. Farm category had a significant effect on corn silage use ($P \leq 0.01$), with corn silage was more commonly used in Ontario (OF, OT farms) compared to WP farms (WP farms = 56%, OF farms = 80%, OT farms = 84%; $P \leq 0.05$). Other commonly used forages include different varieties of haylage and hay. A significant effect was detected between farm categories in all types (grass, legume, mixed) of hay ($P \leq 0.01$). OF farms were less likely to use grass hay within their rations compared to WP and OT farms ($P < 0.05$), use legume hay less than WP farms ($P < 0.05$), and use mixed hay less than OT farms ($P < 0.05$). Grass hay was most commonly used in WP farms ($P < 0.05$) compared to

OT farms. There was a significant effect for farm category for usage of legume ($P = 0.01$) and mixed ($P \leq 0.01$) haylages, with WP farms using less legume and mixed haylage ($P < 0.05$) than OF and OT farms. Commonly used traditional concentrates across all farms include corn grain (58%) and soybean meal (57%; Table 8). Regionally, corn grain was used more on OT farms (73%; $P < 0.05$) than WP farms (50%). Soybean meal was more commonly used on OF farms (70%) than in WP (39%) and OT (56%) farms ($P < 0.05$). There were other significant effects found in concentrates across farms, especially in barley ($P \leq 0.01$), with WP farms most commonly reporting its use in lactation cow rations (69%), OF farms least commonly reporting its use (4%), and OT farms intermediate (24%; $P < 0.05$). Another notable effect was seen in high moisture corn usage across categories ($P \leq 0.01$), with 4% of WP farms reporting use in lactating cow rations compared to 36% in OF farms and 32% in OT farms ($P < 0.05$). In regards to byproduct or coproduct feeds, the most commonly used were canola meal (35%) and corn distiller's grains (33%). Other byproducts included on the survey include beet pulp (8%), brewer's grain (10%), corn gluten meal (10%), soy hulls (4%), cottonseed (3%) and wheat distiller's grains (5%). Significant effects of farm category were observed for canola meal (35% across all categories; $P \leq 0.01$), with OT farms (15%) using it less than WP (49%) and OF farms (37%; $P < 0.05$). Significant effects were seen across categories for both beet pulp and wheat distiller's grain ($P \leq 0.01$), with both being used more often in WP farms ($P < 0.05$) than in OF and OT farms. Overall, significant regional effects were found for most of the surveyed feeds across all categories, with the exception of grass haylage, straw, corn distiller's grains, corn gluten meal, cottonseed, and soy hulls. Of these, the most common feedstuffs nationally were corn distiller's grains, followed by straw and grass haylage. The "other" section contained feeds that were not included in the survey as an option and were instead written in by producers. The most commonly reported other feeds in lactating diets included barley silage (7 responses), and supplements/pellets (13 responses). Unique byproduct feeds found in this section include corn cob meal, potatoes, bakery meal, wheat shorts, hominy and tallow fat, whey permeate, malt sprouts and cover crop silage (Appendix 5).

Dry cow rations showed some significant regional differences (Table 9 for forages, 10 for concentrates and byproduct feeds). Conventional corn silage was again the most common forage fed across Ontario and western Canada at 66% of dry rations but was used less ($P < 0.05$; Table 9) in WP farms (42%) compared to OF farms (81%) and OT farms (77%). The most common forage fed in WP farms was grass hay at 72%, significantly more ($P < 0.05$) than OF farms (26%) and OT farms (40%). Regional differences were similar between lactating and dry rations for other forages, as fewer farms fed haylage, more grass hay and straw was fed compared to lactating diets. Grass hay was fed significantly more ($P < 0.05$) in WP farms (72%) than in Ontario (OF farms = 26%, OT farms = 40%)), while mixed hay was fed more on OT farms (51%; $P < 0.05$) versus WP (24%) and OF farms (21%). Grass haylage ($P < 0.05$) was fed more in WP farms (26%) than OF farms (8%), while mixed haylage was fed less ($P < 0.05$) in WP farms (9%) than OF (31%) and OT farms (26%). Straw was fed significantly less in OT farms (23%) than WP (50%) and OF farms (67%; $P < 0.05$). There were also regional differences for use of concentrates (Table 10). Barley was fed more in WP farms (45%; $P < 0.05$) versus all Ontario farms (OF farms = 0%, OT farms = 15%), and OF farms fed barley to dry cows the least ($P < 0.05$). Soybean meal was fed significantly less on WP farms (17%; $P < 0.05$) than OF farms (43%). Corn grain was also fed significantly more often in OT farms' dry rations (29%; $P < 0.05$) than WP farms (9%)The most common byproduct feeds in dry cow rations were canola meal (20%) and corn distiller's grains (18%; Table 10). Significant regional differences in byproduct feeds were uncommon, with the exceptions of canola meal, which was used less frequently in OT farms (9%) compared to OF (26%) and WP farms (22%; $P < 0.05$), and wheat distiller's grains, which was used on WP farms (9%) but not OF or OT farms ($P < 0.05$).

For heifer rations (Table 11 for forages, Table 12 for concentrates and byproduct feeds), conventional corn silage was again the most common forage fed in OF and OT farms (both 68%), with it being fed significantly less ($P < 0.05$) in WP farms (37%; Table 11). Grass hay was most commonly fed in WP farms (61%), being significantly greater than both OT (23%) and OF farms (32%; $P < 0.05$). Mixed hay was also fed more frequently on OT farms (68%) compared to WP farms (40%; $P < 0.05$). Mixed haylage was fed more in Ontario (OF farms = 53%, OT farms = 36%) compared to WP farms (17%; $P < 0.05$), while straw was again used less in OT farms (10%) than WP (40%) and OF farms (36%; $P < 0.05$). Barley was the highest fed concentrate in WP farms (62%; $P < 0.05$), significantly greater than in Ontario (OF farms = 10%, OT farms = 21%). Soybean meal was fed more in OF (46%) and OT farms (39%) compared to WP farms (16%; $P < 0.05$) and corn grain was fed significantly more in OT farms (57%) compared to WP (22%) and OF farms (33%; $P < 0.05$). Byproduct feeds were less commonly fed in heifer diets, with fewer significant differences between categories (Table 12).

3.4.3 Attitudes

Producer attitudes toward five factors influencing their feed management choices (listed as performance, cost, simplicity, nutrient management and health) followed a clear pattern across regions. For lactating diets (Table 13), the most important factor was performance (average = 1.46), followed by health (average = 2.11), cost (average = 3.46) and simplicity (average = 3.8), and then nutrient management last (average = 4.17). There were some significant differences among categories, as WP farms ranked nutrient management higher ($P \leq 0.01$) than OT and OF farms. For dry cow diets (Table 13), the most important factor was health (average = 1.82), followed by performance (average = 1.86), simplicity (average = 3.53), cost (average =3.63) and then nutrient management last (average = 4.17). Significant differences seen were that WP farms ranked nutrient management higher ($P < 0.05$), and performance lower ($P < 0.05$) than OF and OT farms, and cost lower ($P < 0.05$) than OF farms. For heifer diets (Table 13) nationally the most important factor was performance (average = 1.71), followed by health (average = 2.26), simplicity (average = 3.28), cost (average = 3.62) and nutrient management last (average = 4.14). Significant differences showed again WP farms ranked nutrient management higher ($P < 0.05$) than OF and OT farms and performance lower ($P < 0.05$) than OF farms. There was a significant effect of farm category when respondents were asked to agree or disagree with the statement "Feedstuffs should be tested frequently"($P = 0.02$; Table 14). OT farms were more likely ($P < 0.05$) to feed their lactating and dry cattle more than twice a day compared to OF and WP farms, while OF farms were more likely ($P < 0.05$) to push up feed to their lactating and dry cows than OT farms (Table 15).

3.5 DISCUSSION

3.5.1 Comparison of responses to actual herd demographics

Comparing the survey demographics responses to nationwide numbers from the Canadian Dairy Information Centre and provincial numbers from the DHI Progress Reports showed similarities (Ontario Progress Report, 2018, Western Progress Report, 2018). It is unknown why there was such a poor response from the eastern farmers, especially Quebec due to the large amount of producers from the province. Potentially, Quebec producers could have been more receptive to a survey from Quebec rather than Ontario. The five provinces included in this study contained 3607 dairy farms using DHI as of 2017; based on these farm numbers, the survey had a 6.4% response rate in those provinces combined. Herd size numbers reported here (Table 1) are similar to DHI values. DHI reports a combined average of 110 cows in Ontario and the western provinces, with an average herd size of 164 cows for the 4 western provinces and 91 cows for Ontario, while our survey responses reported an average of 160 cows for the 4 western provinces and 87 cows for Ontario. The number of organic farms (Table 2) also followed national numbers closely, as national numbers show 2.44% of dairy farms are organic, compared to 3.48% of responding farms being organic based on our survey responses (Statistics Canada and Canadian Dairy Commission, 2018). For barn design (Table 2), Ontario had proportionally fewer tiestall responses compared to the number of tiestalls in the province, as tiestall farms were at 49% of Ontario respondents compared to 68.7% provincially based on DHI numbers. Conversely, a greater percentage of robotic farms responded compared to provincial averages, with 18.9% of surveyed Ontario farms being robotic compared to 10.6% provincially based on DHI numbers. Since nearly all robotic farms are also freestall farms, this increase in robotic numbers follows the greater percentage of answering freestall farms. In the 4 western provinces, 88% of farms are freestall, and 20.8% are robotic herds based on DHI numbers, which matches up very closely to the survey farm numbers (88.21% freestall farms, 20.24% robotic herds).

Overall, the demographics of the respondents fairly represent the population demographics in Ontario and Western Canada. It is disappointing there was an inadequate amount of responses in Quebec and Eastern Canada for analysis. This is possibly due to the survey being done from a different region instead of from Quebec. The timeline for when the survey went out may have also depressed the number of responses, as spring is generally a busy time on farms if producers are working on spring seeding. This could have potentially been more of an issue out East, who generally have smaller farms (Statistics Canada and Canadian Dairy

Commission, 2018). But it is likely that the biggest reason for a lower response rate is due to the producer being too busy with work.

3.5.2 Feeding and group management differences

There were differences between freestall and tiestall farms based on survey responses. Freestall and tiestall farms are generally run differently, as tiestall farms can focus feeding more individually as animals are tied up allowing for more controlled feeding, whereas freestall farms feed less often as it is harder to single specific cattle out within a group (Table 15). This is supported by data as tiestall farms generally feed their cows more often than freestall farms ($P \leq 0.01$), although freestall farms push up feed more ($P = 0.03$; Table 15). The greater usage of pasture on tiestall farms is ($P = 0.01$; Table 4) likely due to farmers on tiestall farms letting their cows out for exercise and considering this as 'being on pasture.'

Questions regarding grouping strategies can show how cows are organized in a lactating herd and may provide an indication of whether producers are feeding lactating cattle based on different nutritional requirements throughout lactation. Stage of lactation and age were the two main reasons for grouping cattle (Table 3). Since cattle have different nutritional requirements at different stages of lactation, grouping strategies are often related to the number of rations fed to lactating cattle. Tiestall farms generally do not group cows as they have their own individual stalls. As significantly more tiestall farms have only one group ($P \leq 0.01$) than freestall farms (Table 3). This is expected as most tiestall farms do not keep their cattle in groups, so they mostly answered one. OF farms significantly fed ($P = 0.07$) fewer diets than the WP farms, which were also mostly freestall farms (Table 2). However the difference between freestall and tiestall farms in Ontario was not significant, with 92% of freestall farms using one ration compared to 76.5% of tiestall farms. This difference between regions may be linked with the previous question about grouping, as WP farms had more groups than Ontario farms (OT, OF). Another explanation could be the fact that WP farms had significantly increased herd sizes compared to both Ontario categories (Table 1), which could lead to an increase in the number of rations fed as more feed is needed on these farms. So while feeding and grouping strategies are shown to be different between freestall and tiestall farms, there is little difference in rations fed, showing more regional differences there.

3.5.3 Feeding Strategies

A change in ration was most commonly done due to nutritional requirements, reproductive status, milk production and days in milk according to responses (Table 4). There were no differences due to barn type or region, showing these were universally the most common reasons for changing to a different ration. The most common reasons are connected to each other, as throughout a cow's lactation these factors all change within a cow. A diet too rich in protein can result in an inefficient diet as large amounts of N are unused and expelled as waste, so feeding based on changes in protein requirements effects environmental impact as well. Based on survey responses, the feeding of multiple rations in lactating cattle herds is still uncommon, with only around one-fifth of respondents using two or more rations. Multiple rations was more common in dry cattle (Table 5), with around double the farms feeding two or more dry rations. This is expected as recently dried cows have different requirements versus transition cows close to calving and can be fed differently. However, the majority of farms still fed one ration during the dry period. Another reason could be that first-time calving heifers could be fed differently than previous mothers. For rations between weaning and first calving (Table 6), the most common response was 2 rations, followed by 1 and 3. Diets were changed most commonly due to heifer differences in age, size and reproductive status. Freshly weaned calves have very different requirements compared to larger yearlings, which is why it is puzzling that 30% of all respondents only fed one ration between weaning and first calving. A possible reason for this may be the fact that the rations excluded any diets that included pasture access, which may lead to some diets being left unmentioned on the responses.

3.5.4 Ration ingredients

Differences in feed usage (Tables 7-12) follow national numbers for crops grown in those areas. Barley and wheat are grown in much greater quantities in the West. While 4.9 million acres of barley were grown in the 4 western provinces in 2017, 75,000 acres were grown in Ontario, reflecting the large gap in barley usage in dairy rations (Statistics Canada Table 32-10-0359-01, 2018). Likewise, significant regional differences in use of corn concentrates, silages and soybean products are due to corn and soybeans being more common crops in Ontario than the west. In 2017, 2.06 million acres of corn and 3.13 million acres of soybeans were grown in Ontario, compared to 435,000 acres of corn and 313,000 acres of soybeans grown in all 4 western provinces combined (Statistics Canada Table 32-10-0359-01, 2018). These numbers show that usage of grains and concentrates follow regional growth trends.

Grass hays and haylages were more common in the 4 western provinces while mixed hays and haylages were more common in Ontario (Table 7). Statistics in the survey show there are more grass hays fed in the 4 Western provinces than Ontario (Table 7). However the national data showed that alfalfa was more commonly grown in the Western provinces than Ontario, which is not seen in the data (Statistics Canada Table 32-10-0416-01, 2018). Statistics Canada stated that in 2016 17,214 farms reported growing alfalfa, compared to 37,145 farms in the 4 western provinces. This may be due to the farmer misinterpreting alfalfa as not being a legume, which was seen in the “other” section for some responses (Table 7). Another explanation is the majority of the western province farms growing alfalfa were not dairy farms but potentially beef or another type of farm.

Corn distiller's grains were the most common byproduct feed. Regional differences were found for use of a few byproducts, with beet pulp, bypass fats, canola meal, and wheat distiller's grains being more common in the western provinces. Again, this is likely due to where feeds are being grown as beets, canola, and wheat are more commonly grown in the 4 western provinces versus Ontario. In Ontario during 2017 canola was grown on 43,000 acres, while wheat was grown on 1.01 million acres, with no numbers reported for sugar beets. This is dwarfed by the four Western provinces in 2017, in which canola was grown on 22.835 million acres, wheat was grown on 20.912 million acres, and sugar beets were grown on 26,000 acres (Statistics Canada Table 32-10-0359-01, 2018). However, this does not explain the difference in bypass fats, as well as differences between OF and OT farms over using canola meal in lactating rations. More differences in ingredients used between categories were found in lactating diets compared to both dry and heifer diets, consistent with the fact that lactating rations tend to contain more feed ingredients compared to dry and heifer rations (Tables 9-12). Overall, most differences in feeds can be explained by which crops are grown in each location.

Comparing the US regions to their neighboring Canadian counterparts (WP to northwestern states, Ontario to Northeast and Midwest states; Mowrey and Spain, 1998), the most common feeds are the same in both studies, with corn and soybean products more common in Ontario and barley and wheat products more common in the west. However, there are some major differences when comparing regions, with grass hay being more prevalent out West compared to Ontario having more alfalfa, where the opposite was found in the American counterparts. The American counterparts also used greater amounts of grains and byproducts such as corn grain and soybean meal. Whether this is still true 20 years after the survey by Mowrey and Spain (1998) is unknown.

3.5.5 Attitudes

Of the five areas to rank while balancing rations, performance was generally rated the highest for lactating and heifer rations (Table 13). In dry cow rations, performance was ranked second to health, and production was still rated highest by OT farms. Overall, farmers were more interested in cow performance above all other factors. In Canada, dairy farms operate using a supply management system, unlike all other countries. The Canadian supply management system controls the Canadian dairy industry by fixing the price producers are paid for their milk, using a quota system to control production per farm, and by controlling the amount of imports from other countries (Dairy Farmers of Canada, 2019). For Canadian dairy farmers, producing enough milk to meet their quota will maximize their income from their dairy cattle, which is likely very important for dairy producers, and this focus on production appears to be true for most responding farms. However, since farmers cannot produce over quota in the supply management system, this interest in increasing production seems to be counter-intuitive, unless that farmer was shipping under quota. Even within the quota system, dairy farmers want to get the best production out of their cattle, as there is more focus on getting more production out of a smaller herd than just expanding herd size and production. Improving production efficiency is likely the top goal for Canadian dairy producers and this is reaffirmed with the survey. For dry and heifer rations, respondents may have taken "performance" to mean something different than milk production, unlike when answering for lactating cattle. For dry cattle, respondents could have interpreted it as either production in the next lactation, or maintaining target body condition through the dry period. Both of these factors would be considered important and could explain why production was very important in dry cattle rations. For heifers, "performance" was likely taken to mean growth performance for the heifers, which would be of upmost importance to the producer. The fact that "performance" can be interpreted in different ways could have led to its increased importance among respondents.

Health was rated the second highest factor across lactating cow, heifer, and dry cow rations (Table 13). Health ranks high as farmers want to minimize sickness on their farms, as healthier cows will produce more milk and have more reproductive success while minimizing treatment and veterinary costs. Following health was cost and simplicity, which were generally valued similarly, with cost slightly more important in lactating cow rations and simplicity ranking higher for dry cow and heifer rations. Nutrient management was rated the lowest priority.

Cost being rated lower is interesting as feed costs are a high expense for dairy farmers. Feed costs are the number one expense for Canadian dairy farms, encompassing 27% of all costs in 2010 (Lachapelle et al., 2011). Thus, it may be expected that farmers may place high priority on reducing feed costs, particularly considering Canada's quota system. There is less of a need to constantly expand production, as each farm has a quota to produce. Survey respondents seem to focus more on improving the production efficiency of their cattle to lower costs instead of focusing on cheaper feeds, as suggested by their valuing cow performance and health over feed costs. Yet when comparing to the feeds they use in their rations (Tables 7-8), the survey found farmers generally use feeds more commonly grown within their region, so cost is taken into consideration and may be underrated by respondents. Simplicity is similarly rated to cost and ranks higher in dry and heifer diets. This matches with the ration ingredient responses, which showed that producers use less feed ingredients for those rations compared to lactating cow rations. The low ranking of nutrient management demonstrates that for respondents, productivity takes priority over all else, even if cheaper and more efficient feeding strategies are available. This is an area of opportunity for producer education, particularly for farms in Ontario bordering the Great Lakes. Nutrient management had a higher rating in WP farms, having a higher average rating than cost in dry and heifer diets and a higher average rating than simplicity for lactating and dry diets there. The survey found that nutrient management is less important on OF and OT farms. There was a significant difference in WP farms as well, as production had a lower average rating for heifer and dry cow diets, while cost had a lower average rating in all three types of rations compared to OF and OT farms. It seems that these are the areas that were more often ranked lower for an increase in rank for nutrient management. However, even with this increase, nutrient management still had the lowest average rating among WP farms. The vast majority of respondents used nutritionists, who may have different views than the producers themselves.

There are inconsistencies comparing these results with results for grouping and ration strategies (Tables 3-5, 9-12). Since there are lower levels of precision feeding, there may be expectations for simplicity and cost to rate higher, especially in regards to the dry and heifer rations. There may be some bias shown in this question as farmers, even though answering anonymously, want to appear to be doing the best for their cattle regardless of cost.

3.5.6 Feed management

Questions were asked to determine if farmers were willing to incorporate new feeds along with their attitudes for testing feeds and rebalancing rations (Table 14). St. Pierre and Weiss (2015) showed that nutrient composition within feeds can vary even within samples on farms. These questions were examining whether farmers were managing these potential variations. In survey answers, most farms agreed with frequent testing and rebalancing.

However, even though they tested significantly less, the majority of OT farms agreed with this statement.

Overall, Canadian dairy producers responding to the survey generally follow national numbers for herd size and barn type, and feeding practices seem to follow the types of crops grown within that particular region. Farmers value production and health as the most important factors in creating a dairy ration for all stages of cattle. The Canadian quota system leads to producers focusing more on improving the efficiency of their production to lower costs rather than using cheaper feeds. Numbers do show that although cost is not valued as much by producers, there is still a large impact as farmers will get their feed locally. As the majority of farmers use nutritionists, it would be interesting to hear what their opinion is on creating rations.

Table 1: Average herd sizes across responding Ontario and Western Canadian dairy producers

	Pan-Canadian Farm Location[1]				
	Total	WP	OF	OT	P-value
Herd Size					<0.01
Average	113	160 [a]	115 [b]	57 [c]	
Minimum	12	12	32	25	
Maximum	1100	1100	480	250	
St. Dev.	127	180	87	30	

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

Table 2: Farm demographics across responding dairy producers

	Pan-Canadian Farm Location[1]								
	Total		WP		OF		OT		P-value
	Number of Responses	Total %	Number of Responses	% of WP	Number of Responses	% of OF	Number of Responses	% of OT	
Who is responsible for balancing your rations?									0.08
Nutritionist	188	82.8	68	82.9 [a]	59	79.7 [a]	61	85.9 [a]	
Producer	30	13.2	14	17.1 [a]	9	12.2 [a]	7	9.9 [a]	
Veterinarian	9	4.0	0	0.0 [a]	6	8.1 [ab]	3	4.2 [b]	
Other	0	0.0	0		0		0		
Is your farm organic?									0.93
Yes	8	3.5	3	3.6 [a]	3	4.0 [a]	2	2.8 [a]	
No	222	96.5	81	96.4 [a]	72	96.0 [a]	69	97.2 [a]	
In what type of barn do you house lactating cows?									<0.01
Freestall	140	60.9	74	88.1 [a]	66	88.0 [a]	0	0.0 [b]	
Tiestall	80	34.8	9	10.7 [a]	0	0.0 [b]	71	100.0 [c]	
Other	10	4.4	1	1.2 [a]	9	12.0 [a]	0	0.0 [a]	
Do you utilize a robot for milking cattle?									<0.01
Yes	40	17.5	17	20.2 [a]	23	31.1 [a]	0	0.0 [b]	
No	189	82.5	67	79.8 [a]	51	68.9 [a]	71	100.0 [b]	
No response	1		0		1		0		
Do you provide additional supplements to lactating cattle based on age or stage of lactation?									0.06
Yes	68	37.4	18	29.0 [a]	24	35.3 [a]	26	50.0 [a]	
No	114	62.6	44	71.0 [a]	44	64.7 [a]	26	50.0 [a]	

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

Table 3: Farm demographics questions asking Ontario and Western Canadian dairy producers about group numbers

			Pan-Canadian Farm Location[1]						
	Total Number of Responses	Total %	WP Number of Responses	% of WP	OF Number of Responses	% of OF	OT Number of Responses	% of OT	P-value
How many groups do you keep your lactating cattle in?									<0.01
1	139	61.2	40	47.6 [a]	42	56.8 [a]	57	82.6 [b]	
2	44	19.4	21	25.0 [a]	14	18.9 [a]	9	13.0 [a]	
3	28	12.3	14	16.7 [a]	12	16.2 [a]	2	2.9 [b]	
4+	16	7.1	9	10.7 [a]	6	8.1 [a]	1	1.5 [a]	
Please specify[2] how you separate your cattle into different groups.									
Age	39	44.3	19	44.2 [a]	20	60.6 [a]	0	0.0 [b]	<0.01
Health	18	20.5	10	23.3 [a]	7	21.2 [a]	1	8.3 [a]	0.52
Repro.	16	18.2	6	14.0 [a]	6	18.2 [a]	4	33.3 [a]	0.31
Stage of Lactation	51	58.0	22	51.2 [a]	20	60.6 [a]	9	75.0 [a]	0.46
Other	10	11.4	4	9.3	5	15.2	1	8.3	
Total Responses	88 farms		43 farms		33 farms		12 farms		

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[2] Respondents could answer multiple responses.

[a,b,c] = Numbers with different superscripts within a row differ significantly (*P* < 0.05).

Table 4: Farm demographics questions asking Ontario and Western Canadian dairy producers about feeding strategies

	Pan-Canadian Farm Location[1]								
	Total		WP		OF		OT		
	Number of Responses	Total %	Number of Responses	% of WP	Number of Responses	% of OF	Number of Responses	% of OT	P-value
How many rations do you feed your lactating cattle?									0.07
1	183	81.3	62	74.7 [a]	69	92.0 [b]	52	76.5 [ab]	
2	30	13.3	15	18.1 [a]	6	8.0 [a]	10	14.7 [a]	
3	8	3.6	5	6.0 [a]	0	0.0 [a]	3	4.4 [a]	
4+	4	1.8	1	1.2 [a]	0	0.0 [a]	3	4.4 [a]	
What are your reasons[2] for changing between lactating cattle rations?									
Age	8	19.1	4	20.0 [a]	2	33.3 [a]	2	12.5 [a]	0.54
Nutrient Req.	20	47.6	8	40.0 [a]	2	33.3 [a]	10	62.5 [a]	0.51
DIM	21	50.0	9	45.0 [a]	3	50.0 [a]	9	56.3 [a]	0.8
Milk production	23	54.8	8	40.0 [a]	3	50.0 [a]	12	75.0 [a]	0.11
Repro. Status	17	40.5	7	35.0 [a]	3	50.0 [a]	7	43.8 [a]	0.62
Health	7	16.7	3	15.0 [a]	1	16.7 [a]	3	18.8 [a]	0.96
Other	5	11.9	1	5.0	1	16.7	3	18.8	
Total Responses	42		20		6		16		
Do you give lactating cattle access to pasture at any point during the year?									0.01
Yes	57	25.1	17	20.5 [a]	13	17.3 [a]	27	39.1 [b]	
No	170	74.9	66	79.5 [a]	62	82.7 [a]	42	60.9 [b]	

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[2] Respondents could answer multiple responses.

[a,b,c] = Numbers with different superscripts within a row differ significantly (*P* < 0.05).

Table 5: Farm demographics questions asking Ontario and Western Canadian dairy producers about dry cow management

	Pan-Canadian Farm Location[1]								
	Total		WP		OF		OT		
	Number of Responses	Total %	Number of Responses	% of WP	Number of Responses	% of OF	Number of Responses	% of OT	P-value
Do you give your dry cattle pasture access at any point during the year?									<0.01
Yes	117	52.7	33	41.3 [a]	31	43.1 [a]	53	75.7 [b]	
No	105	47.3	47	58.8 [a]	41	56.9 [a]	17	24.3 [b]	
How many different rations do you feed to your dry cattle and pre-fresh heifers?									0.1
1	132	61.7	43	55.1 [a]	43	59.7 [a]	46	71.9 [a]	
2	79	36.9	34	43.6 [a]	28	38.9 [a]	17	26.6 [a]	
3 or more	3	1.4	1	1.3 [a]	1	1.4 [a]	1	1.6 [a]	
Do pre-fresh heifers (2 months or less prior to calving) get same ration as pre-fresh cows?									0.19
Yes	195	90.7	75	94.9 [a]	64	90.1 [a]	56	86.2 [a]	
No	20	9.3	4	5.1 [a]	7	9.9 [a]	9	13.9 [a]	

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

Table 6: Farm demographics questions asking Ontario and Western Canadian dairy producers about heifer ration management

	Total		Pan-Canadian Farm Location[1] WP		OF		OT		P-value
	Number of Responses	Total %	Number of Responses	% of WP	Number of Responses	% of OF	Number of Responses	% of OT	
Do you give your heifers pasture access?									0.01
Yes	106	49.1	34	43.6 [a]	29	40.3 [a]	43	65.2 [b]	
No	110	50.9	44	56.4 [a]	43	59.7 [a]	23	34.9 [b]	
How many rations do you feed between weaning and first calving?									0.2
1	65	30.4	20	25.6 [ab]	17	23.6 [a]	28	43.8 [b]	
2	81	37.9	31	39.7 [a]	30	41.7 [a]	20	31.3 [a]	
3	52	24.3	22	28.2 [a]	18	25.0 [a]	12	18.8 [a]	
4 or more	16	7.5	5	6.4 [a]	7	9.7 [a]	4	6.3 [a]	
What are your reasons[2] for changing between heifer rations?									
Age	127	85.2	49	84.5 [a]	47	85.5 [a]	31	86.1 [a]	0.98
Size	85	57.1	35	60.3 [a]	31	56.4 [a]	19	52.8 [a]	0.77
Reproductive Status	67	45.0	19	32.8 [a]	32	58.2 [b]	16	44.4 [ab]	0.03
Health	20	13.4	9	15.5 [a]	5	9.1 [a]	6	16.7 [a]	0.49
Other	13	8.7	4	6.9	6	10.9	3	8.3	
Total	149		58		55		36		

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[2] Respondents could answer multiple responses.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

Table 7: Farm demographics questions about use of forage ingredients in lactating rations

	Pan-Canadian Farm Location[1]								
Lactating Diet Ingredient	Canada		WP		OF		OT		P-Value
Forages	# of Responses	%	# of Responses	%	# of Responses	%	# of Responses	%	
Corn silage, BMR	34	15.4	5	6.3 [a]	18	24.0 [b]	11	16.7 [ab]	0.01
Corn silage, conventional	161	72.9	45	56.3 [a]	60	80.0 [b]	56	84.9 [b]	<0.01
Hay, grass	60	27.2	36	45.0 [a]	7	9.3 [b]	17	25.8 [c]	<0.01
Hay, legume	65	29.4	32	40.0 [a]	12	16.0 [b]	21	31.8 [ab]	<0.01
Hay, mixed	64	29.0	22	27.5 [ab]	13	17.3 [a]	29	43.9 [b]	<0.01
Haylage, grass	41	18.6	21	26.3 [a]	10	13.3 [a]	10	15.2 [a]	0.08
Haylage, legume	77	34.8	17	21.3 [a]	34	45.3 [b]	26	39.4 [ab]	0.01
Haylage, mixed	92	41.6	17	21.3 [a]	36	48.0 [b]	39	59.1 [b]	<0.01
straw	80	36.2	27	33.8 [a]	31	41.3 [a]	22	33.3 [a]	0.52

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

Table 8: Farm demographics questions about use of concentrates and byproducts feeds in lactating rations

	Pan-Canadian Farm Location[1]								
Lactating Diet Ingredient	Canada		WP		OF		OT		P-Value
	Response #	%	Response #	%	Response #	%	Response #	%	
Concentrates									
Barley	74	33.5	55	68.8 [a]	3	4.0 [b]	16	24.2 [c]	<0.01
Bypass fats	118	53.4	54	67.5 [a]	38	50.7 [ab]	26	39.4 [b]	<0.01
Corn grain, cracked or ground	128	57.9	40	50.0 [a]	40	53.3 [ab]	48	72.7 [b]	0.01
High moisture corn	52	23.5	4	5.0 [a]	27	36.0 [b]	21	31.8 [b]	<0.01
Molasses	21	9.5	13	16.3 [a]	2	2.7 [b]	6	9.1 [ab]	0.02
Roasted soybeans	27	12.2	4	5.0 [a]	9	12.0 [ab]	14	21.2[b]	0.01
Soybean meal	125	56.6	31	38.8 [a]	57	76.0 [b]	37	56.1 [a]	<0.01
Wheat	18	8.1	10	12.5 [a]	1	1.3 [b]	7	10.6 [ab]	0.03
Byproducts									
Beet pulp	18	8.1	15	18.8 [a]	1	1.3 [b]	2	3.0 [b]	<0.01
Brewer's grains	21	9.5	8	10.0 [ab]	12	16.0 [a]	1	1.5 [b]	0.01
Canola meal	77	34.8	39	48.8 [a]	28	37.3 [a]	10	15.2 [b]	<0.01
Corn distiller's grains	73	33.0	21	26.3 [a]	31	41.3 [a]	21	31.8 [a]	0.13
Corn gluten meal	23	10.4	8	10.0 [a]	11	14.7 [a]	4	6.1 [a]	0.25
Cottonseed	6	2.7	1	1.3 [a]	4	5.3 [a]	1	1.5 [a]	0.23
Soy hulls	8	3.6	3	3.8 [a]	3	4.0 [a]	2	3.0 [a]	0.95
Wheat distiller's grains	10	4.5	10	12.5 [a]	0	0.0 [b]	0	0.0 [b]	<0.01

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

Table 9: Farm demographics questions about use of forage ingredients in dry cow rations

			Pan-Canadian Farm Location[1]						
Dry Diet Ingredient	Total		WP		OF		OT		P-Value
Forages	# of Responses	%	# of Responses	%	# of Responses	%	# of Responses	%	
Corn silage, BMR	25	11.7	3	4.0 [a]	13	18.1 [b]	9	13.9 [ab]	0.02
Corn silage, conventional	140	65.7	32	42.1 [a]	58	80.6 [b]	50	76.9 [b]	<0.01
Hay, grass	100	47.0	55	72.4 [a]	19	26.4 [b]	26	40.0 [b]	<0.01
Hay, legume	20	9.4	12	15.8 [a]	3	4.2 [a]	5	7.7 [a]	0.05
Hay, mixed	66	31.0	18	23.7 [a]	15	20.8 [a]	33	50.8 [b]	<0.01
Haylage, grass	33	15.5	20	26.3 [a]	6	8.3 [b]	7	10.8 [ab]	0.01
Haylage, legume	37	17.4	9	11.8 [a]	17	23.6 [a]	11	16.9 [a]	0.17
Haylage, mixed	46	21.6	7	9.2 [a]	22	30.6 [b]	17	26.2 [b]	<0.01
Straw	101	47.4	38	50.0 [a]	48	66.7 [a]	15	23.1 [b]	<0.01

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

Table 10: Farm demographics questions about use of concentrate and byproduct feeds in dry cow rations

	Pan-Canadian Farm Location[1]								
Dry Diet Ingredient	Total		WP		OF		OT		P-Value
	# of Responses	%	# of Responses	%	# of Responses	%	# of Responses	%	
Concentrates									
Barley	44	20.7	34	44.7[a]	0	0.0[b]	10	15.4[c]	<0.01
Bypass fats	1	0.5	0	0.0[a]	0	0.0[a]	1	1.5[a]	0.32
Corn grain, cracked or ground	38	17.8	7	9.2[a]	12	16.7[ab]	19	29.2[b]	0.01
High moisture corn	17	8.0	1	1.3[a]	7	9.7[ab]	9	13.9[b]	0.02
Molasses	8	3.8	3	4.0[a]	2	2.8[a]	3	4.6[a]	0.85
Roasted soybeans	7	3.3	1	1.3[a]	1	1.4[a]	5	7.7[a]	0.06
Soybean meal	65	30.5	13	17.1[a]	31	43.1[b]	21	32.3	<0.01
Wheat	6	2.8	1	1.3[a]	3	4.2[a]	2	3.1[a]	0.57
Byproducts									
Beet pulp	10	4.7	6	7.9[a]	3	4.2[a]	1	1.5[a]	0.2
Brewer's grains	11	5.2	5	6.6[a]	5	6.9[a]	1	1.5[a]	0.28
Canola meal	42	19.7	17	22.4	19	26.4[a]	6	9.2[b]	0.03
Corn distiller's grains	39	18.3	12	15.8[a]	18	25.0[a]	9	13.9[a]	0.19
Corn gluten meal	6	2.8	1	1.3[a]	4	5.6[a]	1	1.5[a]	0.23
Cottonseed	0	0.0	0	0.0[a]	0	0.0[a]	0	0.0[a]	
Soy hulls	3	1.4	2	2.6[a]	0	0.0[a]	1	1.5[a]	0.4
Wheat distiller's grains	7	3.3	7	9.2[a]	0	0.0[b]	0	0.0[b]	<0.01

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

Table 11: Farm demographics questions about use of forage ingredients in heifer rations

	Pan-Canadian Farm Location[1]								
Heifer Diet Ingredient	Total		WP		OF		OT		P-Value
Forages	# of Responses	%	# of Responses	%	# of Responses	%	# of Responses	%	
Corn silage, BMR	19	9.1	2	2.6 [a]	8	11.1 [ab]	9	14.5 [b]	0.04
Corn silage, conventional	119	56.7	28	36.8 [a]	49	68.1 [b]	42	67.7 [b]	<0.01
Hay, grass	83	39.5	46	60.5 [a]	23	31.9 [b]	14	22.6 [b]	<0.01
Hay, legume	43	20.5	18	23.7 [a]	11	15.3 [a]	14	22.6 [a]	0.4
Hay, mixed	109	51.9	30	39.5 [a]	37	51.4 [ab]	42	67.7 [b]	<0.01
Haylage, grass	35	16.7	21	27.6 [a]	5	6.9 [b]	9	14.5 [ab]	<0.01
Haylage, legume	45	21.4	15	19.7 [a]	17	23.6 [a]	13	21.0 [a]	0.84
Haylage, mixed	73	34.8	13	17.1 [a]	38	52.8 [b]	22	35.5 [b]	<0.01
Straw	62	29.5	30	39.5 [a]	26	36.1 [a]	6	9.7 [b]	<0.01

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

Table 12: Farm demographics questions about use of concentrate and byproduct feeds in heifer rations

Heifer Diet Ingredient	Total		WP		OF		OT		P-Value
	Pan-Canadian Farm Location[1]								
	# of Responses	%	# of Responses	%	# of Responses	%	# of Responses	%	
Concentrates									
Barley	67	31.9	47	61.8 [a]	7	9.7 [b]	13	21.0 [b]	<0.01
Bypass fats	4	1.9	2	2.6 [a]	0	0.0 [a]	2	3.2 [a]	0.33
Corn grain, cracked or ground	76	36.2	17	22.4 [a]	24	33.3 [a]	35	56.5 [b]	<0.01
High moisture corn	23	11.0	3	4.0 [a]	10	13.9	10	16.1 [b]	0.05
Molasses	13	6.2	5	6.6 [a]	4	5.6 [a]	4	6.5 [a]	0.96
Roasted soybeans	9	4.3	0	0.0 [a]	3	4.2 [ab]	6	9.7 [b]	0.02
Soybean meal	69	32.9	12	15.8 [a]	33	45.8 [b]	24	38.7 [b]	<0.01
Wheat	7	3.3	4	5.3 [a]	2	2.8 [a]	1	1.6 [a]	0.47
Byproducts									
Beet pulp	10	4.8	7	9.2 [a]	0	0.0 [b]	3	4.8 [ab]	0.03
Brewer's grains	12	5.7	7	9.2 [a]	4	5.6 [a]	1	1.6 [a]	0.16
Canola meal	43	20.5	21	27.6 [a]	14	19.4 [a]	8	12.9 [a]	0.1
Corn distiller's grains	39	18.6	15	19.7 [a]	12	16.7 [a]	12	19.4 [a]	0.88
Corn gluten meal	11	5.2	1	1.3 [a]	7	9.7 [a]	3	4.8 [a]	0.07
Cottonseed	0	0.0	0	0.0 [a]	0	0.0 [a]	0	0.0 [a]	
Soy hulls	2	1.0	0	0.0 [a]	0	0.0 [a]	2	3.2 [a]	0.09
Wheat distiller's grains	6	2.9	6	7.9 [a]	0	0.0 [b]	0	0.0 [ab]	<0.01

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

Table 13: Farm demographics questions about attitudes on formulating rations

	Performance	Cost	Simplicity	Nutrient Management	Health
Rank how important these factors are to your overall nutrition goals with your lactating cow rations [1].					
Total Average	1.5	3.5	3.8	4.2	2.1
WP[2] Score Average	1.5 [a]	3.7 [a]	3.9 [a]	3.7 [a]	2.2 [a]
OF[2] Score Average	1.4 [a]	3.2 [b]	3.8 [a]	4.5 [b]	2.0 [a]
OT[2] Score Average	1.5 [a]	3.5 [ab]	3.6 [a]	4.3 [b]	2.1 [a]
P-Value	0.43	0.02	0.14	0	0.77
Rank how important these factors are to your overall nutrition goals with your dry cow rations [1].					
Total Average	1.9	3.6	3.5	4.2	1.8
WP[2] Score Average	2.1 [a]	3.8 [a]	3.6 [a]	3.6 [a]	1.8 [a]
OF[2] Score Average	1.7 [b]	3.5 [b]	3.5 [a]	4.6 [b]	1.7 [a]
OT[2] Score Average	1.7 [b]	3.6 [ab]	3.4 [a]	4.3 [b]	2.0 [a]
P-Value	0.01	0.04	0.36	0	0.11
Rank how important these factors are to your overall nutrition goals with your heifer rations [1].					
Total Average	1.7	3.6	3.3	4.1	2.3
WP[2] Score Average	1.9 [a]	3.8 [a]	3.4 [a]	3.7 [a]	2.2 [a]
OF[2] Score Average	1.5 [b]	3.5 [a]	3.2 [a]	4.5 [b]	2.3 [a]
OT[2] Score Average	1.7 [ab]	3.6 [a]	3.2 [a]	4.3 [b]	2.3 [a]
P-Value	0.03	0.08	0.52	<0.01	0.59

[a,b,c] = Numbers with different superscripts within a column differ significantly per question ($P < 0.05$).

[1] = From a score of 1 to 5, with 1 being most important and 5 being least important.

[2] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

Table 14: Farm demographics questions about producers attitudes on utilizing new feeds and rebalancing[1]

	Pan-Canadian Farm Location[2]				
	Total	WP	OF	OT	P-Value
I am willing to incorporate new feeds into rations	Number of Responses	Number of Responses	Number of Responses	Number of Responses	0.96
Total	214	77	72	65	
% Agree	81.8	85.7	81.9	76.9	
Feedstuffs should be tested frequently		[a]	[a]	[a]	0.02
Total	214	78	72	64	
% Agree	91.1	97.4	90.3	84.4	
Rations should be rebalanced often		[a]	[a]	[a]	0.3
Total	213	78	70	65	
% Agree	85.9	87.2	90.0	80.0	

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

[1] = For each statement, farmers chose from one of seven answers ranging from "strongly agree" to "strongly disagree". The rows "% Agree" show the percentage of farmers who chose one of the first three responses, of "strongly agree", "agree" and "somewhat agree".

[2] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

Table 15: Farm demographics questions about questions on feeding practices

	Pan-Canadian Farm Location[1]				
	CANADA	WP	OF	OT	P-Value
How often do you deliver feed to lactating cows?					<0.01
Less than once a day	2	0 [a]	1 [a]	1 [a]	
Once a day	77	43 [a]	30 [a]	4 [b]	
Twice a day	93	24 [a]	32 [ab]	37 [b]	
More than twice a day	44	11 [a]	9 [a]	24 [b]	
How often do you push up feed for lactating cows?					0.03
Never	13	3 [a]	7 [a]	3 [a]	
Once a day	5	2 [a]	1 [a]	2 [a]	
2-4 times a day	81	32 [a]	16 [b]	33 [a]	
5-7 times a day	63	22 [a]	22 [a]	19 [a]	
> 7 times a day	54	19 [ab]	26 [a]	9 [b]	
How often do you deliver feed to dry cows?					<0.01
Less than once a day	51	18 [ab]	27 [a]	6 [b]	
Once a day	112	52 [b]	34 [a]	26 [a]	
Twice a day	44	8 [a]	10 [a]	26 [b]	
More than twice a day	9	0 [a]	1 [a]	8 [b]	
How often do you push up feed for dry cows?					0.02
Never	38	18 [a]	6 [b]	14 [ab]	
Once a day	29	11 [a]	8 [a]	10 [a]	
2-4 times a day	94	30 [a]	30 [a]	34 [a]	
5-7 times a day	26	9 [a]	12 [a]	5 [a]	
More than 7 times a day	29	10 [ab]	16 [a]	3 [b]	

[a,b,c] = Numbers with different superscripts within a differ significantly ($P < 0.05$).

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

4 Experiment 2: Effect of rumen-protected lysine supplementation to total mixed rations differing in crude protein concentration in lactating cows

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4.1 ABSTRACT

A feeding trial was performed to determine the effects of rumen-protected lysine (Lys) supplementation in lactating cattle diets differing in crude protein (CP) content. Twelve multiparous mid-lactation Holstein cows were blocked by days in milk (DIM) into triplicate 4 × 4 Latin squares. Diets were arranged in a 2 × 2 factorial design with a total of 4 diets for each cow including; (1) 15% dietary CP with Lys supplementation top-dressed (LO+Lys); (2) 15% dietary CP with no Lys supplementation (LO-Lys); (3) 17% dietary CP with Lys supplementation top-dressed (HI+Lys); and (4) 17% dietary CP without Lys supplementation (LO-Lys). Periods consisted of 14 d of adaptation followed by a sampling period of 3 d. During sampling periods, daily milk yield and DMI were recorded, along with total collection of urine and feces. Milk, urine, fecal, and plasma samples were collected for additional analysis. No significant interactions were found between CP content and Lys supplementation. An increase in dietary CP from LO to HI led to increases for both DMI and N intake ($P \leq 0.01$). The production of milk ($P = 0.03$), milk fat ($P = 0.05$), and milk protein ($P \leq 0.01$) increased with feeding greater dietary CP. Other production parameters which increased with dietary CP level included milk protein percentages ($P = 0.01$), energy-corrected milk (ECM) yield ($P = 0.02$) and milk urea nitrogen (MUN) ($P \leq 0.01$). However, HI protein diets also significantly increased urine ($P \leq 0.01$) and fecal ($P = 0.04$) production. Total N balance was increased ($P = 0.02$) within cows fed the HI protein diets. Waste components such as fecal and urinary nitrogen (N) and NH_4-N and fecal P were increased ($P \leq 0.01$) with feeding greater dietary CP. Introducing Lys supplementation to the diets increased production of milk ($P \leq 0.01$), milk fat ($P = 0.01$), and milk protein ($P \leq 0.01$), and increased (ECM) yield ($P \leq 0.01$) regardless of dietary CP level fed. An increase in total N balance ($P = 0.04$) was also observed when cows received Lys

supplementation. There was no change in DMI and N intake, MUN, or urine and fecal production and composition as a result of Lys supplementation. No changes were detected in blood glucose, free fatty acids, or β-hydroxybutyrate (BHB) levels as a result of either dietary CP level or Lys supplementation. The study found that supplementing Lys in low CP diets can result in similar milk production to feeding high CP diets without Lys supplementation. In addition, feeding the LO+Lys diet significantly reduces N intake and waste and is a more N efficient diet to feed to lactating cattle.

4.2 INTRODUCTION

Ruminants such as dairy cattle have low N efficiency, due to the rumen microbes also using some of the dietary N(Van Amburgh et al., 2018). This means large amounts of CP that are fed to dairy cattle are left unused by the cow and are instead expelled in urine. Milk N efficiency has been reported at approximately 25% of total ingested N (Huhtanen and Hristov, 2009). Reducing the amount of N waste can reduce feed costs and is beneficial for the environment (Van Amburgh et al., 2018). The easiest and most common way to improve N efficiency is to lower dietary CP content in the ration (Huhtanen and Hristov, 2009). However, this must be done carefully to avoid a negative impact on milk production (Broderick, 2003).

The reduction in performance from feeding inadequate amounts of dietary CP is likely due to the cow needing certain essential amino acids (EAA) for growth and milk production. If there is a limited amount of one or more EAA within the diet as a result of lowering dietary CP levels, the protein production of the cow is unable to continue beyond that EAA, which is called a limiting EAA. This leads to large amounts of excess amino acids being unused by the cattle and excreted in urine and feces (Broderick, 2003). The impacts of rumen microorganisms for use of dietary protein for creating microbial crude protein (MCP) can also cause difficulties in controlling EAA availability for metabolism (Lapierre et al., 2006). Research has shown that the two most common limiting EAA in dairy cattle diets are Met and Lys (NRC, 2001). A way to ensure that adequate amounts of these EAA are available to the cow is by feeding ruminally protected supplements for these EAA. As these supplements are ruminally protected, they are unable to be incorporated into MCP by rumen microbes in the rumen, and are instead digested and absorbed directly by the cow in the small intestine (Robinson et al., 1998). Ruminally protected EAA are a type of rumen undegradable protein (RUP), which includes protein sources that are unable to be used by the rumen microbes to create MCP. These RUP supplements should lead to increased uptake of the limiting EAA by cattle, resulting in increased growth and milk production provided the RUP is available for the digestive processes found in the ruminant small intestine. This supplementation should also lead to an increase in N efficiency in cattle, by reducing the amount of N waste produced (Arriola Apelo et al., 2014). By combining RUP supplements with reducing total dietary CP in the diet, N efficiency could be increased further to reduce N waste, improving the environmental impact from cattle production

Research has shown that lowering CP in diets has increased N efficiency (Broderick et al., 2008). Feeding high protein diets with CP fed at 18% of dietary DM reduced N efficiency with no impact on milk yield compared to feeding 17% CP diets (Broderick, 2003). If CP is lowered to 13-14% CP in the diet, it can have a negative impact on milk yield (Frank and Swensson, 2002; Piepenbrink et al., 1991), although there have been some instances where feeding low CP diets at around 15% CP has no impact on milk yield compared to feeding high CP diets (Olmos Colmenero and Broderick, 2006; Mutsvangwa et al., 2016). Similar milk production has been found with cows fed diets with 17% CP versus cows fed diets with 15% CP with additional supplementation of ruminally protected EAA such as Met and Lys (Leonardi et al., 2003; Arriola Apelo et al., 2014). There is more interest now in moving beyond using just using dietary CP as a measurement and instead using less broad measurements such as AA intake and types of protein consumed to meet demands for ruminant production (Schwab and Broderick, 2017). Research into feeding ruminally protected Lys as the only supplement in protein deficient diets has generally shown no differences in milk yields (Giallongo et al., 2016; Swanepoel et al., 2010; Robinson et al., 1998), although it has been found to increase milk protein % levels (Arriola Apelo et al., 2014; Giallongo et al., 2016). Lys supplementation has also improved N efficiency in cattle (Arriola Apelo et al., 2014). More commonly ruminally protected Lys and Met supplements were added together, sometimes with His included as well for AA supplementation (Lee et al., 2012, Giallongo et al., 2016). When added together, there were varying responses with either no differences in milk yield (Giallongo et al., 2016) or an increase in milk production (Lee et al. 2012; Wang et al., 2010) versus feeding diets without AA supplementation.

The objectives of this study were to investigate the impacts of feeding a rumen-protected Lys supplement on diets with two different levels of CP content (15% vs. 17% of diet DM) where Lys was the limiting EAA for both milk production and N utilization and efficiency.

4.3 MATERIALS AND METHODS

4.3.1 Animals and Diets

All experimental protocols in this study were approved by the Animal Care Committee at the University of Guelph. Twelve multiparous high producing mid-lactation dairy cows (DIM = 132 ± 22.5; daily milk yield =43.5 kg/d ± 8) were housed in a tiestall milking barn with partitions to provide individual feed bunk space. Cows were blocked by lactation number and DIM, and randomly assigned to dietary treatment within triplicate 4 × 4 Latin squares. Eight of the twelve cows were pregnant. Experimental diets were arranged in a 2 × 2 factorial design, with 15% or 17% dietary CP (LO vs. HI, respectively) with or without Lys inclusion (+ Lys vs. – Lys, respectively), for a total of 4 dietary treatments (LO+Lys, LO-Lys, HI+Lys, HI-Lys). The product, USA Lysine Dry Amino Acid (51.2% L-Lys; Kemin Industries Ltd., Des Moines, IA; 11.5 g) was supplemented as a top-dress at each feeding for a total of 23 g/d, or 11.78 g of Lys/d. Complete experimental diets are shown in Table 16, with nutrient composition of diets shown in Table 17. Chopped straw was included in the first two periods before rebalancing the diets due to difference in nutrient composition of the haylage for the second two periods (Table 16). Cows were fed and milked twice daily. Feed intake was measured daily and was offered with a target of 5-10% refusals to promote *ad libitum* intake.

4.3.2 Experimental Procedures

Four experimental periods consisted of 14 d of adaptation followed by 3 d of sample collection. During the data collection period, daily samples were taken for each individual feed ingredient as well as each diet for nutrient analysis into plastic bags before freezing before being sent for analysis. Total collection of feces and urine were performed for periods 2-4. Cows were fitted with Foley urinary catheters attached to a rubber hose leading into a pail containing 250 mL of HCl (1 N) for total urine collection. The pails were weighed at 3 AM and 3 PM to measure total urine output. Stainless steel trays were placed behind the cows in the gutter for feces collection, which was measured by weight immediately after urine measurement. Samples of urine and manure were taken at each weighing period for N analysis into plastic cups which were then sealed and refrigerated before being sent for analysis. Blood samples were taken from the coccygeal vein using a Vacutainer one-use holder (Becton Dickinson, Franklin Lakes, NJ) into test tubes containing 0.10 ml of EDTA (K3) 15% solution immediately before the afternoon feeding and approximately 6 hours after feeding. Blood samples were then centrifuged for plasma collection, and plasma was stored at -20°C. Total daily milk yields were recorded, and milk samples were taken at each milking for analysis.

4.3.3 Analysis

Milk samples were analyzed for fat, CP, milk urea N (MUN), and somatic cell count (SCC) by CanWest Dairy Herd Improvement (Guelph, ON, Canada), and urine, manure, and feed samples were analyzed by A & L Laboratories (London, ON, Canada). Feed was analyzed for dry matter, protein, ADF, NDF, ash, starch, fat, and minerals. Dry matter was determined by convectional forced air (method 934.01, AOAC, 2019 for forages; method 930.15, AOAC, 2019 for grains and dry ingredients). Protein was determined by combustion using a LECO FP628 Nitrogen analyser (Leco Instruments Inc., St. Joseph, MI) (method 990.03, AOAC, 2019). ADF was determined using Ankom Method 5 using an Ankom 200 Fiber Analyzer (ANKOM Technology, Macedon, NY) (method 973.18, AOAC, 2019). NDF was determined using Ankom Method 6 using an Ankom 200 Fiber Analyzer (ANKOM Technology, Macedon, NY) (method 2002.04, AOAC, 2019). Ash was determined using a Blue M Electric programmable asher (Thermal Products Solutions, White Deer, PA) for 3 h at 550 C (method 942.05, AOAC, 2019). Starch was determined using a Megazyme K-TSTA (fatty acid (FFA), and glucose levels using EnzyChrom Ketone Body Assay Kit, QuantiChrom Urea Assay Kit, Abnova Free Fatty Acid Assay Kit (BioAssay Systems, Hayward, CA, USA), and Glucose Colorimetric Detection Kit (Invitrogen, Carlsbad, CA, USA) following the manufacturer’s instructions. Total N of urine and manure was determined by N combustion using a LECO FP628 Nitrogen analyser (Leco Instruments Inc., St. Joseph, MI).

DMI was calculated using DM from feed samples analyzed and as-fed weight. Energy-corrected milk yield (ECM), a value which corrects more energy provided in milk fat and CP, was calculated as (milk yield × [948 + 376 × % fat + 209 × % CP] ÷ 3138). N intake was calculated as (DMI × [%CP ÷ 6.25]). Milk N was calculated as (milk protein ÷ 6.38). Urine components weights (N, NH_4-N) were calculated as (urine weight × component %). Fecal components weight (N, P, NH_4-N) were calculated as (manure weight × manure DM % × component %). Total N balance was calculated as (N intake – [milk N + urine N + fecal N]). Statistical analysis was performed in SAS (version 9.4) using the MIXED procedure with the fixed effects of period, cow, CP, Lys, and CP × Lys, with day as a repeated measure. LSMeans statements were adjusted by Tukey's test for the multiple groups. Significance was determined as $P \leq 0.05$, and tendencies are reported at $0.05 < P \leq 0.10$.

4.4 RESULTS

4.4.1 Milk Production and Composition and DMI

Analysis of the diets showed lower dietary CP levels than the formulations, especially in the first two periods. Periods 1-2 averaged CP levels of 13.2 and 14.7% DM, while periods 3-4 averaged CP levels of 14.6 and 16.2% DM, which were closer to the formulations (Table 16).

Measurements of milk production and composition are shown in Table 18. Across all measurements, there was no significant interaction of dietary CP and supplemental Lys. There was a significant effect of both protein level ($P = 0.03$) and Lys supplementation ($P \leq 0.01$) on milk yield. Milk production was significantly greater when Lys was added to both the LO and HI diets. Yields were similar between cows fed the LO diet with supplemental Lys to cows fed the HI diet without supplemental Lys ($P = 0.95$), as well as being statistically similar to the HI diet with supplemental Lys ($P = 0.45$). Milk fat percentages were not significantly different due to protein level ($P = 0.87$) or Lys supplementation ($P = 0.88$), although significant differences were observed in fat yield as affected by both dietary protein content ($P = 0.05$) and Lys supplementation ($P = 0.01$) due to increased milk yields. For percentage of milk protein there was a significant effect of levels of dietary CP ($P = 0.01$), with cows fed LO diets without Lys having a significantly lower percentage, while no differences were found with Lys supplementation ($P = 0.56$). For milk protein yield, there was a significant effect of both protein levels ($P \leq 0.01$) and Lys supplementation ($P = 0.01$), as cows fed LO diets without Lys had significantly lower milk protein yields than cows fed the other 3 diets, and cows fed HI diets with Lys had greater protein yields than all cows fed LO diets. Milk urea nitrogen (MUN) levels in HI diets were elevated versus LO diets ($P = 0.01$), and there were no significant differences associated with Lys supplementation ($P = 0.84$). There were no significant differences between diets in somatic cell count due to either protein level ($P = 0.65$) or Lys supplementation ($P = 0.62$).

Measurements in DMI and milk production efficiency are shown in Table 18 DMI had a significant effect of dietary CP ($P \leq 0.01$), with the only significant difference being between cows fed LO diets without Lys to cows fed HI diets with Lys, with no significant effect of Lys supplementation ($P = 0.34$). The ratio of milk yield per kg of DMI was significantly greater in the LO diets ($P = 0.05$), with no statistical differences in Lys supplementation ($P = 0.27$). There was a significant effect on ECM yields due to both CP level ($P = 0.02$) and Lys supplementation ($P \leq 0.01$), with the only significant difference being between cows fed LO diets without Lys to cows fed HI diets with Lys. There was a tendency for a greater ratio of ECM produced per kg of DMI in the LO diets ($P = 0.08$).

4.4.2 Blood Metabolites

No significant differences were detected in glucose, BUN, or FFA as a result of either dietary CP content or Lys supplementation ($P \geq 0.16$; Table 19). There was a tendency for BHB to be greater in the HI diets ($P = 0.06$), but BHB levels were not affected by Lys supplementation ($P = 0.71$).

4.4.3 Nitrogen Metabolism

Measurements in N waste are shown in Table 20. Urine volume was significantly greater in cows fed HI diets ($P \leq 0.01$), with no differences caused by Lys supplementation ($P = 0.82$), with cows fed LO diets without lysine producing significantly less urine than cows fed both HI diets. Urine N output (kg/d) was increased in cows fed HI diets compared to cows fed LO diets ($P \leq 0.01$), with no significant response to Lys supplementation ($P = 0.99$). Urine N % ($P \leq 0.01$) increased in cows fed HI diets compared to LO diets, with no significant change due to Lys supplementation ($P = 0.78$). There was no significant effect for urine ammonia (NH_4-N) in both dietary CP ($P = 0.06$) and Lys supplementation ($P = 0.75$) levels. Output of fecal DM (kg/d) showed a significant effect of dietary CP ($P = 0.04$), with no significant effect due to Lys ($P = 0.42$), although there were no statistical differences seen in cows across the four diets. Fecal N output (kg/d), N %, phosphorus output (kg/d), phosphorus % and NH_4-N output (kg/d) all showed a significant effect of dietary CP ($P \leq 0.01$), with no statistical differences seen due to Lys supplementation ($P \geq 0.32$). Fecal N was different between cows fed LO diets and cows fed HI+Lys diets. Fecal N %, and fecal P% was greater in HI diets compared to LO diets. Fecal P was different between cows fed LO-Lys diets and cows fed HI+Lys diets. Fecal NH_4-N was different between cows fed LO diets and cows fed HI+Lys diets. Measurements in N efficiency are shown in Table 21.N intake was significantly greater in the HI diets ($P \leq 0.01$), while also having a significantly lower ratio of milk N output to N intake ($P \leq 0.01$). Lys supplementation did not significantly impact N intake ($P = 0.35$). Total N balance showed a significant effect as a result of both increasing dietary protein content ($P = 0.02$) and Lys supplementation ($P = 0.04$), with the only different results being seen in cows fed LO-Lys diets to cows fed HI+Lys diets.

4.5 DISCUSSION

4.5.1 DMI

HI diets increased DMI in this experiment, consistent with prior research (Broderick, 2003, Piepenbrink et al., 1996). The greater DMI could be explained by the increase in milk production that is found in cows fed high versus low CP diets, as more energy, CP and EAA is required to produce the improved milk yield. Adding ruminally protected Lys as a supplement to the diets did not affect DMI in cattle across diets, similar to previous studies (Wang et al., 2010, Giallongo et al., 2016, Arriola Apelo et al., 2014). Since Lys was fed as a ruminally protected supplement, it likely did not impact rumen digestibility of the diet. This also shows that the supplement had no detrimental effects on DMI. The only significant difference in DMI between the four diets was between the LO-Lys diet and the HI+Lys diet, which can be explained by the high standard error (SE = 1.417) which is greater than what was reported in previous studies (Broderick, 2003). Feeding high amounts of CP decreased the milk yield:DMI ratio in line with previous research (Broderick, 2003). The milk yield:DMI ratio was not impacted by supplemental Lys. Overall there was a positive effect in DMI when a lactating diet has its CP content increased from LO to HI in this experiment.

4.5.2 Milk Production

A significant increase in milk yield in response to greater dietary CP levels has been reported in previous research wherein there were differing dietary CP levels in dairy cattle diets (Broderick, 2003, Piepenbrink et al., 1996, Giallongo et al., 2016). These experiments examined different dietary CP levels for lactation diets, comparing 14-15% dietary CP in the diet DM to 16-18% dietary CP in the diet DM. There have also been previous experiments where milk production does not differ between feeding low and high CP diets (Olmos Colmenero and Broderick, 2006; Mutsvangwa et al., 2016). The differences in results in these prior studies is likely a result of some low protein diets being deficient in protein and/or EAA for the cows, resulting in lower production, whereas in studies with no decrease in milk production, may not have had deficiencies in certain EAA. The increased DMI is also likely caused by greater milk production seen in the HI diets, resulting in greater energy requirements for milk production. The increase in ECM yield as a result of increasing dietary CP has been reported in previous research as well (Broderick, 2003, Broderick et al., 2009), as increased milk and milk protein yields with no effect on milk fat yield would also lead to increased ECM.

The increase in milk yield with Lys supplementation differs from past studies that fed Lys-deficient diets, wherein there was no difference in milk production (Wang et al., 2010; Giallongo et al., 2016; Swanepoel et al., 2010; Robinson et al., 1998). This effect was likely due to the diets in the current experiment having Lys as the limiting EAA. Without supplemental ruminally protected Lys, the cows were likely not receiving enough Lys within their diets, which limited milk production. While other studies have found little to no difference in milk yields with supplemental Lys added to diets (Giallongo et al., 2016, Robinson et al., 1997), these diets in previous studies were not balanced to have Lys as the limiting amino acid, instead Met or potentially His were most likely the limiting amino. Therefore, the diets in previous studies were not Lys-deficient, which is likely the reason for the lack of differences in milk yield between Lys-supplemented diets and controls. Based on the present work, if diets are balanced properly, RUP supplements of Lys can be beneficial to milk production at both low and high dietary CP levels.

4.5.3 Milk Composition

Changes were observed as a result of increased dietary CP in milk fat volume, while milk fat percentages were not affected. This has been reported in similar studies (Broderick, 2003, Piepenbrink et al., 1996). A Lys effect was not seen in prior studies (Arriola Apelo et al., 2014), but these studies also showed no increase in milk yield as well, which impacts milk fat yields. No supplementary Lys effects on milk fat percentage levels were reported in past experiments when either feeding high (16.5% CP; Wang et al., 2012) or low (15% CP) CP diets (Arriola Apelo et al., 2014). These past studies agree with the results seen here for both levels of CP.

Increases in milk protein production and milk protein percentage when feeding HI vs. LO diets are supported by findings in numerous past research studies (Arriola Apelo et al., 2014, Broderick et al., 2003, Leonardi et al., 2003). This increase in the amount f protein produced in milk is to be expected with an increase in dietary protein from 15% to 17% CP. Greater DMI levels may also have led to greater milk protein levels. Lys did not affect milk protein percentage, similar to prior studies comparing low and high CP diets (Wang et al., 2010, Arriola

Apelo et al., 2014). As the supplement did not result in a significant difference in N intake, this may explain the lack of change in milk protein percent. Supplemental Lys leading to an increase in milk protein has been found in past research (Arriola Apelo et al., 2014, Wang et al., 2010).

There was an increase in MUN in the present study feeding HI versus LO, a finding which has often been reported in the past (Arriola Apelo et al., 2014, Broderick et al., 2003, Leonardi et al., 2003). This increase in MUN is to be expected when increasing the amount of CP fed to cattle. Since MUN is a product of ammonia created by protein breakdown within the rumen and the cow, it would be expected for there to be greater protein breakdown in cows that are fed significantly more CP than other cattle. The failure of Lys supplementation to affect MUN has also been reported previously when feeding both high and low CP diets (Giallongo et al., 2016, Arriola Apelo et al., 2014, Wang et al., 2010). Supplementing rumen protected Lys does not affect N levels in milk nor has an impact on ammonia production from protein breakdown within the cow. The similar MUN levels with or without Lys supplementation is most likely due to no diet differences in CP intake or DMI. Since the cow is being provided with a protected supply of the limiting EAA Lys, this essential AA could not be used to produce ammonia from breakdown in the rumen, so this Lys supplement is going to be absorbed in the small intestine for use in the improved milk protein yield as found in Lys supplemented diets in the present study.

In this experiment, supplementing LYS to LO diets resulted in similar milk and fat production to cows fed HI-Lys. However, the percentages of milk components such as milk fat and milk protein were not impacted by Lys, likely due to the supplement not impacting dietary fat and CP intake by the cattle

4.5.4 Blood Composition

This experiment found no significant differences across all diets for blood metabolites. The lack of a dietary CP effect on BUN levels contrasts with previous research (Olmos Colmenero and Broderick, 2006, Piepenbrink et al., 1996), which reported increases in BUN with increased dietary CP. These results were not expected. The levels of BUN numerically increased, albeit not significantly, in cows fed the HI diets, in a similar pattern to the significant increase in MUN levels in cows fed HI diets. MUN levels were also lower in this study to these prior studies, so this could be a result of differences in diet composition and N efficiency, or a smaller sample size. Lys supplementation did not affect BUN levels in the past (Wang et al., 2012). This shows that the Lys supplementation did not impact ammonia production from protein breakdown.

There were no changes in plasma glucose concentrations by providing greater amounts of dietary CP with or without supplemental Lys in the present study which is supported by past research investigating the effect of feeding greater amounts of dietary protein (Giallongo et al., 2016) or Lys (Wang et al., 2012) in dairy cattle rations, although Giallongo et al. (2016) found that adding Lys to protein deficient lactation diets increased blood glucose concentrations. Blood glucose levels can be impacted by increased energy intake from greater DMI, which was only seen in cows fed HI+Lys diets to cows fed LO-Lys diets, so DMI did not change enough to impact blood glucose. Since only dietary CP changed between rations, while all other factors such as NDF were the same across rations, blood glucose should not be impacted. Blood NEFA and BHB levels were not measured in past studies examining the effects of differences in dietary CP or the usage of supplemental lysine. These metabolites were measured in the present study to determine if any dietary treatment was responsible for cows entering negative energy balance, as NEFA and BHB levels become elevated if cows are not receiving enough dietary energy relative to energy outputs in milk. None of the experimental diets caused negative energy balance, which should be the case as the diets had similar NE_L. The absence of dietary treatment effects on blood metabolites in the present study was expected except BUN content. BUN levels are similar to past studies; however, there are no significant differences across the four experimental diets.

4.5.5 Nitrogen Efficiency

An increase in urine volume in lactating cattle due to increasing dietary CP has been observed in numerous studies (Broderick, 2003, Leonardi et al., 2003, Olmos Colmenaro and Broderick, 2006). With elevated N intakes, elevated urine production is expected. Greater amounts of dietary CP should increase protein absorption with resultant increases in water intake required by the cows to dilute the increased amount of N metabolites reaching the kidneys into urine (Broderick, 2003). Greater levels in both urine N production and urine N percent as a result of increasing dietary CP have been reported in previous research (Broderick, 2008, Olmos Colmenaro and Broderick, 2006). Urine NH_4-N concentrations were also elevated in cows fed high CP diets, in agreement with Olmos Colmeraro and Broderick (2006). Again, greater N intakes by cattle also elevated the amount of N that is lost in urine. Lys supplementation did not impact either total urine production or the production of urine N and NH_4-N, or urine N percent. Since there were no significant differences in N intake from Lys supplementation, similar values for urine production parameters are expected as Lys supplementation did not affect urinary N excretion.

Greater amounts of dietary CP increased amounts of all measured fecal components (fecal N, fecal N percent, fecal P, fecal P percent, and NH_4-N), with no effect of supplemental

Lys on any fecal component. Total fecal DM output increased when dietary CP levels were raised in agreement with Broderick et al. (2008). This increase in fecal DM may be explained by increased DMI and represents more waste. Numerous studies (Broderick, 2003, Broderick et al., 2008, Frank and Svensson, 2002, Leonardi et al., 2003) have found that feeding greater amounts of dietary CP increased fecal N percent and fecal N production. Fecal NH_4-N concentrations increased with feeding greater amounts of dietary CP in the past (Frank and Svensson, 2002). Fecal P production and fecal P percent were increase with feeding both high CP diets. This increase in fecal N, P and NH_4-N outputs can lead to issues for producers as this can lead to runoff with a waste of many valuable nutrients if cows are fed high CP diets along with increased diet costs. Measurements of waste production and composition have not been evaluated in past studies involving Lys supplementation. There were no differences in the present study for fecal composition or production due to dietary Lys supplementation. An increase in dietary CP is expected to also increase the amount of N waste. The supplementation of Lys did not impact N waste in both low and high CP diets since N intakes were not affected.

Greater N intakes in cows from increasing dietary CP were reported in previous research (Broderick, 2003). This is expected due to greater amounts of both DMI and CP intake. The present study found that Lys supplementation did not affect N intakes which is supported in past work (Arriola Apelo et al., 2014). N intake was not affected by Lys supplementation, consistent with the failure to detect differences in DMI when supplementary Lys was added to the diet.

Total N balance was greater for cows fed greater amounts of dietary CP, in agreement with Broderick (2009). The significant increase in N intake by cows fed HI diets exceeded the significant increases in urine, milk and fecal N, with overall greater N retention in the animal. Since a total N balance as close to zero as possible is preferred so inputs and outputs are the same, N efficiency decreased in cows fed greater amounts of dietary CP. Total N balance also was significantly greater with Lys supplementation. Rumen protected Lys supplementation only significantly increased milk N of the four values that are used for the total N balance calculation (N intake, urine N, fecal N, milk N), which should result in a net decrease total N balance, not an increase. This increase in total N balance is likely due to numerically greater N intakes with Lys supplementation, even though this increase was not significant. There was no difference in total N balance when Met and Lys were supplemented together in a previous study (Lee et al., 2012), but no research has examined Lys supplementation alone. Adding supplemental Lys to the 15% CP diet led to a similar total N balance in cattle to cows fed the 17% CP diet. This similarity in total N balance is likely due to the greater N intakes in cows fed HI diets being neutralized by increased urine N in cows fed HI diets. This decrease in N intake in cows fed LO+Lys diets from cows fed HI diets leads to cows fed that diet to have a greater N efficiency, as seen in Milk N:N intake. Total N balance showed a significant effect with both greater dietary CP and rumen protected Lys supplementation, with the only difference between cows fed LO-Lys diets and cows fed HI+Lys diets. Cows fed LO+Lys diets show a similar total N balance to cows fed HI diets while resulting in a lower N intake and urine N production, showing that increased N efficiency can occur when using supplemental AA while lowering dietary CP, without impacting milk production.

4.6 CONCLUSIONS

Increasing the dietary CP concentration in lactation diets from 15 to 17% CP in the diet DM affected production (increased DMI, milk production, milk protein percentage, MUN) and waste (fecal and urine outputs). The increase in DMI from greater amounts of dietary CP likely improved milk production, and increased N in the milk and waste. This increase in N intake provides more N for rumen microbes and the cow to provide nutrients for in increased production. The low CP diet was most likely Lys deficient which limited utilization of dietary protein present, lowering milk production.

The supplementation of Lys increased milk production, with no changes in DMI or N intake or waste levels. Milk fat and milk protein increased due to increased milk production as the percentages and ratios did not change. This increase in milk production is expected as adding rumen protected Lys increased the amount of the limiting AA, Lys absorbed by the cow, increasing protein utilization. However, this increase in efficiency and production did not result in many significant changes to N waste, with no significant changes to urine or fecal production or composition. The only N efficiency category significantly increased by supplementing rumen protected Lys was total N balance, with cows fed a low CP diet with additional Lys having a total N balance similar to cows fed a high CP diet without supplemental Lys, similar to the increase in milk production. Supplemental Lys is likely going into increasing milk protein production as well as being used by the cow, which leads to an increase in milk production. This study found that Lys supplementation for low CP diets can be used to improve milk production to levels similar to high CP diets, resulting in increased N efficiency by cattle. This increase in N efficiency can be attributed to use of lower CP diets which reduces DMI and produces less N waste that goes unused by the cow.

Raising dietary CP from 15% to 17% increased DMI along with milk and milk component production. However this increased production is offset by decreased N efficiency, as fecal and urinary output and the output of their components was significantly greater feeding 17% CP diets. Supplementation with rumen-protected Lys improved milk production, while not impacting DMI. Neither urine and fecal outputs, nor their components, were impacted by supplemental Lys. Overall this study found that cows can be fed lower amounts of dietary CP with a supplemental supply of their limiting dietary EAA and be able to produce similar amounts of milk with improved efficiency over feeding a high CP diet. This similar production occurs with significantly lower N intakes and reductions in urinary N production by cows, resulting in more efficient dairy cattle diets.

Table 16: Ingredient composition in experimental diets

	Period 1-2[1]		Period 3-4[1]	
	Dietary CP concentration[2]		Dietary CP concentration[2]	
	LO	HI	LO	HI
Ingredient	% of DM			
Haylage	34.32	39.78	35.38	37.10
Corn Silage	28.37	20.52	23.65	15.87
Wheat Straw	2.69	1.17	0	0
High Moisture Corn	20.11	19.48	22.81	21.58
Lactation Supplement[3]	11.86	17.35	15.56	23.96
Sodium Sesquicarbonate	0.43	0	0.44	0
Hydrolysed Animal Fat	1.04	0.82	1.27	0.84
Dry Cow Premix[4]	0.30	0	0.22	0
Dry Palm Fat	0.89	0.87	0.66	0.66

[1] Diet composition was changed from Period 1-2 to Period 3-4 due to differing nutrient composition in the feed.

[2] LO = Low protein diet (balanced for 15% of DM); HI = High protein diet (balanced for 17% of DM)

[3] Lactation supplement contained DGS, soy meal, soy hulls, canola meal, blood meal, magnesium oxide, biotin, yeast, defluorinated phosphate, wheat shorts, calcium carbonate, s-carb, feather meal, salt, mono dicalcium phosphate, vitamins, trace minerals, magpot sulfate and selenium

[4] Dry cow premix contained Ca, 12%; P, 7%; Na, 4.36%; Cl, 5.7%; Sel, 9.5%; Mg, 16%; S, 1%; K, 0.05%; I, 94 mg/kg; Fe, 7735 mg/kg; Cu, 1576 mg/kg; Mn, 4744 mg/kg; Zn, 4744 mg/kg; Co, 15.76 mg/kg; Vitamin A, 796670 UI/kg; Vitamin D3, 180400 UI/kg; Vitamin E, 12856 UI/kg

Table 17: Nutrient composition of experimental diets

	Period 1-2[1]				Period 3-4[1]			
	Dietary CP concentration[2]				Dietary CP concentration[2]			
	LO		HI		LO		HI	
Nutrient Composition	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
DM (%)	53.02	1.29	54.30	1.55	52.04	2.19	56.47	1.46
NEL (Mcal/Kg of DM)	1.61	0.02	1.60	0.02	1.66	0.03	1.66	0.03
NFC (% of DM)	39.78	1.10	38.06	1.21	40.80	1.75	39.30	1.22
Starch (% of DM)	20.46	1.60	19.77	1.50	23.46	1.74	21.03	1.05
CP (% of DM)	13.21	1.56	14.73	0.93	14.56	0.60	16.23	0.43
NDF (% of DM)	35.51	1.13	35.71	1.24	33.15	1.56	32.97	1.16
ADF (% of DM)	23.92	0.89	24.24	1.14	21.33	1.58	21.33	1.76
Ash (% of DM)	7.17	0.49	7.50	0.30	7.57	0.28	8.30	0.56
Calcium (% of DM)	0.87	0.08	0.97	0.05	0.85	0.07	0.99	0.06
Phosphorus (% of DM)	0.40	0.04	0.40	0.02	0.44	0.02	0.48	0.02
Potassium (% of DM)	1.47	0.08	1.56	0.08	1.46	0.09	1.54	0.08
Sulphur (% of DM)	0.18	0.02	0.20	0.02	0.21	0.01	0.23	0.02
Magnesium (% of DM)	0.25	0.03	0.25	0.02	0.28	0.02	0.31	0.02
Sodium (% of DM)	0.42	0.07	0.35	0.03	0.47	0.04	0.50	0.04
Copper (ug/g of DM)	17.56	2.22	15.47	2.76	18.75	2.00	20.29	1.86
Iron (ug/g of DM)	281.01	41.92	285.72	33.68	356.47	40.54	380.31	37.74
Manganese (ug/g of DM)	67.39	47.91	43.48	3.58	54.29	8.82	63.81	13.03
Zinc (ug/g of DM)	61.57	8.69	53.72	5.42	63.36	5.33	67.77	8.01

[1] Diet composition was changed from Period 1-2 to Period 3-4 due to differing nutrient composition in the feed.

[2] LO = Low protein diet (balanced for 15% of DM); HI = High protein diet (balanced for 17% of DM)

Table 18: Effects of dietary CP concentrations with or without supplemental Lys on DMI and milk production and composition

	Dietary CP concentration[1]							
	LO		HI			*P*-values		
	-Lys[1]	+Lys[1]	-Lys[1]	+Lys[1]	SE	%CP	Lys	P*L
DMI (kg/d)	25.31[a]	26.03[ab]	27.51[ab]	28.21[b]	1.417	**<0.01**	0.34	0.99
Milk yield (kg/d)	34.57[a]	36.60[bc]	36.08[ab]	38.04[c]	1.870	**0.03**	**<0.01**	0.95
Fat %	4.26[a]	4.17[a]	4.17[a]	4.24[a]	0.158	0.87	0.88	0.21
Fat yield (kg/d)	1.44[a]	1.52[a]	1.49[a]	1.60[b]	0.080	**0.05**	**0.01**	0.60
Protein %	3.17[a]	3.22[ab]	3.30[b]	3.29[b]	0.073	**0.01**	0.56	0.36
Protein yield (kg/d)	1.09[a]	1.18[b]	1.19[bc]	1.25[c]	0.056	**<0.01**	**0.01**	0.62
MUN (mg/dl)	6.91[a]	6.49[a]	8.51[b]	8.78[b]	0.482	**<0.01**	0.84	0.34
SCC (000's cells /ml)	192.7[a]	229.5[a]	231.5[a]	153.1[a]	96.32	**0.65**	0.62	0.17
Milk Yield:DMI	1.42	1.48	1.34	1.38	0.087	**0.05**	0.27	0.83
ECM[2] (kg/d)	34.98[a]	37.06[ab]	36.71[ab]	39.02[b]	1.793	**0.02**	**<0.01**	0.88

[1] LO = Low protein diet (balanced for 15% of DM); HI = High protein diet (balanced for 17% of DM); -Lys = No supplemental rumen protected Lys added; +Lys = 11.5 g of supplemental rumen protected Lys top-dressed at each feeding, for 23 g/d.

[a,b,c] Numbers with different superscripts within a row differ significantly ($P < 0.05$).

[2] ECM = (Milk yield × [948 + 376 × % fat + 209 × % CP] ÷ 3138)

Table 19: Effects of dietary CP concentrations with or without supplemental lysine on plasma metabolite concentrations

	Dietary CP concentration[1]							
	LO[1]		HI[1]			*P*-values		
	-Lys[1]	+Lys[1]	-Lys[1]	+Lys[1]	SE	%CP	Lys	P*L
Blood Glucose (mg/dL)	17.29	14.58	17.71	17.94	1.642	0.16	0.36	0.28
Blood NEFA (mmol/L)	0.04	0.04	0.04	0.07	0.015	0.34	0.29	0.28
Blood BHB (mmol/L)	0.85	0.80	0.93	0.94	0.067	0.06	0.71	0.66
BUN (mg/dL)	1.04	1.00	1.07	1.06	0.045	0.25	0.54	0.69

[1] LO = Low protein diet (balanced for 15% of DM); HI = High protein diet (balanced for 17% of DM); -Lys = No supplemental rumen protected lysine added; +Lys = 11.5 g of supplemental rumen protected lysine top-dressed at each feeding, for 23 g/d.

Table 20: Effects of dietary CP concentrations with or without supplemental lysine on urine and feces

	Dietary CP concentration[1]							
	LO[1]		HI[1]			*P*-values		
	-Lys[1]	+Lys[1]	-Lys[1]	+Lys[1]	SE	%CP	Lys	P*L
Urine Volume (kg/d)	28.47[a]	29.56[ab]	32.61[b]	31.92[b]	1.220	**<0.01**	0.82	0.32
Urine N (kg/d)	0.17[a]	0.16[a]	0.21[b]	0.21[b]	0.01	**<0.01**	0.99	0.79
Urine N %	0.59[ab]	0.56[a]	0.65[bc]	0.66[c]	0.024	**<0.01**	0.78	0.29
Urine NH_4-N (kg/d)	0.010[a]	0.011[a]	0.014[a]	0.015[a]	0.001	**0.01**	0.62	0.95
Fecal DM (kg/d)	9.80	9.99	10.32	10.56	0.429	**0.04**	0.42	0.92
Fecal N (kg/d)	0.045[a]	0.045[a]	0.053[ab]	0.054[b]	0.003	**<0.01**	0.71	0.75
Fecal N %	0.46[a]	0.46[a]	0.51[b]	0.52[b]	0.017	**<0.01**	0.88	0.55
Fecal NH_4-N (kg/d)	0.0037[a]	0.0035[a]	0.0042[ab]	0.0046[b]	0.0002	**<0.01**	0.50	0.14
Fecal P (kg/d)	0.013[a]	0.013[ab]	0.015[ab]	0.016[b]	0.001	**<0.01**	0.32	0.52

[1] LO = Low protein diet (balanced for 15% of DM); HI = High protein diet (balanced for 17% of DM); -Lys = No supplemental rumen protected lysine added; +Lys = 11.5 g of supplemental rumen protected lysine top-dressed at each feeding, for 23 g/d.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

Table 21: Effects of dietary CP concentrations with or without supplemental lysine on nitrogen efficiency

	Dietary CP concentration[1]							
	LO[1]		HI[1]			*P*-values		
	-Lys[1]	+Lys[1]	-Lys[1]	+Lys[1]	SE	%CP	Lys	P*L
N intake (kg/d)	0.57 [a]	0.58 [a]	0.68 [b]	0.70 [b]	0.033	**<0.01**	0.35	0.92
Milk N:N intake	0.32 [ab]	0.34 [a]	0.28 [b]	0.29 [b]	0.018	**<0.01**	0.20	0.52
Total N Balance (kg/d)	0.22 [a]	0.25 [ab]	0.26 [ab]	0.29 [b]	0.025	**0.02**	**0.04**	0.99

[1] LO = Low protein diet (balanced for 15% of DM); HI = High protein diet (balanced for 17% of DM); -Lys = No supplemental rumen protected lysine added; +Lys = 11.5 g of supplemental rumen protected lysine top-dressed at each feeding, for 23 g/d.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

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Appendix 1: Questions as they appeared on the survey.

- Which province is your farm located in?
- Who is responsible for balancing your rations?
- Can we contact your nutritionist for ration information? Please provide their contact information if yes.
- Can we have your permission to access your DHI records? Please indicate your DHI herd ID if yes.
- Is your farm organic?
- Approximately how many cows are you milking on your farm?
- In what type of barn do you house lactating cows? Select all that apply.
- Do you utilize a robot for milking cattle?
- How many groups do you keep your lactating cattle in?
- Please specify how you separate your cattle into different groups. Choose all that qualify.
- How many different rations do you feed to your lactating cattle?
- Do you provide additional supplements to lactating cattle based on age or stage of lactation?
- Do you give your first lactating cattle ration group pasture access at any point during the year?
- Approximately how many months of the year do you give lactating cows pasture access?
- Which feeds do you use for your first lactating cattle ration with no pasture access? Check all that apply.
- What is the crude protein content in your first lactating ration with no pasture access?
- Do you give your second lactating cattle ration group pasture access at any point during the year?
- Approximately how many months of the year do you give lactating cows pasture access?
- Which feeds do you use for your second lactating cattle ration with no pasture access? Check all that apply.
- What is the crude protein content in your second lactating ration with no pasture access?
- Do you give your third lactating cattle group pasture access at any point during the year?
- Approximately how many months of the year do you give lactating cows pasture access?
- Which feeds do you use for your third lactating cattle ration with no pasture access? Check all that apply.
- What is the crude protein content in your third lactating ration with no pasture access?
- Do you give your fourth or remaining lactating cattle ration pasture access at any point during the year?
- Approximately how many months of the year do you give lactating cows pasture access?

- Which feeds do you use for your fourth and remaining lactating cattle ration with no pasture access? Check all that apply.
- What is the crude protein content in your fourth and remaining lactating rations with no pasture access?
- What are your reasons for changing between lactating cattle rations? Choose as many as apply.
- Do you give your dry cattle pasture access at any point during the year?
- How many months of the year do you give dry cows pasture access?
- How many different rations do you feed to your dry cattle and pre-fresh heifers when pasture access is limited (i.e., winter season)?
- Do pre-fresh heifers (2 months or less prior to calving) get same ration as pre-fresh cows?
- Which feeds do you use for your first dry cattle ration when or if pasture access is limited? Check all that apply.
- Which feeds do you use for your second dry cattle ration when or if pasture access is limited? Check all that apply.
- Which feeds do you use for your third and remaining dry cattle ration when or if pasture access is limited? Check all that apply.
- What is your target dry period length?
- Do you give your dry cattle pasture access at any point during the year?
- How many months of the year do you give dry cows pasture access?
- How many different rations do you feed to your dry cattle and pre-fresh heifers when pasture access is limited (i.e., winter season)?
- Do pre-fresh heifers (2 months or less prior to calving) get same ration as pre-fresh cows?
- Which feeds do you use for your first dry cattle ration when or if pasture access is limited? Check all that apply.
- Which feeds do you use for your second dry cattle ration when or if pasture access is limited? Check all that apply.
- Which feeds do you use for your third and remaining dry cattle ration when or if pasture access is limited? Check all that apply.
- What is your target dry period length?
- Rank how important these factors are to your overall nutrition goals with your heifer rations.

1. Heifer Performance
2. Decreased Cost
3. Simplicity
4. Nutrient Management
5. Heifer Health

- Rank how important these factors are to your overall nutrition goals with your lactating cow rations.

- Rank how important these factors are to your overall nutrition goals with your dry cow rations.
- How much do you agree or disagree with these statements on nutrient management.
- I am willing to incorporate new feeds into rations
- Feedstuffs should be tested frequently
- Rations should be rebalanced often
- How often do you deliver feed to lactating cows?
- How often do you push up feed for lactating cows?
- How often do you deliver feed to dry cows?
- How often do you push up feed for dry cows?
- How many sources do you purchase feeds from?
- List which feeds are purchased and indicate the source that they are purchased from.
- Do you test the dry matter of wet feeds in your rations?
- Which feeds do you test for dry matter in your rations?
- How often are these feeds tested for dry matter?
- Do you rebalance your rations after testing the feed for dry matter?
- Do you test the nutrient composition of any feeds in your rations?
- Which feeds do you test for nutrient composition in your rations?
- How often are these feeds' nutrient composition tested?
- Do you rebalance your rations after testing the feed for nutrient composition?

Appendix 2: Farm demographics survey on CP contents in lactation rations across Canada

	Pan-Canadian Farm Location[1]								
	Total		WP		OF		OT		P-value
	Number of Responses	Total %	Number of Responses	% of WP	Number of Responses	% of OF	Number of Responses	% of OT	
What is the crude protein content in your first lactating ration with no pasture access?									0.33
<12% CP	1	0.52	1	1.52 [a]	0	0.00 [a]	0	0.00 [a]	
12-14%	25	12.95	6	9.09 [a]	10	14.93 [a]	9	15.00 [a]	
15-17%	113	58.55	34	51.52 [a]	43	64.18 [a]	36	60.00 [a]	
18-20%	48	24.87	21	31.82 [a]	14	20.90 [a]	13	21.67 [a]	
>20%	6	3.11	4	6.06 [a]	0	0.00 [a]	2	3.33 [a]	
What is the crude protein content in your second lactating ration with no pasture access?									0.63
<12% CP	1	2.86	0	0.00 [a]	0	0.00 [a]	0	0.00 [a]	
12-14%	4	11.43	2	14.29 [a]	1	20.00 [a]	1	6.67 [a]	
15-17%	19	54.29	6	42.86 [a]	2	40.00 [a]	11	73.33 [a]	
18-20%	11	31.43	6	42.86 [a]	2	40.00 [a]	3	20.00 [a]	
>20%	0	0.00	0	0.00 [a]	0	0.00 [a]	0	0.00 [a]	

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

Appendix 3: Farm demographics survey on dry matter testing in dairy rations across Canada

	Pan-Canadian Farm Location[1]			
Which feeds do you test for dry matter in your rations?	Canada	WP	OF	OT
Hays	39	26	4	9
Barley silage	15	15	0	0
Corn silage	121	28	49	44
Haylage	128	34	50	44
Barley	4	4	0	0
Corn	9	7	2	0
Brewers grain	5	2	3	0
All feeds	5	4	1	0
Barley pea oat silage	3	1	1	1
Straw	1	1	0	0
HM corn	22	2	10	10
Pea silage	1	1	0	0
TMR	8	1	4	3
All forages	12	1	8	3
Cobmeal	3	0	2	1
Forage rye	1	0	1	0
Beanlage	1	0	0	1
Grain mix	1	0	0	1
How often are these feeds tested for dry matter?	Canada	WP	OF	OT
3x a week	1	1	0	0
Twice a week	5	2	3	0
Once a week	20	10	8	2
Once every 2 weeks	10	3	5	2
Once every 3 weeks	2	0	2	0
Once a month	40	15	16	9
Once every two months	17	9	3	5
Once every 3 months	16	3	7	6
Once every 6 months	4	1	0	3

Once a year	5	1	2	2
Once before starting feeding from new source	33	15	6	12
2-3 times a feed source	7	4	2	1
Fluctuates/as needed	17	2	8	7

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

Appendix 4: Farm demographics survey on nutrient composition testing in dairy rations across Canada

	Pan-Canadian Farm Location[1]			
Which feeds do you test for nutrient composition in your rations?	Canada	WP	OF	OT
Hays	54	27	13	14
Barley silage	8	8	0	0
Corn silage	90	18	43	29
Haylage	90	19	43	28
Barley	2	2	0	0
Corn	3	2	0	1
Brewers grain	2	1	1	0
All feeds	28	15	6	7
Barley pea oat silage	1	0	1	0
Straw	3	2	1	0
HM corn	15	1	7	7
TMR	3	2	1	0
All forages	21	6	9	6
Cob meal	4	0	3	1
Forage rye	1	0	1	0
Beanlage	1	0	0	1
Grain mix	3	2	1	0
Supplements	2	1	0	1
Oat silage	2	2	0	0
Sorghum	1	0	0	1
How often are these feeds' nutrient composition tested?	Canada	WP	OF	OT
3x a week	1	1	0	0
Twice a week	2	2	0	0
Once a week	10	10	0	0
Once every 2 weeks	3	3	0	0
Once every 3 weeks	3	0	2	1
Once a month	23	15	6	2

Once every two months	21	9	8	4
Once every 3 months	19	3	5	11
Once every 6 months	9	1	6	2
Once a year	16	2	5	9
Once before starting feeding from new source	34	13	13	8
2-3 times a feed source	8	4	4	0
Fluctuates/as needed	16	2	10	4

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

Appendix 5: Other feeds used in lactating rations.

	Pan-Canadian Farm Location[1]							
Lactating Diet Ingredient	Canada		WP		OF		OT	
Other Feeds (write-in responses)	# of Responses	%	# of Responses	%	# of Responses	%	# of Responses	%
Barley silage	7	3.17	7	8.75	0	0.00	0	0.00
Minerals	2	0.90	1	1.25	1	1.33	0	0.00
Supplement/Pellets/Mash	13	5.88	4	5.00	4	5.33	5	7.58
Corncob mix	5	2.26	1	1.25	3	4.00	1	1.52
Whey permeate	1	0.45	1	1.25	0	0.00	0	0.00
Methionine	1	0.45	1	1.25	0	0.00	0	0.00
Probiotics	1	0.45	1	1.25	0	0.00	0	0.00
Oat silage	1	0.45	1	1.25	0	0.00	0	0.00
Pea silage	1	0.45	1	1.25	0	0.00	0	0.00
Vitamin mineral premix	1	0.45	0	0.00	1	1.33	0	0.00
Bakery meal	2	0.90	0	0.00	1	1.33	1	1.52
Rye silage	1	0.45	0	0.00	1	1.33	0	0.00
Citrus pulp	1	0.45	0	0.00	1	1.33	0	0.00
Wheat shorts	1	0.45	0	0.00	1	1.33	0	0.00
Hominy	1	0.45	0	0.00	1	1.33	0	0.00
Tallow fat	1	0.45	0	0.00	1	1.33	0	0.00
Oats	4	1.81	0	0.00	1	1.33	3	4.55
Potatoes	1	0.45	0	0.00	1	1.33	0	0.00
Beanlage	1	0.45	0	0.00	0	0.00	1	1.52
Rolled soybeans raw	1	0.45	0	0.00	0	0.00	1	1.52
Fish meal	1	0.45	0	0.00	0	0.00	1	1.52
Peas	2	0.90	0	0.00	0	0.00	2	3.03
Triticale	1	0.45	0	0.00	0	0.00	1	1.52

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

Appendix 6: Other feeds used in dry rations.

	Pan-Canadian Farm Location[1]							
Dry Diet Ingredient	Canada		WP		OF		OT	
Other Feeds (write-in responses)	# of Responses	%	# of Responses	%	# of Responses	%	# of Responses	%
Barley silage	8	3.76	8	10.53	0	0.00	0	0.00
Pellets/Supplement	18	8.45	6	7.89	8	11.11	4	6.15
Premix	3	1.41	1	1.32	1	1.39	1	1.54
Minerals	6	2.82	4	5.26	1	1.39	1	1.54
Refusals	1	0.47	1	1.32	0	0.00	0	0.00
Malt sprouts	1	0.47	1	1.32	0	0.00	0	0.00
Barley pea oat silage	1	0.47	1	1.32	0	0.00	0	0.00
Dry cow grain ration	2	0.94	2	2.63	0	0.00	0	0.00
Oat hay	1	0.47	1	1.32	0	0.00	0	0.00
Rye silage	1	0.47	0	0.00	1	1.39	0	0.00
Oatsandpeas silage	1	0.47	0	0.00	1	1.39	0	0.00
Se salt	1	0.47	0	0.00	1	1.39	0	0.00
Rumensin	2	0.94	0	0.00	1	1.39	1	1.54
Oatlage	1	0.47	0	0.00	0	0.00	1	1.54
Rock lava salt	1	0.47	0	0.00	0	0.00	1	1.54
Oats	2	0.94	0	0.00	0	0.00	2	3.08
Oatsandpeas mix	1	0.47	0	0.00	0	0.00	1	1.54
Peas	1	0.47	0	0.00	0	0.00	1	1.54
Triticale	1	0.47	0	0.00	0	0.00	1	1.54
Barley and oats mix	1	0.47	0	0.00	0	0.00	1	1.54
Potatoes	1	0.47	0	0.00	1	1.39	0	0.00
Pea silage	1	0.47	1	1.32	0	0.00	0	0.00

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

Appendix 7: Other feeds used in heifer rations.

	Pan-Canadian Farm Location[1]							
Heifer Diet Ingredient	Canada		WP		OF		OT	
Other Feeds (write-in responses)	# of Responses	%	# of Responses	%	# of Responses	%	# of Responses	%
Calf Starter	10	4.76	3	3.95	6	8.33	1	1.61
Barley Silage	8	3.81	8	10.53	0	0.00	0	0.00
Oats	5	2.38	2	2.63	0	0.00	3	4.84
Heifer Grain Mix	6	2.86	4	5.26	2	2.78	0	0.00
Heifer Ration Mix	6	2.86	3	3.95	2	2.78	1	1.61
Premix	2	0.95	1	1.32	0	0.00	1	1.61
Pellet/Supplement/Mash	25	11.90	7	9.21	13	18.06	5	8.06
Barley Pea Oat Silage	1	0.48	1	1.32	0	0.00	0	0.00
Malt Sprouts	2	0.95	1	1.32	1	1.39	0	0.00
Minerals	4	1.90	2	2.63	1	1.39	1	1.61
Refusals	4	1.90	1	1.32	1	1.39	2	3.23
Gsp	1	0.48	1	1.32	0	0.00	0	0.00
Cover crop silage	1	0.48	1	1.32	0	0.00	0	0.00
Oat Silage	1	0.48	1	1.32	0	0.00	0	0.00
Rumimax	2	0.95	1	1.32	1	1.39	0	0.00
Vitamin Mineral Premix	1	0.48	0	0.00	1	1.39	0	0.00
Tripper	1	0.48	0	0.00	1	1.39	0	0.00
Oatlage	1	0.48	0	0.00	1	1.39	0	0.00
Cobmeal	1	0.48	0	0.00	0	0.00	1	1.61
Rock lava salt	1	0.48	0	0.00	0	0.00	1	1.61
barley and oats mix	1	0.48	0	0.00	0	0.00	1	1.61
oats and peas mix	1	0.48	0	0.00	0	0.00	1	1.61
Stature 37	1	0.48	0	0.00	0	0.00	1	1.61
Ryelage	3	1.43	0	0.00	2	2.78	1	1.61
Triticale	1	0.48	0	0.00	0	0.00	1	1.61
Peas	1	0.48	0	0.00	0	0.00	1	1.61

Oats and peas silage	2	0.95	0	0.00	1	1.39	1	1.61
Se Salt	1	0.48	0	0.00	1	1.39	0	0.00
Forage Rye	1	0.48	0	0.00	1	1.39	0	0.00
Sorghum	1	0.48	0	0.00	0	0.00	1	1.61
Baylage (oats, triticale, wheat, barley)	1	0.48	0	0.00	1	1.39	0	0.00

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

Appendix 8: Pasture access for other lactating rations

	Total		Pan-Canadian Farm Location[1]						
			WP		OF		OT		P-value
	Number of Responses	Total %	Number of Responses	%	Number of Responses	%	Number of Responses	%	
Do you give your lactating cattle group pasture access at any point during the year?									0.01
Ye	12	27.27	2	9.52 [a]	1	16.67 [ab]	9	52.94	
No	32	72.73	19	90.48	5	83.33 [ab]	8	47.06	
How many months of the year do you give dry cows pasture access?									0.86
2	6	5.50	2	6.45 [a]	1	3.33 [a]	3	6.25 [a]	
3	3	2.75	2	6.45 [a]	1	3.33 [a]	0	0.00 [a]	
4	9	8.26	1	3.23 [a]	3	10.00 [a]	5	10.42	
5	27	24.77	9	29.03	9	30.00 [a]	9	18.75	
6	34	31.19	10	32.26	9	30.00 [a]	15	31.25	
7	13	11.93	2	6.45 [a]	4	13.33 [a]	7	14.58	
8	7	6.42	3	9.68 [a]	0	0.00 [a]	4	8.33 [a]	
>8	10	9.17	2	6.45 [a]	3	10.00 [a]	5	10.42	
How many months of the year do you give heifers pasture access?									0.39
2	1	0.95	0	0.00 [a]	1	3.45 [a]	0	0.00 [a]	
3	7	6.67	3	8.82	4	13.79 [a]	0	0.00 [b]	
4	11	10.48	4	11.76	3	10.34 [a]	4	9.52 [a]	
5	18	17.14	7	20.59	5	17.24 [a]	6	14.29	
6	44	41.90	13	38.24	12	41.38 [a]	19	45.24	
7	10	9.52	2	5.88 [a]	2	6.90 [a]	6	14.29	
8	5	4.76	3	8.82 [a]	1	3.45 [a]	1	2.38 [a]	
>8	9	8.57	2	5.88 [a]	1	3.45 [a]	6	14.29	
Approximately how many months of the year do you give lactating cows pasture access?									0.71
2	3	5.5	2	11.8 [a]	0	0.0 [a]	1	3.9 [a]	
3	4	7.3	1	5.9 [a]	2	16.7 [a]	1	3.9 [a]	
4	6	10.9	1	5.9 [a]	2	16.7 [a]	3	11.5 [a]	
5	12	21.8	2	11.8 [a]	2	16.7 [a]	8	30.8 [a]	

6	23	41.8	9	52.9 [a]	5	41.7 [a]	9	34.6 [a]
7	5	9.1	1	5.9 [a]	1	8.3 [a]	3	11.5 [a]
8	1	1.8	0	0.0 [a]	0	0.0 [a]	1	3.9 [a]
>8	1	1.8	1	5.9 [a]	0	0.0 [a]	0	0.0 [a]

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.

[a,b,c] = Numbers with different superscripts within a row differ significantly ($P < 0.05$).

Appendix 9: Questions on testing and developing rations

	Pan-Canadian Farm Location[1]								
	Total		WP[1]		OF[1]		OT[1]		P-Value
How many sources do you purchase feeds from?	# of Responses	%	# of Responses	%	# of Responses	%	# of Responses	%	<0.01
0	1	0.46	0	0.00 [a]	1	1.39 [a]	0	0.00 [a]	
1	69	31.94	21	26.92 [a]	17	23.61 [a]	31	46.97 [b]	
2	78	36.11	22	28.21 [a]	32	44.44 [a]	24	36.36 [a]	
3	42	19.44	17	21.79 [a]	16	22.22 [a]	9	13.64 [a]	
4	13	6.02	7	8.97 [a]	5	6.94 [a]	1	1.52 [a]	
5 or more	13	6.02	11	14.10 [a]	1	1.39 [b]	1	1.52 [b]	
Do you test the dry matter of wet feeds in your rations?									0.27
Yes	198	92.96	74	96.10 [a]	67	93.06 [a]	57	89.06 [a]	
No	15	7.04	3	3.90 [a]	5	6.94 [a]	7	10.94 [a]	
Total	213		77		72		64		
Do you rebalance your rations after testing the feed for dry matter?									0.68
Yes	122	62.24	41	56.16 [a]	46	68.66 [a]	35	62.50 [a]	
Sometimes	60	30.61	26	35.62 [a]	17	25.37 [a]	17	30.36 [a]	
No	14	7.14	6	8.22 [a]	4	5.97 [a]	4	7.14 [a]	
Do you test the nutrient composition of any feeds in your rations?									0.09
Yes	186	88.15	68	89.47 [a]	67	93.06 [a]	51	80.95 [a]	
No	25	11.85	8	10.53 [a]	5	6.94 [a]	12	19.05 [a]	
Do you rebalance your rations after testing nutrient composition?									0.15
Yes	148	81.77	52	77.61 [a]	58	89.23 [a]	38	77.55 [a]	
Sometimes	28	15.47	11	16.42 [a]	7	10.77 [a]	10	20.41 [a]	

No	5	2.76	4	5.97 [a]	0	0.00 [a]	1	2.04 [a]

[1] WP = Western Provinces (British Columbia, Alberta, Saskatchewan and Manitoba); OF = Ontario Freestall farms; OT = Ontario Tiestall farms.