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Managing Dietary Protein in Cattle as a Means of Reducing Ammonia Emissions to Improve Air Quality

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MANAGING DIETARY PROTEIN IN CATTLE AS A MEANS OF REDUCING AMMONIA EMISSIONS TO IMPROVE AIR QUALITY

by

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Abstract

Particulate matter pollution has become a subject of great concern across the globe. Emissions data has revealed that the agricultural sector is making large contributions to particulate matter through ammonia emissions. Beef and dairy cattle are responsible for producing nearly 50% of annual ammonia emissions in the United States. These animals are often fed amounts of dietary protein that exceed recommendations, resulting in increased excretion of urea and ammonia. These compounds combine with nitrogen oxides in the atmosphere to form $PM_{2.5}$: particulate matter measuring less than 2.5 microns in diameter. Research has shown that through proper dietary management of protein, ammonia emissions in the agricultural sector can be reduced, leading to a healthier environment. Unfortunately, dietary protein is often overfed to cattle to promote increased production. As such, this research aims to better inform producers of the environmental and health risks that arise when dietary protein is not properly balanced, and to encourage evaluation of current diets in order to assess feed efficiency and identify instances of overfeeding.

Keywords: Ammonia, Urea, Dietary Protein, Dietary Management, Cattle

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Managing Dietary Crude Protein in Cattle as a Means of Reducing Ammonia Emissions to Improve Air Quality

The United States has, for quite some time, struggled with pollution and air quality concerns. Thus far, efforts to find a solution to these concerns have focused on reducing emissions from motor vehicles and industrial sources. However, in recent years, is has become clear that agricultural ammonia emissions are contributing to decreased air quality throughout the nation. Though many agricultural emission sources may seem isolated in rural areas, the effects can be felt over a much larger space. "Problems related to visibility and deposition can occur in the immediate vicinity of the ammonia release or affect landscapes hundreds of miles from the emission source" (Ishler, 2017, p. 1). These emissions, and corresponding pollutants, present health concerns for humans and animals alike. Exposure to low levels of ammonia can cause irritation of lung and eye tissue, and elevated levels have a negative impact on animal health and production (Gay, 2009, p. 2). Although the Environmental Protection Agency has not yet established regulations for outdoor ammonia emissions, agricultural producers are being put under increasing public pressure to reduce ammonia production (2017a). Because of the related environmental and health impacts, it is important that agricultural producers implement management techniques to reduce emissions from their livestock. In doing so, producers can contribute to a healthier environment for their animals, thus influencing production, and will be better equipped to adjust to new emissions standards and regulations that may arise as a result of public concern.

Definition of Terms

Amino Acids (AA): the individual chemical units which make up proteins.

Blood Urea Nitrogen: a measurement of the levels of urea in the bloodstream

Dietary Crude Protein (CP): the total amount of dietary protein, or protein equivalent from nitrogen sources (Herdt, 2018).

Dietary Nitrogen (N): nitrogen provided in feed

Metabolized Protein (MP): the protein available for maintenance and production, a combination of protein produced by microbial synthesis for digestion and undegraded intake protein (Hilton, 2018).

Milk Urea Nitrogen: a measurement of urea levels in milk

Nonprotein Nitrogen (NPN): Nitrogen coming from sources other than protein

Negative Energy Balance (NEBAL): a condition in which less energy is utilized than is expended during metabolic processes, resulting in a decreased body weight (Oxford, 2018).

Rumen Degradable Protein (RDP): protein that is broken down in the rumen following consumption.

Rumen Undegradable Protein (RUP): consumed protein that is not degraded in the rumen.

Ammonia in the Pollution Cycle

According to the EPA's most recent emissions inventories, agricultural sources account for 95% of ammonia emissions in the United States, as illustrated in figure 1 (United, 2017b). The majority of ammonia emissions from animal sources results from inefficient feed conversion in circumstances where excess nitrogen is present in the diet. According to Susan Gay, excess nitrogen is excreted in the form of urea, ammonia, and organic nitrogen in the feces of mammals. The enzyme urease, which is also excreted in animal feces, promotes the conversion of urea to ammonia. This conversion occurs rapidly, usually within days, resulting in the production of either ammonium (NH_4^+) or ammonia (NH_3) depending on environmental pH (2009, p. 4). Due to its properties as an ion, NH_4^+ cannot exist on its own, whereas the molecule NH_3 is rapidly converted to its gaseous form and emitted from manure. pH plays a significant role in the ability of ammonia to volatilize, but in most cases, the natural pH of the animals' excreta is sufficient to promote this reaction. Ishler recorded that dairy manure pH typically ranges from 7.0 to 8.5, which allows for fairly rapid emission of ammonia into the atmosphere (2017, p. 1). Once ammonia is released into the atmosphere, it can react with other compounds to form $PM_{2.5}$ (particulate matter measuring less than 2.5 microns in diameter), a pollutant

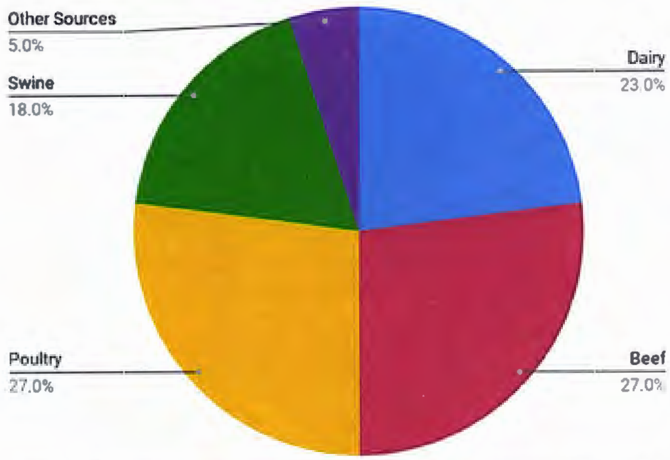

Figure 1: Estimated ammonia emissions from man-made sources in the United States during the year 2002. Adapted from Adams, P. and McQuiling, A. (2015).

that presents a major health concern as its small size allows it to penetrate deep into lung tissue when inhaled, as seen in figure 2. Most commonly, atmospheric ammonia reacts with combustion gasses such as nitric acid or sulfuric acid to form ammonium nitrate or ammonium sulfate (figure 3), which act as precursors for the development of $PM_{2.5}$ (Ishler, 2017, p. 1).

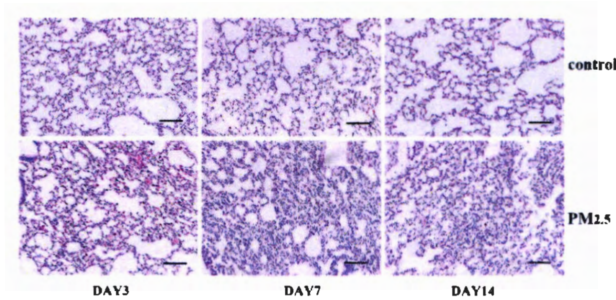

Figure 2: Mice lung tissues pathohistological changes after administration of $PM_{2.5}$ (Wang et al. 2017).

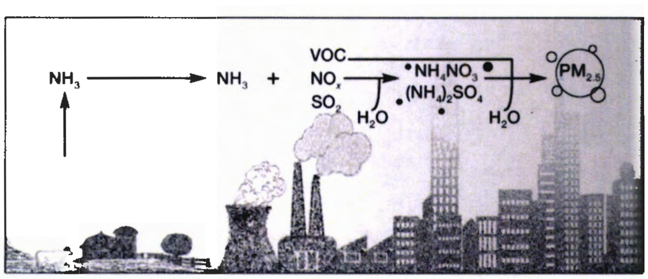

Figure 3: Schematic depicting the formation of $PM_{2.5}$ (Gu et al. 2014).

Effects of Dietary Protein on Ammonia Production

One of the major contributors to ammonia excretion in cattle is elevated levels of dietary protein. High-protein feed contains excess nitrogen, and nitrogen that is not metabolized into animal protein (i.e. milk or meat) is excreted in the urine and feces of livestock, where further microbial action releases ammonia into the air during manure decomposition (Gay, 2009). According to Geppert, protein sources broken down in the rumen are utilized for the synthesis microbial protein, which can be metabolized and absorbed as amino acids. This process also produces ammonia and other compounds that are absorbed in the rumen (2015). Some ammonia can be utilized by microorganisms in the digestive system, but if more ammonia is present than microorganisms can use, it is absorbed through the rumen wall into to the portal vein, where it becomes detoxified into urea by the liver. From the liver, urea is released into blood circulation for recycling or excretion. Ruminants have the unique capability of recycling nitrogen through saliva to return to the rumen for breakdown to ammonia; however, when there is adequate urea in the rumen, it is secreted in the urine and milk (Geppert, 2015). Figure 4 illustrates the basic pathways of protein digestion in cattle, as well as the process of urea recycling. Although much more efficient in their use of nitrogen than other livestock, Ishler found that on average, dairy cows secrete 25 to 35 percent of the nitrogen they consume in milk and almost all the remaining nitrogen is excreted in urine and feces. Of the nitrogen excreted in waste, about half is excreted in urine, and approximately 60 to 80 percent of the nitrogen in urine is in the form of urea (2017, p.1). This would indicate that about 10 to 30 percent of the nitrogen provided in the diet is excreted in the urine as urea and becomes available for conversion to ammonia. Despite this, many producers are hesitant to reduce the amount of protein in their animals' diet due to the important roles it plays in production traits, primarily growth, reproduction, and lactation. Protein is a macronutrient, which means it is required in relatively large amounts to provide adequate energy for life processes and essential compounds that the body cannot produce on its own (Christensen, 2017). Thus, it is important to maintain appropriate levels of dietary protein to ensure that these processes run smoothly. However,

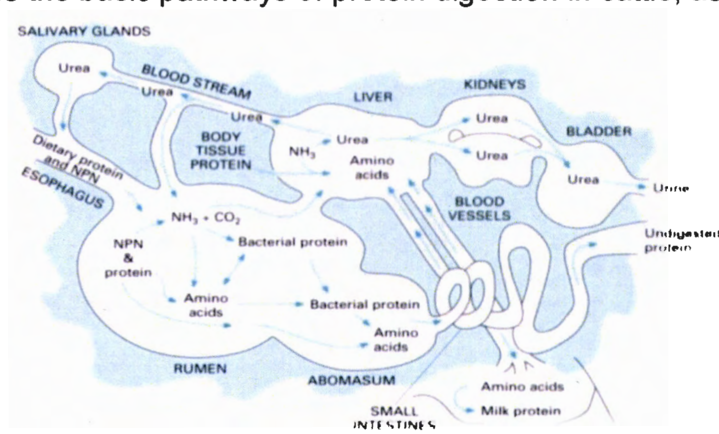

Figure 4: Protein Digestion in Ruminants (Vaga et al. 2017).

overabundance can prove to be just as detrimental to the production value and overall health of the animal.

Protein in Reproduction

The reproductive cycle is a dynamic process, and an animal's dietary needs change with each stage. Protein is especially important during the latter stages of pregnancy in cattle. The last trimester is a period of accelerated fetal growth, and protein acts as the principle building block for many tissues. At parturition, nutritional requirements shift abruptly as milk production rapidly increases and the cow enters negative energy balance (Butler, 2000, p. 449). In cattle, a state of negative energy balance presents a major concern. If an animal's energy requirements are not being met, reproductive processes may be hindered or cease entirely. Protein plays a significant role in maintaining dietary balance, and as such, is often fed in excess (Rabboisson, 2017). While it is vital that an animal's protein requirements are met to provide adequate energy for milk production and reproductive activity, producers must be careful to avoid diets that exceed protein requirements, as excess protein has been associated with reduced reproductive performance (Butler, 2000). "The intake of high dietary protein can result in elevated blood concentrations of ammonia, urea, or both, depending upon the balance of protein fractions present in the rumen and the availability of fermentable carbohydrates. Increased plasma or milk urea nitrogen concentrations are highly correlated with decreased fertility in cows" (Butler, 2000, p. 454). Many different theories have been proposed as to how exactly excess dietary protein affects the reproductive abilities of cows. Generally, it is agreed that feeding protein in excess of dietary requirements can result in decreased conception rates due to increased urea levels, changes to the uterine environment that hinder embryo development, and changes in the levels of hormones essential to pregnancy maintenance and cyclicity.

Conception Rates

In numerous studies involving dairy cows, increased protein was shown to reduce conception rates. This effect has most often been attributed to increased urea levels. Rabboisson's study (2017) showed 43% lower odds of conception in situations where urea was greater than or equal to 7.0 mM in blood or greater than or equal to 420 mg/L in milk compared to cases where urea values were lower, and the association between high urea and decreased conception was even stronger when blood urea levels exceeded the 7.0 mM threshold. In addition, this study found that the success of embryo transfers decreased when donor cows were fed high levels of dietary protein. Although high levels of protein have been associated with decreased pregnancy in dairy cows, this has not been the case in beef cows. "Embryo quality and development was reduced in lactating dairy cows fed excess rumen degradable protein, but embryo transfer and superovulation experiments in beef heifers found no detrimental effect of high dietary crude protein urea on embryo viability, fertilization rate, or embryo quality" (Butler, 2000, p. 454). Geppert's research found that beef heifers fed excess protein seemed to experience far fewer differences in conception rate, especially in comparison to dairy cows (2015). This difference is most often attributed to higher milk production in dairy cattle, although Geppert notes that as both beef and dairy cows experience lactational stress near breeding, extra energy expended to metabolize excess protein may result in a negative energy balance that would affect reproductive function in both beef and dairy cows (2015). Surprisingly, higher levels of dietary protein have been shown to correlate with increased follicle size in beef heifers (Geppert, 2015). Geppert hypothesized that follicle diameter deviation as a result of protein supplementation may be due to greater protein intake increasing insulin like growth factor-1, which may act on ovarian function via the hypothalamo-pituitary-ovarian axis. However, she also concluded that there may be a threshold to the "larger is better" theory, as beef heifers ovulating follicles greater than 15.7 mm in diameter had a decreased probability of establishing a successful pregnancy. Furthermore, these larger follicles may be not be superior to the smaller follicles as there was no difference in estradiol concentrations or subsequent CL volumes (Geppert, 2015). As a result, we cannot conclude that increased dietary protein improves conception rates in beef cows through influencing follicular size without conducting further research. We can conclude, however, that an influx of dietary protein is less harmful to beef heifers when compared to dairy heifers.

Uterine Environment

Proper uterine environment is essential to maintaining pregnancy. If the uterine pH or chemical secretions fluctuate, it can be detrimental to a developing embryo. Research has suggested that excess crude protein consumption alters the uterine environment to be less favorable for embryo development and fertilization (Geppert, 2015). In his research, Butler emphasizes that successful embryo development depends upon the nature of the uterine environment, and the uterine luminal milieu is dynamic, and exhibits marked differences between the stages of the estrous cycle as a consequence of ovarian steroidal regulation of endometrial secretion. His study found that intake of high protein diets by lactating cows has been shown to alter the pH and the concentrations of other ions in uterine secretions, but only during the luteal phase and not at estrus (2000). Uterine pH was also affected in heifers fed excess rumen degradable protein and was associated with reduced fertility. "Plasma urea is inversely related to uterine luminal pH and sequential measurements in lactating cows have demonstrated that uterine pH is dynamically attuned to changes in plasma urea with a time lag of several hours. As a result of feeding diets high in crude protein, increased plasma urea concentrations may interfere with the normal inductive actions of progesterone on the microenvironment of the uterus and, thereby, cause suboptimal conditions for support of embryo development" (Butler, 2000, p. 454). Additional studies have agreed that when cattle are fed excess rumen degradable protein, the urea produced may decrease uterine pH which, in addition to its toxic effect on the embryo, may suppress maternal recognition of pregnancy by altering uterine secretions of magnesium, potassium, and phosphorous, all of which play a significant role in the ability of the mother to recognize the presence of the fetus. Should failure of recognition occur, the fetus would be treated as a foreign invader and destroyed. Furthermore, sperm transport and capacitation are driven by uterine pH; therefore, excess rumen degradable protein may interrupt sperm transport and impair sperm from accomplishing fertilization" (Geppert, 2015, p. 26-27). In all of these circumstances, the producer would have spent time and money to impregnate a cow, only to result in failed fertilization or early termination of pregnancy.

Hormones

Some researchers have postulated that urea can act to interrupt signaling between the hypothalamus and ovary by decreasing gonadotropin release and subsequent hormone response (Geppert, 2015). However, these effects are highly dependent on the stage of reproduction as hormone levels change drastically depending on the cow's reproductive state. For example, high dietary protein has not been shown to have a strong impact on the re-initiation of ovulatory activity in cows that have recently given birth. However, evidence has suggested that reduced concentrations of plasma progesterone during the early breeding period may result from a combination of negative energy balance and high dietary protein intake (Butler, 2000). Reduced progesterone concentrations in lactating dairy cows consuming excess protein is thought to result from competitive action of urea interrupting binding of luteinizing hormone to luteinizing hormone receptors on the corpus luteum as the same effect was not observed in non-lactating cows. (Geppert, 2015). Figure 5 briefly summarizes the relationship between these hormones in the reproductive cycle.

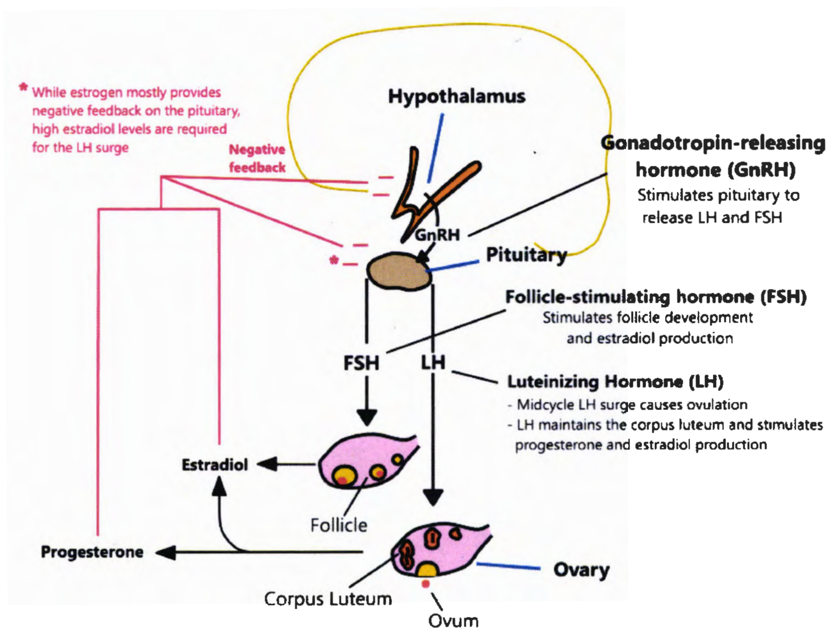

Figure 5: Hypothalamic-pituitary-ovarian axis (Straight, 2018).

Protein in Production

The dietary requirements of cattle change with their stage of production. Young beef cows require much more protein as they grow and build muscle tissue, and dairy heifers must meet steep energy demands during lactation. Thus, meeting the requirements for energy and protein in order to support production and metabolic health can be challenging (Herdt, 2018). As a result, dietary protein is often overfed in cattle to promote increased production. This excess is achieved in a variety of ways. Commercial protein supplements often use nonprotein nitrogen sources like urea to meet nitrogen requirements. When consumed by cattle, nonprotein nitrogen supplements are readily broken down by ruminal microbial protein to ammonia and are then synthesized to high-quality microbial protein (Hilton, 2018). Additionally, high levels of crude protein may be included in the diet directly. However, there is often a threshold at which excess protein loses its positive effect on production traits. Feeding both too little or too much protein can prove to be unprofitable. By improving the efficiency with which their animals utilize protein and properly balancing dietary protein levels, producers can increase production and lessen their environmental impact.

Beef Cattle

The second most common energy deficiency in beef cattle is protein deficiency, which can result in limited growth and development, reduced milk production, decreased reproduction, and poor microbial protein production (Hilton, 2018). As such, beef producers are often concerned that their animals are not getting adequate protein in their diets. Parish recommends maintaining at least 8% crude protein content, stating that "forage dry matter intake as a percent of body weight increases until forage crude protein content as a percentage of dry matter decreases below a threshold of about eight percent (Figure 6). Thus, if a minimum of eight percent crude protein is not maintained in forage crops, cattle will decrease consumption" (2011). Cole found that "typical feed yard finishing diets for beef cattle contain approximately 13 to 13.5% crude protein and are routinely supplemented with 0.5 to 1.0% urea to provide adequate ruminal degradable intake protein" (Cole, 2005, p. 722). To examine the effectiveness of this diet, Cole conducted a study using nine different dietary treatments (table 1), all of which were formulated to meet the nutritional requirements for finishing beef steers gaining over 1.6 kilograms/day (2005). This study

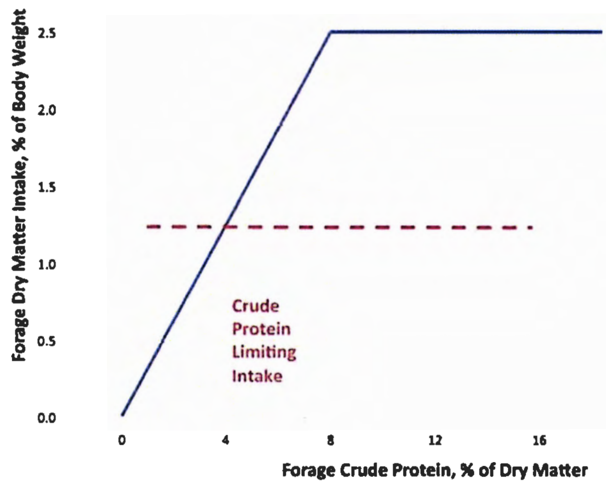

Figure 6: Forage dry matter intake relative to forage crude protein concentration (Parish, 2011).

Table 1

Experimental Design (adapted from Cole et al., 2005)

	100:0 U:CSM	50:50 U:CSM	0:100 U:CSM
11.5% CP	Low CP High Urea Diet	Low CP Moderate Urea Diet	Low CP Low Urea Diet
13.0% CP	Moderate CP High Urea Diet	Moderate CP Moderate Urea Diet	Moderate CP Low Urea Diet
14.5% CP	High CP High Urea Diet	High CP Moderate Urea Diet	High CP Low Urea Diet

Note: U:CSM = ratio of supplement Urea : Cottonseed Meal, CP = crude protein found that the typical feed yard finishing diet, which contains moderate levels of crude protein and moderate to high levels of urea supplementation, resulted in increased total daily nitrogen intake, increased serum urea-nitrogen concentrations, increased fecal nitrogen concentrations, and increased urinary nitrogen concentrations when compared to the other diets studied (Cole, 2005). These results would suggest that current diets are promoting more ammonia emissions than the other diets tested. Preece (2017) found that when crude protein concentrations of beef cattle finishing diets were reduced from 13 to 11.5 percent, ammonia emissions were reduced by 30 to 44 percent. Although this change resulted in a 3.5 percent decrease in average daily gain, the team concluded that “despite requirements to maintain cattle performance, reducing crude protein in beef cattle diets might be the most practical and cost-effective way to reduce ammonia emissions form feedyards” (Preece et al., 2017, p. 9). In some cases, it may be economically beneficial to reduce ammonia emissions despite the cost to performance, though this will vary among operations. Something else to consider is how dietary needs of beef cattle change depending on the stage of production. Cole found that as the steers approached their mature weight, protein deposition decreased. He concluded that if crude protein intake remains the same as an animal’s body weight increases, as it did in the study, the “proportion and quantity of dietary nitrogen excreted in the urine and the proportion of urinary nitrogen that is urea nitrogen increase” (2005, p. 728). Preece noted that phase feeding diets with roughly a 1.5 percent reduction in crude protein during the final 28 to 56 days of feeding can decrease ammonia emissions by as much as 25 percent with “little adverse effect on animal performance” (2017, p. 9). These results further enforce the importance of evaluating the animal’s diet during each stage of production and making necessary changes to meet current dietary needs without exceeding them, as too much protein in the diet results in extra energy being spent on metabolic processes that could have instead been use for growth.

Dairy Cattle

In regard to milk production, dairy cows experience much higher levels of lactational stress and produce much more milk when compared to beef. This is due to the high demand for amino acids for use in milk protein synthesis (Herdt, 2018). Table 2 summarizes the recommended levels of dietary protein for mature dairy cows in mid lactation and shows that maintenance of higher levels of milk production requires more crude protein in the diet.

Table 2

Recommended Minimum Dietary Protein Concentrations (adapted from Herdt, 2018)

Milk (kg/day)	CP (Lrg Breed)	MP (Lrg Breed)	CP (Sm Breed)	MP (Sm Breed)
18	-	-	15.0	12.9
23	-	-	16.4	13.1
27	14.5	11.0	17.6	13.3
32	15.0	11.2	17.5	13.3
36	15.8	11.5	19.0	13.3
40	16.5	11.7	-	-
45	17.3	11.9	-	-
50	17.8	12.0	-	-
55	18.3	12.1	-	-

Note: protein requirements are expressed as % Dry Matter, CP = crude protein, MP = metabolizable protein

However, there is a metabolic energy cost associated with excreting excess nitrogen, which can result in lower production and overall performance, "if the liver is overloaded with ammonia, elevated blood urea nitrogen will occur as well as an increase in milk urea nitrogen" (Ishler, 2017, p. 2). Several studies have recorded that urea-nitrogen concentrations in the urine of lactating dairy cows escalated as dietary crude protein concentration increased. One study recorded a 42% increase in the urinary urea concentration of lactating dairy cows when crude protein was increased from 14.4 to 19.8% (Cole, 2005). Because changes in crude protein can result in a large increase in urea concentration, maintaining appropriate levels of dietary protein is essential to achieving optimal production. Furthermore, studies have shown that similar increases in dietary protein have no significant improvement in milk production. Olmos and Broderick concluded that poor nitrogen utilization was associated with diets high in crude protein, and that an increase in crude protein from 15 to 19% showed no noteworthy increase in milk yield (2003). Mutsvangwa's study (tables 3 and 4) found that through manipulation of dietary crude protein and rumen degradable protein, they could decrease milk urea concentrations without experiencing decreased productivity. They found that milk yield and composition were unaffected by dietary treatment, and that the only milk component to experience significant changes was milk fat yield in the low crude protein diet, which was greater in cows fed low rumen degradable protein compared to high rumen degradable protein.

Table 3

Experimental Design (adapted from Mutsvangwa et al., 2016)

	14.9% CP	17.5% CP
63% RDP	Low CP, Low RDP	High CP, Low RDP
69% RDP	Low CP, High RDP	High CP, High RDP

Note: RDP = Rumen Degradable Protein, CP = crude protein

Table 4

Experiment Results (adapted from Mutsvangwa et al., 2016)

	Low CP		High CP	
	Low RDP	High RDP	Low RDP	High RDP
Milk Yield (kg/d)	38.3	38.5	39.0	39.4
Fat (%)	3.68	3.53	3.60	3.50
Fat (kg/d)	1.43	1.30	1.40	1.38
Protein (%)	3.30	3.25	3.28	3.26
Protein (Kg/d)	1.25	1.30	1.25	1.30
Lactose (%)	4.56	4.55	4.50	4.52
Lactose (kg/d)	1.73	1.75	1.78	1.80

Note: RDP = Rumen Degradable Protein, CP = crude protein

Feeding Strategies

There are many different methods of decreasing dietary crude protein in cattle diets, each with its own benefits and drawbacks. What works for one producer may not be the best option for another. Thus, it is important for producers to research various strategies and work with a nutritionist to decide which option provides the best diet for their operation. It is also important to take into account product availability and cost, as these vary greatly depending on season and location.

Feed Variability

Changing feed can have a significant impact on dietary protein levels. Feeds are extremely variable in protein digestibility. The protein in common grains and protein supplements is usually between 75% and 85% digestible, whereas alfalfa hay protein is 70% digestible and grass hays are only 35% to 50% (Hilton, 2018). However, balancing a ration to prevent overfeeding of nitrogen can be a difficult process as feeds vary greatly in cost, protein content, and availability depending on location. A popular feeding practice in the cow-calf sector involves pairing crude protein coproducts with low quality forage or corn stalks. Geppert cautions that while cost-effective, this diet is likely to result in over supplementation of protein (2015). In forages, crude protein levels vary greatly depending on the season. Cool-season grasses typically contain higher crude protein levels than warm-season grasses, especially if warm-season grasses are receiving inadequate nitrogen fertilization (Parish, 2011). The type of forage also makes a significant impact. Legumes for example, have a much higher protein content than grasses. Forage maturity also has an impact on protein content. Forage that is allowed to mature before harvest contains lower crude protein concentrations than forage harvested earlier in the season (Parish, 2011). Table 5 summarizes the crude protein content of some popular forages.

Table 5

Forage Crude Protein Ranges by Species and Maturity (adapted from Parish, 2011)

Forage	Maturity	Crude Protein
Alfalfa	Bud	22 – 26
	Early Flower	18 – 22
	Mid Bloom	14 – 18
	Full Bloom	09 – 13
Corn Silage	Well Eared	07 – 09
	Poorly Eared	07 – 09
Tall Fescue, Orchardgrass	Vegetative – Boot	12 – 16
	Boot - Heat	08 – 12
Annual Ryegrass	Vegetative – Boot	12 – 16
	Boot – Heat	08 – 12
Bermudagrass	4 weeks old	10 – 12
	8 weeks old	06 – 08
Red Clover	Early Flower	14 – 16
	Late Flower	12 – 14

Note: Crude Protein is given as % dry matter

Supplementation

Changes in the source and ruminal degradability of nitrogen can make a significant impact on the efficiency with which nitrogen is utilized in ruminants. By utilizing high quality forage while maintaining sufficient rumen degradable protein, the efficiency with which rumen degradable protein is recycled can be increased (Herdt, 2018). According to Herdt, “Microbial protein has an excellent amino acid profile”, and diets that promote microbial protein production often meet amino acid requirements as long as metabolized protein requirements are met (2018, p. 11). This strategy can allow for increased efficiency without significant increase in dietary protein. Nonprotein nitrogen sources, such as urea, can also be utilized by rumen microbes. The ammonia produced by consumed urea can be utilized by ruminal bacteria to produce proteins when sufficient energy is available (Parish, 2011). However, Parish cautions the use of urea, as it can be toxic if used improperly. "If energy sources are limited in the rumen…large amounts of urea can enter the circulatory system and when the amount of urea entering the bloodstream exceeds the capacity of the liver to remove it, cattle can suffer from ammonia toxicity or urea poisoning with death resulting in less than 30 minutes" (Parish, 2011, p. 6). Because of this, urea is most effective when used with high-energy diets that contain low crude protein content. When using nonprotein nitrogen sources, the frequency of supplementation must be carefully monitored to avoid overconsumption and subsequent toxicity, especially when using molasses-based supplements. Unlike mineral blocks, which control consumption by balancing the mineral and salt content, supplements that contain molasses taste much sweeter and therefore run a higher risk of being overconsumed. If allowed, cows will keep coming back to the supplement because of the pleasant taste. Because of this, Parish recommends that liquid or solid molasses-based supplements containing urea and range cubes containing nonprotein nitrogen be fed in smaller amounts on a daily basis rather than feeding large amounts infrequently. She also suggests "filling cattle up on hay before placing liquid supplements or 'lick tanks' in pastures" to avoid overconsumption (Parish, 2011, p. 6).

Conclusion

Through management of dietary protein, it is possible to reduce the levels of urea excreted by cattle and thus limit ammonia production among livestock, reducing its availability for $PM_{2.5}$ formation. Ishler postulates that "the key to improving nitrogen efficiency of the cow is to balance the various protein fractions along with providing adequate carbohydrates and their fractions" and goes on to discuss the idea that nutritional imbalances are often the result of nutrients being fed in improper amounts or ratios. Nutritional imbalances related to protein often arise when nitrogen is fed in excess of requirements, excessive rumen degradable protein is fed relative to fermentable carbohydrates, diets are improperly balanced for rumen undegradable protein, or there is an imbalance of amino acids (2017, p. 2). If dietary protein levels are not managed properly, it not only results in increased ammonia emissions but can have a negative impact on health and production. As such, the goal of achieving proper balance of dietary protein should be desirable to most livestock producers. This can be achieved in many ways, though it is highly recommended to consult with a nutritionist before making significant dietary changes. Producers must evaluate their own rations and take into account the costs and benefits of adjusting their ration to limit excess nitrogen. When practical, reducing the amount of dietary protein can result in better production and decreased environmental impact.

Reflective Writing

This project is the culmination of all the skills and knowledge I have gained working towards my bachelor's degree. Throughout this project, I strengthened my critical thinking skills, creative writing, interpersonal communication, and data analysis skills. From the very beginning, I had to analyze all possible topics to choose the one that best suited me. I spent a lot of time researching different areas of interest to determine whether enough information was available and where I could access it most easily. Once I decided to write about the relationship between dietary protein and ammonia production in cattle, I worked with my committee members to determine which format would be the most persuasive to my target audience. In the end, I chose to present my research in the form of a research paper, accompanied by a trifold pamphlet and research poster for visual reference.

When I began writing, I never anticipated how far I would delve into the concepts surrounding ruminant nutrition and digestion. As a part of my major, I had taken a basic animal nutrition course which got me excited to further study this topic. However, I didn't fully grasp the complexity of ruminant digestion until I began my research. Now, I understand how little I truly know about these processes, and how much research has yet to be conducted in this field. I will continue to educate myself about ruminant digestion and nutrition, and I look forward to exploring new research as it becomes available. Perhaps I may even be a part of it, which I never thought possible. When I first began my undergraduate journey, I thought that research meant working in a laboratory, and since I started my capstone project with no laboratory experience, I was skeptical as to how I could contribute. However, I quickly became involved in other forms of research. I helped my mentor collect samples for her own research and spent a lot of time analyzing and compiling emissions data into charts and graphs that could be easily interpreted. My interest in the research process steadily grew, and I gained an appreciation for how much work goes into a research project, both in and out of the laboratory. I was also provided with great networking opportunities and was ecstatic to learn about other students' capstone projects. Through this project, I became more familiar with research being conducted in other disciplines. I examined research related to the environmental impacts of atmospheric ammonia and its importance as a precursor for particulate matter pollutants. Many a night was spent discussing these ramifications with my roommate, a natural resource major. I also have many coworkers who are studying to enter the medical field, and to my surprise, the effects of ammonia and $PM_{2.5}$ on the human body quickly became a hot office topic. I was excited to be able to share this with my colleagues and gain insight from their perspective.

Although I was fascinated with the interdisciplinary aspects of this research, my ultimate goal with the project is to inform beef and dairy producers of the effects that overfeeding protein can have on the environment and their animals' health and present a strategy for how to manage it. I also hope that this research helps prepare producers for potential changes in regulation standards. As the public becomes more engaged in emissions management, producers may be forced to make changes to meet new regulation standards for outdoor ammonia emissions. If producers are aware of potential changes and take the opportunity to adjust early, they will be able to explore more options and choose the most cost-effective means of management for their operation.

This experience has helped shape my future goals, and I will carry it with me as I move forward with my education and pursue a career in veterinary medicine. Not only has my honors capstone had a dominating presence in my graduate school applications, it has prepared me to contribute to my chosen graduate program and further their research goals. Conducting this research has deepened my appreciation of my educational experience. At times, I felt it was unnecessary to take certain classes or complete certain projects, but all of those experiences helped me develop the skills I needed to complete my capstone and will continue to aid me in my graduate studies. Perhaps my greatest reward is the relationships I have made with my mentor and departmental honors advisor. Their patience and encouragement aided me greatly in my efforts to gain acceptance to the veterinary program. Both my mentor and departmental honors advisor are faculty in the veterinary program, and the relationship I've built with them will give me the support and confidence I need to succeed in veterinary school. I know that I can always turn to them for advice and guidance, and I truly value their input.

There were many ups and downs associated with completing this project. The lack of research surrounding the specific production effects of reducing dietary protein in beef cattle was frustrating, and the dynamic nature of the topic was at times overwhelming. However, learning to navigate emissions data and the opportunity I had to participate in the student research symposium proved to be invaluable experiences. I am extraordinarily proud of what I have created with the help of my capstone committee. When I began my undergraduate education, it seemed like a daunting task, but I was able to produce a body of work that I am eager to share.

The best advice I can give to students preparing to begin their capstone project is to choose a topic you're passionate about, even if you don't know a lot about it. If you're excited to learn and find a knowledgeable mentor who is eager to guide you, it will be a worthwhile experience. Start early and make it your own. No two projects are alike. I spent more time than necessary worrying about my project because it wasn't like the examples I had read through. Also, know your audience. The format and length of your final product can vary greatly depending on who is going to be reading, watching, or listening to it. If you have absolutely no idea what you want to, don't worry. Meet with your departmental honors advisor and have a brainstorming session. They know what's going on in the department and can help you narrow down your area of interest. At times, the project may seem daunting, but it's definitely worth the effort.

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Ashley Houston

Professional Biography

Ashley Houston is set to graduate from Utah State University with a Bachelor of Animal, Dairy, and Veterinary Science. During her four years working towards this degree, Ashley decided to emphasize in Bio Veterinary Science and pursue a minor in Chemistry. She made the Dean's List on four separate occasions and remained in good academic standing throughout her time at Utah State University. She was an avid participant in university life, joining the Animal Science Club and Pre-Veterinary Club as well as spending time as a Resident Assistant who planned events for Campus Housing and Residence Life. Ashley has accepted an offer admissions to Washington State University College of Veterinary Medicine and will be joining the class of 2022.