**Review on Recent Advances in Enhancing Nitrogen Utilization Efficiency in Dairy Cattle; Nutritional, Productive and Economic Perspectives**

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**ABSTRACT**

*Efficient nitrogen utilization is an important way for improving dairy cattle productivity, economic viability, and environmental sustainability. However, the study showed that maximum dietary nitrogen converted into milk protein and production is 35%. most of the protein is lost in the form of manure and urine. This review aimed that to asses the recent advances in nitrogen utilization efficiency through nutritional. microbial genetic and management strategies. Nutritional intervention such as precision feeding (improve NUE up to 18%), crud protein reduction (reduced nitrogen loss by 20%), amino acid balancing and supplementations with rumen protected methionine and lysine (increase nitrogen retention by 15%) has significant improved NUE without decreasing milk yield. Modifying rumen microbiota using probiotics, essential oil, and tannins has further increased microbial protein synthesis and nitrogen retention by 15%. Genetic difference between breeds showed that Holstein Frisian and Norwegian red has higher NUE vales accounts 30 and 33% respectively compared to jersey and other breed 21-27%, highlighting the importance of of selective breeding enhancing NUE is closely associated with higher milk yield, better milk composition, reduced nitrogen excretion and lower feed costs, with high return of economic benefits around 25%. integrated through approaches. Therefore, it is recommended to combine precision feeding by phase feeding system, rumen microbial management and supported by critical research with continuedly has able to promote definite productive and eco-friendly dairy farming system.*

**Key word;** nitrogen utilization efficiency, dairy cattle, precision feeding, rumen microbe, genetic selection

1. **INTRODUCTION**

Nitrogen is avital nutrients in dairy cattle diets primarily supplied through dietary protein to support maintenance, growth, reproduction, and milk production. however, the efficiency with which dairy cows convert dietary nitrogen in to milk protein is notably low typically only about 15–35% on average, of the feed N eaten is secreted in milk. About 65–85% of feed N is expelled in manure(Duinkerken et al., 2011). This in efficient not only represent a significant economic loss but also contributed to environmental issue such as ammonia vitalization, nitrous oxide emissions and nitrate leaching. improving nitrogen utilization efficiency has therefore become a key goal in modern dairy production system (Keim & Anrique, 2011).

Overview of the past decades various strategies have been explored and implemented to enhance nitrogen utilization efficiency( Keim & Anrique, 2011; Lavery & Ferris, 2021; Munyaneza et al., 2017; Sinclair et al., 2014). These includes, Firstly, precision feeding techniques, which is adjusting crud protein level and balancing essential amino acids to meet the cow requirement accurately. Secondly, use of rumen protected nutrients**,** by supplemented Diets with rumen protected amino acids like methionine and lysine to improve nitrogen retentions and milk protein synthesis. Thirdly, use of selective breeding, identifying and breeding cows with traits associated with lower nitrogen excreted and improved metabolic efficiency. Fourthly, enhancing manure management practices, by implementing strategies to capture and recycles nitrogen from manure, reducing environmental loss. Further research has documented how the ruminal microbiota affects NUE, indicating that modifying rumen microbial populations may be a viable way to increase nitrogen efficiency.

**Objectives**

* To review recent advances in improving nitrogen utilization efficiency (NUE) in dairy cattle with nutritional, genetics, and management stratagem and to highlights their implication for sustainable dairy production economic, and environmental protection.

1. **METHODOLOGY**

A comprehensive analysis of peer-reviewed journal articles published was provided the foundation for this review. Scientific databases, Google Scholar, Web of Science, and PubMed were used to gather the literature. Among the search terms were environmental nitrogen losses, rumen fermentation, feed protein reduction, amino acid balancing, nitrogen use efficiency, and dairy cattle. Relevance, scientific quality, and real-world application were taken into consideration when choosing studies. The review summarizes current advancements, identifies new trends, and suggests future research %directions through the use of results from experimental inquiries, meta-analyses, and field investigations.

**3.0. RESULTS OF LITERATURE REVIEW**

**3.1.** **Nutritional Strategies to Enhance NUE**

The required nutritional strategies to optimize protein transmission services but reducing nitrogen losses are necessary to increase the efficiency of nitrogen consumption in dairy cattle (Plomaritou et al., 2025; Powell et al., 2010; Sinclair et al., 2014). Large amount of nitrogen excretion from overfeeding crude protein (CP) contributes to environmental pollution and economic inefficiencies (Cronk, 2023). In order to improve nitrogen retention and milk protein yield, recent developments in ruminant nutrition highlight the need of precise feeding, balancing amino acid profiles, and using protected nutrients (Lavery & Ferris, 2021). in addition profitable dairy systems are instantly embracing innovations including blends of rumen undegradable protein, rumen-protected amino acid supplementation, and dynamic feeding techniques(Shi et al., 2023).

Figure 1 Nutritional Strategies to Enhance NUE

Condensed crud protein is an important strategies especialy methionine and lysine that has emerged as one of the most effective nutritional strategies to enhance nitrogen utilization efficiency in dairy cattle (Munyaneza et al., 2017; Pecota & Collins, 2019; Zhang et al., 2021; Zhou et al., 2022). This strategies stud to minimize execs nitrogen utilization and subsequent urinary nitrogen excretion which is one of the primary contributors to environmental nitrogen pollution without compromising milk production (Guliński et al., 2016; Keim & Anrique, 2011; Shi et al., 2023). Since only the maximum of 35% of dietary nitrogen is converted in to milk protein under conventional feeding system, fine tuning amino acids, can significantly improve.

Some studies indicated that dropping cp levels by 1-2% points and compensating with RP amino acids can reduced nitrogen excretion by maximumly20%, while improving NUE by maximumly15% (Table 1). Furthermore, this technique emphasizes its usefulness in high-performance herds by supporting stable or enhanced milk protein output (Sinclair et al., 2014; Zhang et al., 2021). Methionine and lysine are delivered in protected forms to ensure that they bypass the rumen and are absorbed in the small intestine for efficient protein synthesis (Shi et al., 2023). Since nutrient use efficiency is a key component of sustainable dairy farming, including RP-AA in low-protein diets has benefits for the environment and the economy.

Table 1 Nutritional Strategies to Enhance NUE

|  |  |  |  |
| --- | --- | --- | --- |
| strategies | purpose | Result in % | Sources of the review |
| Lowering of crud protein | Decrease nitrogen excretion | 20% | (Munyaneza et al., 2017) |
| RU protein | enhance nitrogen use efficiency | 15% | (Lavery & Ferris, 2021) |
| Precision of feeding | Add as nitrogen use efficiency | 18% | (Pecota & Collins, 2019) |
| rumen protein Blend | enhance nitrogen use efficiency  lowering nitrogen efficiency | 12%  25% | (Powell et al., 2010),  (Hartinger et al., 2018) |
| Supplementation frequency | Additional milk protein  Reduced nitrogen loss | 9%  10% | (Shi et al., 2023) |
| Lysin supplements | Increase nitrogen utilization  Increase gut microbial bacteria | 10% | (Li et al., 2022) |

In the other way precision feeding is an example of shifting of dairy nutrition, from total rations to specific targeted nutrient delivery (Lavery & Ferris, 2021). Its major principle lies in adapting the nutritional supply to match the exact requirement of cows based on their production stage, milk yield, and physiological conditions (Garnett et al., 2015; Lavery & Ferris, 2021). According to this scholar listed above, Precision feeding greatly improves nitrogen use efficiency (NUE) and lowers nitrogen losses to the environment by avoiding nutrient oversupply, particularly crude protein (CP). The current study result indicate that applying this technique can increase the use of nitrogen efficiently about the maximum of 18% and decrease the urinary nitrogen defecations and greenhouse gas emission (Pozo-Leyva, et al., 2024) . The result is achieved through the use of decision-support software and real-time monitoring innovations that dynamically adjust diets to guarantee cows get just the right amount of protein and energy to suit their needs without going overboard (Biju  Raseel, K. & Rasanath, 2021; Pozo-Leyva et al., 2022).

Rumen protected amino acid, are one of the basic strategies like methionine and lysine which is by pass rumen degradation and are absorbed in the small intestine, improve protein synthesis and nitrogen use by 10% (Biju  Raseel, K. & Rasanath, 2021; Erdman et al., 2021; Pozo-Leyva et al., 2022; Sinclair et al., 2014). A balanced, slow-release amino acid profile is produced by blending RP-AA with Rumen Undegradable Protein (RUP). This can reduce urine nitrogen by up to 25% and increase nitrogen utilization efficiency (NUE) by 12% (Pozo-Leyva, et al., 2024). Further increasing milk protein by 9% and reducing nitrogen loss by about 10% can be achieved by optimizing the timing and frequency of RP supplementation.

**3.2. role of rumen microbe and nitrogen recycling**

Rumen has it is own microbes which has a vital role in nitrogen efficiently utilize by facilitating the breakdown of dietary protein in to microbial protein. Balanced microbial population has significant ability to capture nitrogen and minimized ammonia accumulations and excretions. Protein provides the amino acid needed for the maintenance of vital function, growth, milk production and reproduction. Dairy cows can utilize different nitrogen sources because of their ability to synthesis amino acids and protein from non-protein nitrogen sources. This ability is associated with the presence of rumen microbes in their body. Dietary proteins are degraded by microbes in the rumen to amino acid and goes to ammonia and branched chain fatty acids. the bacterial population uses ammonia in order to grow. Dietary feed includes the use of feed additive’s such as tannin, essential oil, probiotics and have been showed to modulate the rumen microflora, improving nitrogen retention, and reducing of nitrogen loss. Precision feeding is important technique to capture and recycling to enhance nitrogen retention by delivering urea to the rumen through saliva or directly across the rumen wall, particularly when protein intake is small. Avital components of dairy nutrition are improved rumen function which enhance microbial protein synthesis and reduction of nitrogen excretion in the form of urine. Improving NUE requires optimizing the rumen microbiota. In order to improve protein synthesis lowering of nitrogen loss and encourages of fermentation certain microorganism and microbial addition are the most important methods.

The most used probiotics in ruminant nutrient is saccharomyces cerevisiae in which to increase ammonia collection and improve fiber digestion for both can enhance nitrogen use efficiency by 12%(Pecota & Collins, 2019). the same way megashrk elsdenii probiotics promotes the growth of other important microbes and it helps to regulate the rumen ph. in ideally in high concentrate diets. Which may be increase NUE by 10%(Chmelíková et al., 2021).essential oil and tannins are the probiotics which is important to microbial modifications , reshaping the rumen microbial community to favored nitrogen efficient species and lower ammonia production, even though they are not microbes (Li et al., 2022). Depending on type and quantity these compounds have been demonstrated to increase microbial protein synthesis and nitrogen retention by 15%(Cronk, 2023; Li et al., 2022)

When combined, these treatments provide synergistic advantages for improving protein efficiency and lowering nitrogen losses in dairy cattle. the most effective way to improve the NUE of dairy cows is to match the dietary nitrogen content and energy supply during rumen fermentation by changing the diet composition (Li et al., 2022). According to different scholars about the efficiency of nitrogen utilization overview of microbiological species and additives utilized in modern dairy nutrition may be found below:

probiotic yeast , like saccharomyces cerevisiae and live yeast culture improves rumen stability and fiber digestion, leading to a notable increase in microbial protein synthesis and NUE (Zhang et al., 2021) . in addtions this yeast increases microbial protein by 80 – 150 gram/day. Similarly megasphaera elsdenii , is a lactic acid utilizing bacteria that supports microbial growth and reduces acidosis leading to increase nitrogen flow to the lower gut (Zhou et al., 2022). Butayrivibirio fibrisolvens also facilitates nitrogen recycling by breaking down fibrous feeds and promoting microbial protein formations increase nitrogen captures from forage-based diets (Keim & Anrique, 2011).

Feed additives such as essential oils and condensed tannins further enhance nitrogen recycling. essential oils regulate microbial populations by suppressing proteolytic bacteria reducing ruminal ammonia concentrations and improving microbial nitrogen efficiency(Zhang et al., 2021). Condensed tannins protect dietary proteins from rumen degradations, increase post ruminal protein absorption and lowering urinary nitrogen excretion (Patra et al., 2020). The findings definitely indicate that nitrogen utilization can be significantly enhanced by modifying the rumen microbial environment, either by increasing the activity of natural bacteria or by adding specific additions (Duinkerken et al., 2011; Guliński et al., 2016; Xu et al., 2021). In line with sustainable and fruitful dairy farming, these tactics not only promote increased microbial protein production but also lessen nitrogen waste and environmental contamination.

Table 2 rumen microbiota and nitrogen recycling

|  |  |  |  |
| --- | --- | --- | --- |
| Beneficiary organism | Importance | Consequence | Reference |
| Saccharomyces cerevisiae | Enhance fiber digestion  Stimulate bacteria | Increase microbial protein  Increase the number by 150g/day | (Garnett et al., 2015) |
| Megasphaera elsdenii | Uses lactic acid  Reduces acidosis  Promote microbial growth | Increase protein yield  Increase flow of yield | (Zhang et al., 2021) |
| Prevotela spp. | Digest protein  Absorb protein | Increase ammonia utilization | (Zhou et al., 2022) |
| Fibrisolvens | Fiber breakdown | Reduced nitrogen loss  Increase nitrogen capture | (Li et al., 2022) |
| Yeast culture | Increase bacterial growth  Fermentation regulation | Enhance nitrogen utilization  By more than 12% | (Sheng et al., 2018) |
| Oil blend | Microbial population change  Reduce proteolytic bacteria | Reduce ammonia accumulation  Increase microbial efficiency | (Li et al., 2022) |
| Tannins | Bind protein  Reduce rumen protein degradation  Promote post rumen digestion | Enhance microbial protein  Reduced urinary nitrogen | (Li et al., 2022; Sheng et al., 2018) |

**3.3. Nitrogen Utilization Efficiency for Milk yield and Milk Composition**

Dietary protein intake is the most important factor determining milk production, milk composition, milk nitrogen efficiency, urinary nitrogen losses, urea content in milk and consequently, ammonia emissions from dairy cow manure(Guliński et al., 2016). Dietary protein intake is the most important factor determining milk production. The level of NUE is determining the milk production directly proportionally. Which means that when the level of the nitrogen utilization efficiency is increased by one unit, the milk production also increases by equivalently ( ) (Chmelíková et al., 2021).

milk composition, milk nitrogen efficiency, urinary nitrogen losses, urea content in milk and consequently, ammonia emissions from dairy cow manure are different sign relationship with the level of dietary proteins specially rumen degradable protein (Guliński et al., 2016; Shi et al., 2023). According to the nutrition requirements, two main protein sources are available to cows: rumen degradable protein, provided to the animal through ruminal synthesized microbial proteins, and rumen undegradable protein that escapes ruminal degradation (Arriaga et al., 2009; Chmelíková et al., 2021; Cronk, 2023; Guliński et al., 2016; Hartinger et al., 2018; Shi et al., 2023). The utilizations of nitrogen efficiency are an important indicator of the dairy cows can effectively change nutritional nitrogen firstly from protein in to milk yield (Hartinger et al., 2018).

Figure 2 Nitrogen Efficiency and Milk Yield

In different production system about 35% of nitrogen consumed is changed in to milk protein but the majority of the consumed protein is lost by feces and urine (Arriaga et al., 2009; Chmelíková et al., 2021; Cronk, 2023; Guliński et al., 2016; Hartinger et al., 2018; Shi et al., 2023). According to the authors listed before milk compositing specially milk protein is directly correlated with NUE and it can inversely relate with dietary proteins (Plomaritou et al., 2025). Because when the amount of rumen degradable protein is increase in high level, the nitrogen utilization is less and the amount of nitrogen loss in the form of urine and manure is relatively high. Efficiently use of nitrogen utilization is the most important for milk protein composition, milk yield, economic and ecological sustainability(Lavery & Ferris, 2021; Plomaritou et al., 2025; Sinclair et al., 2014). This indicated that the enhance of nitrogen utilization in to microbial protein can directly helps for increasing milk yield and composition, less amount of nitrogen loses and reduced the amount of feed costs. Precision feeding is one of the best approaches in which diets are carefully balanced to meet both milk yield and nitrogen utilization efficiency and economical collaborations (Guliński et al., 2016; Keim & Anrique, 2011; Sheng et al., 2018).

**3.5. Nitrogen Utilization Efficiency in dairy cow breeds**

Nitrogen utilization efficiency are significantly different between dairy cow breeds, which is influenced by different in metabolic ability milk production potential and adaptation for feeding systems (Figure *3*) (Downey & Tucker, 2023; Lavery & Ferris, 2021). These breeds have specific characteristics essential to optimizing herd management strategy in improving productivity, economic return and environmentally friendly (Carroll et al., 2023; Manzanilla-Pech et al., 2023). Holstein Frisian cows are exhibit higher NUE values ranging from 26 up to 32% due to her greater milk production which dilutes the maintenance nitrogen requirement across a larger volume of milk. in contrast jersey cows producing milk richer in fat and protein but lower in total milk production than that of Hf and generally lower NUE than HF. Other breeds like brown swiss and Ayrshire have 24to29 and 22 to 27% moderate levels NUE respectively (Carroll et al., 2023; Kononoff, 2024; Manzanilla-Pech et al., 2023; Murray et al., 2024).

This indicated that their balance performance between yield and milk quality traits. Guernsey cow breeds show similar to jersey with NUE values between 21 to 25 %. Cross breeds such as Norwegian red have 27 to 33% and Swedish red and Whitehorn has 25 to 30% ability to utilize the nitrogen efficiently. Similar study showed that suggest that Mont billiards cattle breed has moderated NUE values about 23 to 28% and gives an advantage in dual purpose system (Kononoff, 2024; Murray et al., 2024). Other research suggested that cows with naturally lower nitrogen excretion rates and higher feed conversion efficient could be selectively breed for further enhance of NUE. Integrating genetic selection with sophisticated nutritional management can enhance genetic potential and contributed to both economic and environmental sustainability(Kononoff, 2024; Lassen et al., 2023; Marcondes et al., 2023; Murray et al., 2024; Tavernier et al., 2024). Based on the above listed scholar findings, the following are summery of maximum ability of NUE values in major dairy breeds.

Figure 3 maximum NUE values in major dairy breeds

According to the researchers listed before is breed, nitrogen utilization and milk protein composition has direct relationships (Figure 4). Cows with naturally lower nitrogen excretion and higher feed conversion efficiency can be identified and also breeding by selection (Garnett et al., 2015; Lavery & Ferris, 2021). This goes to long term improvement in use of nitrogen and milk yields increasement. In general, enhancing nitrogen utilization efficiency in important to achieve higher milk yield, but reducing feed cost and impacts of environment (Garnett et al., 2015; Nadeau et al., 2007; Wattiaux & Ranathunga, 2016).

Figure 4 Milk Composition and NUE Indicators

# **3.6. Nitrogen Utilization Efficiency for Feed Economic Importance**

# Improving the utilization efficiency of dairy cow offers significant economic importance in different approaches the most one is precision feeding which tailors ration to animal requirements and can reduce feed cost by 20% (Sinclair et al., 2014). In other way using rumen protected amino acid improves milk yield by 10% and reducing crude protein levels and balancing amino acids can enhance NUE by 20% lowering cost related with nitrogen waste (Erdman et al., 2021). Feed additives such as enzyme or probiotics also further boost nitrogen retention by 5-10% and also incorporating high quality forages can reduced reliance on expensive protein supplement by 15% (Biju  Raseel, K. & Rasanath, 2021; Feng & Kebreab, 2020; Sinclair et al., 2014). According to the above list scholars, group phase feeding by production level can reduce protein overfeeding costs by 25%. Additionally, improved manure handling conserves nitrogen for using fertilizer saving 15-20% on nutrient inputs (Pozo-Leyva et al., 2022).

Table 3 Nitrogen Utilization Efficiency for Feed Economic Importance

|  |  |  |  |
| --- | --- | --- | --- |
| Approach | Economic function | Economic Benefit (%) | Reference |
| Precision feeding | Reduce feed cost | 20 | (Rathnayake et al., 2023) |
| Rumen protected feeding | Increase milk yield | 12 | (Pozo-Leyva et al., 2021) |
| Cp reduction | Increase NUE | 22% | (Prestegaard-wilson et al., 2022) |
| Feed additives | Increase nitrogen retention | 8% | (Erdman et al., 2021) |
| High quality fed | Reduced protein supplements | 18% | (Guliński et al., 2016; Powell et al., 2013; Pozo-Leyva et al., 2021) |
| Phase feeding | Reduced protein over fed | 25% | (Guliński et al., 2016; Montes et al., 2013; Powell et al., 2013; Pozo-Leyva et al., 2021) |
| Improved manure | Reduce d nitrogen loss | 40% | (Nevens et al., 2006; Powell & Rotz, 2015; Rathnayake et al., 2023) |

Altogether those strategies (Table *3*) not only enhance feed efficiency and productivity but also importance significant to economic sustainability of dairy farming’s (Biju  Raseel, K. & Rasanath, 2021; Feng & Kebreab, 2020; Sinclair et al., 2014). Recent advance in dairy nutrition science emphasize the growing advantages of increasing utilization of nitrogen efficiently for both economic gains and environmental sustainability. Precision feeding enables by real time ration balancing technology and software that has shown reduced feed cost about 20% particularly by minimizing protein overfeeding. in recent meta-analysis report about 12% and more offering substantial profit margin in high producing herds (Pozo-Leyva et al., 2022; Pozo-Leyva, Casanova-Lugo, López-González, Celis-Álvarez, et al., 2024). Another strategy crude protein reduction when compared with amino acids supplementation not only improve NUE by 22% but also mitigate nitrogen excretion through reducing compliance and waste management cost (Powell et al., 2016; Powell & Rotz, 2015).

The inclusion of feed additives such as 3nitrooxypropanol and essential oils has given traction due to their importance of nitrogen retention and decreasing methane delivering by 5-8% increase nitrogen capturing efficiency (Rathnayake et al., 2023). Simultaneously feeding high digestible forages including improved legume variety decrease reliance on commercial protein concentrates by 18% similar with economic and environmental goals (Feng & Kebreab, 2020; Rathnayake et al., 2023). Phase feeding based on location, stage has been increase using automated monitoring system reducing protein wastages by 25% (Feng & Kebreab, 2020; Rathnayake et al., 2023).

Figure 5 Relationship between NUE and economic benefits. In dairy cattle

In addition to those all about listed above (Table *3*), improved manure nitrogen recovery through acidification or covered storage can reduce nitrogen loss by 40% and saving synthesized fertilizer cost by 20% (Biju  Raseel, K. & Rasanath, 2021; Rathnayake et al., 2023). These finding underscore that integrating modern nitrogen utilization efficiency enhancing strategies can substantially improve economic profitability, reduced feed cost and input cost and insured align with increasingly sever of environmental regulation making them highly relevant for both high producing company and small holder dairy farming systems (Feng & Kebreab, 2020; Pozo-Leyva et al., 2022; Pozo-Leyva, Casanova-Lugo, López-González, Cruz-Tamayo, et al., 2024). In general nitrogen utilization efficiency and economic return has positively correlated in each other, means that when the cows utilize nitrogen efficiently there is an advantage of dairy farmers in positive ways. when nitrogen utilization increases by two hands theirs also similar economic gains as shown (Pozo-Leyva, et al., 2024).

**CONCLUSION**

Improving the utilization of nitrogen efficiently in dairy cattle has an important way of enhancing milk production, reduce feed cost, and minimizing environmental impacts. Nitrogen loss through manure and urine represents the major economic reduction and contributions of environmental pollutions. Over the past consecutive decades considerable progress has been made in identifying nutritional, microbial, genetics and management strategies to address the challenges of nitrogen loss. Nutritional strategies like precision feeding, crud protein reduction, amino acid balancing and use of rumen protected nutrients have shown great improvements in nitrogen utilization without compromising milk yield and composition. Managing rumen microbes through feed additives such as probiotics, essential oils and tannins gives additional opportunity by enhancing microbial protein synthesis and nitrogen retention. More over genetic selection for cows with superior nitrogen utilization trait represents a promising long-term solution for more improvement. Moreover, enhancing the utilization ability of nitrogen efficiently has direct relationships with economic returns. Such as lowering of feed cost, reduced nitrogen excretion, related waste management cost, and improving milk yield and composition. improved manure management also has great role for further improvements by conserving nitrogen for use as fertilizer and enhancing environmental stability. In general, integrating precision nutrition, microbiome management, selective breeding and efficient manure handling has promising pathway to achieve higher productivity, economic gain and modern dairy production system that has ecofriendly to environmental safety.

**RECOMMENDATION**

To further study and enhance nitrogen utilization in dairy cattle and support sustainable dairy farming the following recommendation was given.

* Adopt the precision feeding via individual or group phased feeding strategy to compliance protein supply and cow’s requirement and reduce nitrogen loss and feed cost.
* Improve nitrogen retention and milk production synthesis with out scarifying milk composition by using utilization of rumen protected amino acids through methionine and lysine incorporated in diets.
* Use feed additives to optimized rumen fermentations and enhance microbial protein synthesis and re duce nitrogen excretions
* Use high NUE cows by genetic selection with naturally higher feed efficiency and lower nitrogen excretion which focused on breeds like Holstein Frisian.
* Further enhance more researches to support rumen microbial manipulation, amino acid supplementation, and NUE monitoring technology to increase continual improvements.

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