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Relationship between feed efficiency indices and performance of dairy animals

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Abstract

Feed efficiency is a key determinant of productivity, profitability, and sustainability in dairy production systems. This review highlights the relationship between major feed efficiency indices, including Feed Conversion Ratio (FCR), Residual Feed Intake (RFI), Residual Gain (RG), and Gross Feed Efficiency (GFE), and their influence on milk production, reproduction, health, and environmental sustainability in dairy animals. Efficient animals require less feed to maintain comparable production, resulting in lower feeding costs, improved metabolic health, enhanced reproductive performance, and reduced greenhouse gas emissions. The review also discusses the role of genetic selection, precision nutrition, and advanced management practices in improving feed utilization efficiency. Integrating feed efficiency indices into dairy breeding and nutritional programs can enhance productivity while promoting economically viable and environmentally sustainable dairy farming.

Keywords: Feed efficiency, feed conversion ratio, residual feed intake

Introduction

Feed efficiency is a critical determinant of productivity and profitability in dairy production systems. It reflects how effectively animals convert feed nutrients into milk, body weight gain, and reproductive performance. Rising feed costs, accounting for nearly 60–70% of total production expenses, have made improving feed efficiency a priority in modern dairy farming (Van Arendonk *et al.*, 2018) ^[11]. Efficient animals not only reduce input costs but also minimise environmental impacts through reduced methane emissions and nutrient excretion.

In recent years, the focus has shifted from merely increasing production to improving efficiency per unit of input. This shift is particularly important in countries like India, where feed resources are limited and often of variable quality.

The relationship between feed efficiency indices and dairy animal performance is essential for optimizing production systems and ensuring long-term sustainability.

Concept of Feed Efficiency in Dairy Animals.

Feed efficiency is traditionally defined as the ratio of output (milk yield or weight gain) to input (feed intake), most commonly expressed as milk yield per unit of dry matter intake (DMI).

According to the National Academies of Sciences, Engineering, and Medicine (NASEM)—formerly the NRC—the formula is calculated as follows:

Feed Efficiency = Energy Corrected Milk (kg or lb)/DMI (kg or lb)

Energy Corrected Milk (ECM): This adjusts milk production to a standard 3.5% fat and 3.2% true protein.

ECM = (0.327* milk weight) + (12.95*fat weight) + (7.2*protein weight).

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While this definition is simple and easy to measure, it does not account for differences in maintenance requirements, body condition changes, or the physiological status of animals. Modern dairy science has therefore introduced more refined measures of feed efficiency, including Residual Feed Intake (RFI), Residual Gain (RG), and Gross Feed Efficiency (GFE). These indices consider various biological factors such as metabolic efficiency, digestion, nutrient partitioning, and energy balance (Pryce *et al.*, 2014)^[6].

Two cows producing the same amount of milk may differ significantly in feed intake due to differences in digestion efficiency or metabolic processes, highlighting the importance of advanced efficiency indices (Tempelman *et al.*, 2015)^[10].

Feed Conversion Ratio (FCR) and Dairy Performance

- Lower FCR values indicate better efficiency, as animals require less feed to produce the same amount of milk.
- $FCR = DMI / \text{milk yield or average daily gain}$.
- It signifies the amount of kilograms of feed to produce one kilogram of milk or meat. Lower FCR values correlate with reduced methane emissions and lower nitrogen excretion per unit of product.
- Efficient cows with low FCR values tend to produce higher relative milk yield (milk per unit body weight), even if their absolute feed intake is lower
- Cows with longer rumination time and slower feeding rates exhibit better feed utilisation efficiency, leading to improved milk production and metabolic stability.

Residual Feed Intake (RFI)

It is a modern metric used to assess feed efficiency in dairy cattle. Unlike traditional measures like the Feed Conversion Ratio (FCR), RFI is designed to be independent of production levels, making it a valuable tool for identifying animals that are inherently more efficient at utilizing nutrients.

RFI is defined as the difference between an animal's actual feed intake and its expected intake based on maintenance and production requirements.

$$RFI = \text{Actual DMI} - \text{Expected DMI}$$

In dairy systems, RFI represents the variation in feed consumption that cannot be explained by the energy requirements for maintenance and milk production (Nehme Marinho & Santos, 2022)^[4]. A key advantage of RFI is that it is phenotypically independent of production levels. This allows farmers to select for efficient cows without unintentionally selecting for lower milk yields. "Low RFI" (more efficient) cows can consume significantly less dry matter (up to 3.8 kg/day less) while maintaining the same level of energy-corrected milk (ECM) yield as "high RFI" (less efficient) cows (Nehme Marinho & Santos, 2022)^[4]. Improved RFI is strongly linked to environmental sustainability; efficient cows tend to produce less methane per unit of feed consumed. Efficient cows often show better reproductive performance, such as fewer "days open," suggesting that the underlying metabolic mechanisms for efficiency may also support overall cow health (Nehme Marinho & Santos, 2022)^[4].

Animals with negative RFI values are considered more efficient because they consume less feed than expected while maintaining similar levels of production

RFI has been shown to reduce feed intake without compromising milk production or quality, making it a

valuable trait for genetic improvement programs (Tempelman *et al.*, 2015)^[10].

Residual Gain (RG)

It is an efficiency metric that measures the difference between an animal's actual weight gain and its predicted weight gain based on its feed intake and body weight.

While Residual Feed Intake (RFI) focuses on how much feed is "left over" after meeting production needs, Residual Gain flips the perspective:

It identifies animals that grow faster than expected for a given amount of feed consumed.

In the dairy industry, this is particularly relevant for managing replacement heifers, where the goal is to reach breeding weight efficiently without excessive fat deposition.

High RG heifers reach their target breeding weights earlier or with less total feed, reducing the "non-productive" cost period of a dairy cow's life.

Unlike standard average daily gain (ADG), RG is statistically adjusted for feed intake.

This means selecting for high RG allows producers to find animals with superior growth genetics rather than just those that eat the most.

A critical relationship in dairy production is ensuring that high RG does not result in over-conditioning (excess fat). Studies show that RG is generally more correlated with lean tissue growth than fat deposition compared to simple weight gain metrics.

Residual gain is calculated as:

$$RG = \text{Actual ADG} - \text{Expected ADG}$$

Feed Efficiency and Reproductive Performance

The relationship between feed efficiency and reproductive performance is complex and influenced by energy balance, metabolic status, and hormonal regulation (Seymour *et al.*, 2021)^[8].

Most reproductive issues in dairy cows stem from a Negative Energy Balance during early lactation, where energy output in milk exceeds energy intake. High-efficiency cows are often better at managing their metabolic reserves during this transition period, which supports the resumption of the oestrous cycle.

Efficient cows tend to have more stable metabolic profiles (lower NEFA and BHBA levels), which provides a better environment for oocyte development and prevents early embryonic loss. Higher efficiency is often associated with better regulation of Insulin-like Growth Factor-1 (IGF-1). IGF-1 is essential for follicular dominance and the secretion of estradiol, which triggers estrus. Inefficient cows (high RFI) often experience higher oxidative stress and inflammation, which can impair the hypothalamus-pituitary-ovarian axis and delay ovulation.

Recent studies suggest that selection for improved RFI does not adversely affect reproductive traits and may even enhance fertility by optimizing energy use and reducing metabolic stress (Stephansen *et al.*, 2025)^[9].

Feed efficiency has been associated with better body condition stability, shorter calving intervals, and improved conception rates, especially when combined with balanced nutrition and proper management practices (Wanapat *et al.*, 2024)^[12].

Feed Efficiency and Health Status

Cows typically exhibit better metabolic health due to optimal nutrient utilisation and reduced metabolic load. This lowers the incidence of disorders such as ketosis, acidosis, and fatty liver syndrome (Wanapat *et al.*, 2024)^[12].

Efficient cows (low RFI) tend to have lower blood concentrations of Beta-hydroxybutyrate (BHBA) and Non-esterified fatty acids (NEFA) during early lactation. High levels of these metabolites are clinical indicators of negative energy balance, which leads to ketosis and fatty liver syndrome. Inefficient cows (high RFI) often show signs of increased liver stress. Research has shown that inefficient animals have higher concentrations of liver enzymes like AST (Aspartate Aminotransferase), suggesting potential subclinical liver damage or excessive metabolic workload (Nehme Marinho & Santos, 2022)^[4]. Inefficient cows require more oxygen for maintenance, which can lead to the production of Reactive Oxygen Species (ROS). This oxidative stress can damage immune cells and increase the cow's vulnerability to environmental pathogens.

Some evidence suggests efficient cows maintain better Body Condition Score (BCS) in early lactation, which preserves the digital fat pad in the hoof, potentially reducing lameness.

Behavioural indicators such as feeding time, rumination activity, and resting patterns have been found to correlate with feed efficiency and health status. Efficient cows tend to have stable feeding behaviour and higher rumination time, which supports rumen health and nutrient digestion.

Furthermore, early detection of health problems through changes in feeding behaviour can improve feed efficiency and reduce production losses, emphasising the importance of integrating precision livestock technologies in dairy management.

Genetic and Nutritional Strategies to Improve Feed Efficiency

Genomic selection for traits like RFI has gained significant attention, as it allows identification and breeding of animals with superior efficiency. RFI is the preferred genetic trait because it is independent of production levels. Selecting for low RFI identifies cows with inherently lower maintenance requirements and better metabolic efficiency.

Selecting for moderate body size (avoiding overly large cows) reduces the "maintenance tax"—the energy required just to keep the animal alive—thereby improving overall herd efficiency (Ruban, 2024)^[7].

The efficiency of a dairy cow is heavily limited by fibre digestion. Improving the Neutral Detergent Fibre digestibility (NDFD) of silages ensures faster passage rates and higher energy extraction per kilogram of dry matter (Nehme Marinho & Santos, 2022)^[4]. Compounds like monensin alter rumen fermentation to produce more propionate (a primary energy source) and less methane, improving feed efficiency by 2% to 4%. Feeding rumen-protected methionine and lysine allows for lower crude protein diets, reducing the energy cost of excreting excess nitrogen as urea. Nutritional strategies such as precision feeding, balanced ration formulation, and inclusion of feed additives (e.g., enzymes, probiotics) have also been shown to enhance feed utilisation efficiency (Wanapat *et al.*, 2024)^[13].

Environmental Implications of Feed Efficiency

Feed production is a dominant contributor to the environmental burden of livestock, often accounting for more than 50% of the total greenhouse gas (GHG) emissions in

poultry and monogastric supply chains. Efficient animals produce less methane, nitrogen, and other greenhouse gases per unit of milk, contributing to climate change mitigation (Wanapat *et al.*, 2024)^[13].

High feed efficiency reduces the total quantity of crops required for animal maintenance. This lowers the pressure to convert natural habitats into agricultural land, which currently accounts for nearly half of the world's habitable area.

Agriculture utilises approximately 70% of global freshwater withdrawals. Improving feed efficiency reduces resource use, including land, water, and energy, thereby enhancing the sustainability of livestock systems (Stephansen *et al.*, 2025)^[9].

In ruminants (cattle and sheep), improved FE is linked to reduced enteric methane production per kilogram of product. Efficient digestion reduces the fermentation waste that escapes as methane (Llonch *et al.*, 2018)^[11].

Animals require less feed, which indirectly conserves the vast amounts of water used for crop irrigation and processing (Our World in Data). By minimising the total feed required, the industry reduces emissions associated with fertiliser application, crop cultivation, and the transport of feed ingredients.

Selection for feed-efficient animals has been shown to significantly lower the carbon footprint of dairy production systems, making it a key strategy for sustainable livestock development.

Conclusion

Feed efficiency indices such as FCR and RFI are essential tools for evaluating and improving dairy animal performance. Recent research highlights their strong association with milk production, reproduction, health, and environmental sustainability (Stephansen *et al.*, 2025)^[9].

The integration of genetic selection, precision nutrition, and advanced monitoring technologies offers significant potential for improving feed efficiency in dairy systems. Efficient animals not only enhance productivity and profitability but also contribute to sustainable livestock production (Wanapat *et al.*, 2024)^[13].

Conflict of Interest

Not available

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