***Review Article***

**EFFECT OF DCAD ON DRY MATTER INTAKE, MILK YIELD, AND OVERALL HEALTH OF TRANSITION CATTLE AND BUFFALO: A COMPREHENSIVE REVIEW**

**ABSTRACT**

This review focuses on managing dairy animals during the transition period using the dietary cation-anion difference (DCAD) concept. The authors have compiled and evaluated research on both dairy cattle and buffalo, examining the effects of DCAD on nutrient utilization, milk yield, milk composition, blood metabolites, urine pH, hypocalcaemia, ketosis, negative energy balance, and overall health. The findings indicate that DCAD is an effective management strategy for the transition period in dairy animals. However, while extensive research has been conducted on dairy cattle, there is a notable gap in knowledge regarding buffaloes. Therefore, more research on this species is necessary.

**INTRODUCTION**

The dairy industry has gradually improved over the last few decades, primarily focusing on production, while other crucial aspects like management and health often receive less attention. The transition period is the most critical time in dairy production, as proper management during this phase can significantly impact the animal's health and production status. Effective management and appropriate nutritional care are essential during this period to fully realize the animal's genetic potential. The Dietary Cation-Anion Difference (DCAD) is a practical, easy-to-implement, and reliable nutritional management system developed for dairy animals. The concept of DCAD, represented by the formula ([Na+]+[K+])−([Cl−]+[S−]) = mEq/100g of DM, has been familiar in dairy science for over two decades. This article reviews research on both dairy cattle and buffalo, evaluating the effects of DCAD on dry matter intake (DMI), nutrient intake, milk yield, milk composition, urine pH, blood metabolites, hypocalcaemia, ketosis, negative energy balance, and overall health.

1. **Effect of DCAD and Nutrient interaction on its utilization and digestibility**

The dietary cation-anion difference (DCAD) plays a critical role in optimizing nutrient utilization and digestibility in dairy cows, particularly during late gestation and the transition period. Numerous studies have explored the effects of varying DCAD levels on different aspects of dairy cow nutrition and health.

**1.1 Metabolic Effects and Digestibility**

Apper-Bossard et al. (2010) investigated the metabolic effects of increasing DCAD (0, 150, or 300 mEq/kg of DM) in diets with low and high starch content. They observed that rapidly degraded starch reduced rumen pH and the acetate to propionate ratio but did not significantly affect overall digestibility. Increasing DCAD levels led to higher DMI and urinary pH, with these effects being more pronounced when cows were fed a 40% concentrate diet. The study concluded that increasing DCAD acted as a buffer for rumen pH without negatively affecting nutrient digestibility and degradability. El-Mashed et al. (2015) explored the effects of 0 and -150 mEq/kg DM DCAD on digestibility, rumen fermentation, and milk production in twenty Friesian cows. They found that negative DCAD resulted in approximately 50% organic matter digestibility, with no significant impact on crude fiber digestibility. The study concluded that varying DCAD levels influenced nutrient and organic matter digestibility. Martins et al. (2016) studied the influence of different DCAD treatments (+290, +192, +98, and −71 mEq/kg DM) on ruminal fermentation and total apparent digestibility in lactating cows. They observed that higher DCAD levels increased ruminal pH and the concentrations of acetic and butyric acids, although serum calcium concentration decreased. Notably, neutral detergent fiber (NDF) total apparent digestibility increased linearly with higher DCAD levels. The study concluded that ruminal pH and NDF digestibility are positively correlated with the cation level in the diet.

**1.2 Rumen pH and Microbial Activity**

Sharif et al. (2008) examined the effects of varying DCAD levels on rumen pH and microbial activity. They discovered that a high DCAD diet improved rumen pH, which subsequently increased DMI. Additionally, the study reported higher concentrations of ruminal ammonia nitrogen (NH3-N) and acetate, while propionate and butyrate levels decreased. The positive DCAD diet also led to increases in blood pH, bicarbonate (HCO3), and urine pH. These changes were associated with improvements in milk yield and composition, demonstrating the beneficial effects of high DCAD on rumen pH and microbial activity.

1. **Effect of Feeding DCAD on Urinary pH**

Numerous studies on dairy animals have shown that lowering the dietary cation-anion difference (DCAD) during the prepartum period is closely associated with metabolic acidosis, as evidenced by reduced plasma bicarbonate and lower urinary pH. This section reviews key research findings on the impact of feeding DCAD on urinary pH and associated metabolic outcomes. Kour et al. (2024) reported that the group fed the -100 DCAD diet had significantly lesser DM, nutrient intake and urine pH.

**2.1 Urinary pH and Calcium Homeostasis**

Mellau et al. (2004) conducted an experiment to determine the effect of anionic salt supplementation on urinary pH and calcium homeostasis in cows. The dietary treatments included wrapped grass silage with ammonium chloride and ammonium sulfate salt solution, compared to a control ration. They observed that anion supplementation with highly fermentable carbohydrates lowered urine pH to below 7.0, indicating metabolic acidosis, and enhanced calcium homeostasis. This phenomenon was further validated using a standardized intravenous EDTA infusion. The study concluded that prepartum feeding of anionic salts or combining them with highly fermentable carbohydrates before parturition can significantly decrease urinary pH and improve the calcium status of the animal.

**2.2 Trend in Urinary pH with Varying DCAD**

Roche et al. (2007) investigated the effects of two DCAD levels (-20 and +18 mEq/100 g DM) administered twice daily for 24 days on dairy cows, accompanied by an intensive calcium balance study. They found that feeding a negative DCAD reduced urinary pH and increased calcium absorption from the gastrointestinal tract, alongside a reduction in blood pH. Ganjkhanlou et al. (2010) evaluated the effects of three diets with DCAD levels of +13, 0, and -13 mEq/100 g DM during the transition period in cows. Ammonium chloride and ammonium sulfate were used to decrease DCAD. They observed a decreasing trend in urinary pH with decreasing DCAD levels, with mean urinary pH values of 7.9, 6.81, and 6.0, respectively. Additionally, they noted that milk production and 3.5% fat-corrected milk (FCM) increased with decreasing DCAD. Weich (2012) conducted a study on Holstein dairy cows during the transition period, comparing treatments of +12, +12/-16, and -16 mEq/100 g DM. The study found that supplementing anions induced metabolic acidosis, reduced urine pH, and increased postpartum dry matter intake (DMI) in the negative DCAD group compared to the positive DCAD group.

**2.3 Comparison of Anionic Supplementation**

Rodrigues et al. (2018) conducted an experiment on non-lactating, multiparous, pregnant crossbred cattle to compare the effects of ammonium chloride (CON) versus a commercial anionic supplement (SUPP) on urinary pH. Their analysis indicated that urine pH was significantly lower in the SUPP group (6.12) compared to the CON group (7.15). Additionally, the SUPP did not reduce concentrate intake in animals compared to CON, which was beneficial for animal health.

1. **Effect of DCAD on Milk Yield, Composition, and Calcium Status**

The fundamental mechanism underpinning the impact of dietary cation-anion difference (DCAD) on milk yield, composition, and calcium status is the increased tissue receptivity to parathyroid hormone during acidosis. This condition enhances the production of active vitamin D, which subsequently boosts intestinal absorption of calcium (Charbonneau et al., 2006). Conversely, supplementing positive cations during the prepartum period can lead to metabolic alkalosis, which reduces tissue responsiveness to parathyroid hormone, hampers calcium mobilization, and predisposes the animal to hypocalcaemia, milk fever, and various other metabolic disorders (Goff et al., 2004).

**3.1 Impact on Milk Yield and Composition**

Roche (2003) utilized natural pasture with a DCAD range from 0 to +76 mEq/100 g to study its effects on dairy cows. They observed symptoms of systemic acidosis with decreased DCAD levels. When DCAD levels reached +21 mEq/100 g, there was a noted decrease in dry matter intake, body weight gain, milk protein, and milk yield. The study concluded that while an increase in dietary cation-anion difference can have positive effects on lactating cows to a certain extent, higher levels of DCAD can lead to a decrease in milk yield. Gelfert & Staufenbiel (2008) found that feeding anionic salts activated calcium metabolism by inducing metabolic acidosis, which prevented severe hypocalcaemia, particularly in the last two to three weeks before parturition. This also enhanced calcium absorption. Some studies indicated better postpartum calcium balance in cows administered anionic salts along with a high-calcium diet. They concluded that a dietary calcium concentration of 9 g to 12 g/kg dry matter, combined with anionic salt during the prepartum period, is necessary to prevent parturient paresis.

**3.2 Comparative Studies on DCAD Levels**

Shahzad et al. (2008) evaluated the influence of four different DCAD levels on mineral concentration, milk yield, and composition in Nili Ravi buffaloes. They observed that a negative (-11) DCAD diet increased calcium and chloride homeostasis and balance in buffaloes, similar to cattle, while phosphorus, sodium, and potassium balance was better with positive DCAD. They found that increasing DCAD levels resulted in higher milk yield, and milk fat, but calcium concentration was significantly higher with low DCAD. Iwaniuk et al. (2015) analyzed data from 43 articles published between 1965 and 2011 to determine the response of DCAD on feed dry matter intake and milk production. The DCAD levels in these studies ranged from -68 to +811 mEq/kg of diet DM. The use of dietary buffers like NaHCO3 and K2CO3 helped increase DCAD. The analysis showed that milk production increased by 1.7% with an increase in DCAD. It was concluded that for every 100 mEq/kg increase in DCAD, there was an increase in NDF digestibility, pH units, and FCM/DMI units. Diehl et al. (2018) investigated the effect of feeding a -2 (neutral) or -21 (acidogenic) mEq/100 g of dry matter DCAD diet with varying calcium concentrations (1.3% or 1.8%) on blood mineral composition and milk production. They observed higher milk yield after 45 days in milk for cows on an acidic diet but no difference in milk component percentage. The results suggested that an acidic DCAD diet during the prepartum period could increase blood mineral concentrations, especially calcium, which is critical for animal health during the transition period. Glosson et al. (2020) studied the influence of acidogenic prepartum diets on dairy production in 81 multiparous cows. The DCAD diets were +6 mEq/100 g of DM, -24 mEq/100 g of DM with low dietary calcium, and -24 mEq/100 g of DM with high dietary calcium. They observed no difference in daily milk production, but cows fed positive DCAD exhibited subclinical hypocalcaemia, whereas those fed negative DCAD did not have any cases of subclinical hypocalcaemia. Peters (2020) conducted a meta-analysis of studies on DCAD and non-fibrous carbohydrates (NFC), involving over 300 cows and more than 50 different types of feed, to study its effect on milk fat yield. The study found that increasing DCAD had a positive linear effect on milk fat yield for all levels of NFC, but the effect was less pronounced with high NFC. Thus, it was concluded that both DCAD and NFC should be considered when formulating diets to increase milk fat yield.

1. **Effect of DCAD on Milk Fever and Overall Health During Transition Period**

The transition period, which spans three weeks before and after parturition, is critical for dairy cows as they undergo significant metabolic and physiological changes. One major concern during this period is the incidence of milk fever (parturient paresis), which is linked to hypocalcaemia. Numerous studies have demonstrated the influence of dietary cation-anion difference (DCAD) on the occurrence of milk fever and overall health during this critical phase.

**4.1 Mechanisms of Milk Fever and DCAD Influence**

Goff & Horst (2003) explored acid-base physiology and its role in the pathogenesis of milk fever, finding that hypocalcaemia is often due to the failure of calcium homeostatic mechanisms exacerbated by metabolic alkalosis from high dietary cation intake, especially excessive dietary potassium. They noted that hypomagnesaemia could reduce tissue responsiveness to parathyroid hormone (PTH), though this can be rectified.

**4.2 Meta-Analyses and Large-Scale Studies**

Charbonneau et al. (2006) performed a meta-analysis of 22 published studies involving 75 treatment groups, identifying that lower DCAD levels reduced clinical milk fever incidence, blood bicarbonate, and blood CO2, while increasing ionized calcium in blood before and at calving. They concluded that reducing DCAD in the prepartum stage decreased the risk of clinical milk fever from 16.4% to 3.2%. Goff (2006) emphasized the challenges in maintaining calcium homeostasis during the transition period, highlighting the risks of metabolic alkalosis due to high DCAD, which reduces PTH effectiveness and can lead to milk fever. He stressed the importance of managing other minerals, such as potassium, magnesium, and phosphorus, to prevent conditions like the "downer cow" syndrome. Lean et al. (2006) analyzed data from over 130 trials to assess milk fever risk using DCAD equations. They found that negative DCAD diets, supplemented with calcium and phosphorus prepartum, could mitigate milk fever risks, particularly when combined with higher magnesium levels.

**4.3 Hypocalcaemia**

Hu et al. (2007) investigated early lactating exotic cattle breeds and found no significant differences in milk production, or composition with varying DCAD levels but noted better calcium homeostasis and health with lower DCAD diets. Kurosaki et al. (2007) reported a 50% reduction in hypocalcaemia cases in cows fed anionic salts prepartum, underscoring the efficacy of anionic salts in preventing metabolic diseases. DeGaris & Lean (2008) observed that cows on low-DCAD diets had higher plasma calcium and vitamin D concentrations, indicating better calcium homeostasis and reduced milk fever incidence. Similarly, Wu et al. (2008) found that cows on negative DCAD diets had higher plasma calcium levels, improved calcium homeostasis, and better overall health compared to those on positive DCAD diets. Seifi et al. (2010) reported significantly higher calcium concentrations and lower milk fever incidence in cows fed high concentrations of anionic salts prepartum. Shahzad et al. (2011) noted that negative DCAD diets increased nutrient intake, digestibility, and serum calcium levels, reducing the incidence of milk fever and other metabolic disorders.

**Recent Findings and Practical Implications**

Bhikane & Syed (2014) and Goff et al. (2014) highlighted the importance of managing DCAD to control milk fever and improve overall health during the transition period. Sakha et al. (2014) observed reduced subclinical hypocalcaemia and increased total serum calcium with lower DCAD levels, recommending the use of anionic diets prepartum to prevent hypocalcaemia. Wu et al. (2014) found no significant differences in health parameters between cows fed anionic salts for 3 weeks and those fed for 6 weeks prepartum, suggesting that the duration of anionic salt feeding may not critically impact health outcomes. Babir et al. (2017) confirmed that negative DCAD diets decreased milk fever and mastitis incidences, supporting their use in prepartum diets to enhance health and reduce post-parturient problems.

1. **Effect of DCAD on NEFA and BHB Levels**

Non-esterified fatty acids (NEFA) and β-hydroxybutyrate (BHB) are critical indicators of energy balance and metabolic health in dairy cows, particularly during the transition period. The dietary cation-anion difference (DCAD) significantly influences these metabolites, with numerous studies examining how altering DCAD impacts NEFA and BHB levels in dairy cows.

**5.1 Studies on NEFA and BHB Levels**

Melendez et al. (2002) investigated the effects of anionic salt supplementation on NEFA and BHB levels in transition cattle. They supplemented diets with various anionic salts, including calcium chloride, calcium propionate, and calcium boro-gluconate. Despite the supplementation, they observed no significant differences in ion concentration, NEFA, BHB, and glucose levels in blood samples collected post-calving. This suggests that the specific salts used and their administration methods may not significantly influence NEFA and BHB levels. Fiore et al. (2017) conducted a study on Bubalus bubalis (water buffalo) around calving and early lactation. They collected blood samples from 50 buffaloes 7 days prepartum and postpartum. They observed increased NEFA and BHB levels near calving, indicative of elevated lipolysis and ketogenesis as the animals mobilized body fat to meet energy demands. Postpartum, they noted increased levels of cholesterol, AST, ALT, urea, NEFA, and BHB, reflecting the metabolic adaptations and energy requirements during early lactation.

**5.2 Comprehensive Analyses**

Lean et al. (2019) analyzed data from 31 experiments involving 1,571 cows. They reported that prepartum diets with negative DCAD improved plasma calcium levels and reduced the risks of clinical hypocalcaemia, retained placenta, and metritis. Notably, they found decreased BHB levels before calving in cows on negative DCAD diets, suggesting a lower risk of ketosis and negative energy balance. This highlights the potential benefits of negative DCAD diets in managing metabolic health and reducing the incidence of metabolic disorders.

**5.3 Farm-Based Studies**

Melendez et al. (2021) conducted two studies on grazing and dry lot dairy farms. In the first study, they found higher calcium concentrations but lower BHB levels in cows with urine pH between 6-7. This suggests that moderate urinary pH, indicative of effective anionic salt supplementation, is associated with better calcium metabolism and lower BHB levels, reducing ketosis risk. In the second study, they observed higher stillborn cases in cows with urine pH < 6.0 compared to those with pH ≥ 7.0. This underscores the importance of maintaining an optimal urine pH to prevent adverse outcomes. They concluded that prepartum anionic diets increase blood calcium concentration and reduce BHB levels, lowering ketosis risk.

1. **Effect of DCAD on In Vitro Rumen Fermentation Parameters**

The dietary cation-anion difference (DCAD) can influence rumen fermentation parameters, which are critical for understanding the overall digestive efficiency and health of dairy cows. Various studies have explored how different DCAD levels impact rumen microbial activity, gas production, pH, and dry matter degradability.

**6.1 Studies on Positive DCAD Levels**

Barabad et al. (2020) explored the effects of positive DCAD levels of +150, +250, and +350 mEq/kg DM on microbial fermentation properties, gas production, and dry matter degradability in vitro. Their findings indicated significant differences in gas production parameters and ruminal pH across the different DCAD levels. The study concluded that a DCAD level of +250 mEq/kg DM appears to be the most appropriate supplement for dairy cows, optimizing both gas production and dry matter degradability while maintaining a stable rumen pH. Kour et al. (2021) found that negative DCAD (-50 & -100) had better PF, NH3-N and EMMP then control prepartum diet and highest value was observed with -100 DCAD, whereas, postpartum control had better *in vitro* parameters than positive DCAD (+200 & +400) but no deleterious effect was observed, thus, suggesting that, both positive and negative DCAD are safe for use in ruminants.

**6.2 Studies on Negative DCAD Levels**

Yang et al. (2021) investigated the effects of negative DCAD diets on rumen fermentation and microbial populations. They used DCAD levels of +338, +152, and -181 mEq/kg DM. Their observations included. This study concluded that altering the DCAD level does not significantly impact the rumen fermentation parameters or the overall ruminal environment, suggesting that the rumen's microbial ecosystem is resilient to changes in dietary cation-anion balance. Overall, these findings highlight the complexity of rumen fermentation dynamics and suggest that while positive DCAD levels can enhance certain fermentation parameters, negative DCAD levels may not detrimentally affect the rumen environment, allowing flexibility in dietary formulations for dairy cows.

**Conclusions**

The dietary cation-anion difference (DCAD) significantly influences various physiological and metabolic aspects of dairy cows, particularly during the transition period. The studies reviewed provide a comprehensive understanding of how different DCAD levels impact urinary pH, milk yield and composition, calcium status, incidence of milk fever, overall health, and rumen fermentation parameters. Managing DCAD levels should be part of a comprehensive nutritional strategy, considering the animal's entire transition period and overall metabolic health. Optimizing DCAD levels is crucial for enhancing dairy cow health and productivity, particularly during the critical transition period. More data to authenticate DCAD levels in buffalo is required.

**DECLARATIONS**

1. **Ethical approval:** Not applicable
2. **Consent to participate:** Not applicable
3. **Written consent for publication:** Not applicable
4. **Availability of data and material:** Not applicable
5. **Code of availability:** Not applicable

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