Formulation of Rations with Optimal Cations and Anions (DCAD) for Lactation

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Michigan State University
East Lansing

May '05
<table>
<thead>
<tr>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Is there an optimal DCAD for lactating cows; can DCAD be too high or too low?</td>
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<td>2. Is optimal DCAD different in cool vs. hot weather?</td>
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<td>5. Can quality of drinking water affect DCAD?</td>
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<td>6. Keys for Practical Ration Formulation?</td>
</tr>
</tbody>
</table>
Introduction & Background

**DCAD**: meq/100g of dietary DM
**DCAD**: (strong cations) – (strong anions)

**DCAD₃**: (Na + K – Cl)

**DCAD₄**: (Na + K – Cl – S)

- if 0.2% S = -13 meq from S/100g DM

expanded (Goff et al. 1997):

(1.0Na + 1.0K + 0.15Ca + 0.15Mg) – (1.0Cl + 0.6S + 0.5P)

• **Responses**: DMI, MY, milk composition, acid-base status
Background: Requirements

NRC (2001) requirement for K, Na, Cl, S

Factorial method (for Na, K, & Cl):

\[ R \text{ (g/day)} = \frac{M + L + G + P}{AC} \]

S set at 0.2% of dietary DM

Based on NRC (2001) requirements:

\[ \text{DCAD4} = +16 \text{ meq/100 g DM} \]

for dairy cows yielding 55 to 120 lb/day

Note:

There is NO dietary requirement for DCAD *per se.*
DCAD for Lactation: Research 1995 & Before

√ Escabosa et al. (1984) - TX

√ Tucker et al. (1988) - KY

• West et al. (1991; 1992) – GA

√ Sanchez et al. (1994 a, b) - FL

• Ghorbani et al. (1995) - KY

• Delaquis & Block (1995) - QE
**Escobosa et al. (1984): Experimental**

**Experimental:**
- 12 each Jersey & Holstein cows
  (1\textsuperscript{st} trimester lactation)
- Split-plot design, repeated measures
- Texas: hot weather

<table>
<thead>
<tr>
<th>Treatments</th>
<th>DCAD\textsubscript{3}</th>
<th>Na,%</th>
<th>K,%</th>
<th>Cl,%</th>
</tr>
</thead>
<tbody>
<tr>
<td>+20</td>
<td>0.18</td>
<td>0.83</td>
<td>0.34</td>
<td>0.34</td>
</tr>
<tr>
<td>-14</td>
<td>0.24</td>
<td>0.87</td>
<td></td>
<td>1.67 \textsuperscript{b}</td>
</tr>
<tr>
<td>+35</td>
<td></td>
<td></td>
<td></td>
<td>0.36</td>
</tr>
</tbody>
</table>

\textsuperscript{a} 1.7\% NaHCO\textsubscript{3}; \textsuperscript{b} 2.28\% CaCl\textsubscript{2}
# Results: Escobososa et al. (1984)

## DCAD3 Treatment $^{a,b,c} (P < 0.05)$

<table>
<thead>
<tr>
<th>Item</th>
<th>+20</th>
<th>-14 (Cl)</th>
<th>+35 (Na)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI, lb/d</td>
<td>39.4$^a$</td>
<td>27.8$^b$</td>
<td>46.5$^c$</td>
</tr>
<tr>
<td>MY, lb/d</td>
<td>39.8</td>
<td>36.5</td>
<td>42.3</td>
</tr>
<tr>
<td>Protein, %</td>
<td>3.31$^a$</td>
<td>3.19$^b$</td>
<td>3.43$^c$</td>
</tr>
<tr>
<td>Fat, %</td>
<td>3.57$^{ab}$</td>
<td>3.51$^b$</td>
<td>3.82$^a$</td>
</tr>
</tbody>
</table>

**Conclusion:**

Cl $\rightarrow$ ↓ DMI, Protein%

CaCl$_2$ palatability effect?

Na $\rightarrow$ ↑ DMI, Protein%

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Tucker et al. (1988): Experimental

12 Holstein cows (96 to 272 DIM)

- Pre-trial MY = 48 to 75 lb/cow per day
- three, 4 x 4 Latin squares
- Each square: different “ion square”: for each Na, K, and Cl
- Made by varying KCl, NaCl, CaCl$_2$, KHCO$_3$, NaHCO$_3$, CaCO$_3$
### Treatments & Squares

<table>
<thead>
<tr>
<th>Treatments</th>
<th>DCAD3</th>
<th>DCAD4&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Na square</th>
<th>K square</th>
<th>Cl square</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>0.26</td>
<td>0.26</td>
<td>0.97</td>
<td>1.33</td>
<td></td>
</tr>
<tr>
<td>Cl%</td>
<td>0.62</td>
<td>0.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K%</td>
<td>1.12</td>
<td>1.52</td>
<td>1.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na%</td>
<td>0.79</td>
<td>0.79</td>
<td>0.56</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>Na square</td>
<td>0.33</td>
<td>0.73</td>
<td>1.12</td>
<td>1.52</td>
<td></td>
</tr>
<tr>
<td>K square</td>
<td>0.10</td>
<td>0.73</td>
<td>1.33</td>
<td>1.91</td>
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</tr>
<tr>
<td>Cl square</td>
<td>0.79</td>
<td>0.33</td>
<td>0.97</td>
<td>0.62</td>
<td></td>
</tr>
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</table>

<sup>a</sup> S% = 0.27

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Tucker et al. (1988):

Results and Interpretation:

1. DMI and MY increased linearly with increasing DCAD
2. No effect of DCAD on 4%FCMY
3. No effect of “square” --- Na, K, Cl --- all used to vary DCAD had similar effects
4. Overall, as DCAD increased from (-27, -17, -7, & +3 meq) improved lactational performance
Question?

1. Is there an optimal DCAD for lactating cows, and can DCAD be too high or too low?
Sanchez et al. (1994a):
Experimental:
- Meta-analysis (GLM)
- 10 macromineral (factorial) experiments
- Univ FL 1980s
  (5 cool season; 5 warm season) pooled
- Mid-lactation cows, incomplete block designs, factorial arrangements; 2X milking
- 1022 cow-period means
- Daily DMI, MY, 4%FCMY, protein%, fat%
Optimal DCAD_4: Mid-lactation Cows

DCAD_4: meq (Na + K - Cl - S)/100g of DM

MY

DMI

4% FCMY

+25 meq

pounds/day
Milk Yield & DCAD4

DCAD4: meq (Na + K - Cl - S)/100g of DM

-23 -18 -13 -8 -3 7 12 17 22 27 32 37 42 47

pounds/day

Tucker et al. (1988)
West et al. (1991)
West et al. (1992)
DCAD Lactational Responses?
Hu & Murphy (2004)

Materials & Methods:
• Meta-analysis (Mixed Models)
• 12 studies from literature (1984 – 1997)
• 17 trials; 35 to 54 dietary treatments
• DCAD3 = +26; ranged: -19 to +64 meq/100 g
• MY = 51 lb/d; ranged: 33 to 79 lb/d
• Daily DMI, MY, 4% FCM yield milk composition; acid-base status
Optimum DCAD?:

- DCAD$_3 = 40$ meq/100 g
- DCAD$_4 = 28$ meq @ 0.2\%S; = 19 meq @ 0.33\%S
Milk Yield & Optimum DCAD

*Optimal DCAD?*:

- DCAD\(_3\) = 34 meq/100 g
- DCAD\(_4\) = 22 meq @ 0.2\% S; = 13 meq @ 0.33\% S
4% FCM & Optimum DCAD

Optimal DCAD?:

\[ \text{DCAD}_3 = 49 \text{ meq/100 g} \]

\[ \text{DCAD}_4 = 37 \text{ meq @ 0.2\% S} = 28 \text{ meq @ 0.33\% S} \]
Blood pH & Optimum DCAD


NOTE: Blood pH of 7.38 to 7.42 “normal” range

Optimal DCAD?: DCAD3 = 20 to 40 meq

DCAD4 = 7 to 27 meq @ 0.2% S; = 0 to 19 meq @ 0.33% S
Summary of Meta-analysis:
DCAD Lactational Responses
Hu & Murphy (2004)

Optimum DCAD? 4

–DMI: +19 to +28 meq
–unadjusted MY: +13 to +22 meq
–4%FCMY: +28 to +37 meq
–Blood pH 7.38 to 7.42 (normal range) within DCAD +20 to +40 meq/100g DM
Question?

1. Is there an optimal DCAD for lactating cows, and can DCAD be too high or too low?

Taking the whole set of lactational performance variables from all of the published reports…….

Overall Answer:

Optimal DCAD4 = +25 to +30 meq/100g DM
Question?

2. Is optimal DCAD different in cool vs. hot weather?
Sanchez et al. (1994b)

Experimental: *Cool vs. Warm Season?*

- Empirical modeling (regression analysis)
- 15 macromineral (factorial) experiments UF, UGA, UKY 1980s (7 cool season vs. 8 warm season)
- Mid-lactation cows, incomplete block designs; 2X milking
- 1444 cow-period means
- Daily DMI, MY, 4% FCM, protein%, fat%
### GA Studies: JDS Abstracts

<table>
<thead>
<tr>
<th>Study</th>
<th>Duration</th>
<th>Conditions</th>
<th>Treatment</th>
<th>Effect</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wildman et al., 2002:</strong></td>
<td>56-d heat stress study</td>
<td>42 Holsteins, 188 DIM</td>
<td>NaHCO₃ &amp; K₂CO₃</td>
<td>DCAD₄: +30 vs. +45 meq</td>
<td>No effects: DMI, ECMY, %fat or prot. No differences in cation source. Authors: &quot;+30 meq apparently sufficient for acid-base homeostasis.&quot;</td>
</tr>
<tr>
<td><strong>Wildman et al., 2003:</strong></td>
<td>42-d heat stress study</td>
<td>32 Holsteins, 225 DIM, 2 X 2 factorial</td>
<td>15 vs. 17% CP X</td>
<td>DCAD₃: +25 vs. +45 meq</td>
<td>No effects on DMI. Increasing DCAD3: MY 69 vs. 61 lb/d. No effect of DCAD with 15% CP on DMI or MY.</td>
</tr>
<tr>
<td><strong>Wildman et al., 2004a:</strong></td>
<td>83-d, Apr, May &amp; Jun in GA</td>
<td>8 Holsteins (47 DIM), 4 X 4 Latin Sq.</td>
<td>2 X 2 factorial: 15 vs. 17% CP X</td>
<td>DCAD₃: +25 vs. +50 meq</td>
<td>Increasing DCAD3: DMI &amp; 3.5% FCMY; (P &lt; 0.01).</td>
</tr>
<tr>
<td><strong>Wildman et al., 2004b:</strong></td>
<td>84-d, Aug 8 – Nov 6 in GA</td>
<td>8 Holsteins (180 DIM), 4 X 4 Latin Sq.</td>
<td>2 X 2 factorial: 33 vs. 42% UIP/CP X</td>
<td>DCAD₃: +25 vs. +50 meq</td>
<td>UIP X DCAD; response to DCAD with higher UIP (P &lt; 0.01).</td>
</tr>
</tbody>
</table>

*NO* in the respective cells indicates no significant effects or responses. *YES* indicates significant effects or responses.
Question?

2. Is optimal DCAD different in cool vs. hot weather?

Taking all of the published reports......

**Answer:** Optimum

\[ \text{DCAD}_4 = +25 \text{ to } +30 \text{ meq/100g DM; } \]

?????? +35meq ????

(limited data – 8 cows)
Questions?

3. Does level of MY or “stage of lactation” affect optimal DCAD?
4. To increase DCAD, is Na or K the better choice; or, can Cl or S (SO₄²⁻) be lowered?

Choices = Na-bicarb, K-carb; $price/meq cation?
(Na-carb or K-bicarb are not available for rations or are too pricey)
Cation Source and DCAD?
Mooney and Allen (2002) JDS Abstract

• 40 multiparous Holstein cows (high yielding)
• Short-term lactational responses
• 2 X 2 factorial + control
• Cations Na vs. K as salts with anions Cl vs. HCO₃
• NaHCO₃ (1%, dry basis)
• NaCl, KCl, and KHCO₃, iso-molar basis
# Cation Source and DCAD?

*Mooney and Allen (2002) JDS Abstract*

<table>
<thead>
<tr>
<th>Trt</th>
<th>DCAD4 meq/100g</th>
<th>DMI, lb/d</th>
<th>3.5FCMY, lb/d</th>
<th>Fat, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>16</td>
<td>61.3</td>
<td>84.9</td>
<td>3.83</td>
</tr>
<tr>
<td>NaCl</td>
<td>16</td>
<td>61.3</td>
<td>86.9</td>
<td>3.74</td>
</tr>
<tr>
<td>KCl</td>
<td>17</td>
<td>61.7</td>
<td>86.0</td>
<td>3.80</td>
</tr>
<tr>
<td>NaHCO₃</td>
<td>28</td>
<td>61.3</td>
<td>86.9</td>
<td>3.88</td>
</tr>
<tr>
<td>KHCO₃</td>
<td>26</td>
<td>61.7</td>
<td>88.2</td>
<td>3.89</td>
</tr>
</tbody>
</table>
**Cation Source (Na vs. K) ?**

*Mooney and Allen (2002) JDS Abstract*

<table>
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<tr>
<th>Trt</th>
<th>DCAD4 (meg/100g)</th>
<th>DMI, lb/d</th>
<th>3.5FCMY, lb/d</th>
<th>Fat, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>16</td>
<td>61.3</td>
<td>84.9</td>
<td>3.83</td>
</tr>
<tr>
<td>Na salts of Cl or HCO₃</td>
<td>16 or 28</td>
<td>61.3</td>
<td>86.9</td>
<td>3.81</td>
</tr>
<tr>
<td>K salts of Cl or HCO₃</td>
<td>17 or 26</td>
<td>61.7</td>
<td>87.1</td>
<td>3.85</td>
</tr>
</tbody>
</table>
Questions?

3. Does level of MY or “stage of lactation” affect optimal DCAD?

4. To increase DCAD, is Na or K the better choice; or, can Cl or S (SO$_4^{-2}$) be lowered?

A: Choices = Na-bicarb, K-carb; $price/meq cation?

Overall: NO differences in cow performance between ions: Na vs. K sources
**Extra “High” Lactational Demand for K?**

- Whole raw milk is 0.15% K
- Early lactation demand, high MY? Greater K requirement than NRC (2001)?
- 6 Israeli Holstein cows (wk 2 lactation)
- Early lactation, in negative K balance; therefore, higher “requirement” – a concern?
- Early lactation DMI = 29 lb/d (quite low?); K intake low;
- Early lactation, cows must quickly increase DMI.
- K requirement (M + L) no different  
  
  cows must eat!
Question

4. Can quality of drinking water affect DCAD?
Drinking Water Quality and DCAD

Example: Top OSU lactating Holstein cow
- Milk yield = 50 lb 3.5FCM/day (90 DIM)
- Water intake = 26 gal/day; DMI = 48 lb/day

<table>
<thead>
<tr>
<th>Ion</th>
<th>Diet, %</th>
<th>Water, ppm</th>
<th>D + W, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>1.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>0.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DCAD</td>
<td>+16</td>
<td></td>
<td>??</td>
</tr>
</tbody>
</table>

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Drinking Water Quality and DCAD

Example: Top OSU lactating Holstein cow

- Milk yield = 50 lb 3.5FCM/day (90 DIM)
- Water intake = 26 gal/day; DMI = 48 lb/day

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<td>0</td>
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<tr>
<td>Cl</td>
<td>0.28</td>
<td>0</td>
<td>0.28</td>
</tr>
<tr>
<td>S</td>
<td>0.20</td>
<td>0</td>
<td>0.20</td>
</tr>
<tr>
<td>DCAD</td>
<td>+16</td>
<td></td>
<td>+16</td>
</tr>
</tbody>
</table>
“High Quality Water” and DCAD

Example: Top OSU lactating Holstein cow

- Milk yield = 50 lb 3.5FCM/day (90 DIM)
- Water intake = 26 gal/day; DMI = 48 lb/day

<table>
<thead>
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<th>Water, ppm</th>
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</thead>
<tbody>
<tr>
<td>Na</td>
<td>0.22</td>
<td>30</td>
<td>0.23</td>
</tr>
<tr>
<td>K</td>
<td>1.04</td>
<td>30</td>
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</tr>
<tr>
<td>Cl</td>
<td>0.28</td>
<td>30</td>
<td>0.29</td>
</tr>
<tr>
<td>S</td>
<td>0.20</td>
<td>30</td>
<td>0.21</td>
</tr>
<tr>
<td>DCAD</td>
<td>+16</td>
<td>→</td>
<td>+16</td>
</tr>
</tbody>
</table>
"High Cation" Water and DCAD

Example: Top OSU lactating Holstein cow

- Milk yield = 50 lb 3.5FCM/day (90 DIM)
- Water intake = 26 gal/day; DMI = 48 lb/day

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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>0.22</td>
<td>500</td>
<td>0.47</td>
</tr>
<tr>
<td>K</td>
<td>1.04</td>
<td>30</td>
<td>1.05</td>
</tr>
<tr>
<td>Cl</td>
<td>0.28</td>
<td>30</td>
<td>0.29</td>
</tr>
<tr>
<td>S</td>
<td>0.20</td>
<td>30</td>
<td>0.21</td>
</tr>
<tr>
<td>DCAD</td>
<td>+16</td>
<td></td>
<td>+26</td>
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</table>

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**High sulfate: Water and DCAD**

Example: Top **OSU** lactating Holstein cow

- Milk yield = 50 lb 3.5FCM/day (90 DIM)
- Water intake = 26 gal/day; DMI = 48 lb/day

<table>
<thead>
<tr>
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<tr>
<td>Cl</td>
<td>0.28</td>
<td>30</td>
<td>0.29</td>
</tr>
<tr>
<td>S</td>
<td>0.20</td>
<td>500</td>
<td>0.28</td>
</tr>
<tr>
<td>DCAD</td>
<td>+16</td>
<td></td>
<td>+11</td>
</tr>
</tbody>
</table>


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**Higher sulfate: Water and DCAD**

Example: Top OSU lactating Holstein cow

- Milk yield = 50 lb 3.5 FCM/day (90 DIM)
- Water intake = 26 gal/day; DMI = 48 lb/day

<table>
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<tr>
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<td>Cl</td>
<td>0.28</td>
<td>30</td>
<td>0.29</td>
</tr>
<tr>
<td>S</td>
<td>0.20</td>
<td>1000</td>
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<tr>
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<td>+6</td>
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“High Anions” Water and DCAD

Example: Top OSU lactating Holstein cow
  • Milk yield = 50 lb 3.5FCM/day (90 DIM)
  • Water intake = 26 gal/day; DMI = 48 lb/day

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<td>500</td>
<td>0.28</td>
</tr>
<tr>
<td>DCAD</td>
<td>+16</td>
<td></td>
<td>+5</td>
</tr>
</tbody>
</table>

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### "Nasty Anionic" Water and DCAD

Example: Top OSU lactating Holstein cow
- Milk yield = 50 lb 3.5FCM/day (90 DIM)
- Water intake = 26 gal/day; DMI = 48 lb/day

<table>
<thead>
<tr>
<th>Ion</th>
<th>Diet, %</th>
<th>Water, ppm</th>
<th>D + W, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>0.22</td>
<td>30</td>
<td>0.23</td>
</tr>
<tr>
<td>K</td>
<td>1.04</td>
<td>30</td>
<td>1.05</td>
</tr>
<tr>
<td>Cl</td>
<td>0.28</td>
<td>500</td>
<td>0.53</td>
</tr>
<tr>
<td>S</td>
<td>0.20</td>
<td>1000</td>
<td>0.37</td>
</tr>
<tr>
<td>DCAD</td>
<td>+16</td>
<td></td>
<td>-1</td>
</tr>
</tbody>
</table>

May '05
Question?

4. Can quality of drinking water affect DCAD?

ANSWER: YES

Especially with abnormally high concentrations of anions.

(+16 → -1 meq/100 grams)
Take Home

Don’t bother to worry about ration DCAD, if you haven’t analyzed the drinking water!
5. Keys to Practical Formulation

1. Analyze Na, K, Cl, S (wet chemistry, not NIRS)
2. First meet NRC (2001) req.: K, Na, Cl, & S
3. Check DCAD: ? In range +25 to +30 meq/100 g DM
4. B/t: +20 to +40 meq small diff. in DMI or MY
5. DCAD too low, remove Cl or S if possible
6. To raise DCAD: add Na-bicarbonate or K-carbonate; no response difference between Na & K sources; $/meq?
7. There are no “requirements” for concentrations of Na, K, Cl, S, or DCAD!
8. DCAD is concentration expression
Conclusions & Summary

1. Optimum DCAD4 = +25 to +30 meq/100g for maximum DMI & MY; +20 to +40 meq/100g small differences in response

2. Research reports, summaries, advertisements: Is DCAD correctly calculated, quoted? DCAD4 or DCAD3?

3. In evaluation & formulation, what is feed intake associated with particular DCAD4, K%, Na%, Cl%, S%? Concentrations of mineral elements (including DCAD4) are not requirements!
Conclusions & Summary

4. To hit target DCAD4 (+25 to +35 meq/100g):
   • Reduce Cl & S in basal ingredients or supplements as much as possible?
   • Add Na-bicarbonate or K-carbonate if needed ~ similar; $cost/meq?

5. Excessive excretion of K, Na, Cl & S (beyond crop needs) are potential problems in dairy farm systems!
THE END

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