IMPACT OF MACRO MINERAL NUTRITION (NA, K, MG, CA) OF DAIRY COWS ON NUTRIENT EXCRETION

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ABSTRACT

Macro minerals (sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg) are important nutrients in dairy rations that must be fed at an appropriate level to optimize animal production and health. Overfeeding leads to increased excretion in feces and urine. Land application of macro minerals in dairy manure is not currently under regulatory control, and over-application can lead to excessive concentrations in soils which impact crop production. In this paper, we discuss nutrient balance studies for evaluating mineral excretion, methods for estimating excretion on farms, and procedures for managing nutrient excretion on farms.

INTRODUCTION

Manure is an inevitable byproduct of the production of meat and milk for human consumption. It has value as a fertilizer but also adds significant operating, equipment, and facility cost to the dairy operation. Feeding management programs on the dairy are focused on optimizing herd performance and health while accepting manure as the inevitable by-product. At the last Idaho Nutrient Management conference, we discussed designer manures and outlined methods for decreasing manure production and excretion of nitrogen, phosphorus, and potassium (Norell, et al., 2012). This year's paper is a continuation, focusing on the macrominerals sodium, potassium, magnesium, and calcium. These minerals are called "macro" because cattle require relatively large amounts per day and intakes are expressed in grams or percentages. The micro minerals are required in much smaller amounts and intakes are expressed in milligrams or parts per million.

University of Idaho researchers evaluated nutrient balance for eight large dairy operations in the Magic Valley area (Hristov et al., 2006). Dairy operations import nutrients in feed, bedding, animals, and fertilizer while exporting nutrients in milk, animal sales, and manure applied on nearby farm ground. On average, the dairies imported 300.7 tons of K per year and exported 118.8 tons of K per year. The average surplus was 191.9 tons of K or 76 kg of K per cow per year. The amount of surplus will vary on depending on K feeding levels, available crop ground, crop yield, and manure application rate.

Overfeeding macrominerals results in higher excretion rates in manure and can lead to an excessive salt load in soils after multiple years of manure application (Chang et al., 2004). Salt accumulations can cause toxicities in plants, induce water stress, seal soil air surfaces, and lower crop yields. Also, if there is an imbalance in the concentration of Ca, K, and Mg ions in the soil, a deficiency can occur due to cation competition. For example, if there are high concentrations of K in the soil, whether from manure, fertilizer or other source, the plant can take up a disproportionate amount of K cations compared to Ca and Mg cations, thus triggering Ca or Mg deficiency in the plant (Moore and Ippolito, 2009).

BALANCE STUDIES WITH MACROMINERALS

The classical method for evaluating nutrient utilization in livestock is a balance study which compares inputs and outputs for that nutrient. Researchers carefully measure nutrient intake from feed and water, assess nutrient content in milk, quantify nutrient excretion in feces and urine, then calculate the balance by subtracting milk, urinary and fecal losses from intake. A positive balance means the animal is adding to body reserves, growing, and/or using nutrients for a developing fetus while a negative balance means the animal is drawing down body reserves for that particular nutrient. Example nutrient balance data are shown in Table 1 from dairy feeding trials with the four macrominerals and are discussed below.

Table 1. Example nutrient balance studies for calcium, potassium, magnesium, and sodium.

Study and treatments	---------------------------------Nutrient Balance Categories-----------------------------				
Taylor et al., 2009	Ca Intake (g)	Milk Ca (g)	Fecal Ca (g)	Urinary Ca (g)	Balance (g)
0.52% Ca	125	48	88	0.6	-11
0.78% Ca	191	49	139	0.5	+2
1.03% Ca	248	49	168	0.9	+30
Fisher et al., 1994	K Intake (g)	Milk K (g)	Fecal K (g)	Urinary K (g)	Balance (g)
1.60% K	368	52	55	209	+40
3.13% K	745	52	63	631	-78
4.57% K	1019	46	70	672	+125
Holtenius et al., 2008	Mg Intake (g)	Milk Mg (g)	Fecal Mg (g)	Urinary Mg (g)	Balance (g)
0.19% Mg	30	2	23	4	+2
0.43% Mg	71	2	54	7	+8
Rauch et al., 2012	Na Intake (g)	Milk Na (g)	Fecal Na (g)	Remainder (g)	
0.3% Na	84	15	22	47	
0.5% Na	143	15	33	95	

<u>Calcium (Ca)</u>. Taylor et al., 2009 recently compared diets varying in Ca concentration (0.52%, 0.78% and 1.03% of dry matter) to early lactation cows. Calcium content was altered by increasing the level of limestone mineral in the diet. Dry matter intake did not differ between diets but daily Ca intake increased from 125 grams/cow with the 0.52% Ca diet to 248 grams/cow with 1.03% Ca diet. Milk yield and Ca excreted in milk (48 to 49 grams) did not differ between diets. The primary route of Ca excretion is in feces. Absorption of dietary Ca in the intestine is a tightly controlled process and varies in part due to demand for Ca. Digestibility of Ca is typically low, ranging from 15 to 35% of the consumed Ca. In this study, Ca excretion in feces ranged from 88 to 168 grams/day and digestibility ranged from 26.5 to 30.8% of consumed Ca. Urinary excretion of Ca was less than 1 gram per day across the three diets. Overall, early lactation cows on the 0.52% diet had a negative Ca balance and were drawing Ca reserves from bone while the other two diets had positive balances and were adding to Ca reserves.

Magnesium (Mg). Holtenius et al., 2008 evaluated Mg absorption and excretion in diets varying in Mg and K concentration and fed to cows averaging 45 lbs of milk/day. High dietary K levels can inhibit Mg absorption which in turn can lead to grass tetany in cattle. This is a very important interaction that nutritionists pay very close attention to while formulating rations. Results for the two Mg diets (0.19% and 0.43% of dry matter) with a 1.9% K intake were reported in Table 1. Supplemental Mg was supplied by magnesium oxide. As expected, enhancing Mg dietary concentration increased Mg intake from 30 grams/day to 71 grams/day and increased fecal plus urine Mg from 27 grams/day to 61 grams/day. Mg digestibility was low (23%) and did not vary between dietary treatments. Mg excretion was primarily via feces (87%) rather than by urine (13%).

Potassium (K). Fisher et al., 1994 compared diets varying in K concentration (1.6%, 3.1%, and 4.6% of dry matter) to mid-lactation cows. Potassium content was altered by increasing the level of potassium carbonate in the diet. Dry matter intake did not differ between diets but daily K intake increased from 368 grams/day with the 1.6% K diet to 1019 grams/day with the 4.6% K diet. Milk yield was reduced at the highest K intake and K excretion via milk was slightly lower on this treatment. Digestibility of dietary K tends to be very high and typically ranges from 75 to 90% of intake which means the primary route of K excretion is via urine rather than feces. In this study, the proportion of K excretion in urine increased from 79% on the 1.6% K diet to 90% on the highest diet and overall K excretion in urine and feces increased from 264 grams/day to 742 grams/day. The 1.6% and 4.6% diets had positive K balance while the 3.1% K diet had a negative balance. These data illustrate that dairy cattle can tolerate very high K levels without adversely affecting animal performance. Overfeeding K does leads to a significant increase in urine production and increased K excretion in urine.

Sodium (Na). Rauch et al., 2012 evaluated diets with and without buffers. Results for the control diet (0.3% of dry matter) and the diet with sodium bicarbonate buffer (0.5% of dry matter) are reported in Table 1. Adding sodium bicarbonate to the diet increased Na intake from 84 to 143 grams/day but did not influence Na excretion in milk (15 grams/day). Fecal excretion was 11 grams higher per day on the higher Na diet. The researchers did not report urinary Na nor a net balance for the study. The remaining Na (intake minus excretion in milk and feces) was most likely excreted in urine rather than adding to body stores. Dietary buffers serve an important role in dairy nutrition but they must be carefully evaluated to ensure an economical response is occurring to justify the increase in sodium excretion.

ESTIMATING MACROMINERAL EXCRETION ON FARMS

Complete balance studies are an important research tool but are impractical to use on commercial dairies. Prediction equations would be a useful alternative if they are robust to account for important farm to farm differences such as varying milk yield, feed intake, dietary concentrations, and mineral availability. Equations are available to predict total K excretion (Nennich et al., 2005) and to predict Na excretion in urine (Nennich et al., 2006) but none are available for predicting total Na, Mg, and Ca excretions in manure (feces + urine). The other alternative is to perform a partial balance study. It is possible to collect the necessary information and samples to estimate daily nutrient intake and to estimate nutrient excretion in milk. Excretion would be estimated as the difference between intake and the amount excreted in milk. This estimate would not be totally correct in that it does not account for any nutrient retained in the animal which can be a sizeable number.

Researchers at the University of California have conducted a partial balance study on thirty nine large commercial dairies in central California (Castillo et al., 2013). Extensive feed sampling was conducted to properly account for dietary differences between production pens. Average milk yield and cows per pen were recorded to properly measure weight intake and excretion across pens. Water samples were collected from the well and water intake estimated from milk yield, body weight, and average environmental temperature. Milk samples were analyzed to allow calculation of nutrient excretion in milk.

Results of the California partial balance study are shown in Table 2. Note the large variation between herds which is due to differences in nutrient intake, milk yield, and milk nutrient content. Estimated macromineral excretion rates are reasonably similar to published mineral balance trials. Ranking on median excretion rate per day, K was highest, Ca second, Cl third, Na fourth, and Mg fifth.

Table 2. Distribution of mineral excretion from thirty nine commercial dairies (Castillo et al., 2013) [1]

	Distribution percentile		
Mineral	10^{th} percentile	Median	90^{th} percentile
	-----------------------mineral excreted (g/cow/day)----------------------		
Calcium	97	160	194
Chloride	69	105	168
Magnesium	62	77	94
Potassium	240	321	425
Sodium	64	97	125

[1]Excretion estimated by mineral intake from TMR plus mineral consumed from livestock water minus mineral in daily milk production.

Approximate National Research Council (NRC) requirements and estimated intake concentrations are shown in Table 3. Note that mineral concentrations include the mineral in the total mixed ration (TMR) plus the mineral consumed from well water. Observed mineral concentrations on farms were significantly higher than NRC requirements for all five minerals and can be partially explained by current feeding practices.

First, rations are formulated to meet nutrient requirements plus some overhead to allow for differences in feed composition over time and to ensure adequate intake. Overfeeding by 20% is a common practice. Second, dairy cattle can tolerate excess minerals within limits so exact formulation is not practiced and may not be economical. For example, alfalfa hay is high in K and it would be very difficult to feed at exactly NRC requirements if alfalfa was the only forage in the diet. Third, special feed additives provide specific nutrients to the diet or serve a specific function but the additive further increases mineral intake beyond NRC requirements. Some common examples are calcium salts of fatty acids (a rumen bypass fat source) and sodium bicarbonate plus magnesium oxide (rumen buffers). Fourth, dietary requirements do evolve over time as milk production continues to climb and new research becomes available. Potassium feeding levels are increased for early lactation cows and for cows undergoing heat stress (Harrison et al., 2012). Finally, current research is evaluating DCAD (dietary cation anion difference) for high producing lactating cows. K and Na levels may be increased to achieve the desired DCAD ratio in the diet which optimizes feed intake and milk yield.

Table 3. Approximate 2001 NRC requirements and nutrient concentrations on commercial dairy operations (Castillo et al., 2013) [1, 2]

	NRC	Distribution percentile		
Mineral	requirement	10th percentile	Median	90th percentile
	--------% of dry matter--------			
Calcium	0.55	0.65	0.80	1.00
Chloride	0.25	0.44	0.62	0.83
Magnesium	0.16	0.30	0.35	0.37
Potassium	1.03	1.30	1.62	1.93
Sodium	0.21	0.30	0.46	0.60

[1]Thirty-nine CA dairies.
[2]Concentration in TMR plus mineral consumed through water intake

MANAGING MACROMINERAL EXCRETION ON THE DAIRY

Several practices are available to assist in managing macromineral excretion on the dairy. It will involve close teamwork between dairy owner, dairy nutritionist, and feeding crew on the farm. Key practices for managing excretion are discussed below.

Identify "major suppliers" for feed analysis. Ideally all feeds would be tested but producers have financial limits on how much they can spend on feed testing. There are two key factors for determining when a feedstuff should be analyzed (Moore and Robinson, 2007a). First, how variable is the nutrient content of the feed? Second, how much of the dietary nutrients are provided by the feed? Forages are highly variable in mineral content and provide 50 to 75% of the dietary intake of Ca, K, and Mg. Clearly all forages should be analyzed for macromineral content. Most other feedstuffs are likely to be small contributors for each specific nutrient and thus do not need as frequent chemical analysis. Commercial feed additives and mineral supplements will have a guaranteed feed analysis and not require additional testing. Variability in nutrient content for individual feeds can be found in the 2001 NRC and from a more recent analytical data set summarized by Beede (2005).

Analyze feeds using wet chemistry methods. Mineral concentrations are best measured in the lab by wet chemistry methods. NIR analyses are tempting due to their lower cost but NIR is not as accurate in determining mineral concentrations as wet chemistry.

Create a historical library of feed analysis and manure. Tracking feed analysis over time will provide sufficient data to identify average composition for a dairy's common feed suppliers and to identify lots of feed with unusually high or low nutrient content.

Analyze water supplies. Livestock water supplies typically have a very low concentration of macrominerals (see Table 4) and provide only a few grams of each mineral per day under normal water consumption rates (Socha et al., 2009; Castillo et al., 2007; Castillo et al., 2013). However, "worst case" water supplies can provide 50% or more of the animal's daily requirements for that nutrient (Table 4). Ration adjustments may be required if the livestock water supply has high mineral content. See Beede (2006) for a thorough discussion on water quality evaluation and cattle performance. Beede (2009) reviews procedures to solving problems with poor water quality. Parlor water use becomes a significant source of minerals in the waste stream if it contains high mineral concentrations.

Table 4. Amount of mineral supplied by water sources in the United States, based upon analysis of 3651 water samples (Socha et al., 2009).

Mineral	Average concentration ppm	Amount of mineral supplied daily by an average water source[1]	Maximum Concentration ppm	Amount of mineral supplied daily by maximum conc water[1]
Calcium	65	7 g	590	62 g
Chloride	59	6 g	727	76 g
Magnesium	24	3 g	682	72 g
Potassium	4	0 g	33	3 g
Sodium	46	5 g	1556	163 g

[1]Estimated water intake (231 lbs/day), assuming 50 lbs dry matter intake, 0.5% dietary sodium in dry matter, 60% dry matter TMR, 60 degree F, and 75 lbs of milk per cow per day.

Formulate diets to meet nutrient requirement plus some overhead. Dairy cows that consume inadequate amounts of essential nutrients can suffer from a host of health problems and often have reduced milk production and reduced reproductive efficiency. Because of numerous uncertainties associated with mineral nutrition, including variation in mineral concentrations of TMR feedstuffs, the lack of information regarding mineral absorption, and potential antagonism with other minerals, diets are often formulated so that mineral intake by cows exceeds mineral requirements. Overfeeding minerals can inflate feed costs, reduce absorption of other minerals because of increased antagonism, and have adverse effects on rumen microbes and the cow (i.e., toxicity). Even if overfeeding minerals has no negative effects on the cow or feed costs, it will certainly result in greater manure excretion of minerals. Example desired nutrient compositions in dairy rations that include considerations for uncertainty are shown in Table 5 below (Weiss, 2012; Weiss, undated). High K concentration in the diet reduces Mg absorption in the intestine and results in a higher adjustment factor for Mg to ensure adequate intake.

Table 5. Accounting for uncertainty with mineral feeding (Weiss, undated).

Mineral	Approximate Concentration to meet NRC requirement	Recommended adjustment factor
Calcium	0.60 to 0.75%	1.1 to 1.2x
Chloride	0.24 to 0.28%	1.1 to 1.2x
Magnesium	0.18 to 0.20%	1.25 to 1.5x
Potassium	1.0 to 1.1%	1.1 to 1.2x
Sodium	0.20 to 0.22%	1.1 to 1.2x

Avoid free choice feeding of mineral. Supplemental salt and phosphorus minerals are commonly fed free choice in a section of the feed manger due to their relatively low cost and as insurance that the cow's needs are met. However, intake of free choice mineral varies widely between cows and is best managed by proper supplementation through the TMR rather than free choice feeding. Utilizing salt blocks will decrease daily free choice consumption over loose granular salt (NRC 2001) if some free choice feeding "must" be practiced.

Avoid free choice feeding of sodium bicarbonate. As precaution, some dairies provide cows with a free choice sodium bicarbonate in the feedbunk or in a mineral feeder. The rationale is that cows will consume sodium bicarbonate when they need additional buffer in their diet and sudden changes in buffer consumption would indicate potential problems with the ration. Researchers have not been able to demonstrate that cows have the nutritional wisdom to consume additional sodium bicarbonate under acidosis conditions (Keunen et al., 2003) and free choice feeding is not recommended when attempting to control intake and excretion of Na by cows.

Evaluate response to sodium bicarbonate feeding. Cattle response to force feeding of sodium bicarbonate varies between diets, forage base, and level of bicarbonate feeding. Responses have been larger for diets high in corn silage; wet rations (>55% moisture); low fiber; limited hay; finely chopped forage; periods of heat stress; or when slug feeding occurs (Hu and Murphy, 2005; Krause, 2008). Feed dollars can be saved and sodium excretion reduced if response to sodium bicarbonate is evaluated and buffer is removed from the diet when no response is observed. Determining the contribution of buffers to the manure salt load is a key role for the herd nutritionist (Moore and Robinson, 2007b) and provides important information for controlling sodium intake and excretion.

Evaluate DCAD in dairy rations. Dietary cation-anion difference, or DCAD, is a composite measure of mineral intake that is used in formulating diets for dry and lactating cows. In close-up dry cows, a negative DCAD can help prevent metabolic problems and in lactating cows, a positive DCAD can help increase milk production and milk components. The most common equation to determine DCAD is based on the dietary concentration of the cation minerals Na and K, and the anion minerals Cl and S. The DCAD formula is shown below. Note, enter mineral concentrations on a 100% dry matter basis.

$$\text{DCAD mEq/100g DM} = [(\%\text{Na} \times 43.5 + \%\text{K} \times 25.6) - (\%\text{Cl} \times 28.2 + \%\text{S} \times 62.5)]$$

The recommended DCAD for dry cows less than 3 weeks prior to calving is -10 to -15 mEq/100 g dietary DM. To achieve a negative DCAD, feedstuffs lower in Na and K are chosen and supplemental sources of chlorine plus sulfur are added. Finding forages low in K is an important step in achieving a negative DCAD and some dairies refrain from applying manure to crop ground designated for growing forage for dry cows. A recent summary by Beede, 2005 and Hu and Murphy, 2004 indicates a positive DCAD of 25 to 40 mEq/100 g DM is effective and adequate to maximize feed intake and milk production in lactating cows. To achieve a positive DCAD, feedstuffs high in Na and K are chosen and supplemental sources of Na and K added to the diet. Increasing the dietary DCAD to the recommended range has been shown to improve milk yield and DM intake of lactating dairy cows in hot or cool environmental conditions.

Avoid overfeeding Na and K to keep DCAD in the appropriate range and reduce mineral excretion in manure. For a detailed discussion on DCAD and the process of diet formulation for DCAD, see Beede, 2005. Recent research documents a large milk response to increasing DCAD concentration by increasing K content in diets for high producing early lactation cows (Harrison et al., 2012). Producers and their nutritionists will be evaluating the economic benefits versus the environmental impact of increased K excretion in manure.

Manure handling impacts mineral distribution in manure storages. Dairies that handle manure by flushing with recycled flushwater have more K and Na in the primary storage lagoon and less in solid manure than dairies that handle manure by scraping (Strahm et al., 2000). Thus, there is a greater potential for salt accumulation in the crop ground used to land apply liquids from the primary storage lagoons on flush dairies than on scrape dairies.

CONCLUSIONS

Macrominerals are very important nutrients in dairy rations and producers will continue to focus on optimizing production, health, and efficiency of their dairy herds. Accuracy in ration formulation, accuracy in feed preparation, and feeding management will play critical roles in controlling macromineral excretion on dairies. Livestock water supplies in Idaho have not been surveyed for macromineral content. A survey of water supplies would be very useful for identifying potential risk of excessive nutrient intakes from water on Idaho dairy operations. Data on nutrient composition of various manures are lacking on Idaho dairies. Research evaluating the nutrient variation in solid manure, separated solids, compost, and lagoons on Idaho dairy operations differing in manure handling methods and cattle housing would be valuable for identifying nutrient management issues and for guiding application rates.

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