Estimation of mineral balances in dairy herds including minerals in the drinking water

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A survey on mineral content in the drinking water and its relationship to mineral excretion in Merced County dairy herds

A new regulatory process related to the environmental impact of dairy farms will be affecting the dairy industry in the USA. A recent publication of the American Society of Agricultural Engineers concluded that an improved ability to predict nutrient excretion will be essential information for technical service providers and producers to consider when developing nutrient management plans for individual farms (Nennich et al. 2005). The official software of the National Research Council for dairy cattle (NRC 2001) might be considered one of the most current tools for nutrient balance and may be used to estimate nutrient excretion.

According to the NRC (2001), water is the most important nutrient for lactating dairy animals. But, good quality water is a scarce commodity in many areas of the United States and the world (Murphy 1992). In the USA, the availability of abundant, clean drinking water may become a challenge in the future as dairy farms are forced to move away from population centers and relocate (Beede 2005). Water contaminants have been reported to affect animal performance and health (Challis et al. 1987, Solomon et al. 1995, NRC 2001). The lack of controlled research studies makes difficult to evaluate the importance of water quality in dairy herds (Chase 2002, Socha et al. 2002). In some cases, nutritionists have not recognized the supply of minerals from water during formulation of diets due to the concern that minerals in water may be of low biological availability. However, minerals in water can, in some situations, be more biologically available than the minerals present in feeds (NRC 2001). Water used by lactating animals is supplied by three sources; the drinking water consumed voluntarily, the water present in the feeds, and the water formed within the body as a result of oxidation processes. The first two are the most important and, for practical purposes, together they represent total water intake.

Feeding certain minerals in excess of requirements may lead to environmental concerns due to run-off and land application of waste containing high mineral concentrations. The prediction of mineral excretion in dairy animals and the chemical composition of manure need to be considered as important as protein or energy dietary balances. This paper is part of a survey on feeding management and nutrient balances carried out on dairy herds in Merced County California. The aim of this specific work was to estimate mineral balances and mineral excretion in lactating animals including the minerals in the drinking water, according to mineral requirements of the NRC (2001) for dairy cattle.

Source of information

Fifty one dairy farms were randomly selected in Merced County, California. Dairy producers were contacted by phone and/or visited directly. All dairies were visited one or more times to obtain information on nutritional management, herd characteristics, diet composition and to sample concentrate feeds and water.

The NRC (2001) software for dairy cattle was used for calculation of mineral balances. The final mineral balance to estimate daily excretion for each mineral was obtained as indicated by the software output on the difference between the total dietary supplies (TDS) –total absorbed required (TAR) for pregnancy, lactation, and growth. The TAR for maintenance components (fecal, urinary, sweat, and miscellaneous losses), are daily removed from the body, and under normal conditions, daily excreted and replaced with new dietary minerals.

The minerals water contribution was estimated based on the mineral contents in the drinking water and the daily drinking water intake, which was calculated using the formula recommended by the NRC (2001); Water Intake (kg/cow/day) = 15.99 + 1.58*DMI, kg/day + 0.90*milk, kg/d + 0.05 sodium intake, g/day + 1.20 * min temperature, C° ; where, DMI = dry matter intake (Murphy et al. (1983, quoted by NRC 2001).

The mineral excretions were calculated for lactating animals in the different production groups or diets (e.g. fresh cows, 1st lactation, low, medium and high milk yield), and by farm according to the proportion of animals in each production group. Mineral composition of silages and hays were based on NRC (2001) data base. Samples of the mixed concentrate feeds (grains, by-products, minerals, and vitamins premixes) and water samples were analyzed for total soluble salts (TSS), Ca, P, Mg, K, Na, Cl, S, Cu, Fe, Mn, Se and Zn. using reference methods of the U.S. Environmental Protection Agency (EPA)

General dietary characteristics

The average milk production and DMI per farm in this survey were 30.9 ± 5.31 kg/cow/d (ranging from 18.9 to 45.1) and 21.8 ± 2.2 kg/cow/d (ranging from 16.3 to 26.2), respectively. The average number of lactating animals per dairy was 809 ± 899 ranging from 110 to 5010, with a median of 523 cows. The main ingredients used for lactating animals are described in Table 1. In more than 75% of the farms, diets were based on 5 dietary ingredients, which were corn silage, alfalfa hay, processed corn grain, whole cottonseed, and canola meal. Between 50 to 75% of the dairies also used almond hulls. Almost 30 other different feeds (forages, grains and byproducts) were used in less than 50% of the dairies.

Minerals in the diet, water, and balance

The results of mineral content from 51 water troughs in this study are shown Table 2. Information from different sources (NRC 2001, EPA, World Health Organization) was used to determine upper desired levels for humans and livestock. Only 14% of the samples can be referred to as saline water with TSS > 1000mg/L. Base on the information presented in Table 2, 7 minerals are considered in excess of the desired levels.

The information on mineral concentration in the water is similar to a previous survey on 101 samples collected in dairy farms throughout the state of California (Socha et al. 2002). These authors indicated minerals that tended to be of greatest concern in California were Na and Mn, which exceeded the desired livestock levels in 64 and 41% in the water samples, respectively. The results of the present work indicate similar trends when compared to Socha et al. (2002), but with greater values not only for Na and Mn, but also for Cl and sulfates.

The results of this study on daily dietary mineral intakes, the contribution of minerals in the water and the final excretion for each mineral are presented in Table 3. The table shows the average daily dietary intake of each mineral for lactating dairy cows on the 51 dairies, the participation of minerals consumed from the drinking water and the estimated daily mineral excretion per cow.

Dietary Ca contents in this survey were close to the requirement for cows producing 30 kg milk/d. The NRC (2001) indicates that requirements of absorbed Ca that must enter the extracellular compartment for maintenance and production are fairly well known. In other words, the Ca excretion calculated in this survey should be close to the real Ca excretion. Average contribution of Ca from drinking water relative to the total Ca excretion was low (~ 4%).

The concentrations of P in the water averaged 0.11 mg/L, representing a small contribution to the total P intake and excretion. Values of P content in the diet were similar to those indicated by Dou et al. (2003) for the U.S. dairy diets. The estimations of P excretion in Table 3 are similar to those values reported by Wu et al. (2005), and Weiss and Wyatt (2004).

The Mg in the diets estimated in this work was in the same range of a recent publication (Weiss 2004). The data of Weiss (2004) were compiled from 8 experiments with lactating animals under different feeding conditions, and with Mg digestibility measured using total collection of feces and urine. The author concluded that the apparent digestibility of Mg was 30% lower than the mean value calculated by the NRC (2001) model. The reason for this lower digestibility of Mg was the high concentrations of dietary K. Weiss (2004) observed that cows had to consume an additional 18 g of Mg/day for every 1 percentage unit increase in dietary K above 1% to maintain the same intake of digestible Mg as that consumed when fed a diet with 1% K. These results and the mean concentration of K observed in this survey (1.6%), indicate that Mg excretion in Table 3 should be taken with precaution. The impact of Mg in the water on Mg intake was 3.2% in average.

Excretion of K in this survey was estimated to be almost 300 g/cow/d. This is 100 g/cow/d lower than the calculations of Grant (1997) for cows producing 32 kg milk/d with 1.2% K in the diet. This difference can be explained by the differences observed in K dietary contents. The K was low in the drinking water with non detected contribution to the diets and excretion.

Due to its close relationship, Na and Cl are discussed together. Daily intakes of Na and Cl in the diets were high respect to the NRC recommendations, and highly variable. These variations might be related to difficulties in obtaining good estimations of free choice consumption of salts on some farms. However, dietary concentrations of Na and Cl in this study were comparable to those obtained in an extensive review of literature by Sanchez et al. (1994). Of all the minerals evaluated in water, Na had the greatest contribution to the total daily excretion, averaging almost 17% of the mean Na excreted. Excretion of Na (64 g/cow/d) in our survey is comparable to the data of Bannink et al. (1999), which estimated a Na excretion of 56 g/cow/d from 10 feeding trials with lactating cows producing 25.2 kg milk/d. The mean Cl water contribution to Cl excretion was 12%. In spite of the ability of cows to consume excesses Na and Cl with limited impact on performance, the contributions of these minerals to the environmental should be considered (e.g. soil salinisation). The NRC (2001) suggests that more research is required to establish the requirements and appropriate concentrations of Cl and Na in diets for dairy cattle and should be consider their relationships with other minerals (Sanchez et al. 1994), which could greatly reduce the amount supplemented and excreted.

The S requirement was set at 0.20% of dietary DM by the NRC (2001), suggesting that the maximal tolerable level should remain at 0.40% of diet DM, with higher concentrations being potentially detrimental to absorption of Cu and Se. Mean dietary S concentration in this study was 0.27%, and ranged from 0.20 to 0.40%. Ivancic and Weiss (2001) studied the dietary effect of S and Se concentration in lactating dairy cows. The authors concluded that increasing S concentration in the diet (e.g., 0.21, 0.41, and 0.70%), significantly reduced DMI, and yields of milk, milk protein, and milk fat. This negative effect was larger when cows were fed with 0.271 ppm compared with 0.135 ppm of Se. The mean water contribution of S excretion in this survey averaged 15%. In some farms S coming from water must be included in the diet to decrease excretion, to minimize interactions with other minerals (e.g. Se), and possible negative effects on lactation performance. The estimation of S excretion was 16 ± 9.4 g/cow/d.

Based on the Zn, Ca, and S contents in the diets obtained in this survey, some interactions with Cu absorption can be expected (NRC 2001, Spears 2003, Beede 2005). The mean dietary concentration of Cu in the rations of the farms analyzed in this study was 15 mg/kg. This concentration is 2.7 fold lower than the established upper limit of 40 mg/kg, and 35% more than the requirement (11 mg/kg) suggested by the NRC (2001). Dietary and excretion Cu contribution from the drinking water was low. But, Cu intake and excretion were highly variables, ranging from 123 to 772; and 119 to 767 mg/cow/d, respectively.

Iron can interfere with absorption of Cu and Zn when dietary levels are over 250 mg/kg DM (NRC 2001). The average concentration of Fe was below 200 mg/kg DM, but about 10% of the dairy farms had high dietary levels of this mineral. The mean contribution of Fe coming from the drinking water to the total Fe excretion was very low. The excretion of this mineral averaged 4201±983 mg/cow/d based on its coefficient of absorption, which was set at 10% in feedstuffs for adult animals by the NRC (2001).

Recently, Weiss and Socha (2005) estimated the maintenance requirements for Mn by dairy cows. The authors concluded that the dietary requirements were 1.6 and 2.7 times higher for lactating and dry cows, respectively, compared to those calculated using the NRC (2001) model. Daily Mn consumption in this survey averaged 67.1 ± 22.8 mg/kg DM (from 23 to 142 mg/kg). These amounts can apparently support maintenance and production requirements of Mn with no negative effects on the animal. Despite the high concentrations of Mn in some water samples (Table 2), the average contribution of Mn from water to the total diet and excretion was insignificant or less than 1% (Table 3). Estimated Mn excretion was 1456 mg/cow/d, from 572 to almost 2459 mg/cow/d.

Current regulations established by the Food and Drug Administration limit Se supplementation to 0.3 mg/kg of diet. The mean values obtained in this survey were over (20%) the mentioned limit. These differences might be explained by the lack of Se data content in feeds. Assuming that most feedstuffs contain some Se, it is expected that total mixed rations would result in concentrations above the recommended level. Possible interrelationship between nutrients that may affect absorption and metabolism of Se would alter the requirement of this mineral (NRC 2001, Ivancic and Weiss 2001). The NRC (2001) concluded that data concerning the interaction between Zn and Se are lacking. The estimated average contribution of Se excretion from water was 35%. The excretion for Se was highly variable and averaged 1.4 ± 2.6 mg/cow/d. This value can be also related to the methodology used to estimate the efficiency of dietary Se utilization by the animals. The NRC (2001) established that requirements of Se using the factorial approach is difficult because the deposition of Se in body tissues. As cows consume more Se, the concentration of Se in milk and in the conceptus increases, indicating that probably Se excretion in this survey was overestimated. In a meeting on Se (Selenium in the Environment, Essential Nutrient, Potential Toxicant, 1995) it was concluded that while minimum Se requirements are very well documented, the optimum dietary Se for human and animals for adequate function of the immune system, protection against infectious disease, and for physiological stress will require continued research.

Dietary Zn content in this survey was 68.2 ± 25.8 mg/kg DM. This amount is 5 mg/kg DM higher than the requirement set by the NRC (2001) for a cow producing 40 kg milk/d. In approximately 40% of the dairies cows were fed with more than 63 mg/kg DM, or 1300 mg/cow/d of Zn. Also, in 12% of the dairies Zn in the diet was too low, under the minimum recommended (35 mg Zn /kg DM). The mean content of Zn coming from the drinking water was negligible, except in one dairy in which 377 mg/cow/d were consumed from the water, representing 28% of the mean excretion. Estimated excretion of Zn ranged from 480 to 2592 mg/cow/d.

Based on the minerals analyzed in this study, a lactating dairy cow producing approximately 30 kg milk/d might excrete 750±117 g of minerals/d, ranging from 451 to 1019 g/cow/d. The proportion coming from the water represented a mean of 4 ± 3.3% (from 0.3 to 20%). In some dairies, the control of these amounts can represent a reduction of manure production and land applications. The results of this survey indicate that minerals in the water may affect excretion of them, suggesting that their contribution from water needs to be controlled and included when formulating diets to manage mineral balances and reduce minerals excretion. When an unmanageable excess of minerals coming from the water is affecting soil quality (e.g. salinization) or animal performance, other methods to improve water quality should be analyzed (filtration, reverse osmosis, etc).

Final considerations

In order to obtain more accurate estimates of mineral balance in dairy herds to optimize animal performance and minimize environmental impacts caused by excessive excretion of minerals, it would be necessary to produce more detailed information on mineral concentrations in feeds, including differences between areas of feed production like forages, grains and byproducts. Improvements in diet formulation could be achieved by improved access to analytical methods for trace mineral analyses, and by publication of nutrient composition of feeds with complete mineral analysis. For those minerals that receive substantial contribution from water, like Na and Cl in this study, water analysis might allow nutritionists to minimize the use of some supplemental sources like free-choice salts. Other example is Se, which is the only mineral in the United State regulated by the Food and Drug Administration. Little is known about Se content in feeds for dairy cows, and this lack of knowledge may, in many instances, force nutritionists to not even consider dietary contribution from dietary ingredients other than the supplemental source. A software for ration formulation, that integrate minerals from drinking water, indicates excesses of minerals consumed and potential interactions among minerals that might affect animal health and performance, and to estimate daily excretion in feces and urine, is required to facilitate diet formulation and to minimize possible environmental impacts.

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TABLE 1. Main feeds used for lactating animals in 51 dairy farms in Merced County, California (USA)

% Farms	Forages	Grains	Proteins and By-products
>75	Corn silage, alfalfa hay	Corn grain, cotton seeds	Canola meal
75-50			Almond hulls
50-25	Wheat and/or oat hay, alfalfa haylage	Barley	Dry distillery grains (DDG), whey wet & permeate, rice bran, wheat middling & bran
<25	Wheat and/or oat silage, Sorghum hay and silage, pastures	Soybean seeds	Soybean meal, sugar beet pulp, soy hulls, corn gluten feed & meal, corn germ, citrus pulp, sunflower meal, bakery, raisins, grain screening

TABLE 2. Water trough mineral composition in 51 dairy farms from Merced County, California

	Average (mg/L)	SD	Min	Max	(μ) Upper desired levels	(¥) Samples exceeding (μ) (%)
Total soluble salts	592	367.3	74	2200	1000	14
Calcium	60	33.7	10	140	100	22
Phosphorus	0.1	0.06	0.01	0.45	ND(λ)	ND(λ)
Magnesium	23	18.4	1.4	76	50	10
Potassium	3.25	1.94	1.0	8	10	0.0
Sodium	106	98.0	8.0	500	50	70
Chloride	83	85.4	3.2	390	100	31
Sulfur	24	34.3	1.0	160	ND(λ)	ND
Sulfate(κ)	53	48	4.0	210	50	39
Copper	≤0.005	ND	≤0.005	0.03	1.0	0.0
Iron	0.07	0.19	0.002	1.3	0.2	10
Manganese	0.13	0.26	0.01	1.1	0.05	43
Selenium	≤0.005	ND	≤0.005	0.06	0.05	<2
Zinc	0.05	0.13	0.02	0.91	5	0.0

μ Upper desire levels for humans and cattle (NRC 2001; US EPA; World Health Organization)

¥ % of samples exceeding upper desire levels

κ Sulfate, n=33

λ Not detected, not determined

TABLE 3. Estimations of daily minerals intake, drinking water minerals contribution, and net minerals excretion in lactating dairy cows (n=51 dairy farms)

	Daily intake (γ)				Water contribution (δ)				Excretion (ε)			
	Mean	SD	min	max	Mean	SD	min	max	Mean	SD	min	max
	(g/cow/d)				(g/cow/d)				(g/cow/d)			
Calcium	186	39.6	97	299	5.5	3.4	ND	15	150	36.3	72	247
Phosphorus	96	19.5	57	142	ND(η)	ND	ND	ND	69	17.1	39	114
Magnesium	71	14.7	41	112	2.3	1.9	ND	8	67	14.5	39	106
Potassium	338	51.6	236	520	ND(η)	ND	ND	ND	297	48.8	211	485
Sodium	83	31.8	8	173	10.6	10.0	ND	51	64	30.7	26	153
Chloride	104	26.8	54	168	8.4	12.9	ND	83	71	26.8	15	140
Sulfur	59	11.2	40	87	2.4	3.2	ND	14	16	9.4	1	40
	(mg/cow/d)				(mg/cow/d)				(mg/cow/d)			
Copper	326	139.2	123	772	0.5	0.4	ND	2.3	322	138.9	119	767
Iron	4232	985.9	1657	6534	10.8	49.1	ND	355.4	4201	982.6	1627	6495
Manganese	1457	491.5	573	2459	10.2	22.1	ND	101.5	1456	491.4	572	2459

Selenium	8	2.8	4	15	0.5	0.1	ND	0.7	1.4	2.56	-3	9
Zinc	1489	579.0	559	2720	11.2	52.5	ND	377.4	1375	569.3	480	2592

γ Total daily intake including minerals in drinking water

δ The minerals water contribution was estimated based on the minerals contents in the drinking water and the daily drinking water intake, which was calculated using the formula recommended by NRC (2001);Water Intake (kg/cow/day) = 15.99 + 1.58*DMI, kg/day + 0.90*milk, kg/d + 0.05 sodium intake, g/day + 1.20 * min temperature, C^{o} (where, DMI = dry matter intake)

ε Excretion (feces + urine) = Total Dietary Supply – Total Absorbed Required for gestation, lactation and growth (NRC, 2001)

η ND = non-detected or less than 0.1%

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