Solubililty of Magnesium from Feed Grade Sources in an In Vitro Ruminal + Abomasal System[a]

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Summary and Conclusions

1. In order for magnesium (Mg) from a supplemental source to be bioavailable to the dairy cow it must be solubilized into the liquid matrix of the digesta and it must be absorbed from the digestive tract. For many supplemental sources solubilization may be the primary factor limiting the amount of bioavailable Mg.

2. In our studies, an *in vitro* [ruminal + abomasal] system was used to test the solubility of Mg from feed grade sources. Solubility of Mg, as a percentage of the total Mg in the sample source, ranged from 81.0% [Magnesium Phosphate-Sweden] to 37.2% [SuperMag-Greek] and averaged 59.1% for the 11 sources evaluated.

3. The percentage soluble Mg in the total dry weight of commonly used magnesium oxide sources ranged from 40.1% [Feedox-U.S.A.] to 19.7% [SuperMag-Greek]. Three sources, Magnesium Phosphate-Sweden, Rumen-Mate-U.S.A. and Min-Ad-U.S.A., had relatively lower total soluble Mg primarily because they contained less total Mg in their whole dry weight. These three sources are not used principally in dairy rations as sources of supplemental Mg, but provide other nutrients [calcium, phosphorus, sodium, potassium, sulfur and microminerals] and other potential nutritional attributes (i.e., buffering and alkalizing).

4. Sources used primarily to provide supplemental Mg should be bid and purchased by dairymen, and feed and premix manufacturers on a Mg solubility basis.

5. Prudence should be exercised to ascertain the origin of the product in question. Over time a particular supplemental source may have the same

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commercial or label name, but may be from a different origin; therefore, the Mg solubility of a particular brand may change over time.

6. Because of the variation in Mg solubility among sources it is impossible and foolhardy to recommend a single specific concentration for total Mg in lactation rations. The appropriate concentration to maximize lactational performance will depend on the supplemental source used.

Introduction

Bioavailability of magnesium (Mg) from inorganic feed supplements is a function of 1) solubilization or release of the Mg into the liquid phase of the digesta and 2) the absorbability of the solubilized Mg from the digestive tract. Solubility of Mg may vary depending on origin of the supplemental source. Furthermore, solubility is not equal to bioavailability. However, if the Mg in a supplemental source is not solubilized in the digestive tract liquid phase, most likely it will not be absorbed and will not be available to the dairy cow.

There are various inherent characteristics about supplemental Mg sources which may influence the solubility and consequently the bioavailability of their Mg (Beede and Lough, 1988). Probably the most important factor is particle size of the material. Researchers in Scotland (Wilson, 1981; Hemingway, 1985) demonstrated that bioavailability under a variety of feeding conditions with cattle and sheep was higher always for sources of magnesium oxide (MgO) with smaller average particle size. Also, it was found that sources of different origin, but having similar average particle size or a similar distribution of particle sizes had different bioavailabilities. A practical problem is that as particle size decreases some materials are dustier. These sources are often shunned by feed mill operators because of their adverse handling properties. However, they may have the highest bioavailable Mg contents. Dustiness may represent an acceptability problem to the cow if the supplemental Mg source is provided in a loose supplement or concentrate fed separately from the forage portion of the ration. However, dustiness is not a problem generally in total mixed rations.

The country of origin or mining site within a country (i.e., origin of the mother ore) and processing method are factors affecting solubility and bioavailability. There is considerable variation in geological origin and hardness, as well as particle size of sources. Characterization of the solubility of sources from different origins has not been done. Temperature of calcination (i.e., heating or burning, which is part of the process to produce some commercial calcined magnasites or magnesium oxides from native magnesium carbonates) affects solubility and bioavailability. In an extensive series of studies Wilson (1981) and coworkers found that the optimum temperature of calcination was in the range of 1472 to 2021°F. Bioavailability of Mg was less for materials burned below 1472°F or above 2021°F.

Several lactation experiments (O'Connor et al., 1988; Teh et al., 1985; Beede and Lough, 1988) demonstrated significant lactational responses of 5 to 10% (3 to 7 pounds extra 4% FCM per cow per day) by increasing total Mg concentrations to .38 to .48% of ration dry matter compared with current NRC (1988, Update 1989) recommendations (.2 to .25% of ration dry matter). However, other studies have not shown positive responses. One of the possible explanations for differences in response may be the source used in a particular study and thus, the solubility or bioavailability of the Mg in the supplemental source.

Therefore, the objectives our studies were to characterize and rank the solubilities of 11 sources of supplemental Mg. The commercial name, origin and sampling source of the materials evaluated are described in Table 1. Eight of these sources were commercially available MgO. Three products were not primarily MgO but were used in the U.S.A. or Europe as mineral supplements for ruminants; they contained less total Mg than the MgO materials and also generally were used to provide other nutrients (i.e., other macro and trace minerals) or digestive tract or dietary buffering.

Experimental

The laboratory studies were done utilizing an ***in vitro*** system [ruminal + abomasal] designed to simulate some of the important features of the dairy cow's digestive tract. The rumen is the first compartment for potential solubilization and absorption of Mg. Additionally, the low pH of the abomasal fluid may facilitate additional solubilization and that soluble Mg may be absorbed in the digestive tract after the abomasum (i.e., especially in the small intestine).

About 100 mg of each Mg source were weighed separately into test tubes. Just prior to the experiment, a substrate composed of maltose, cellobiose, casein hydrolysate, L-lysine and urea, and an artificial saliva buffer (without added Mg) were added to the tubes. Live ruminal fluid from a ruminal fistulated cow fed a diet containing 50% concentrate and 50% alfalfa was collected, strained and transported to the lab under anaerobic conditions. The ruminal fluid was added to the tubes and the total mixture was incubated at 102.2°F for intervals of 0, 6, 12, 24, 36, and 48 h. Tubes were hand swirled at these time intervals also. At the end of each incubation interval some of the tubes were removed and a portion of the liquid phase was retained for subsequent analysis of solubilized Mg. The pH of the ruminal system ranged from 6.95 to 6.30 over the course of the incubation. This was to simulate the normal range in ruminal pH.

After sampling the liquid phase in the ruminal stage of the system the remaining contents of the tubes were subjected to a simulated abomasal environment by adding a hydrochloric acid and pepsin solution and mixing every 15 min for 1 h. Typically, the pH of liquid was less than 2. At the end of 1 h a portion of the liquid phase was sampled for determination of solubilized Mg.

Results and Discussion

Table 2 shows the percentages of the total Mg from the supplemental sources which were detected in the liquid phase of the ***in vitro*** system, after incubation in the ruminal stage (averaged from 12 to 48 h), the abomasal stage, and the sum of the ruminal + abomasal stages. Listing of sources is arranged according to relative Mg solubility in the ruminal + abomasal system. Relative solubility was calculated as: Mg solubility of a specific source divided by the average Mg solubility of all 11 sources evaluated.

Percentage of the total Mg in the supplemental MgO sources which was solubilized in the ruminal stage averaged 13.9% and ranged from 6.5% (SuperMag-Greek) to 22.6% (MagOx-U.S.A.). Among these same sources, solubility of the total Mg in the abomasal stage ranged from 30.7% (SuperMag-Greek) to 53.9% (FeedOx-U.S.A.) and averaged 45.2% for all sources in the study. Obviously, solubility of Mg from all sources was considerably greater in the abomasal stage than in the ruminal stage. This likely was due to the much lower pH of the abomasal incubation. The pH of the ruminal system was intentionally maintained within a optimal range which would sustain normal ruminal function for a lactating dairy cow. This pH range (6.95 to 6.3) may be higher than that occurring at certain times of the day in some dairy cows fed high concentrate rations with a lot of highly fermentable carbohydrates. Some sources with lower than average ruminal Mg solubility in our studies (i.e., Magnesium Phosphate-Sweden, Chinese pink MgO, Min-Ad-U.S.A., MagFeed-Greek and SuperMag-Greek) may have higher Mg solubilities in a ruminal system with lower pH. However, the general relative ranking among the sources would not vary greatly.

The total (ruminal + abomasal stages) percentage of soluble Mg averaged 59.0% and ranged from 81.0% (Magnesium Phosphate-Sweden) to 37.2% for SuperMag-Greek. Among the MgO sources, the percentage of the total Mg which was solubilized was about twice as high for FeedOx-U.S.A. and MagOx-U.S.A. as it was for MagFeed-Greek and SuperMag-Greek. Magnesium solubility of other sources fell between these bounds. This ***in vitro*** system gave very similar results for different samples of common origin. For example, FeedOx-U.S.A. and MagOx-U.S.A. were from a common origin but were distributed through different routes as were the two sources originating from Greece. Their Mg solubilities and position in the relative ranking were quite similar (Table 2).

Knowing the percentage of the total Mg in a source which will solubilize is only part of the consideration in purchasing a supplemental source to provide soluble Mg. The total Mg content of a particular source must be considered as well. Total soluble Mg in the whole weight of the source equals ([total Mg concentration of the source] X [solubility of Mg of the source in the ruminal plus abomasal system]). This calculation yields the percentage total soluble Mg of the whole weight of the sample source. Because these sources are typically bought on a whole weight basis, establishing a relative ranking on this basis will aid in making an informed purchasing decision. Table 3 shows the percentage total soluble Mg and relative ranking on that basis of the supplemental sources evaluated in our studies.

Among the MgO sources FeedOx-U.S.A. and MagOx-U.S.A. had the highest percentages of total soluble Mg, about 40%. MagFeed-Greek and MagOx-Greek had the lowest soluble Mg, 21.7 and 19.7%, respectively. Therefore, on this basis some sources ranked about twice as high as other sources. Suggesting that either the low ranking sources had only half as much value as the high ranking sources in providing soluble Mg or that the high ranking sources had twice as much value as the low ranking sources. The other MgO sources studied, Chinese pink, CoMag-Turkish, BayMag-Canada, and Magal-Spanish, had relative rankings of 0.81, 0.79, 0.68, 0.63, compared with FeedOx-U.S.A. (Table 3).

The other three supplements in our studies, Magnesium Phosphate-Sweden, Rumen-Mate-U.S.A., and Min-Ad-U.S.A. had lower relative rankings than the MgO sources. This was primarily because they had lower concentrations of total Mg in their whole dry weight (see Tables 1 and 3). These sources are not included in diets primarily to provide supplemental or soluble Mg. They have other nutritional claims and attributes such as sources of calcium, phosphorous, sodium, potassium, sulfur and microminerals and as dietary buffers and alkalizers. These other nutritional attributes may justify inclusion of these products in rations, if they are priced appropriately based on their nutritional merits.

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TABLE 1. Description of supplemental magnesium sources evaluated.

Lab #	Name/Origin	Sampling Source	Percent Total Mg (label)
1.	MagFeed-Greek American Minerals, Inc. 301 Pigeon Point Rd. New Castle, DE 19720	Batkins Feed & Grain Co. 104 N Oak St. Batkins, OH 45306	53.0
2.	SuperMag-Greek American Minerals, Inc. 301 Pigeon Point Rd. New Castle, DE 19720	American Minerals, Inc. New Castle, DE 19720	53.0
3.	CoMag-Turkish Istanbul, Turkey	U.S. Terra Corp. 1050 S. Fed. Hwy. Delray Beach, FL 33444	53.0
4.	Magox-U.S.A. Basic Chemicals Combustion Engineering, Inc. 7887 Hub Parkway Cleveland, OH 44125	Harvest Brands, Inc. P. O. Box 46 Pittsburg, KS 66762	54.0
5.	Chinese Pink Granule Peoples Republic of China	Sampled from the ship "Irish Sea" by Mr. Ted Huntsman	54.0
6.	BayMag-Canada BayMag Plant 200, 1144-29 Ave., NE Calgary, Alberta T2E 7PI	Ragland Mills, Inc. Rt. 8, Box 168 Neosho, MO 64850	58.0
7.	Magnesium Phosphate-Sweden Boliden Kemi AB Box 902 S-251 09 Helsingborg Sweden	Boliden Kemi AB Helsingborg, Sweden	24.0
8.	Feedox-U.S.A. Southeastern Minerals P. O. Box 1866 Bainbridge, GA 31717	UF Dairy Research Unit Hague, FL	54.0
9.	Magal-Spanish *formerly:* Magnesitas de Rubian Montalban N.3 Madrid 14, Spain *currently:* ERT North America, Inc. 1 Walter Street White Plains, NY 10601	High Springs Milling High Springs, FL	52.0
10.	Min-Ad Inc., U.S.A. 1630 25th Ave. Greeley, CO 80631	Min-Ad Inc. Greeley, CO 80631	14.0
11.	Rumen-Mate - U.S.A. Pitman-Moore, Inc. 421 East Hawley St. Mundelein, IL 60060	High Springs Milling High Springs, FL	16.6

TABLE 2. Percentage of total magnesium in supplemental source solubilized in *in vitro* ruminal + abomasal system, and relative Mg solubility.

Source (Lab #)	Percent of Total Magnesium of Source Solubilized In: Ruminal Stage	Abomasal Stage	Ruminal + Abomasal	Relative Mg Solubility[a]
Average	13.9	45.2	59.0	1.00
Magnesium Phosphate (#7)	11.2	69.8	81.0	1.37
Rumen-Mate (#11)	27.9	47.3	75.2	1.27
Feedox (#8)	20.4	53.9	74.3	1.26
MagOx (#4)	22.6	51.1	73.7	1.25
Chinese (#5)	11.7	48.2	59.9	1.01
Turkish (#3)	14.6	45.1	59.7	1.01
Min-Ad (#10)	1.4	50.8	52.2	0.88
Spanish (#9)	14.5	33.8	48.3	0.82
BayMag (#6)	14.2	33.2	47.2	0.80
Greek (#1)	7.6	33.4	41.0	0.69
Greek (#2)	6.5	30.7	37.2	0.63

[a]Relative Mg solubility = Mg solubility of a specific source divided by average Mg solubility of all 11 sources evaluated.

TABLE 3. Relative ranking by total soluble magnesium in sources tested. Total soluble magnesium in source = magnesium concnetration of source X solubility of Mg of source in ruminal + abomasal system.

Source (Lab #)	% Total Mg of Source	X	% Soluble Mg in Source	% Total Soluble Mg of Source[a]	Relative Ranking[b]
FeedOx (#8)	54.0		.743	40.1	1.00
MagOx (#4)	54.0		.737	39.8	.99
Chinese (#5)	54.0		.599	32.3	.81
Turkish (#3)	53.0		.597	31.6	.79
BayMag (#6)	58.0		.472	27.4	.68
Spanish (#9)	52.0		.483	25.1	.63
Greek (#1)	53.0		.410	21.7	.54
Greek (#2)	53.0		.372	19.7	.49
Magnesium Phosphate (#7)	24.0		.810	19.4	.48
Rumen-Mate (#11)	16.6		.752	12.5	.31
Min-Ad (#10)	14.0		.522	7.3	.18

[a]Percentage total soluble Mg of whole weight of source.

[b]Relative ranking compared with the source (FeedOx, #8) containing the largest quantity of soluble magnesium as determined by the ruminal + abomasal evaluation system.