Comparison of Four Magnesium Oxide Sources Each Fed at Three Dietary Concentrations to Lactating Cows[1]

FLORIDA DAIRY CHECK-OFF

David K. Beede[2], German G. Davalos[2] and Estelle M. Hirchert[2]
Dairy Science Dept., IFAS
University of Florida, Gainesville 32611

SUMMARY and CONCLUSIONS

1. A series of recent experiments demonstrated that supplementation of magnesium (Mg) above current NRC (1989) recommendations (.2 to .25% of diet DM) resulted in increased fat-corrected milk yield.

2. Maximal lactational response in different experiments depended upon what Mg source was supplemented and the milk production level (stage of lactation) of cows. For midlactation cows supplemented with feed grade magnesium phosphate, .48% total dietary Mg resulted in greatest milk yield. When midlactation cows were provided additional dietary Mg as MgO maximal lactational response was obtained between .27 and .32% total dietary Mg. In one study with early lactation high producing cows, maximal fat-corrected milk yield was achieved with .45% total dietary Mg. Milk fat percentage was increased in one of these experiments although the basal diet would not be characterized as a milk fat-depressing diet.

3. The source, particle size and calcining temperature of various commercially available MgO sources may affect animal performance. However, in an experiment reported herein no differences in milk yield were detected due to MgO sources having different *in vitro* solubilities. One possible explanation is that the residence time of MgO in the rumen can be quite long and ultimately adequate Mg can be released to support the needs of midlactation cows.

Direct costs of part of the research reported herein were shared by the Florida Dairy Check-Off, BayMag, Inc., Calgary, Alberta, Canada; Magnesitas de Rubian, SA, Madrid, Spain; Premier Services Corp., Middleburg Heights, OH; and, state of Florida appropriations. Mention of commercial products does not constitute either endorsement or disapproval by the authors, Dairy Science Department, Institute of Food and Agricultural Sciences, or the University of Florida.

Associate Professor, Graduate Research Assistant and Biologist, respectively.

Presented at the 29th Florida Dairy Production Conference, Gainesville, April 14-16, 1992

INTRODUCTION

Traditionally in ruminant nutrition magnesium (Mg) has been considered almost entirely as it relates to hypomagnesemic tetany. Consequently, the vast majority of research in Mg nutrition has dealt with establishing the minimum requirement to prevent this metabolic disease. Recently more effort has gone into characterizing availability of Mg in various feedstuffs and supplemental sources and studying metabolic interrelationships. Information regarding the dietary requirement of Mg and the recommended allowance to maximize lactational performance and efficiency of dairy cattle is quite limited. We shall present evidence that published minimum requirements and even proposed recommendations are not always maximally efficacious for lactation. To date much research examining the dietary requirement has used the factorial approach (ARC, 1980) where absorption of Mg from feedstuffs has been estimated and used to scale to requirements for body maintenance and productive functions. An alternate approach would be to supplement diets with various Mg salts at graded concentrations and measure a response (e.g., milk yield or blood serum Mg concentrations).

Objectives of this paper are to 1) summarize recent research describing the availability of Mg from feed grade Mg sources and discuss factors affecting availability, and 2) describe recent experiments designed to determine the optimum Mg allowance for lactating Holstein cows when diets were supplemented with Mg above NRC (1989) recommendations.

SUPPLEMENTAL SOURCES AND AVAILABILITY

Magnesium oxides (MgO) have been the major source of supplemental feed grade Mg for livestock diets in North America. Magnesium sulfate ($MgSO_4$) and the double sulfate of Mg and K are found in combination with other minerals in some supplements. Feed grade magnesium phosphate (MgP) has been available in Scandinavia and Europe for some time.

All feed grade MgO products are not equal in physical and chemical characteristics. They vary in origin [raw ore, or other crude chemical preparations which have been calcined (or burned), brine, seawater and so-called firebrick], chemical purity, Mg content [48 to 60%], particle size, acceptability by animals, and perhaps of major importance, availability.

Wilson (1981) conducted extensive studies with sheep and cattle at the University of Glasgow, Scotland, to compare various Mg sources. Magnesium oxide sources compared were "Spanish", "Chinese 30-Mesh", "Chinese Granular", "American Brine MgO-Prilled 30" and "Greek". Several different evaluation techniques were used to relate preparation procedures and physical properties of the sources to nutritional value for ruminants. Major findings of Wilson's (1981) Ph.D. thesis work included the following.

1) Various sources of MgO varied in Mg availability. Availability studies using chromic oxide as an indigestible external digestibility marker showed that Mg from

"Greek" MgO was least available (25%), followed by the "American Brine" product (26%), the "Chinese Granular" (30%), the "Chinese 30-Mesh" (32%) and the "Spanish" (37%).

2) Magnesites calcined at temperatures of 1472 to 2012°F resulted in MgO with higher Mg availability for sheep compared with calcining at 1202°F or less. However, calcining at 2372°F for 3 h also reduced availability.

3) Particle size of various sources also affected Mg availability. Wilson (1981) separated MgO from Greece, Spain and China into various particle sizes. Availability increased as particle size decreased. Likewise, Henry et al. (1986) demonstrated the importance of particle size and source on Mg availability. Apparent absorption by crossbred wethers was 24.4, 9.0, 15.3, -8.5 and 16.3% with reagent grade $MgSO_4$, MgO (12x40 mesh prill from seawater), MgO (30x100 mesh prill from seawater), MgO (12x40 mesh prill from brine) and -100 mesh calcined magnesite, respectively. Jesse et al. (1981) also noted similar findings for the relationship of particle size and availability.

4) Using intraruminal nylon bags (pore sizes 24um or 43um) Wilson (1981) found a positive correlation ($r=.572$, $P<.005$) between availability and solubility after 48 h in situ. In her studies the "Spanish" MgO disappeared from bags most readily. The nylon bag technique was proposed as a reasonably accurate and quick method to rank various Mg sources according to availability.

5) Chemical reactivity of MgO with various laboratory reagents has been a method to characterize various MgO sources. However, it was found that chemical reactivity and/or solubility were poorly correlated with estimates of availability. For example, "Spanish" MgO with a relatively poor rate of reactivity in .4N citric acid (over 30 min) had superior availability whereas, "Greek", "Chinese" and "American Brine" with higher reactivity rates (less than 30 min) had relatively lower availabilities. Another chemical technique, ammonium ion exchange, demonstrated no relationship to Mg availability in ruminants. These results strongly suggest that chemical reactivities of MgO sources in the laboratory hold little useful relationship to solubility and absorption potential of Mg in the ruminant digestive tract.

In several lactation experiments (O'Connor et al., 1988; Teh et al., 1985; Lough et al., 1990) to be detailed subsequently in this paper, it was demonstrated that significant lactational responses of 5 to 10% (3.1 to 7.0 lb extra 4% FCM yield/ cow per day) were achieved by increasing total dietary Mg concentrations to between .38 to .48% of ration DM compared with current NRC (1989) recommendations (.2 to .25% of ration DM). However, other studies have not shown positive responses (Table 1). One possible explanation for difference in response may be the source used in a particular study and thus, the solubility or availability of the Mg in the supplemental source. Many earlier studies did not cite the origin, or chemical and physical characteristics of the MgO source tested.

Mg SOLUBILITY: *IN VITRO* RUMINAL + ABOMASAL EXPERIMENTS

Availability of 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. Certainly solubility is not equal to availability. However, if the Mg in a supplemental source is not solubilized in the digestive tract liquid phase, it may not be absorbed and available to the dairy cow.

Therefore, the objective of recent work in our laboratory was 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 2. Eight of these sources were commercially available MgO. Three products were not primarily MgO but were used in North America 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 macrominerals and trace minerals) or as buffering or alkalizing agents.

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). Details of this laboratory procedure were given previously (Beede et al., 1989).

Table 3 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 each source 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., MgP-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 should not vary greatly.

The total (ruminal + abomasal stages) percentage of soluble Mg averaged 59.0% and ranged from 81.0% (MgP-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 3).

Knowing the percentage of the total Mg in a source which will solubilize is only part of the consideration in knowing the nutritional value of a supplemental source. The total Mg content of a particular source should 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 might aid in making informed purchasing decisions. Table 4 shows the percentage total soluble Mg and relative ranking on that basis of the supplemental sources evaluated in our *in vitro* system.

Among the MgO sources FeedOx-U.S.A. and MagOx-U.S.A. had the highest percentage of total soluble Mg, about 40%. MagFeed-Greek and SuperMag-Greek had the lowest soluble Mg, 21.7 and 19.7%, respectively (Table 4). Therefore, on this basis some sources ranked about twice as high as other sources. The other MgO sources studied, Chinese pink, CoMag-Turkish, BayMag58-Canada, and Magal-Spanish, had relative rankings of 0.81, 0.79, 0.68, 0.63, compared with FeedOx-U.S.A. (Table 4).

The other three supplements in our studies, MgP-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 2 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 Ca, P, Na, K, S 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.

Subsequent to the laboratory evaluation, a lactational performance experiment was conducted using four of the MgO sources: MagFeed-Greek (19.7% total soluble Mg), Magal-Spanish (25.1% total soluble Mg), BayMag58-Canadian (27.4%

total soluble Mg) and MagOx-U.A.S. (39.8% total soluble Mg) to test whether the solubility of Mg *in vitro* affected lactational performance. These results are reported subsequently in this paper (Florida Experiment 3).

REQUIREMENTS AND DIETARY ALLOWANCES OF Mg

ARC (1980) made the most quantitative attempt to establish the dietary requirement for Mg (Table 5). The factorial method was used where net requirements were calculated for inevitable minimum endogenous loss (E), body growth (G), pregnancy (P), and lactation (L). This total net requirement was then adjusted depending on the coefficient of absorption (A). Obviously, the estimate [E + G + P + L)/A] is only as reliable as the accuracy of each of the factors used to obtain the estimate. Conceptually sound, the method however is plagued with technical problems associated particularly with estimation of endogenous losses (E) and the coefficient of absorption (A). The overall mean absorption coefficient of .294 was proposed to estimate the minimum requirement and .17 was recommended to allow for safety margin (ARC, 1980). Additionally, values for the coefficient of absorption have been derived primarily for Mg in natural diets, and do not necessarily apply to Mg supplemented in salt forms. ARC (1980) notes that prediction of the coefficient of absorption is ultimately an uncertain procedure due to wide variation in estimates for different classes of animals and feedstuffs. Also, estimates of needs for productive functions may not necessarily take into account differing rates of turnover of Mg in the specific body tissues (e.g., mammary gland) related to those functions (e.g. milk production). These effects also may influence daily requirements.

Feeding graded concentrations of Mg from one or various sources and measuring some specific biological response is another approach to estimating requirements and/or recommendations for particular productive functions. For example, plasma or serum concentrations have been used as an index of Mg status because about 60 to 80% of Mg in serum or plasma exists in the ionized state and is available for tissue assimilation (Wilson, 1964). Thus, under conditions of potential grass tetany low plasma or serum Mg may suggest deficiency. Magnesium in excess of requirements is excreted primarily in urine and the renal threshold may be reached at a Mg content in serum of 1.8 to 2.0 mg/100ml. Thus, 2.0 mg/100ml serum Mg is considered the lower limit below which tetany may be a problem. ARC (1980) summarizing results of five experiments found 2.0 mg/100ml serum Mg adequate and consistent with the proposed minimum requirement. However, this relationship of minimum plasma or serum Mg concentration with prevention of tetany may not hold if the biological response of interest is something different (e.g., daily milk yield).

NRC (1989) suggested that the Mg requirement for lactating dairy cows is .2% to .25% of the daily dietary DM consumption (Table 5). This empirical value more accurately represents a recommended allowance with a built-in safety margin taking into account differences in availability of Mg inherent in feedstuffs. The higher value is recommended for early lactation and higher yielding cows.

The conventional concept of Mg nutrition of the lactating cow has been to provide minimum dietary requirements to minimize or eliminate health problems and sustain normal productivity. However, the key role of Mg-requiring enzymes in phosphate transfer reactions and protein, lipid and carbohydrate metabolism suggests provision above minimum requirements may enhance productivity. Additionally, Mg mobilization in older animals is limited (NRC, 1989).

The traditional factorial-type concept in macromineral nutrition basically implies that these nutrients (at or above minimum requirement) cannot be or are not capable of being dietary agents to enhance productivity. With other macrominerals (Bell, 1984; Schneider et al., 1986; Beede et al., 1983) this basic premise appears to be challenged. Some macrominerals may have only a momentary role in enhancing digestion and metabolism, but then are excreted. Their quantities, as daily dietary supplements, would be in excess of those needed as determined by net balance and efficiency of absorption estimates (factorial method). Several more recent studies with lactating dairy cattle suggest the need for Mg supplementation above minimum recommendations in certain situations.

Kentucky Experiment. Teh et al. (1985) conducted an experiment with 36 early-lactation Holstein cows to evaluate optimum dietary MgO addition and to examine its interaction with $NaHCO_3$. Additionally, the report provided information about lactational responses to Mg allowances above minimum requirements (ARC, 1980; NRC, 1989). Basal diet was 50% corn silage and 50% concentrate, dry basis, to which 0, .4, or .8% MgO and 0 or .8% $NaHCO_3$ were added. The MgO used in the experiment had a particle size distribution of: 2.6% greater than 20 mesh; 48.6% 20 to 100 mesh; and 50.3%, less than 100 mesh (MagOx, Basic Chemical Co., Cleveland, OH). Magnesium contents of the diets were .22, .44 and .56% of the diet DM. Actual daily milk production (uncorrected for fat content) pooled across $NaHCO_3$ treatments was 9.8% greater with .4% MgO (.44% total dietary Mg) compared with 0 or .8% MgO. No differences in milk fat percentage or ruminal acetate-to-propionate ratio were detected when MgO was added without $NaHCO_3$, but with $NaHCO_3$ plus MgO acetate-to propionate ratio was increased. The basal diet apparently was not fat-depressing (average milk fat content 3.64%). One interpretation of results of this experiment could be that the major effect of MgO on lactational performance was to supply additional Mg above current recommendations (NRC, 1989; ARC, 1980) needed to maximize lactational response. Dry matter intake (ranging from 3.17 to 3.35% of BW) was not affected by .4 or .8% compared with 0% added MgO.

Florida Experiment 1 (O'Connor et al., 1988). Pursuant to the report of Teh et al. (1985) and with the suggestion that provision of dietary Mg above currently held requirements and recommendations (ARC, 1980; NRC, 1989) might enhance lactational performance of dairy cows an experiment was conducted using MgP. Feed grade MgP was selected to provide supplemental Mg because we were interested in evaluating the optimum allowance of dietary Mg *per se*. An *in vitro* experiment in our laboratory suggested that feed grade MgP was not as effective as MgO for resisting pH change with sequential additions of .1N sulfuric acid in ruminal fluid. It was reasoned that MgP instead of MgO would decrease the possibility of potential "buffering or alkalizing action" suggested for MgO (Emery, 1983). Requirement and allowance of the nutrient Mg, could be considered separately from effects (e.g. alkalizing action) the salt forms might possess.

Forty-eight midlactation Holstein cows were assigned in an incomplete randomized block design to one of 16 dietary treatments arranged in a 4 x 2 x 2 factorial. Variable dietary factors (as a percentage of total diet DM) included: 1) Mg = .26, .38, .48 and .60%, 2) Na = .24 and .62%, and 3) K = 1.14 and 1.59%. Each cow received a different dietary treatment in each of three 35-day experimental periods. Each treatment was fed to three different cows in each period yielding a total of nine different cows in the entire experiment. No dietary treatment followed another treatment in a subsequent period more than once in the whole experiment.

The total mixed diet was 50% corn silage and 50% concentrate, dry basis. All 16 dietary treatments were composed primarily of this basal diet, varying only slightly by replacing appropriate amounts of ground corn by mineral salts (MgP, NaCl, and $KHCO_3$) to create varying concentrations of Mg, Na and K. Phosphorus and Ca contents were equalized among all treatments by additions of dicalcium phosphate and calcium carbonate as needed. Phosphorus content averaged .62 $\pm$ .01% indicating virtually no difference in P content among the 16 treatments even when MgP was added. Hemingway (1985a) reported no difference in the availability of P from MgP or dicalcium phosphate when fed to sheep. Thus, varying dietary P contents or P availabilities were not factors in interpretation of responses to varying Mg concentrations in our experiment.

Table 6 presents the main effects of varying dietary mineral concentrations on feed DM intake, lactational performance and milk composition. Responses are listed relative to analyzed mineral concentrations of the diets (expressed as percentage of diet DM and grams of mineral intake per cow per day). There were no effects of dietary Na or K on these dependent variables.

There was a linear effect ($P<.02$) of increasing dietary Mg on daily DM intake; a curvilinear effect was noted also ($P<.06$) (Table 6). Least-square means for DM intake were equal (54.2 lb/d) at .26, .38 and .48% Mg in the diet DM; however, intake decreased 4.9% (51.5 lb/d) as total dietary Mg increased to .6%. Actual daily milk yields (unadjusted for fat content) were affected in a curvilinear fashion with increasing dietary Mg. Actual yield increased linearly (55.1, 56.2 and 57.7 lb/d) as Mg content increased from .26 to .38 to .48% of the diet DM and then declined to 55.1 lb/d at .6% Mg.

There were no influences of dietary mineral concentrations on milk fat percentage. Average milk fat percentage for the total experiment was about 3.6% suggesting no milk-fat depression with the basal diet. Milk protein percentage decreased slightly with increasing dietary Mg (linear effect, $P<.03$). On a 4% fat-corrected basis, milk yield response was curvilinear (Table 6, $P<.003$). With .26% Mg, fat-corrected yield was 50.6 lb/d and increased to 52.4 and 54.2 lb/day with

.38 and .48% Mg and then declined to 51.5 lb/d with .60% total dietary Mg. There was a 3.6 lb or 7% increase in fat-corrected milk yield as Mg increased from .26 to .48% Mg. Current NRC (1989) requirement for Mg is .2%. Dietary Mg increased ($P<.01$) blood plasma Mg concentrations (2.52, 2.44, 2.57 and 2.68 mg/100 ml) with .26, .38, .48 and .60% Mg, respectively.

Florida Experiment 2 (Lough et al., 1990). In this study 36 midlactation Holstein cows were used in a randomized incomplete block design to evaluate varying Mg supplemented from one of two sources, MgO (Magal, Magnesitas de Rubian, S. A., Madrid, Spain) and a magnesium proteinate (MgPr) (Albion Laboratories, Inc., Clearfield, UT) which contained Mg which had been proteinated with soy protein isolate. The MgO was added to the basal diet (.21% Mg) to provide .32%, .37% and .43% total dietary Mg. The MgPr was added to the basal diet to provide .23%, .25% and .27% Mg. Dietary Mg concentrations were formulated based on known or assumed availability estimates for MgO (35% availability, Hemingway, 1985a) and MgPr (95% availability, as indicated by the supplier). Therefore, bioavailable Mg at three graded concentrations from each source was formulated to be equivalent. Cows were fed a total mixed ration with 41:4:55 corn silage:cottonseed hulls:concentrate. Daily DMI was greater ($P < .05$) for cows fed MgO-diets than MgPr-containing diets (54.6 vs. 52.9 lb). Similarly, daily milk production was greater ($P < .06$) with MgO- vs. MgPr-containing diets (57.1 vs. 55.3 lb, Table 7). No changes in milk fat percentage due to treatments were detected; average milk fat percentage pooled across treatments was 3.45%. Milk fat yield was greater ($P < .05$) with MgO than with MgPr (1.98 vs. 1.90 lb/d), largely due to higher daily milk yield. Milk protein percentages increased with MgPr supplementation compared with MgO. No dose response related effects on milk yield occurred within Mg source, in contrast to O'Connor et al. (1988). Of both supplemental sources and all graded concentrations, .32% total dietary Mg from MgO consistently resulted in greater numerical increases in DMI, milk yield, fat percentage, fat yield, 4% FCM yield, protein percentage, and milk protein yield than any other treatment; however the differences were not large. Lack of a response to MgPr suggested that either the availability was not as high as suggested by the manufacturer or that sufficient total bioavailable Mg was not provided to result in a lactational response.

Florida Experiment 3. Based on the Mg solubility results from the ruminal + abomasal *in vitro* system (described previously in this paper) a lactation experiment was designed utilizing 86 midlactation Holstein cows in a randomized incomplete block design. The total mixed basal diet was composed of about 32% corn silage, 13% alfalfa hay and 55% concentrate, dry basis. To the basal diet (Control, .21% Mg), four of the MgO sources: MagFeed-Greek (21.7% total soluble Mg - *in vitro* system), Magal-Spanish (25.1% total soluble Mg - in vitro system), BayMag58-Canadian (27.4% total soluble Mg - in vitro system) and MagOx-U.S.A. (39.8% total soluble Mg - in vitro system) were each supplemented to yield concentrations of .27,% .35% and .46% total dietary Mg (4 x 3 factorial). Particle size distributions of MgO sources used in the lactation study are shown in Figure 1. Considering source effects, daily DMI was higher with MagFeed-Greek vs. Magal-Spanish, BayMag58-Canadian and MagOx-U.S.A. ($P < .02$) and DMI was greater with Magal-Spanish vs. BayMag58-Canadian and MagOx-U.S.A ($P < .08$) as determined by orthogonal contrasts (Table 8, 9). Milk yield was greater with MagFeed-Greek vs. Magal-Spanish, BayMag58-Canadian and MagOx-U.S.A. ($P < .12$). Milk fat percentage was lower for Control than supplementation of Mg from all of the sources($P < .05$).

Daily DMI decreased linearly ($P < .001$) as supplemental Mg increased from .21% (Control) to .46% total Mg (pooled across sources) with the two highest concentrations having the most depressing effects (Table 9). Overall, there was a linear increase in 3.5% FCM yield as total dietary Mg increased from .21% to .46% of the diet DM. These results do not support the hypothesis that varying degrees of *in vitro* Mg solubility affect the availability of Mg to the lactating dairy cow because the least soluble source (MagFeed-Greek) resulted in the highest DMI and FCM yield. However, Mg supplementation (pooled across supplemental sources) above the current NRC (1989) recommendation(.20%) did result in a linear increase in FCM yield.

One possible explanation for the results of our recent experiment is offered from results of Noller et al. (1986). In a series of trials the dissolution of MgO and Mg balance of ruminally-fistulated Angus steers were determined. Considerable retention of MgO occurred within the rumen over time. Total ruminal contents were collected and the amount of Mg was analyzed; all Mg was assumed to be from MgO. When no supplemental MgO was fed 15 g of MgO were recovered. In two trials when 300 g of coarse MgO were fed each day for 7 d, 43% and 45% of the total MgO from the 7 d period were recovered from the rumen on d 8. When 150 g of fine MgO were fed daily for 7 d, 30% of the total fed was collected from the rumen on d 8. An additional trial showed that 25% of MgO fed over a 19-d period was still in the rumen 9 d after cessation of MgO supplementation. These results indicate that the residence time of MgO in the rumen, and perhaps the rest of the digestive tract, is considerably longer than that of much of the solid phase digesta. It may be that the Mg from MagFeed-Greek (with the lowest Mg solubility in our *in vitro* system) resided in the rumen for a long period of time and eventually was released, contributing available Mg. Thus, for example, if Mg in MagFeed-Greek was potentially soluble, given enough time, adequate Mg ultimately was released and supplied to cows at a steady rate. Blood plasma Mg concentrations from samples collected on d 30 of each period did not differ among MgO sources indicating that each source provided adequate Mg to maintain blood Mg (Table 11). Supplementing MgO above control (.21% Mg) did increase plasma Mg concentrations ($P < .07$).

Least squares means of plasma macromineral concentrations from blood samples taken from each cow on the last day of each experimental period are shown in Tables 10 and 11. Plasma Mg concentrations were lower for cows fed control compared with those supplemented with one of the MgO sources ($P < 07$). There was tendency for a linear increase in plasma Mg as dietary concentration of Mg increased ($P < .13$). Plasma concentrations of Na ($P < .01$) and K ($P < .03$) were higher for cows fed BayMag58-Canadian than MagOx-U.S.A. pooled across supplementation concentrations. Plasma P concentrations responded in a curvilinear fashion to increasing total dietary Mg; P was highest with .27% total dietary Mg.

Discussion. Results of Teh et al. (1985), O'Connor et al. (1988), Lough et al. (1990) and Florida Experiment 3 showed positive production responses to supplemental Mg above currently suggested requirements and recommendations for lactating dairy cows (NRC, 1989; ARC, 1980). In another study (Bremel et al., 1985) Mg was supplied as MgO or $MgSO_4$ at .2, .3, .4 and .5% of the total mixed diet, dry basis. Dry matter consumption was greater with .2, .3, and .4% Mg from MgO than with .5% Mg from MgO or .3 or .5% Mg from $MgSO_4$. Cows fed .4 and .5% Mg from $MgSO_4$ had lower milk yields than cows fed .2% Mg. These results suggest that using $MgSO_4$ to supply added Mg for .4 and .5% total dietary Mg may affect DM intake and milk yield deleteriously. Probably the acidogenicity of and high sulfate from $MgSO_4$ caused reduced performance with .4 and .5% Mg treatments (Wang and Beede, 1992).

Further testing will be required to establish if supplying Mg from other Mg sources at the optimum allowances found in the Kentucky and Florida studies will be equally efficacious for milk yield and production efficiency. Relative difference in availability of various supplemental Mg sources (Wilson, 1981), potential palatability problems at relatively high levels of supplementation (e.g. about 1% MgO if .48% Mg is to be supplied in diets similar to the basal diet used in these experiments) and potential toxicity with the anion associated with Mg in specific Mg salts (e.g. $MgSO_4$) will require additional study before sound practical allowances can be set.

REFERENCES

Agricultural Research Council. 1980 (reprinted 1984). Nutrient Requirements of Ruminant Animals. Commonwealth Agricultural Bureaux, London.

Beede, D.K., E.M. Hirchert, D.S. Lough, W.K. Sanchez and C. Wang. 1989. Solubility of magnesium from feed grade sources in an *in vitro* ruminal + abomasal system. *In:* Proc. 26th FL Dairy Production Conference. p. 47.

Beede, D.K., P.G. Mallonee, P.L. Schneider, R.K. Braun, R.J. Collier, A.P. Graden, M.H. Ruiloba and C.J. Wilcox. 1983. Potassium and sodium concentrations in diets for lactating dairy cattle. J. Dairy Sci. 66 (Suppl. 1):160.

Bell, F.R. 1984. Neuroendocrine control of ingestive behavior in cattle. Can. J. Anim. 64 (Suppl. 1):326.

Bremel, D.H., R.W. Hemken, R.J. Harmon and J.A. Jackson, Jr. 1985. Dietary addition of magnesium in different concentrations and forms to dairy cows in early lactation. J. Dairy Sci. 68 (Suppl. 1):138.

Emery, R.S. 1983. Importance of magnesium in maintaining milk fat. In: role of Magnesium in Animal Nutrition, J.P. Fontenot, G.E. Bruce, K.E. Webb, Jr. and V.G. Allen (Eds.) John Lee Pratt Nutrition Program, VPI, Blacksburg, VA.

Erdman, R.A., R.W. Hemken, and L.S. Bull. 1982. Dietary sodium bicarbonate and magnesium oxide for early postpartum lactating dairy cows: Effects on production, acid-base metabolism and digestion. J. Dairy Sci. 65:712.

Erdman, R.A., R.L. Botts, R.W. Hemken, and L.S. Bull. 1980. Effects of dietary sodium bicarbonate and magnesium oxide on production and physiology in early lactation. J. Dairy Sci. 63:923.

Hemingway, R.G. 1985a. The evaluation of magnesium phosphates and oxides as dietary supplements for ruminants. Proc. Boliden Kemi AB Symposium on Magnesium in Ruminant Nutrition, Helsingborg, Sweden.

Hemingway, R.G. 1985b. A comparative assessment of the dietary availability to sheep of magnesium in calcined magnesites and magnesium phosphates. Supplement in Proc. Boliden Kemi AB Symposium on Magnesium in Ruminant Nutrition, Helsingborg, Sweden.

Henry, P.R., D.P. Ledoux, R.O. Van Ravenswaay and C.B. Ammerman. 1986. Bioavailability of magnesium sources for sheep. Amer. Soc. Anim. Sci. So. Sec., Feb 2-5, Orlando, FL. p. 75 (Abstr.)

Jesse, B.W., J.W. Thomas, and R.S. Emery. 1981. Availability of magnesium oxide particles of different sizes and surfaces. J. Dairy Sci. 64:197.

National Research Council. 1989. Nutrient requirements of dairy cattle. 6th rev. ed., Nat'l Acad. Sci. Washington, DC.

Noller, C.H., L.J. Wheeler, and J.A. Patterson. 1986. Retention of supplemental magnesium oxide in the rumen and implication in balance studies. J. Anim. Sci. (Suppl. 1):405.

O'Connor, A.M., D. K. Beede, and C. J. Wilcox. 1988. Lactational response to dietary magnesium, potassium, and sodium during winter in Florida. J. Dairy Sci. 71:971.

Schneider, P.L., D.K. Beede and C.J. Wilcox. 1986. Responses of lactating cows to dietary sodium source and quantity and potassium quantity during heat stress. J. Dairy Sci. 69:99.

Teh, T.H., R.W. Hemken, and R.J. Harmon. 1985. Dietary magnesium oxide interactions with sodium bicarbonate in early lactation. J. Dairy Sci. 68:881.

Wang, C. and D. K. Beede. 1992. Effect of diet magnesium on acid-base status and calcium metabolism of dry cows fed acidogenic salts. J. Dairy Sci. 75:829.

Wilson, A.A. 1964. II. Hypomagnesemia and magnesium metabolism. The Veterinary Record 76:1382.

Wilson, C.L. 1981. Magnesium supplementation of ruminant diets. Ph.D. Thesis. Univ. Glasgow, Scotland.

TABLE 1. SUMMARY OF EXPERIMENTS WITH MAGNESIUM OXIDE FED TO LACTATING COWS

Source	MgO	Milk Yield (lb/d)	Fat (%)	Fat yield (lb/d)
1. Thomas & Emery (1969)	a) Control	37.7	2.82	1.06
	b) 1.0-1.35% MgO in concentrate mix[a]	33.3	3.31*	1.03
2. Erdman et al., (1980)	a) Control (.15%Mg)	76.0	3.80	2.73
	b).8% MgO in diet dry matter (.61%Mg)	76.9	3.62	2.69
3. Jesse et al., (1981)	a) Control	47.4	2.19	1.03
	b) .8% MgO in concentrate	45.8	2.78*	1.23*
	mix (varying MgO particle size)	46.0	2.78*	1.28*
		45.4	2.95*	1.30*
4. Erdman et al., (1982)	a) Control (.24% Mg)	76.2	3.26	2.38
	b) .8% MgO (.67% Mg)	77.5	3.96*	3.02*
5. Thomas et al., (1984)	a) Control	54.0	2.50	1.34
	b) .5% MgO (as fed) (18% Mg)[b]	48.9	3.02*	1.48
	.5% MgO (as fed) (.6% Mg)[c]	55.1	2.75*	1.52
	.5% MgO (as fed) (.84% Mg)[d]	50.4	2.94*	1.48
6. Teh et al (1985)	a) Control (.22%Mg)	77.5	3.60	2.80
	b) .4% MgO (.45%Mg)	84.4	3.63	3.06
	c) .8% MgO (.56%Mg)	76.7	3.71	2.84

[a] Calculated from information given in Thomas and Emery (1969).
[b] Ground form
[c] Prilled form
[d] Fine powder form
* Signifies difference from control within experiment ($P<.05$).

TABLE 2. DESCRIPTION OF SUPPLEMENTAL Mg 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 Bch, FL 33444	53.0
4.	MagOx-U.S.A. Basic Chemicals combustion Engineering, Inc. 7887 Hub Pkwy 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 T2I 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 Magnesitas de Rubian Montalban N.3 Madrid 14, Spain	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 3. PERCENTAGE OF TOTAL Mg IN SUPPLEMENTAL SOURCE SOLUBILIZED IN *IN VITRO* RUMINAL + ABOMASAL SYSTEM, AND RELATIVE Mg SOLUBILITY.

Source	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
Mg Phosphate-Swedish	11.2	69.8	81.0	1.37
Rumen-Mate-U.S.A.	27.9	47.3	75.2	1.27
Feedox-U.S.A.	20.4	53.9	74.3	1.26
MagOx-U.S.A.	22.6	51.1	73.7	1.25
Chinese	11.4	48.2	59.9	1.01
CoMag-Turkish	14.6	45.1	59.7	1.01
Min-Ad-U.S.A.	1.4	50.8	52.2	0.88
Magal-Spanish	14.5	33.8	48.3	0.82
BayMag58-Canadian	14.2	33.2	47.2	0.80
MagFeed-Greek	7.6	33.4	41.0	0.69
SuperMag-Greek	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 4. RELATIVE RANKING BY TOTAL SOLUBLE Mg IN SOURCES TESTED. TOTAL SOLUBLE Mg IN SOURCE = Mg CONCENTRATION OF SOURCE X SOLUBILITY OF Mg OF SOURCE IN RUMINAL + ABOMASAL SYSTEM.

Source	% Total Mg of Source	X	% Soluble Mg in Source	% Total Soluble Mg of Source[a]	Relative Ranking[b]
FeedOx-U.S.A.	54.0		.743	40.1	1.00
MagOx-U.S.A.	54.0		.737	39.8	.99
Chinese	54.0		.599	32.3	.81
CoMag-Turkish	53.0		.597	31.6	.79
BayMag58-Canadian	58.0		.172	27.4	.68
Magal-Spanish	52.0		.483	25.1	.63
MagFeed-Greek	53.0		.410	21.7	.54
SuperMag-Greek	53.0		.372	19.7	.49
Mg Phosphate-Swedish	24.0		.810	19.4	.48
Rumen-Mate-U.S.A.	16.6		.752	12.5	.31
Min-Ad-U.S.A.	14.0		.522	7.3	.18

[a] Percentage total soluble Mg of whole weight of source.
[b] Relative ranking compared with the source (FeedOx-U.S.A.) containing the largest quantity of soluble magnesium as determined by the ruminal + abomasal evaluation system.

TABLE 5. SUMMARY OF PUBLISHED DIETARY MAGNESIUM REQUIREMENTS AND RECOMMENDATIONS (ALLOWANCES) FOR LACTATING DAIRY COWS

Source	Breed/Production Level/Body Weight		Requirement (g/day)	Recommendation (g/day)	%[a]
1. ARC (1980)	Jersey	22 lb milk/day	8.3	14.4	
		44	12.6	21.8	
		66	16.8	29.1	
	Ayrshire	22	9.4	16.2	
		44	13.6	23.5	
		66	17.9	30.9	
		88	22.1	38.2	
	Friesian	22	10.4	17.9	
		44	14.6	25.3	
		66	18.9	32.6	
		88	23.1	40.0	
2. NRC (1989)	900 to 1700 lb BW; 14 to 86 lb milk/ day				.2
	900 to 1700 lb BW; 58 to 143 lb milk/day				.25

[a] As a percentage of diet DM.
[b] Calculated from estimated DM intake of 44 and 55 lb/day for 44 and 66 lb/day milk yield, respectively.

TABLE 6. PERFORMANCE AND MILK COMPOSITION RESPONSES TO VARYING DIETARY MINERAL CONCENTRATIONS (O'Connor, et al., 1988)

Item	Magnesium				Sodium		Potassium	
As percent of diet	.26	.38	.48	.60	.24	.62	1.14	1.59
Variable mineral intake, g/d	64	93	118	140	59	149	277	382
Dry matter intake, lb/d[a]	54.2	54.2	54.2	51.5	53.7	53.1	53.5	52.9
Actual milk yield, lb/d[b,c]	55.1	56.2	57.7	55.1	56.2	55.9	56.2	55.9
Milk fat, %	3.57	3.57	3.61	3.59	3.61	3.56	3.58	3.59
4% FCM yield, lb/d[d]	50.6	52.4	54.2	51.5	52.4	52.0	52.2	52.0
Milk protein, %[e]	3.31	3.30	3.28	3.27	3.29	3.27	3.28	3.27

(Variables: Magnesium, Sodium, Potassium)

[a] *Linear Mg effect (P<.02); curvilinear effect (P<.06).*
[b] Not adjusted to equal fat content.
[c] Curvilinear Mg effect (P<.001).
[d] Curvilinear Mg effect (P<.003).
[e] Linear Mg effect (P<.03).

TABLE 7. MAGNESIUM OXIDE AND Mg PROTEINATE: LEAST SQUARES MEANS OF LACTATIONAL PERFORMANCE AND MILK COMPOSITION (Lough et al., 1990).

Source	Control	MgO - Supplemental			Mg Pr - Supplemented		
% Mg[a]	.21	.32	.37	.43	.23	.25	.27
Item							
DMI[b,1]	52.4	55.5	54.0	54.2	52.2	52.6	53.7
MY[b,2]	54.2	57.3	56.8	56.8	55.7	54.4	55.9
Fat, %	3.46	3.48	3.48	3.41	3.41	3.45	3.45
Fat yield[b]	1.87	2.00	1.98	1.94	1.89	1.87	1.92
4% FCMY[b]	49.6	52.9	52.4	51.8	50.7	49.8	51.1
Protein, %[3]	3.35	3.35	3.33	3.31	3.39	3.43	3.37
Protein yield[b,4]	1.81	1.92	1.89	1.87	1.87	1.85	1.87

[a] % Mg = percent in total ration DM.
[b] DMI = dry matter intake (lb/d); MY = milk yield, unadjusted for fat percentage (lb/d); Fat yield (lb/d); 4% FCMY = 4.0% fat-corrected milk yield (lb/d); Protein yield (lb/d).
[1] Pooled MgO-supplemented vs. pooled MgPr-supplemented ($P<.05$).
[2] Pooled MgO-supplemented vs. pooled MgPr-supplemented ($P<.06$).
[3] Quadratic Mg Pr effect ($P<.09$).
[4] Control vs. pooled MgO, MgPr ($P<.09$).

TABLE 8. MAGNESIUM OXIDE SOURCE BY TOTAL DIETARY Mg CONCENTRATION: LEAST-SQUARES MEANS OF LACTATIONAL PERFORMANCE AND MILK COMPOSITION. (Davalos et al., 1992).

Source	Control	MagFeed-Greek			Magal-Spanish			BayMag58-Canadian			MagOx-U.S.A.		
% Mg[a]	.21	.27	.35	.46	.27	.35	.46	.27	.35	.46	.27	.35	.46
Item													
DMI[b]	48.5	49.8	48.5	47.8	48.9	48.5	46.7	48.5	46.5	46.0	47.6	45.8	46.5
MY[b]	54.8	55.7	56.8	56.4	56.2	55.3	52.0	56.4	54.6	54.6	55.1	54.0	55.9
FCMY[b]	54.6	56.8	57.7	56.4	58.4	56.6	54.6	57.9	56.6	55.3	57.0	55.3	56.2
Fat %	3.50	3.65	3.63	3.56	3.78	3.64	3.77	3.70	3.77	3.62	3.73	3.68	3.54
Protein %	3.39	3.42	3.35	3.34	3.34	3.64	3.39	3.39	3.36	3.36	3.38	3.34	3.32

[a] % Mg = percent total Mg in total ration DM.
[b] DMI = dry matter intake (lb/d); MY = milk yield, unadjusted for fat percentage (lb/d); FCMY = 3.5% fat-corrected milk yield (lb/d).

TABLE 9. POOLED EFFECTS OF (1) MAGNESIUM OXIDE SOURCE AND (2) TOTAL DIETARY Mg CONCENTRATION ON LACTATIONAL PERFORMANCE AND MILK COMPOSITION OF MIDLACTATION HOLSTEIN COWS (Davalos et al., 1992)[a].

(1) Source effects:

	Control	MagFeed Greek	Magal Spanish	BayMag58 Canadian	MagOx U.S.A.
DMI[b,1]	48.5	48.7	48.0	47.1	46.7
MY[b,2]	54.8	56.2	54.6	55.3	55.1
FCMY[b]	54.6	57.0	56.6	56.6	56.2
Fat %[3]	3.50	3.61	3.73	3.70	3.65
Protein %	3.39	3.37	3.36	3.37	3.35

(2) Mg concentration (% of diet DM) effects:

	.21 (Control)	.27	.35	.46
DMI[b,4]	48.5	48.7	47.4	46.9
MY[b]	54.8	55.7	55.3	54.6
FCMY[b,5]	54.6	57.5	56.6	55.5
Fat %	3.50	3.72	3.68	3.62
Protein %	3.39	3.38	3.35	3.35

[a] Main effects (1) pooled by supplemental sources across dietary Mg concentrations and (2) pooled by dietary Mg concentration across supplemental sources

[b] DMI = dry matter intake (lb/d); MY = milk yield, unadjusted for fat percent (lb/d); FCMY = 3.5% fat-corrected milk yield (lb/d).

[1] MagFeed-Greek vs. Magal-Spanish, BayMag58-Canadian, MagOx-U.S.A. ($P < .02$); Magal-Spanish vs. BayMag58-Canadian, MagOx-U.S.A. ($P < .08$).

[2] MagFeed-Greek vs. Magal-Spanish, BayMag58-Canadian, MagOx-U.S.A. ($P < .12$)

[3] Control vs. Greek, Spanish, Canadian, U.S.A. ($P < .05$)

[4] Linear effect considering control and all supplemental Mg concentrations ($P < .001$).

[5] Linear effect considering control and all supplemental Mg concentrations ($P < .03$).

TABLE 10. MAGNESIUM OXIDE SOURCE BY TOTAL DIETARY Mg CONCENTRATION: LEAST-SQUARES MEANS OF BLOOD PLASMA MACROMINERAL CONCENTRATIONS (mg/ 100 ml) OF MIDLACTATION HOLSTEIN COWS.

Source	Control	MagFeed-Greek			Magal-Spanish			BayMag58-Canadian			MagOx-U.S.A.		
% Mg[a]	.21	.27	.35	.46	.27	.35	.46	.27	.35	.46	.27	.35	.46
Item													
Mg	2.17	2.24	2.22	2.25	2.20	2.25	2.30	2.28	2.20	2.27	2.23	2.29	2.33
Ca	9.75	9.51	9.72	9.62	9.84	9.62	9.64	9.58	9.52	9.72	9.76	9.65	9.54
Na	326.4	328.3	326.2	324.4	323.8	323.7	322.9	329.0	328.2	328.2	323.7	323.3	321.9
K	23.5	23.2	23.1	23.4	23.2	23.4	22.6	23.6	23.0	24.6	22.8	23.2	22.6
P	4.88	5.08	4.62	4.97	5.03	4.96	4.96	5.23	4.61	4.84	5.05	4.75	4.83
Cl	315.7	315.8	314.2	311.4	312.7	309.2	313.9	310.8	309.8	313.5	311.3	311.7	309.0

[a] % Mg = percent total Mg in total ration DM.

TABLE 11. POOLED EFFECTS OF (1) MAGNESIUM OXIDE SOURCE AND (2) TOTAL DIETARY Mg CONCENTRATION ON BLOOD PLASMA MACROMINERAL CONCENTRATIONS (mg/ 100 ml) OF MIDLACTATION HOLSTEIN COWS.

(1) Source effects:

	Control	MagFeed Greek	Magal Spanish	BayMag58 Canadian	MagOx U.S.A.
Mg[1]	2.17	2.24	2.25	2.25	2.28
Ca	9.75	9.61	9.70	9.61	9.65
Na[2]	326.4	326.3	323.5	328.5	323.0
K[3]	23.5	23.3	23.1	23.7	22.9
P	4.88	4.89	4.99	4.89	4.88
Cl	315.7	313.8	311.9	311.4	310.7

(2) Mg concentration (% of diet DM) effects:

	.21 (Control)	.27	.35	.46
Mg[4]	2.17	2.24	2.24	2.29
Ca	9.75	9.67	9.63	9.63
Na	326.4	326.2	325.4	324.3
K	23.5	23.2	23.2	23.3
P[5]	4.88	5.10	4.73	4.90
Cl	315.7	312.7	311.2	312.0

[a] Main effects (1) pooled by supplemental sources across dietary Mg concentrations and (2) pooled by dietary Mg concentration across supplemental sources.
[1] Control lower than the average of treatments with supplemental MgO ($P < .07$).
[2] BayMag58-Canadian vs. MagOx-U.S.A. ($P < .01$).
[3] BayMag58-Canadian vs. MagOx-U.S.A. ($P < .03$).
[4] Linear effect ($P < .13$).
[5] Quadratic effect ($P < .05$).

Figure 1. Particle size distribution of MagFeed-Greek, BayMag58-Canadian, Magal-Spanish and MagOx-U.S.A. sources used in the lactational performance experiment.