EFFECT OF DIETARY CALCIUM AND PHOSPHORUS LEVELS ON MAGNESIUM UTILIZATION IN SHEEP

by

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INTRODUCTION

Hypomagnesemic tetany, also known as grass tetany, grass staggers, wheat pasture poisioning and lactation tetany, occurs frequently in cattle and sheep. It is responsible for large economic losses to the livestock producer. The metabolic disturbance occurs most frequently in older beef cows nursing calves less than 60 days of age, but it has been reported in cows in late stages of gestation. The disease affects ewes in early lactation, with those nursing twin lambs being more susceptible. The main symptoms of hypomagnesemic tetany are subnormal blood serum magnesium; incordination; undue excitement; twitching and tetanic contractions of muscles; a fast, pounding heart beat; convulsions; and death.

Several factors may be predisposing to the occurence of grass tetany. An insufficient intake of magnesium and impaired availability of magnesium, particularly during times of relatively high requirements, have been suggested by a number of researchers. Since only a small amount of magnesium is stored in the body, serum magnesium levels quite rapidly reflect intake or alimentary absorption. Adequate daily intake and absorption of magnesium are required for continuous protection.

Suggestions have been made that supplemental calcium and/or phosphorus may be used as an aid in the prevention of grass tetany. Researchers, using small laboratory animals, have found that high levels of dietary calcium and/or phosphorus appear to be detrimental to magnesium absorption and utilization, especially when accompanying marginal to low dietary magnesium. No metabolism study has been conducted in which very high dietary levels of either calcium or phosphorus, or both were fed to ruminants.

The investigation reported here was designed to study the relative effects of different dietary levels of calcium and phosphorus alone and in combination, on magnesium utilization in sheep, in an attempt to ascertain the magnitude of involvement of these two elements, especially as related to hypomagnesemic tetany.

REVIEW OF LITERATURE

Magnesium Metabolism

Rook and Storry (1962) and Maynard and Loosli (1969) reported that the animal body contains about 0.05% by weight of magnesium, with nearly 60% of the element in the skeleton, 40% in the cells of the soft tissue and only about 1% in the extracellular fluids. Wilson (1964) reported that the magnesium in the extracellular fluid exists either as free ions or is bound to the albumin fraction of serum protein. The ability to mobilize magnesium in the bone decreases with increasing age (Hemingway *et al.*, 1963).

Field (1960), using ^{28}magnesium to study the relationship between blood and bone magnesium in a sheep, reported that the largest exchange of magnesium occurred at the sternal end of the ribs and the epiphysis of the femur.

The concentration of magnesium in plasma or serum for reputedly normal cattle, sheep and goats ranges from about 1.2 to 3.8 mg per 100 ml (Rook and Storry, 1962). Wilson (1964) reported that the majority of healthy animals have plasma or serum concentrations between 1.7 to 3.0 mg per 100 ml and that symptoms of nervous origin are likely to occur if the concentration falls below 1.2 mg per 100 ml.

The function of magnesium in the hard tissues is unknown (Pike and Brown, 1967). However, many physiological functions of magnesium within the soft tissues have been established. Rook and Storry (1962) and Stewart and Frazer (1963) reported that magnesium serves as a co-factor for many enzymatic reactions and is a necessary component of many enzymatic reactions and is a necessary component of many neuromuscular activities. They reported that a low concentration of magnesium, relative to calcium, at the myoneural junction increases the release of acetylcholine, decreases the activity of acetylcholine esterase and decreases the excitability thresholds of the presynaptic nerve and muscle membranes, thereby producing tetany. Magnesium serves as a co-factor of adenosine triphosphate, choline acetylase and choline esterase. It is an important co-factor in all phosphate transferring systems and in the utilization of energy (Pike and Brown, 1967).

Perry, Cragle and Miller (1967) reported a net secretion of magnesium occurred in the upper small intestine in 3-month old calves. Rook and Storry (1962) and Wilson (1964) reported that the jejunum and ileum of the small intestine are the primary sites of magnesium absorption. Few changes occur in the intestinal concentration of magnesium in passage through the cecum and large intestine. Care and Van't Klooster (1964) reported that in sheep net absorption of magnesium increased as the concentration in the small intestine increased until maximum absorptive capacity was reached. Stewart and Moodie (1956) and Field (1961b) reported that the principal sites of magnesium absorption in sheep appeared to be the duodenum and the remainder of the small intestine, although small amounts were absorbed from the rumen and cecum.

Storry (1961a) reported that in sheep favorable conditions for magnesium uptake occurred in the abomasum and duodenum. A decrease in the concentration of ultrafilterable calcium and magnesium occurred *in vitro*, due to the binding of these ions on the suspended material in the digesta when the acidity of the abomasal digesta was reduced (Storry, 1961b). Garner (1949) found free magnesium to be absent from alkaline rumen contents in vitro.

Smith (1959, 1966) found that young milk fed calves could absorb up to 40% of the dietary magnesium from the large intestine. However, this ability decreased rapidly with increasing age. Smith (1963) found that increasing the small intestine transit time in the calf increased apparent magnesium absorption.

Availability and degree of absorption of magnesium from different feeds vary considerably. In a review of balance trials, Blaxter and McGill (1956) reported 30 to 50% availability of magnesium from feedstuffs. A value of 33% was suggested for use in estimating dietary needs. Digestibility of magnesium was found to be between 23.5 and 33.5% in dairy cows on a variety of stall rations (Rook, Balch and Line, 1958). When early cut herbage was fed, 72.6 to 94.7% of the magnesium was excreted in the feces. Ferrando, Catsaounis and Papastendiades (1964) reported that apparent magnesium absorption in sheep fed alfalfa hay ranged from 38 to 41%. Using ^{28}magnesium, McAleese, Bell and Forbes (1961) found that the magnesium status of an animal has an important bearing on the efficiency of magnesium absorption. Lambs fed a magnesium-deficient diet excreted 25 to 30% of the dietary magnesium in the feces, whereas the lambs fed supplemental magnesium excreted 50 to 52%.

Rook, Campling and Johnson (1964) fed dairy cows some partially purified diets low in magnesium. They found that magnesium availability was approximately 25 to 35% and that the needs of lactating cows could be met by feeding basal diets which provided 9 or 13 g of magnesium per day.

Storry and Rook (1963) reported that the daily endogenous fecal magnesium of the non-lactating dairy cows was 2 mg per kilogram of body weight. Endogenous loss of magnesium amounting to 3.5 mg per kilogram of body weight for both old cows and calves was reported by Blaxter and McGill (1956).

Rook _et al_. (1958) reported that urine is the major disposal route from the body for magnesium absorbed in excess of body requirements. During periods of magnesium deficiency, urinary excretion of magnesium almost completely ceased in dairy cattle. Kemp _et al_. (1961), Stewart and Frazer (1963) and O'Kelley and Fontenot (1969) reported that urinary magnesium excretion appeared to be proportional to the level of magnesium intake. Rook _et al_. (1958) indicated that urinary magnesium excretion should be zero when serum magnesium values approached 2.15 mg per 100 ml.

Investigations have been made in an attempt to estimate the renal threshold for magnesium, which is the serum or plasma magnesium concentration at which urinary excretion of magnesium ceased. Rook _et al_. (1958) estimated that the renal threshold for lactating dairy cows is 2.10 to 2.20 mg of magnesium per 100 ml of blood serum. Storry and Rook (1963) reported that the urinary magnesium threshold occurred when serum magnesium values approached 1.5 to 1.8 mg per 100 ml, depending upon the individual animal.

Rook and Storry (1962) reported the magnesium renal threshold concentration to be about 2 mg per 100 ml of serum in sheep. L'Estrange and Axford (1964) found that the renal threshold in two lactating ewes was 1.37 and 1.94 mg per 100 ml of serum.

The degree of absorption and availability of magnesium from magnesium supplements varies considerably. The availability of magnesium in various salts was determined by measuring the increase in urine excretion when the salts were fed to two non-lactating cows (Storry and Rook, 1963). They found that magnesium availability was highest for magnesium citrate, intermediate for magnesium oxide, lactate, acetate and nitrate, and lowest for magnesium sulfate and chloride.

Gerken and Fontenot (1967) found that apparent magnesium availability in yearling steers was significantly higher from magnesium oxide than from dolomitic limestone. Moore, Fontenot and Tucker (1971) found that there was no significant difference in apparent magnesium absorption between rations supplemented with magnesium oxide and magnesium carbonate. Ammerman _et al_. (1972) found that apparent magnesium absorption in sheep was 56, 52, 52 and 9% for magnesium carbonate, magnesium oxide, magnesium sulfate and magnesite, respectively. True absorption values, calculated by including intake and excretion data obtained during the basal period, were 72, 72, 78 and 14% respectively.

Rook and Balch (1958), working with dairy cows, and Field (1961a), working with sheep, studied the effects of abruptly changing from a wintering ration to fresh-cut spring herbage on magnesium metabolism. Magnesium absorption, as indicated by urinary excretion, was decreased when the spring herbage was fed.

Magnesium is required for normal function of a number of enzymatic reactions and is absorbed from the small intestine. The major route of excretion for magnesium absorbed in excess of requirements is the urine. There is considerable variation in the availability of magnesium from feedstuffs.

Hypomagnesemic Tetany in Ruminants

Sjollema (1932), Dryerre (1932), Sims and Crookshank (1956), Blaxter and McGill (1956) and Doza (1959) have reported detailed descriptions of the symptoms of hypomagnesemic tetany in cattle. Herd and Peebles (1962) reported the symptoms in sheep. The symptoms include nervousness, loss of appetite, viciousness, staggering, profuse salivation, grinding of teeth, anxious or wild look, a pounding heart beat and the onset of tetany. Later a comatose state develops, followed by convulsions and then rapid death.

Sjollema (1932) observed that the occurance of hypomagnesemic tetany was correlated with blood serum magnesium levels. Dryerre (1932) reported that serum magnesium values of afflicted cows were between 0.1 and 1.16 mg per 100 ml, compared to normal values of 1.8 to 3.0 mg per 100 ml. Allcroft (1954) reported that the occurance of tetany is associated with low serum magnesium. Later, Beardsley, McCormick and Southwell (1963) reported that animals afflicted with hypomagnesemic tetany have serum magnesium values between 0.2 and 1.0 mg per 100 ml.

Hypomagnesemic tetany is most prevalent in older cows during the early stages of lactation (Blaxter and McGill, 1956; Sims and Crookshank, 1956; Beardsley *et al*., 1963). However, it has been reported in gestating animals (Crookshank and Sims, 1955; Beardsley et al., 1963). The disease usually occurs during the early weeks of the grazing season of grasses or cereal forages (Allcroft, 1954; Crookshank and Sims, 1955; Blaxter and McGill, 1956; Beardsley et al., 1963). Cases of tetany in cows receiving low-magnesium wintering rations were reported by Leffel and Mason (1959).

Prior to the coma state, hypomagnesemic tetany may be treated effectively. Allcroft (1954), Crookshank and Sims (1955), Blaxter and McGill (1956) and Beardsley et al. (1963) reported that immediate intravenous injections of calcium, magnesium or a combination of calcium and magnesium were effective in alleviating the condition. Wilson (1964) reported that intravenous infusions of magnesium are only temporarily beneficial. He indicated that magnesium in excess of the normal blood level is rapidly excreted in the urine and the proportion of the magnesium diverted to body stores is relatively small. An adequate daily intake of magnesium is required for continuous protection.

Hypomagnesemic tetany is characterized by low blood magnesium. The occurrance of the metabolic disorder in beef cattle is most likely during early stages of lactation. Cows grazing cereal forages and lush spring pastures appear to be most susceptible to grass tetany.

Effect of Dietary Calcium and Phosphorus on Hypomagnesemia

Tufts and Greenberg (1938) studied the effect of dietary calcium levels on magnesium requirements of rats. At low or moderate calcium levels, 5 mg of magnesium was adequate for normal growth rates and successful breeding of the rats. However, deficiency symptoms appeared during pregnancy and lactation and early in the life of the young, indicating that the mother's milk was deficient in magnesium.

With borderline dietary magnesium, high dietary calcium resulted in deficiency symptoms, shorter life span and decreased blood plasma magnesium. Duckworth (1939) reported that high dietary calcium intakes by rats reduced magnesium retention and caused a loss of magnesium from the body.

Colby and Frye (1951) studied the effects of feeding high-calcium (2.52%) and normal magnesium to young rats. High-calcium hastened the onset of severe magnesium deficiency symptoms by 3 to 4 days, decreased growth rate, markedly lowered magnesium blood levels and increased mortality rates. Hegsted, Vitale and McGarth (1956) fed 0.2, 0.6 or 1.8% calcium in combination with 0, 0.003, 0.006, 0.009 or 0.12% magnesium to weanling rats and found that high levels of calcium were detrimental to growth rate and mortality at low levels of magnesium intake (0 or 0.003%) but not when magnesium intake was near the minimum requirement.

Vitale et al. (1959) fed three levels of calcium (0.2, 0.6 and 1.2%) and two levels of magnesium (0.02 and 0.19%) to weanling rats on purified diets. High levels of dietary calcium were usually detrimental to growth in rats fed the low-magnesium diets and in two experiments resulted in intensified kidney lesions. Added magnesium reversed the effects of high-calcium levels. High-calcium reduced serum cholesterol at both levels of magnesium.

Meintzer and Steenbock (1955) conducted a series of metabolism trials in which young rats were limit fed a semi-synthetic diet containing 0.016 or 0.3% phosphorus, 0.012 or 1.0% calcium and 0.02 or

0.34% magnesium. The levels of these minerals were attained by adding calcium carbonate, magnesium phosphate or phytate. Dietary additions of calcium or phosphorus in the inorganic form did not affect magnesium absorption, but phytic acid did reduce it slightly.

Forbes (1961, 1963) studied the effect of two levels of calcium (0.4 and 0.8%), magnesium (0.0142 and 0.0420%) and phosphorus (0.19 and 0.5%) in weanling male albino rats. Blood serum magnesium was lowered by the high-calcium levels at both levels of magnesium and by the high-phosphorus in combination with the low-magnesium diet but not with the high-magnesium diet. The high level of magnesium resulted in increased gain when the high-calcium and low-phosphorus diet was fed. McAleese and Forbes (1961) fed young albino rats purified diets containing 0.2, 0.4 or 0.8% calcium and found that blood serum magnesium decreased with each increase in dietary calcium.

Toothill (1963) fed rats a purified diet containing 0.02% magnesium. Calcium levels of 0.34 and 0.68% and phosphorus levels of 0.39 and 0.78% were fed. Apparent absorption of magnesium was significantly reduced by increasing dietary calcium or phosphorus and further reduced significantly by simultaneously increasing both calcium and phosphorus. The high level of calcium decreased the apparent absorption of phosphorus at each level of phosphorus. Vermeulen (1959) reported that urinary magnesium excretion was not affected by high-calcium rations fed to rats used to study a urinary stone disease. The high-calcium fed rats had increased urinary calcium, decreased phosphorus, an increase of four times the normal urinary citrate and a slightly alkaline urine (pH 7.3, compared to pH 6.7 for control rats).

Chutkow (1962) dosed intraperitoneally or by nasogastric intubation young male albino rats with ^{28}magnesium chloride. In normal and deficient rats, low dietary phosphorus (0.20%) increased absorption and renal loss of magnesium and depressed endogenous fecal excretion. These data suggest that the main action of phosphorus may be the depression of magnesium absorption.

Bunce _et al_. (1965) fed male weanling rats purified diets containing 0.65% calcium, 0.3, 0.5 or 1.0% phosphorus and 0.013, 0.026 or 0.100% magnesium. High intakes of phosphorus lowered the apparent absorption of magnesium when magnesium was ample, but improved absorption when magnesium was limiting. High intakes of magnesium reduced apparent absorption of phosphorus only when ample quantities of phosphorus were consumed. Calcium absorption was improved by increasing dietary phosphorus at the 0.026% level of magnesium but unaffected at the 0.013% level.

Bunce, Chiemcharsi and Phillips (1962) used semi-purified diets containing 0.008% magnesium, 0.3, 0.6, or 0.9% calcium and 0.22, 0.4 or 0.9% phosphorus to study the effects of these dietary factors on the magnesium deficiency syndrome of the weanling dog. Both elevation of calcium from 0.6 to 0.9% and phosphorus from 0.4 to 0.9% of the diet increased the severity of magnesium deficiency symptoms, with the phosphorus effect being more pronounced. Reduction of dietary phosphorus to 0.22% was observed to alleviate the magnesium deficiency symptoms, but no differences were observed following a reduction of dietary calcium to 0.3%.

House and Hogan (1955) observed a calcinosis syndrome, decreased growth rate and early mortality in weanling guinea pigs of both sexes fed a purified diet containing 0.8% calcium, 0.9 or 1.7% phosphorus and normal levels of other minerals. They showed that the symptoms were more severe when a diet containing 1.7% phosphorus was fed and that added potassium and magnesium alleviated the symptoms. Magnesium was the critical element in the syndrome because soft tissue calcification occurred when magnesium intake was suboptimal although potassium was high.

O'Dell et al. (1957), in a balance study with nearly mature guinea pigs, found that high-phosphorus (0.9 or 1.8%) caused the absorption of calcium and magnesium to be 50% less than that obtained with a low-phosphorus (0.4%) purified diet. Guinea pigs on a 0.9% calcium, 0.3% magnesium and 0.4% phosphorus diet absorbed 70% of the calcium and 90% of the magnesium in the diet of which 62 and 87%, respectively, were excreted by the kidney. O'Dell (1960) reported that high intake of phosphorus prevents the loss of calcium and induces symptoms of magnesium deficiency.

Maynard et al. (1958) fed 1-week-old weaned guinea pigs purified diets with added minerals to provide 0.4 or 1.0% calcium, 0.27, 0.48 or 0.72% phosphorus and 0.06, 0.12 or 0.34% magnesium. The diets that contained either high- or low-magnesium, calcium and phosphorus but with constant ratios produced good growth rates and no soft tissue calcification. Increasing the calcium or phosphorus to magnesium ratios resulted in decreased serum magnesium, elevated serum inorganic phosphorus, poor growth and enlarged, damaged and calcified kidneys. Raising only the dietary calcium or phosphorus level produced nearly as marked an effect as raising both together.

Morris and O'Dell (1961) fed young guinea pigs purified diets containing 0.9% calcium, 0.4 and 1.7% phosphorus and 0.003 and 0.3% magnesium to study the effects on tissue composition. When the dietary phosphorus level was 0.4%, normal tissue content of calcium, phosphorus, magnesium and ash in the kidney, heart, muscle and bone was maintained with 0.003 or 0.3% magnesium. However, when the phosphorus level was 1.7%, even 0.3% magnesium did not maintain normal tissue composition.

Two levels of calcium (0.6, 1.2%), three of phosphorus (0.3, 0.6, 0.9%) and five of magnesium (0.005, 0.01, 0.02, 0.04, 0.08%) were fed in purified diets to day-old cockerels to determine the magnesium requirement of the chick at these various dietary calcium and phosphorus levels (Nuggara and Edwards, 1963). When calcium or phosphorus was increased in the diet, mortality rate increased and magnesium had to be increased for maximal gain.

Chicco et al. (1967) reported that body weight and bone ash were increased with increasing calcium and phosphorus in the diet of young chicks. Supplemental magnesium up to 0.4% improved both bone mineralization and weight gain on a 0.45% calcium diet. Addition of magnesium supplement tended to overcome adverse effects of a deficiency in calcium and phosphorus. Scott, Nesheim and Young (1969) reported that high dietary calcium or phosphorus increases the magnesium requirement in chicks. Feeding high-calcium with low-phosphorus levels did not cause a marked reduction on blood serum magnesium levels in growing pullets. It was found that high dietary calcium accentuates the effects of low-magnesium diets and results in lower blood serum magnesium and decreased egg production, egg size, weight of the shell and magnesium content of the yolk.

Dishington (1966) orally dosed two ewes with 5 g of magnesium and 3.6 or 13.7 g of phosphorus per day for 7 weeks. Blood serum magnesium was higher at the low-phosphorus level. Gunn (1969) reported no difference in serum magnesium values in Scottish Blackface hill ewes orally dosed with either 12 g of calcium carbonate or 13 g of monosodium phosphate three times per week when compared to similarly managed ewes that were not dosed. Serum magnesium values tended to remain significantly higher for another group of undosed ewes that permanently ranged on hill pasture.

Chicco _et al_. (1973) reported that fecal magnesium excretion was increased, and serum magnesium decreased by feeding high-calcium (0.43 _vs_. 0.13%) and phosphorus (0.36 _vs_. 0.12%) semi-purified rations to wethers in metabolism studies. Magnesium content of the bone was decreased ($P < .05$) by supplemental calcium but phosphorus had no effect.

Dutton and Fontenot (1967) reported that form of dietary phosphorus had no significant effect on absorption and retention of magnesium and calcium. Inorganic phosphorus and organic phosphorus (phytic acid) were compared in sheep fed two levels of magnesium. The decrease in blood serum magnesium that occurred from the beginning of the trial to the end on the low-magnesium rations and the increase on high-magnesium rations was significantly greater when inorganic phosphorus was fed.

Wise, Ordoveza and Barrick (1963) reported that calciumto phosphorus ratios lower than unity (0.4:1 and 0.8:1) resulted in reduced growth and poor nutrient conversion in young Hereford calves fed a semi-purified ration. Blood serum magnesium was markedly reduced at the 0.4:1 calcium to phosphorus ratio.

In research with rats, dogs and guinea pigs, and limited work with sheep and cattle, high levels of dietary calcium and/or phosphorus appeared to be detrimental to magnesium absorption and utilization, especially when accompanying marginal to low dietary magnesium. Growth rates and blood serum magnesium were decreased, and mortality rates and soft tissue calcification were increased by high dietary calcium and/or phosphorus.

Calcium and Phosphorus Fertilization

Hunter (1949) studied various calcium to magnesium ratios ranging from 1:4 to 32:1 and two levels of phosphorus in greenhouse pot studies with alfalfa. The pH of all soils was the same and the cation exchange capacity was not exceeded. The calcium to magnesium ratio had no effect on yield. Magnesium was absorbed to a lesser extent than calcium and levels in the plant decreased rapidly as the amount of available magnesium decreased with increasing calcium to magnesium ratio. Magnesium content of alfalfa ranged from 0.62 to 0.17% for the 1:4 and 32:1 ratios, respectively. The percent calcium in alfalfa increased as the calcium to magnesium ratio increased from 1:4 to 4:1, but further increases in the ratio resulted in only slight increases in calcium. Phosphorus values in the plant were not affected by decreasing calcium to magnesium ratios from 32:1 to 4:1 but the 1:1 and 1:4 ratio gave a significant increase in phosphorus. High-phosphorus level in the soil gave a 30% increase in phosphorus in the plant.

Welte and Werner (1963), in extensive pot experiments using sand cultures showed that in an acid substrate, magnesium deficiency could be corrected by adding magnesium and lime to raise the pH. Raising soil pH alone was more effective than adding magnesium at low pH. If high levels of calcium carbonate were added, the positive influence of lime was decreased by the antagonistic effect of the calcium ion.

Albrecht and Schroeder (1942) studied the effects of adding calcium at 3 milliequivalent intervals between 0 and 12 milliequivalents to soils at pH 5.2 and 6.8 that were used to grow spinach and potatoes. They found that crop yields were increased by adding calcium to the soil at both pH levels. The magnesium addition to each soil was constant. However, as calcium was added to the soil, magnesium content of the plant was increased, along with the calcium content. Concentration of magnesium in crops grown on the neutral soil was not as great as in the crops grown on the acid soil with no treatment.

Smith, Fleming and Poorbaugh (1957) reported that magnesium absorption was low and potassium absorption was high by grape vines grown on highly acid soils (pH 4.5). Bear and Toth (1948) reported that conditions approach optimum for the cation, including magnesium, nutrition of alfalfa when 65% of the cation exchange capacity of the soil is represented by calcium, 10% by magnesium, 5% by potassium and 20% by hydrogen ions.

Horvath (1959) reported that superphosphate fertilization of pasture and hay land was implicated in some cases of hypomagnesemia in West Virginia.

Magnesium content of plant material appears to be influenced by soil acidity, calcium to magnesium ratio and possibly by superphosphate fertilization.

OBJECTIVES

The main objective of this experiment was to determine the effects of dietary calcium and phosphorus levels on apparent absorption and blood serum level of magnesium. The effects on calcium and phosphorus metabolism, apparent digestibility, and nitrogen balance were also studied.

EXPERIMENTAL PROCEDURE

Two metabolism trials were conducted with 12 wether lambs, averaging 35.9 kg. The experimental design was a 2 x 2 factorial with two dietary levels of calcium and of phosphorus. Prior to the beginning of the first trial, the lambs were placed in three outcome groups (blocks) of four based on breed and weight. For the first trial, the four lambs within each block were randomly allotted to the following four rations: 1) low calcium and low phosphorus (low Ca + low P); 2) High calcium and low phosphorus (high Ca + low P); 3) Low calcium and high phosphorus (low Ca + high P); and, 4) High calcium and high phosphorus (high Ca + high P). The levels of dietary calcium were 0.4 and 1.4% and the levels of dietary phosphorus were 0.3 and 1.3%. For the second trial, the lambs within each block were reallotted to the four rations by incomplete randomization, the restriction being that no lamb would receive the same ration as in the first trial. All lambs were drenched with thiabendazole[1] to control internal parasites prior to the initiation of each metabolism trial.

The ingredient and chemical compositions of the experimental rations is shown in table 1. Calcium, magnesium and phosphorus determinations were conducted on the ground hay, corn cobs, ground shelled corn and soybean meal prior to formulation of rations. The hay and shelled corn were ground in a hammer mill through a 1.27 cm

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[1]Merck Chemical Division, Merck & Co., Rahway, N.J.

TABLE 1. INGREDIENT AND CHEMICAL COMPOSITION OF RATIONS FED

Item	Low P		High P	
	Low Ca	High Ca	Low Ca	High Ca
Ingredient composition, g/day				
Orchardgrass hay	80.00	80.00	80.00	80.00
Corn cobs	160.00	160.00	160.00	160.00
Cerelose[a]	40.00	40.00	40.00	40.00
Ground shelled corn	458.68	459.68	459.68	459.68
Soybean meal	49.60	49.60	49.60	49.60
Iodized salt	4.80	4.80	4.80	4.80
Limestone	5.60	24.44	5.60	24.44
Monosodium phosphate	0.32	0.32	29.21	29.21
Vitamins A and D[b]	+	+	+	+
Total	800.00	818.84	828.80	847.64
Chemical composition, %				
Dry matter	89.87	89.90	90.63	90.03
Composition of dry matter				
Crude protein	10.28	10.34	10.37	10.20
Crude fiber	15.07	14.82	14.84	14.35
Ether extract	2.75	2.74	2.83	2.73
Nitrogen-free extract	67.74	65.74	64.29	63.70
Calcium	0.42	1.43	0.43	1.37
Phosphorus	0.26	0.25	1.31	1.27
Magnesium	0.12	0.13	0.12	0.12

[a]A commercial preparation of glucose, Corn Products Refining Co., New York, New York.

[b]Levels were 1250 I. U. vitamin A and 375 I. U. vitamin D per kilogram of ration.

screen and the corn cobs were ground through a 0.64 cm screen. Calculated crude protein, crude fiber, TDN and magnesium contents were approximately equal among the four rations. A premix was made containing all the ration ingredients except hay and corn cobs. Prior to the feeding, the hay, corn cobs and premixes were weighed and mixed by hand. The lambs on the low Ca + low P, high Ca + low P, low Ca + high P and high Ca + high P rations were fed 400, 409, 414 and 423 g, respectively, twice daily (800, 818, 828 and 846 g per day, respectively). The lambs were maintained in false bottom metabolism stalls similar to those of Briggs and Gallup (1949).

Prior to the beginning of each trial, all lambs were fed a basal ration consisting of 50.0% orchardgrass hay, 34.5% ground ear corn, 15.0% soybean meal and 0.5% iodized salt. Each trial consisted of a 5-day transition period, during which the experimental rations were introduced at the rate of 10.0 percentage units per feeding, followed by a 10-day preliminary period and a 10-day collection period, during which total fecal and urinary collections were made. The preliminary period of each trial began with the feeding in which 100% of the experimental ration was fed.

Once daily, total fecal collections were made, thoroughly mixed, weighed and a 10% sample was placed in a glass container with a tight fitting lid. These samples of daily excretion were composited, kept under refrigeration and preserved with thymol. For trial 1, fecal samples were dried in a forced-draft oven set at approximately 60 C until a constant weight was reached. Then the dried samples were allowed to air-equilibrate for 3 days and finely ground for analysis. Fecal samples for trial 2 were prepared for analysis as follows: 1) the wet composite from each lamb was thoroughly mixed and nitrogen was determined on triplicate 5 g samples, 2) duplicate 200 g samples of each composite were dried for 3 days in a forced-draft oven set at approximately 100 C and 3) the dried samples were allowed to air-equilibrate for 3 days and finely ground for analysis.

A plastic funnel, placed under a metal grid on the floor of the metabolism stall directed the urine into plastic jars. Each jar contained 15 ml of 1:1 (w/w) sulfuric acid and water and 485 ml of water. During the collection period of the first trial, it was determined that 15 ml of the sulfuric acid solution was not sufficient to maintain urine acidity for the sheep fed the high-calcium, high-phosphorus ration. An additional 5 ml of the 1:1 sulfuric acid and water were added to maintain acidity. The urine was collected once daily and the volume was measured. The urine was diluted to constant weight and a 2% sample by volume was placed in a plastic container with a tight fitting cap and stored under refrigeration. The samples for each lamb were composited for each 10-day collection period.

Juglar blood samples were taken 30 min. prior to the feeding that began the transition period and 30 minutes prior to the first feeding after the end of the collection period. The blood samples were allowed to coagulate by heating in a water bath at 37 C for 30 min. and the serum was separated by centrifugation. Serum samples were stored frozen until analyzed for minerals.

Feeds, feces, urine and blood serum were analyzed for calcium and magnesium with a Perkin-Elmer 403 Atomic Absorption Spectrophotometer by the method of Willis (1961) and Trudeau and Freier (1967). Total phosphorus in feeds, feces and urine and serum inorganic phosphorus were determined by the method of Fiske and Subbarow (1925). Prior to analysis for calcium, phosphorus and magnesium, feeds and feces were wet ashed by the method of Sandell (1950). Crude fiber in feeds was determined by the method of Whitehouse, Zarow and Shay (1945). The other proximate components and urinary nitrogen were determined by the methods of A.O.A.C. (1970).

The data were statistically analyzed by analysis of variance. Orthogonal comparisons (Snedecor, 1956) were made to test for significance between calcium and phosphorus levels and for significant interaction.

RESULTS AND DISCUSSION

Magnesium. The magnesium balance data are given in table 2. Apparent magnesium absorption, expressed as percent of intake, was significantly lower ($P < .05$) for the lambs fed the high-calcium rations. The lack of effect on apparent absorption, expressed as grams per day appeared to be due, at least partly, to a higher dietary intake of magnesium for the high-calcium rations. High-calcium rations had no effect on urinary excretion or retention of magnesium. The increased fecal excretion of magnesium accompanying the feeding of 1.4% calcium may be partly caused by the higher dietary level of magnesium. Chicco et al. (1973) reported that feeding a ration containing 0.43% calcium increased fecal magnesium in wethers, compared to a ration containing 0.13% calcium. Duckworth (1939) reported that high-calcium intake by rats reduced magnesium retention. Meintzer and Steenbock (1955) reported that high levels of calcium (1.0%) did not affect magnesium absorption. Forbes (1963) reported that rats fed a high-calcium (0.8%), low-magnesium (140 ppm) diet had a negative magnesium balance. Vermeulen (1959) reported that urinary magnesium was unaffected by high dietary calcium in rats used to study a urinary stone disease.

Apparent magnesium absorption and urinary excretion were significantly lower ($P < .01$) and fecal magnesium excretion was greater ($P < .01$) for the lambs fed the high-phosphorus rations. The lower urinary magnesium excretion was probably due to the lower absorption noted for these animals (Rook et al., 1958). Similarly, Chicco et al. (1973) reported that fecal magnesium excretion was increased by

TABLE 2. EFFECT OF DIETARY LEVEL OF CALCIUM AND PHOSPHORUS ON MAGNESIUM BALANCE.

Ration	Intake	Excretion		Apparent absorption		Retention
		Fecal	Urinary			
	g/day	g/day	g/day	g/day	% of intake	g/day
Low Ca-low P	0.86	0.48	0.35	0.37	43.32	0.02
High Ca-low P	0.93	0.54[a]	0.36	0.39	41.73[b]	0.03
Low Ca-high P	0.86	0.53[c]	0.27[c]	0.33[c]	38.43[c]	0.06
High Ca-high P	0.91	0.61[ac]	0.24[c]	0.30[c]	32.93[bc]	0.06

[a]Values for the high-calcium rations were significantly ($P < .01$) different than for the low-calcium rations.

[b]Values for the high-calcium rations were significantly ($P < .05$) different than for the low-calcium rations.

[c]Values for the high-phosphorus rations were significantly ($P < .01$) different than for the low-phosphorus rations.

feeding rations containing 0.36% phosphorus to wethers, compared to feeding 0.12% phosphorus. Meintzer and Steenbock (1955) reported that inorganic phosphorus at a level of 0.3% did not affect magnesium absorption in rats, but phytic acid at the same level did reduce it slightly. Chuktow (1962) reported that low-phosphorus (0.2%) increased absorption and renal loss of magnesium in rats. Toothill (1963) reported that absorption of magnesium was significantly reduced when dietary phosphorus was increased from 0.39 to 0.78% in rats and further reduced when dietary calcium was also increased. Forbes (1963) reported that high dietary phosphorus (0.5%) increased magnesium retention slightly in rats fed a low-magnesium (0.0142%) diet. House and Hogan (1955) reported that magnesium retention was decreased by feeding a high-phosphorus (1.7%), low magnesium diet to guinea pigs. O'Dell et al. (1957) and O'Dell, Morris and Regan (1960) reported that high-phosphorus (1.8%) rations resulted in a 50% reduction in magnesium absorption in guinea pigs, when compared to a low-phosphorus (0.4%) diet.

Blood serum magnesium levels (table 3) were not significantly affected by dietary calcium levels. However, final serum magnesium levels were lower than initial values for all rations. These results agree in part with those of Gunn (1969), in which he reported no difference in serum magnesium in ewes dosed three times per week with 12 g of calcium carbonate. Chicco et al. (1973) reported that serum magnesium was decreased by feeding high-calcium (0.43%) rations to wethers. Colby and Frye (1951), Forbes (1961, 1963) and McAleese and

TABLE 3. EFFECT OF DIETARY LEVEL OF CALCIUM AND PHOSPHORUS ON BLOOD SERUM MAGNESIUM, CALCIUM AND INORGANIC PHOSPHORUS.

		Blood serum levels, mg/100 ml.		
Time	Ration	Magnesium	Calcium	Inorganic Phosphorus
Initial	Low Ca-low P	2.60	11.62	6.15
	High Ca-low P	2.51	11.62	6.38
	Low Ca-high P	2.54	11.48	6.97
	High Ca-high P	2.33	11.23	6.95
Final	Low Ca-low P	2.42	11.09	7.45
	High Ca-low P	2.34	11.45[a]	7.84
	Low Ca-high P	2.20[b]	9.07[c]	12.80[c]
	High Ca-high P	2.28[b]	10.75[ac]	10.93[c]

[a]Values for the high-calcium rations were significantly ($P < .05$) different than for the low-calcium rations.
[b]Values for the high-phosphorus rations were significantly ($P < .05$) different than for the low-phosphorus rations.
[c]Values for the high-phosphorus rations were significantly ($P < .01$) different than for the low-phosphorus rations.

Forbes (1961) reported that increased levels of calcium (0.4 to 2.5%) resulted in decreased serum magnesium in the rat. Maynard et al. (1958) reported that high dietary calcium to magnesium ratios in guinea pigs resulted in decreased serum magnesium. Scott et al. (1969) reported that feeding high-calcium with low-magnesium levels did not cause a marked reduction in serum magnesium levels in growing pullets.

Blood serum magnesium levels were lower ($P < .05$) for the lambs consuming the high-phosphorus rations. Dishington (1966) reported similar results, in that serum magnesium was increased in a ewe dosed with 3.6 g of phosphorus per day, but only a small increase occurred when another ewe was dosed with 13.7 g of phosphorus per day. Gunn (1969) reported no difference in serum magnesium values when ewes were orally dosed with 13 g of monosodium phosphate three times per week. Forbes (1961) and Maynard et al. (1958) reported that feeding high levels of phosphorus (0.5 or 0.72%, respectively) decreased serum magnesium in weanling rats and guinea pigs, respectively. Wise et al. (1963) reported that a 0.4:1 calcium to phosphorus ratio markedly lowered serum magnesium in young Hereford calves, compared to a 0.8:1 or greater calcium to phosphorus ratio.

Calcium. The calcium balance data are given in table 4. Apparent calcium absorption was not affected by level of calcium, when expressed as percent of intake. However, when expressed as grams per day apparent calcium absorption was higher ($P < .01$) for the high-calcium fed lambs. Fecal calcium excretion was greater ($P < .01$) for the high-calcium fed lambs. Urinary calcium was not affected by level of calcium. Calcium

TABLE 4. EFFECT OF DIETARY LEVEL OF CALCIUM AND PHOSPHORUS ON CALCIUM BALANCE.

Ration	Intake	Excretion		Apparent absorption		Retention
		Fecal	Urinary			
	g/day	g/day	g/day	g/day	% of intake	g/day
Low Ca-low P	3.04	2.77	0.15	0.27	9.22	0.13
High Ca-low P	10.57	9.41[a]	0.21	1.20[a]	11.11	0.99[a]
Low Ca-high P	3.22	2.59	0.07[b]	0.55	19.28	0.48
High Ca-high P	10.42	9.49[a]	0.06[b]	0.93[a]	9.00	0.87[a]

[a]Values for the high-calcium rations were significantly ($P < .01$) different than for the low-calcium rations.
[b]Values for the high-phosphorus rations were significantly ($P < .01$) different than for the low-phosphorus rations.

retention was higher ($P < .01$) for the high-calcium fed lambs. These results agree in part with those of Chicco et al. (1973) who reported that fecal and urinary calcium excretions were greater for wethers fed a high-calcium (0.43%) ration. Forbes (1963) reported that high dietary calcium (0.8%) increased apparent calcium absorption and balance only when phosphorus was also high (0.5%) in rats. Toothill (1963) reported that calcium intake had no significant effect on calcium absorption.

Apparent calcium absorption and retention were not affected by level of dietary phosphorus. Urinary calcium excretion was lower ($P < .01$) for the high-phosphorus fed lambs. Chicco et al. (1973) reported that a low-calcium (0.14%), high-phosphorus (0.36%) diet increased fecal calcium excretion while calcium absorption was increased by wether lambs on a high-calcium (0.42%), high-phosphorus (0.36%) ration. O'Dell et al. (1957) reported that high-phosphorus (1.8%) decreased calcium absorption by 50% along with a trend for decreased calcium retention, compared to a 0.4% phosphorus diet fed to nearly mature guinea pigs. There was a trend for decreased calcium retention at high levels of phosphorus. Forbes (1961) and Bunce et al. (1965) reported that calcium absorption was improved by increasing the dietary level of phosphorus in the weanling rat, but Toothill (1963) reported that high dietary phosphorus (0.70%) had no significant effect on apparent calcium absorption.

Blood serum calcium was higher ($P < .05$) for the lambs that received the high-calcium rations (table 3). These data agree with the retention data and with the results of Chicco et al. (1973). They reported that plasma calcium was significantly greater in high-calcium (0.43%) fed wethers, Wise et al. (1963) reported that dietary calcium did not influence serum calcium values in young calves. Forbes (1963) reported that serum calcium was not affected by high-calcium (0.8%) diets fed to rats.

Blood serum calcium was lower ($P < .01$) for the high-phosphorus fed lambs. These results are similar to those reported by Chicco et al. (1973) from feeding a high-phosphorus ration (0.36%) to wether lambs. Wise et al. (1963) reported that elevation of dietary phosphorus effected a distinct linear decrease in serum calcium at all dietary calcium levels in calves. Forbes (1963) reported serum calcium in rats was not affected by high dietary phosphorus (0.5%).

Phosphorus. The phosphorus balance data are given in table 5. Apparent phosphorus absorption, fecal and urinary excretion and retention were not significantly affected by dietary calcium level. These results are not in accord with those reported by Chicco et al. (1973) who found that fecal phosphorus was significantly increased by supplemental calcium. In the rat, Toothill (1963) reported that high dietary calcium decreased apparent phosphorus absorption at each level of phosphorus intake. However, Forbes (1963) reported that phosphorus absorption was depressed by high dietary calcium only when low-phosphorus diets were fed.

Apparent phosphorus absorption, fecal and urinary excretion and retention were greater ($P < .01$) for the wethers fed the high-phosphorus

TABLE 5. EFFECT OF DIETARY LEVEL OF CALCIUM AND PHOSPHORUS ON PHOSPHORUS BALANCE.

Ration	Intake	Excretion		Apparent absorption		Retention
		Fecal	Urinary			
	g/day	g/day	g/day	g/day	% of intake	g/day
Low Ca-low P	1.87	1.65	0.18	0.22	11.92	0.04
High Ca-low P	1.87	1.69	0.07	0.18	9.60	0.11
Low Ca-high P	9.79	5.97[a]	2.27[a]	3.82[a]	39.05[a]	1.56[a]
High Ca-high P	9.68	7.19[a]	1.14[a]	2.49[a]	25.62[a]	1.35[a]

[a]Values for the high-phosphorus rations were significantly ($P < .01$) different than for the low-phosphorus rations.

rations. The differences in urinary excretion and retention were probably due, at least in part, to the differences noted in absorption. Calcium level appeared to exert a slight influence on the route of phosphorus excretion for the high-phosphorus rations, as there was a trend toward an interaction between calcium and phosphorus on the high-phosphorus rations. When high dietary calcium was added to the high-phosphorus ration, fecal phosphorus excretion was increased, whereas level of dietary calcium had no marked effect when the low level of phosphorus was fed. Perhaps this may have been due to the formation of insoluble calcium phosphate compounds in the gut. Chicco et al. (1973) also reported that fecal phosphorus was increased by feeding high-phosphorus rations. O'Dell et al. (1957) reported that apparent phosphorus absorption was not affected by level of phosphorus in the diet, but retention was increased at each added level of phosphorus in guinea pigs. Forbes (1963) reported that urinary phosphorus excretion was increased in rats fed high-phosphorus diets.

Blood serum inorganic phosphorus was not significantly affected by level of calcium (table 3). Serum inorganic phosphorus levels were higher ($P < .01$) for the lambs fed high-phosphorus levels. However the level was not increased as much when a high-calcium level was fed as when a low-calcium level was fed. This is in agreement with the fecal and urinary excretion data. Chicco et al. (1973) reported a trend toward decreased plasma phosphorus from feeding 0.42% calcium. Wise et al. (1963) reported serum inorganic phosphorus levels in calves were not significantly influenced by dietary calcium. The increased serum inorganic phosphorus level with the increased dietary phosphorus level agrees with the results of Chicco _et al_. (1973) who reported that plasma phosphorus levels were increased by feeding 0.36% phosphorus to wethers, compared to feeding 0.12%. Wise _et al_. (1963) reported that serum inorganic phosphorus was markedly increased by higher dietary levels of phosphorus in calves and that the response of blood phosphorus to increase of this element is rapid and directly related to the amount in the feed.

Nitrogen Utilization. Data on nitrogen utilization are presented in table 6. Calcium or phosphorus levels did not exert significant effects on apparent absorption, urinary excretion and retention of nitrogen. Lambs on all rations were in positive nitrogen balance. There was a slight, but non-significant trend for increased nitrogen retention by the lambs on the high-phosphorus rations.

Apparent Digestibility. Data on the apparent digestibility of rations are presented in table 7. The apparent digestibility of dry matter, crude protein, crude fiber and nitrogen-free extract was not significantly affected by level of dietary calcium or phosphorus. Apparent digestibility of ether extract was increased ($P < .05$) for the lambs receiving the high-calcium rations and decreased ($P < .01$) for the lambs receiving the high-phosphorus rations.

Dry Matter of Collected Feces. The dry matter content of the collected feces are shown in table 8. Lambs receiving the high-calcium rations produced feces with higher ($P < .05$) dry matter content and those fed the high-phosphorus rations produced feces with a lower ($P < .01$) dry matter. Lambs receiving the low-calcium, high-phosphorus ration experienced a diarrhea condition which began on the third or fourth day

TABLE 6. EFFECT OF DIETARY LEVEL OF CALCIUM AND PHOSPHORUS ON NITROGEN BALANCE.

Ration	Intake	Excretion		Apparent absorption		Retention
		Fecal	Urinary			
	g/day	g/day	g/day	g/day	% of intake	g/day
Low Ca-low P	11.82	4.63	5.47	7.19	60.79	1.72
High Ca-low P	12.16	4.77	5.47	7.39	60.79	1.92
Low Ca-high P	12.45	4.82	5.00	7.63	61.29	2.62
High Ca-high P	12.42	4.93	5.24	7.57	60.96	2.34

TABLE 7. EFFECT OF DIETARY LEVEL OF CALCIUM AND PHOSPHORUS ON APPARENT DIGESTIBILITY.

	Apparent digestibility by ration, %			
Component	Low Ca Low P	High Ca Low P	Low Ca High P	High Ca High P
Dry matter	76.43	74.41	73.48	72.97
Crude protein	60.79	60.79	61.29	60.96
Crude fiber	62.24	63.69	60.36	62.83
Ether extract	79.97	84.63[a]	74.75[b]	78.81[ab]
Nitrogen-free extract	83.06	82.30	81.69	80.95

[a]Values for the high-calcium rations were significantly ($P < .05$) different than for the low-calcium rations.
[b]Values for the high-phosphorus ration was significantly ($P < .01$) different than for the low-phosphorus ration.

TABLE 8. EFFECT OF DIETARY LEVEL OF CALCIUM AND PHOSPHORUS ON FECES DRY MATTER AND URINE VOLUME.

Parameter	Ration			
	Low Ca Low P	High Ca Low P	Low Ca High P	High Ca High P
Dry matter of feces, %	41.52	44.68[a]	18.43[b]	39.76[abc]
Urine volume, liters per day	1.12	1.34	0.65	1.48

[a]Values for the high-calcium rations were significantly ($P < .05$) different than for the low-calcium rations.
[b]Values for the high-phosphorus rations were significantly (P .01) different than for the low-phosphorus rations.
[c]The interaction between the level of calcium and phosphorus was significant ($P < .01$).

of the transition period and continued during the time they received this ration. The feces for these lambs lacked the usual pelleted form of sheep feces and were noticably wetter than the feces from the other lambs. The low dry matter content in the feces of the high-phosphorus fed sheep was partly corrected by adding calcium to give an approximately 1:1 calcium to phsophorus ratio. This is indicated by a significant interaction ($P < .01$) of dietary calcium and phosphorus level.

Urine Volume. Data for urine volume are given in table 8. Urine volume was not significantly affected by level of dietary calcium or phosphorus. There was a trend for decreased urine volume by the lambs fed the low-calcium, high-phosphorus ration. However, this was not significant due to the large variation among individuals.

SUMMARY

A 2 x 2 factorially designed experiment was conducted to study the effects of feeding two levels of calcium and phosphorus, alone and in combination,on magnesium utilization in ruminants. Twelve wether lambs were used in two metabolism trials. The two levels of calcium were 0.4 and 1.4% and the two levels of phosphorus were 0.3 and 1.3%.

Apparent magnesium absorption, expressed as percent of intake was lower for the high-calcium fed lambs ($P < .05$) and for the high-phosphorus fed lambs ($P < .01$). Urinary magnesium excretion was lower ($P < .01$) for the high-phosphorus fed lambs. Urinary calcium excretion was lower ($P < .01$) for the high-phosphorus fed lambs. Calcium retention was higher ($P < .01$) for the high-calcium fed lambs. Apparent phosphorus absorption, phosphorus retention and urinary phosphorus excretion were higher ($P < .01$) for the lambs fedthe high-phosphorus level. Serum magnesium was lower ($P < .01$) and serum inorganic phosphorus was higher ($P < .01$) for the high-phosphorus fed lambs. Serum calcium was higher ($P < .05$) for the high-calcium fed lambs and lower ($P < .01$) for the lambs receiving the high-phosphorus rations. Apparent digestibility of ether extract and dry matter content of the feces were higher ($P < 05$) for the lambs fed the high-calcium level and lower for the high-phosphorus fed lambs ($P < .01$). The significant ($P < .01$) interaction between calcium and phosphorus levels on dry matter of feces indicates that high dietary calcium was partially effective in reversing the detrimental effects of high-phosphorus level.

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APPENDIX

TABLE 1. DAILY APPARENT MAGNESIUM ABSORPTION

Trial No.	Ration	Sheep No.	Magnesium absorption g/day
1	Low Ca-low P	11	0.37
1	Low Ca-low P	4	0.35
1	Low Ca-low P	3	0.33
2	Low Ca-low P	5	0.42
2	Low Ca-low P	1	0.38
2	Low Ca-low P	12	0.38
Average			0.37
1	High Ca-low P	5	0.41
1	High Ca-low P	7	0.43
1	High Ca-low P	9	0.35
2	High Ca-low P	2	0.42
2	High Ca-low P	10	0.40
2	High Ca-low P	3	0.32
Average			0.39
1	Low Ca-high P	8	0.38
1	Low Ca-high P	1	0.32
1	Low Ca-high P	12	0.29
2	Low Ca-high P	11	0.38
2	Low Ca-high P	4	0.28
2	Low Ca-high P	6	0.33
Average			0.33
1	High Ca-high P	2	0.29
1	High Ca-high P	10	0.34
1	High Ca-high P	6	0.27
2	High Ca-high P	8	0.29
2	High Ca-high P	7	0.28
2	High Ca-high P	9	0.31
Average			0.30

TABLE 2. EXAMPLE OF ANALYSIS OF VARIANCE
(APPARENT MAGNESIUM ABSORPTION, PERCENT OF INTAKE)

Source	Degrees of freedom	Sums of squares	Mean squares	F
Total	23	718.28	31.23	
Outcome group (blocks)	2	120.89	60.45	4.72
Treatment	3	379.38	126.46	9.87**
Level of calcium	(1)	75.39	75.39	5.89*
Level of phosphorus	(1)	280.99	280.99	21.94**
Calcium X phosphorus interaction	(1)	22.99	22.99	1.79
Trial	1	7.38	7.38	0.58
Treatment X trial interaction	3	31.28	10.43	0.81
Error	14	179.35	12.81	0.

*P < .05
*P < .01

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EFFECT OF DIETARY CALCIUM AND PHOSPHORUS LEVELS ON MAGNESIUM UTILIZATION IN SHEEP

by

Carl Daniel Pless, Jr.

(ABSTRACT)

A 2 x 2 factorially designed experiment was conducted to study the effects of feeding two levels of calcium and phosphorus alone and in combination,on magnesium utilization in ruminants. Twelve wether lambs were used in two metabolism trials. The two levels of calcium were 0.4 and 1.4% and the two levels of phosphorus were 0.3 and 1.3%.

Apparent magnesium absorption, expressed as percent of intake was lower for the high-calcium fed lambs ($P < .05$) and for the high-phosphorus fed lambs ($P < .01$). Urinary magnesium excretion was lower ($P < .01$) for the high-phosphorus fed lambs. Urinary calcium excretion was lower ($P < .01$) for the high-phosphorus fed lambs. Calcium retention was higher ($P < .01$) for the high-calcium fed lambs. Apparent phosphorus absorption, phosphorus retention and urinary phosphorus excretion were higher ($P < .01$) for the lambs fed the high-phosphorus level. Serum magnesium was lower ($P < .01$) and serum inorganic phosphorus was higher ($P < .01$) for the high-phosphorus fed lambs. Serum calcium was higher ($P < .05$) for the high-calcium fed lambs and lower ($P < .01$) for the lambs receiving the high-phosphorus rations. Apparent digestibility of ether extract,and dry matter content of the feces were higher ($P < .05$) for the lambs fed the high-calcium level and lower for the high-phosphorus fed lambs($P < .01$). The significant ($P < .01$)

interaction between calcium and phosphorus levels on dry matter of feces indicates that high dietary calcium was partially effective in reversing the detrimental effects of high-phosphorus level.