12-1981

Effects of potassium fertilization of fescue pastures on metabolism of magnesium, calcium and potassium in lactating beef cows

David L. Hodge

To the Graduate Council:

I am submitting herewith a thesis written by David L. Hodge entitled "Effects of potassium fertilization of fescue pastures on metabolism of magnesium, calcium and potassium in lactating beef cows." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Science.

M. C. Bell, Major Professor

We have read this thesis and recommend its acceptance:

J. B. McLaren, J. W. Holloway

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by David L. Hodge entitled "Effects of Potassium Fertilization of Fescue Pastures on Metabolism of Magnesium, Calcium and Potassium in Lactating Beef Cows." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Science.

M. C. Bell

M. C. Bell, Major Professor

We have read this thesis
and recommend its acceptance:

J. B. McLaren

J. W. Holloway

Accepted for the Council:

L. Evans Roth

Vice Chancellor
Graduate Studies and Research

EFFECTS OF POTASSIUM FERTILIZATION OF FESCUE PASTURES ON METABOLISM OF MAGNESIUM, CALCIUM AND POTASSIUM IN LACTATING BEEF COWS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

David L. Hodge

December 1981

ACKNOWLEDGMENTS

The author wishes to express his appreciation to Dr. M. C. Bell for his advice and guidance in conducting the research and preparation of this manuscript. The author wishes to thank Dr. J. B. McLaren for his advice and help in conducting the statistical analysis and review of this thesis. The author is grateful to Dr. J. W. Holloway for serving as a committee member, and his advice, suggestions and criticism of this manuscript are appreciated.

The author is grateful to Gayle Lambert and Chris Reynolds for their assistance in conducting trials and laboratory analysis.

Appreciation is expressed to all fellow graduate students and laboratory personnel who assisted in collection and analysis of the data.

The author acknowledges the use of The University of Tennessee Computing Center, Knoxville, Tennessee, in obtaining the results shown here.

The author is most deeply indebted to his parents, Robert and Joanne, for their support and sincere encouragement throughout his college career.

ABSTRACT

The objectives of this research were to determine what effects high K fertilization of fescue pastures had on plasma levels of Mg, Ca and K and on the metabolism of Mg, Ca and K in beef cows in early lactation.

Balance trials were conducted using beef cows with young suckling calves in February and March, 1980 and 1981. Cows were placed on one of two adjacent fescue pastures. Both pastures were fertilized with N (112 kg/hectare) and P (169 kg/hectare). One pasture received no fertilization of K and the other, 224 kg/hectare. The internal (acid-detergent lignin)--external (Cr_2O_3) indicator technique was used to determine fecal dry matter output and dry matter consumption of the cows. Urine volume was estimated using creatinine ratios. Milk production (calf-suckle technique) was estimated and sampled for all cows.

Cows on the control pasture consumed more dry matter and Mg. Cows consuming the K-fertilized pastured had reduced urinary Mg excretion, indicating reduced absorption of the Mg. Excretion of Mg in the milk remained the same regardless of treatment. Cows on the K-fertilized pasture tended to have depressed plasma Mg values with a higher incidence of hypomagnesemia. Nine cows on the K-fertilized pasture were hypomagnesemic compared with only four on the control pasture, although no symptoms of grass tetany were seen. This relationship suggests that in a tetany-prone year, the number of cases

of grass tetany could be higher because of pasture fertilization with K. There were no differences between treatment in plasma Ca values, but plasma K tended to be higher in cows on the K-fertilized pasture.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Mg is a required macromineral nutrient making up approximately 0.05% of an animal's body (Rook and Storry, 1962). It is the fourth most abundant cation in the body. The element is primarily an intracellular cation where it is second only to K in amount (Care, 1967). Only 1% of the body Mg is located in the extracellular fluids; whereas 70% is stored in the bone and the remainder in the soft tissues (Fontenot, 1980).

In 1928 Sjollema linked a metabolic disorder that causes tetanic convulsions and death in livestock to a low level of Mg in the serum (Grunes *et al*., 1970). The disease has come to be known primarily as grass tetany but is also referred to as grass staggers, hypomagnesemia, lactation tetany and wheat pasture poisoning. Many factors are interrelated in the etiology of grass tetany, but the disease is associated with Mg because of the low Mg content of the blood and because feeding adequate amounts of Mg alone will circumvent the disorder. Grass tetany has been reported in calves, steers (Sims and Crookshank, 1956), lambs (McAleese and Forbes, 1959) and dairy cows (Butler, 1963); but the primary problem in the Southeastern U.S. is with older, lactating beef cows grazing lush spring pastures (Grunes *et al*., 1970). The outward signs of grass tetany include anorexia, hyperexcitability to external stimulus, incoordination, muscle tremors, viciousness, tetanic convulsions and death (Aikawa, 1971).

The amount of research available on hypomagnesemia and grass tetany is voluminous, but the relationship of Mg and other complicating factors to grass tetany is still not clear. Balance studies using the beef cow on pasture are limited. Knowledge of the absorption and excretion of Mg and related minerals is necessary in order to further investigate the causes of grass tetany.

The objectives of this research were to determine what effects high K fertilization of fescue pastures had on plasma levels of Mg, Ca and K and on the metabolism of Mg, Ca and K in beef cows in early lactation.

CHAPTER II

REVIEW OF LITERATURE

I. METABOLIC FUNCTION OF MAGNESIUM

Mg makes up a large part of the minerals found within an animal's body. Because it is involved in many biological processes, it is important to have a good understanding of its metabolism.

Physiological Function

Rook and Storry (1962) report that the Mg in bones and teeth is necessary for their integrity. Significant amounts of Mg are also found in the soft tissues. It is essential for normal neuromuscular function and it is a cofactor in energy metabolism, being involved in reactions of the Kreb cycle and oxidative phosphorylation. Mg is also a cofactor in metabolism of protein and fat (Lehninger, 1975).

Plasma and Serum

Although only 1% of the total body Mg is in the plasma, researchers have examined the content of Mg in the bloodstream in many different experiments. Rook and Storry (1962) place a normal range for Mg in serum between 1.2 to 3.8 mg/dl. A survey was conducted in the British Isles which included 200,000 cows during a period of over two years. It was found that the mean serum Mg level was 2.1 mg/dl (Ross and Halliday, 1975). Hall and Reynolds (1972), in work done in Tennessee, took blood samples from 12 cows suffering from grass tetany at the time clinical symptoms were evident. Mean value for plasma Mg was 0.79 $\pm$ .19 mg/dl. Forbes (1972) took blood samples from 25 tetanic cattle and reported an average value of 1.4 mg Mg/dl plasma. In addition, 88% of the animals examined had some degree of hypocalcemia. Baker et al. (1979) attained a similar relationship in sheep which were given a milk-based infusion into their abomasum.

Plasma Mg has been shown to decrease when cows were changed abruptly from a winter ration to young pasture grasses (Rook and Balch, 1958; Ramsey et al., 1979). Field (1962) has correlated the ability to absorb Mg with serum Mg. Intake of Mg has been related to Mg content of the plasma (Kemp et al., 1961; O'Kelly and Fontenot, 1969). Others have shown that by increasing the oral intake of Mg with supplements, plasma Mg was increased (Hansard et al., 1975; Boling et al., 1979). Conversely, Ritchie and Hemingway (1963), using lactating ewes with a mean value of 1.0 mg Mg/dl plasma, found no response over a 24-hour period to daily drenches of 4 grams of Mg as either magnesium oxide or magnesium nitrate.

Hypomagnesemia in itself creates a vicious cycle. Anorexia is a symptom of hypomagnesemia, and a reduction or lack of feed intake will produce hypomagnesemia due to decreases in Mg intake (Herd, 1966; Ammerman et al., 1971). Some researchers have found plasma Mg and urinary excretion of Mg to have a similar relationship (Rook et al., 1958; Storry and Rook, 1963; House and Mayland, 1976a), while others have not (Field, 1962; Stillings et al., 1964). Age seems to have an effect on the Mg content of the plasma, with younger animals having higher plasma Mg when compared with more mature animals (House and Van Campen, 1971; Chicco et al., 1973; Fisher et al., 1978).

Absorption and Excretion

Research that has been conducted on the sites and method of Mg absorption has been quite extensive and has produced varying results. In many papers the researchers mention apparent absorption. Apparent absorption is simply the difference between the amount of a nutrient taken in and the amount excreted in the feces. It is referred to as apparent because endogenous sources of the nutrient are not considered. Rook and Storry (1962) have summarized the daily endogenous Mg estimates determined by different workers. These estimates were 2.2 to 4.0 mg/kg bodyweight in calves, 1.5 to 5.0 mg/kg bodyweight in cows and 100 to 250 mg per animal in sheep. Total fecal Mg encompasses both endogenous Mg and the unabsorbed Mg from the diet.

Early work on the sites of Mg absorption showed that little absorption of Mg occurs from the rumen (Care and Van't Klooster, 1965; Phillipson and Storry, 1965). More recently these results have been contradicted. Tomas and Potter (1976) fed a low-Mg diet to sheep which had a rumen fistula, a tube in the cranial one-third of the omasum, a tube in the cranial one-third of the abomasum and a re-entrant duodenal cannula. Supplementary Mg was added by way of the different cannulas in the digestive tract. When Mg was added caudal to the pylorus, there was a decrease in plasma Mg concentration and urinary Mg excretion with an increase in the excretion of Mg in the feces. This indicates that the absorption of Mg post-ruminally is insufficient for normal metabolism, and that the stomach area is the principal site of Mg absorption. These same researchers found the reticulorumen to be the primary site of Mg absorption with no significant absorption from either the omasum or abomasum. Field and Munro (1977), calculating absorption of Mg from changes in urinary excretion, reported similar conclusions except that their data indicated that some absorption from the omasum takes place. Other work also shows the stomach area to be the main site for absorption of Mg (Ben-Ghedalia et al., 1975; Stevenson and Unsworth, 1978). In addition to the reticulorumen, Mg is also absorbed from the large intestine, and a net secretion occurs in the small intestine (Grace et al., 1974; Ben-Ghedalia et al., 1975; Tomas and Potter, 1976), although Perry et al. (1967) has reported absorption of Mg from the small intestine in calves.

There are other factors which can affect the absorption of Mg. Rayssiguier and Poncet (1980) found that by supplementing hay with lactose, absorption of Mg in the stomach region was increased in sheep. Hypomagnesemia will increase the absorption of Mg while the excretion in the urine remains low (McAleese et al., 1961). Other components will be discussed later in this chapter.

It has been postulated that Mg is absorbed by an active transport mechanism (Field and Munro, 1977). Brown et al. (1978) with in vivo data and Martens et al. (1978) using evidence from an in vitro study, further substantiate this theory.

It appears that the excretion of Mg is highly variable between individual animals showing that individual differences in the ability to absorb Mg exist (Rook and Balch, 1958). In independent work, the average excretion of Mg in the feces, expressed as a percentage of intake, has been calculated to be 83% (Rook and Balch, 1958; Kemp et al.,

1961) with the latter group of researchers reporting a range of between 67 to 93% for freshly cut forage. When feeding typical winter rations, Rook et al. (1958) found that fecal excretion of Mg ranged from 66.5 to 77% of intake.

Urinary excretion of Mg appears to be the route that an animal will use when Mg is absorbed in excess of requirement. This was demonstrated by Jesse et al. (1981) when they administered 3.0 g Mg intravenously into three nonlactating Holstein cows and completely recovered an equivalent amount of the dose in the urine. In 1960, Wilson reported that Mg is excreted in the urine only when the amount of Mg filtered by kidney glomeruli exceeds the amount reabsorbed by the kidney tubules (Fontenot, 1980). Storry and Rook (1963) found a threshold value of 1.46 mg and 1.76 mg Mg per deciliter of plasma in two different dairy cows. Chicco et al. (1972), using sheep, found the threshold value to be 1.63 mg/dl plasma. Above the threshold value there is a linear relationship between urinary loss of Mg and serum Mg concentration, but below that value urinary excretion of Mg drops to almost zero. Urinary Mg excretion may be a better indicator of the Mg status of an animal. When an animal is changed to a diet low in Mg content, the concentration of Mg in the urine will decrease before that in the plasma (Kemp et al., 1961; Fisher et al., 1978). The first group of workers using dairy cows found that unless the daily excretion of Mg was less than 1 gram, hypomagnesemia did not occur. It appears that urinary Mg has a close relationship with dietary levels of Mg consumed by an animal (Field et al., 1958;

Field, 1962). Garces and Evans (1971) reported that growing cattle excreted 14% of their intake of Mg in the urine.

Hypomagnesemia is often seen in the cow either in late pregnancy or early lactation. Barlet et al. (1979) have provided information that fetal plasma Mg is independent of the levels of Mg in the dam, using hypo-, normal and hypermagnesemic sheep. Hypomagnesemic cows and cows suffering a reduced intake of Mg still produce milk with the same concentration of Mg (Rook and Storry, 1962; Ritter, 1979). Wilson (1980) reported that cows with hypomagnesemia would increase the production of milk if given an oral supplement of Mg as Epsom salts; thus it appears that hypomagnesemia may reduce milk production.

II. REQUIREMENT FOR MAGNESIUM BY RUMINANTS

The National Research Council (1975, 1976, 1978) has determined the percentage of Mg that should be found in the diet of different ruminants. The adult sheep requires 0.06% Mg in its diet, while the needs of growing beef steers and heifers range from 0.04 to 0.10%. They recommend that beef breeding stock consume a diet which contains 0.18% Mg. In dairy cattle, calves require 0.07% Mg while heifers, cows and bulls will need 0.16%. Because of the loss of Mg in the milk, the lactating dairy cow will need 0.20% Mg in her ration.

Since the needs of ruminants are being discussed, the requirements of the rumen microbes should not be overlooked. Chamberlain and Burroughs (1962) showed that Mg was not needed for in vitro cellulose digestion by rumen microorganisms. In subsequent work, where the rumen fluid was serially diluted, Mg supplementation increased cellulose digestion *in vitro* (Ammerman *et al*., 1971). These same workers found the same response *in vivo*. Recently, Wilson (1980) showed that supplements of 2 g of Mg per day, as Epsom salts, increased the apparent digestibility of hay being fed to sheep. Also in hypomagnesemic, lactating cows, milk and fat production was significantly increased only when extra Mg was given orally.

III. FACTORS AFFECTING MAGNESIUM UTILIZATION

Pearson *et al*. (1949) appear to be the first to suggest that grass tetany may not be due simply to a lack of dietary Mg. They noticed that young wheat plants from pastures where grass tetany occurred seem to have adequate Mg but a high content of K. Since that time other factors have been implicated as having an influence on the metabolism of Mg. What follows is a discussion of those factors.

Nitrogen

Heavy N fertilization of pasture has been shown to depress Mg levels in the serum (Bartlett *et al*., 1957) and decrease apparent availability of Mg (Stillings *et al*., 1964). Sims and Crookshank (1956) examined factors related to wheat pasture poisoning and concluded that fertilization by N, K or both did not influence blood parameters in cows or ewes grazing the wheat pastures. In Oklahoma and Texas, N fertilization produced changes in the chemical composition of winter wheat, generally increasing the indices that help determine the tetany-producing potential of a pasture (Stewart *et al*., 1981).

During a grass tetany outbreak in New Zealand, samples were taken from 19 farms with tetany producing pastures. After chemical analyses of the forages were completed, it was suggested that the outbreak may have been aggravated by a high protein-low energy intake (Metson et al., 1966). This relationship was then shown by Mayland et al. (1974), who in a five-year study harvested forage samples from two plots that had produced grass tetany. In this experiment carried out amid the spring tetany period, they found that there was a rapid increase in the ratio of N to total water-soluble carbohydrate. A further examination was accomplished by feeding wethers a semi-purified diet (25.6% crude protein) with different amounts of readily fermentable carbohydrate supplemented by addition of either starch or sucrose. The addition of starch to the diet produced no significant differences, but the addition of sucrose decreased ruminal ammonia level and increased both urinary excretion and apparent absorption of Mg (House and Mayland, 1976a). Grace and MacRae (1972) examined the effect of protein supplementation on net Mg absorption in cannulated sheep. No differences due to protein content of the diet were noted. Independent work by Moore et al. (1972a) and Horst and Jorgensen (1974) was published that showed increasing urinary excretion of Mg and decreasing fecal Mg when N intake was high. Based on the previous discussion of urinary excretion of Mg, it appears that N does not interfere with the absorption of Mg but perhaps interferes with its utilization within the animal's body (Fontenot, 1980). Wilcox and Hoff (1974) suggested that N fertilization of forages produced a situation where high concentrations of ammonia are produced in the rumen which decrease the availability of Mg. The literature reviewed tends to indicate that available energy is involved more than N intake on ruminal ammonia and Mg availability. Energy and its relationship to Mg metabolism will be discussed later in the section.

Minerals

K was first examined for its effect on hypomagnesemia and grass tetany because it, along with N, seemed in high concentration in wheat pasture where grass tetany was a problem. Lambs fed diets with N and K composition similar to wheat pasture during wheat pasture poisoning outbreaks had a 38% increase in fecal Mg excretion and lower Mg retention than lambs fed a control diet (Fontenot et al., 1960). Moore et al. (1972b) conducted metabolism studies designed to separate the effects of N and K intake on Mg metabolism. N had no effect other than a trend toward increased urinary excretion of Mg. The K caused an increase in fecal excretion of Mg and a decrease in serum Mg. Since the time that researchers have started investigating K and its role with Mg, results have been variable. Pearson et al. (1949) added 5% K to the diet of mature ewes and found no effect on serum Mg. Sims and Crookshank (1956) reported on experiments conducted on wheat pasture poisoning. They noted that N or K fertilization of wheat pastures resulted in no change in the chemical composition of the forage or the blood of cows and ewes. Muriate of potash was applied to pastures at rates of 0, 100 and 200 pounds per acre producing no significant differences between treatments (Hemingway et al., 1963; Ritchie and Hemingway, 1963). Odell et al. (1952) also reported no effect of K intake on Mg metabolism. Other researchers have found a depression of plasma and serum Mg values due to high dietary K and/or K fertilization of pastures (Kunkel et al., 1953; Bohman et al., 1969; Erdman et al., 1980). Suttle and Field (1967) in their studies on Mg in ruminant nutrition reported that 27 g of K placed in fistulated wethers on a hay and concentrate ration depressed serum Mg, decreased the urinary excretion of Mg and increased fecal outputs of Mg. The control group was then supplemented with K and a balance study repeated. Results of the second experiment were similar to the first except for a lack of change in serum Mg. In other metabolic investigations with dry cows (Field and Suttle, 1979) and wethers (House and Van Campen, 1971; Newton et al., 1972), a similar relationship developed. High K intakes lead to a lowering of urinary Mg excretion with an accompanying increase in fecal excretion of Mg. A discussion by Rook et al. (1958) indicates that K in excess of requirements interferes with the absorption of Mg from the alimentary tract. This helps to explain why Suttle and Field (1967) noted a depression of plasma Mg only in hypomagnesemic cows, and why the results of K's effect on Mg in serum and plasma have been variable. Studies have been conducted using the radioisotope Mg-28 injected into the bloodstream. From these experiments it has been shown that the increase in fecal output of Mg is due to the lack of absorption rather than the endogenous secretion of Mg in the gastrointestinal tract (House and Van Campen, 1971; Newton et al., 1972).

Kemp and t'Hart (1957) analyzed a large number of grass samples from pastures where tetany had and had not occured. They found that a ratio of K to Ca plus Mg content (K/Ca + Mg) was significantly correlated to the incidence of hypomagnesemic tetany. They also established a ratio of 2.2 as the value that delineated the tetany-producing potential of a pasture. Those results have been confirmed by Butler(1963).

Grass tetany has been associated with hypoglycemia and ketosis (Grunes et al., 1970). The secretion of insulin can be stimulated in dogs by infusions of K (Hiatt et al., 1972). Lentz et al. (1976) showed that intravenous injections of K in cattle increased the plasma levels of both K and insulin with a resulting drop in plasma glucose concentrations. They hypothesized that dietary K increased plasma K which stimulates release of insulin. This disturbance of energy metabolism leading to hypoglycemia or ketosis could play a role in the etiology of grass tetany. Ramsey et al. (1979) showed that cows switched from stored feed to lush spring pasture which is characteristically high in K, resulted in increased insulin and decreased Mg in the plasma.

To investigate effects of Ca and P intake of ruminants on Mg metabolism, Wise et al. (1963) fed different ratios of Ca to P to calves and found a low Ca, high P ration led to a decrease in serum Mg values. Pless et al. (1973) found that apparent absorption of Mg was depressed by high P only when Ca intake was high also.

There is evidence to show that Al may also be involved in grass tetany. Allen et al (1980), in field investigations of cattle which had died from grass tetany, found that the undigested particles in the rumen contained high levels of Al as did the pastures the animals were grazing. Later, in an *in vitro* study on the solubility of Mg in rumen fluid, ryegrass and buffer solution, increased Al resulted in a decrease in Mg solubility. They also found that 4,000 ppm of Al added to bermudagrass hay depressed serum Mg levels in steers. Contrary to these data, Valdivia *et al*. (1978) fed 1,200 ppm Al to steers with no effect on serum Mg.

Other minerals have been studied in relation to Mg utilization. The apparent absorption of Mg has been depressed in steers fed rations containing 1,000 ppm of Fe (Standish *et al*., 1971). A diet containing 3% Na (as salt) increased the apparent absorption of Mg in sheep (Mosley and Jones, 1974).

Organic Acids

Burt and Thomas (1961) found that 1% citric acid added to the diet of four- to six-month old calves caused a drop in serum Mg levels. Other researchers have reported similar results, sometimes with hypomagnesemic tetany resulting (Bohman *et al*., 1969; Scotto *et al*., 1971). DeGregorio *et al*. (1981) tested a hypothesis that potassium chloride and/or citric acid would increase the plasma clearance of Mg by lowering tubular reabsorption of Mg in the kidney. In both normal and hypomagnesemic sheep, intraruminal infusion of citric acid and citric acid plus potassium chloride caused reductions in the net tubular reabsorption of Mg with a corresponding increase in Mg excretion in the urine. *Trans*-aconitate has also been implied to have a role in grass tetany (Burau and Stout, 1965). There are reports in the literature which show that citric acid and trans-aconitic acid did not affect Mg metabolism (Kennedy, 1968; House and Van Campen, 1971).

Age and Physiological State of Animals

The age of an animal appears to play a role in Mg metabolism. Chicco et al. (1973) found that when sheep were fed a diet low in Mg, the older sheep reduced voluntary intake sooner and suffered from a more rapid decrease in plasma Mg. Field (1967) suggested that older animals are more susceptible to hypomagnesemia due to a reduction of intake of Mg. Hemingway et al. (1963) found that in ewes that had just lambed, the older the animal the greater the temporary fall in plasma Mg. Field (1962), in balance trials with sheep, used the same animals in consecutive years at ages four and five years. The sheep tended to have higher plasma Mg values and urinary excretion of Mg when the trials were done in the first year. The reason older animals appear to be more susceptible to hypomagnesemia is that bone Mg can be mobilized and translocated for use elsewhere in the body by young animals, but older animals lack this ability (Rook, 1961; Beckmann, 1977). Other physiological states of an animal will play a role in the metabolism of Mg. Late pregnancy and early lactation remove Mg from the body of an animal. The concentration of Mg in the milk was not affected by Mg status (Rook and Storry, 1962) and the plasma Mg of the fetus was not affected by the plasma Mg of its mother (Barlet et al., 1979).

Energy

It has been reported that during an outbreak of tetany, the ratio of N to energy in the pastures is increased (Metson et al., 1966; Mayland et al., 1974). House and Mayland (1976b) fed rations containing varied ratios of N to sucrose and found the rations with higher ratios had lower apparent digestibilities of Mg. It is logical to assume that increasing the intake of energy would lower this ratio and make dietary Mg more available. Lomba et al. (1968) found that diets containing more dry matter or energy resulted in dry cows having a lower Mg retention which was due to increased urinary excretion of Mg indicating increased absorption. Lactose added to hay fed to sheep increased the absorption of Mg in the stomach region and overall apparent absorption (Rayssiguier and Poncet, 1980). Madsen et al. (1976) found that glucose added to hay or vegetative grass did not influence apparent absorption of Mg in sheep but did increase plasma Mg values.

Miscellaneous

Environmental factors have an influence on grass tetany which often occurs on cold, wet mornings when animals are on a rapidly growing pasture (Allcroft, 1954). Kemp and t'Hart (1957) correlated the incidence of tetany with mean 24-hour temperature. They state:

> About five days after a rise in temperature from a level below 14°C there is an increase in the number of tetany cases, whereas on an average of five days after a fall in temperature there is a fall in the number of cases. Thus during the brief fluctuations a time-lag of five days is to be noted between action (change in temperature) and reaction (number of tetany cases), and we associate this time-lag with a change in the mineral composition of the pasture brought about by the temperature.

Kemp et al. (1966) completed a digestion trial in which animal fat was added to winter rations of lactating cows. The supplementary fat caused an increase in excretion of Mg in the feces, thus decreasing the apparent availability. Forages with high crude protein have been linked with hypomagnesemia and these forages also have a high level of fatty acids (Moore et al., 1972a; Horst and Jorgensen, 1974).

Fasting has been shown to result in aggravated hypomagnesemia sometimes leading to tetany (Herd, 1966). An increased water intake by way of a drench increased urinary outputs of Mg by 33%--an increase which resulted in a reduced retention of Mg (Field, 1967).

Vitamin D has been shown to increase the apparent availability of Mg in forages containing low amounts of crude protein (Stillings et al., 1964). Boling and Evans (1979) found that serum Mg levels were lowered by an injection of cholecalciferol with the effect lasting three days after the injection. Another hormone that has been investigated is parathyroid hormone, but Todd et al. (1962) found no response to injections of parathyroid extracts in dairy cows.

Species of forage consumed will affect the incidence of grass tetany. For example, legume pastures and hays have a lower incidence of grass tetany and a higher content of Mg (Fleming, 1973). Thill and George (1975) reported on nine cool-season grasses. They found reed canarygrass, orchardgrass, tall oatgrass and Canada sildrye to have K/Ca + Mg ratios greater than 2.2, while smooth bromegrass, Kentucky bluegrass, crested wheatgrass, tall wheatgrass and meadow foxtail have less than a 2.2 ratio.

IV. PREVENTION OF HYPOMAGNESEMIA AND/OR GRASS TETANY

Since the one common factor in grass tetany is hypomagnesemia, it seems that to prevent grass tetany an adequate intake of Mg must be assured to prevent hypomagnesemia (Bell, 1980). Most of the literature on prevention of grass tetany is involved with increasing the amount of Mg taken in by the animal. The four methods to be discussed are: fertilization of pastures with Mg in hopes of increasing the Mg content of the plant, foliar application of Mg in hopes that it will adhere to the outside of the plant, feed supplements and drenches and slow-releasing bullets.

Magnesium Pasture Fertilization

The advantage to fertilization of pastures to increase the Mg content of the herbage is that it insures that if the animals are grazing, then they are consuming enough Mg. A disadvantage is that in the United States soil types are such that high levels of fertilization are sometimes necessary to significantly change the composition of the plant (Grunes et al., 1970). It has been shown that the application of kieserite ($MgSO_4 \cdot H_2O$) to grasses and legumes and fed as hay will increase the Mg composition of forages and apparent retention of Mg by sheep (Reid et al., 1979). Thompson and Reid (1981) fertilized orchardgrass with 2,240 kg of Mg per hectare and found that the concentration of Mg in the forage was increased. When the forage was fed to sheep it increased apparent absorption and retention of Mg, and when fed to cattle resulted in an increase of plasma Mg values.

Mayland and Grunes (1974) found that 600 kg of Mg per hectare was necessary to increase the composition of wheat pasture to 0.20% Mg. One hundred and fifty kg N per hectare was equivalent to 200 kg of Mg per hectare with the two effects being additive. There was no effect from fertilization with calcined magnesium or magnesium limestone as reported by McConaghy et al. (1963).

Foliar Pasture Application

In work done at The University of Tennessee, Knoxville, it was shown that Mg applied as a magnesium oxide-bentonite slurry to fescue pasture and hay increased the Mg of the fescue samples. This effect was expected to last for about a month, provided no heavy rainfall was encountered (Reynolds, 1980). Magnesium oxide-bentonite-water slurries containing 20 to 30 kg of magnesium oxide per hectare have been recommended during an outbreak of grass tetany. This is an effective method to prevent grass tetany, but it is very dependent on severity of wind and rainfall (Wilkinson and Studemann, 1979). Rogers and Poole (1971) applied 33.6 kg of calcined magnesite per hectare to a spring pasture as a fine dust and reported that serum Mg levels were significantly increased in hypomagnesemic lactating beef cows consuming the pasture. They suggested that this method was more effective in preventing grass tetany than a one-to-one mixture of calcined magnesite molasses fed free choice.

Feed Supplements

This method is the most straightforward way to prevent grass tetany, but inadequate consumption of the supplement by some animals does pose a problem. In a review of prevention of grass tetany, Bell (1980) discusses this problem. He identifies three causes of inadequate consumption of a supplement. They are the lack of palatability of the supplement, unfamiliarity with the supplement and cow variation. Even with those problems, Mg supplementation has been shown to be effective in preventing grass tetany (Allcroft, 1954; Butler, 1963; Hansard et al., 1975). Moore et al. (1971) and Gerken and Fontenot (1967) compared supplementation with either magnesium oxide or dolomitic limestone. In both experiments, the ration supplemented with magnesium oxide had superior apparent absorption values of Mg. It also resulted in the steers having higher plasma Mg values. In addition, the feeding of dolomitic limestone resulted in a depression of the digestibilities of the energy constituents of the ration. Magnesium phosphate mixed in a concentrate has been shown to increase the Mg concentration in the plasma of cows over those receiving no supplement (Ritchie and Fishwick, 1977). Magnesium phosphate has been reported to yield similar results when compared with magnesium oxide (Fishwick and Hemingway, 1973). Favorable effects on Mg metabolism have been derived from providing a readily available source of energy (Madsen et al., 1976; Rayssiguier and Poncet, 1980). Bell (1980) reported that Fordyce et al. found no favorable effects from readily available carbohydrates when supplementing beef cow rations. Boling et al. (1979) compared supplementation of magnesium oxide or energy with control cows receiving no supplement. The magnesium oxide group had increased plasma Mg over controls, but the effects from the extra energy were variable. The energy alone could not prevent grass tetany with one cow in that group succumbing. McLaren et al. (1975) used two different supplements. A 1:1:1:4 mixture of magnesium oxide, salt, dry molasses and cottonseed meal and a magnesium chloride, liquid molasses mixture did increase the Mg in the plasma over controls, but the results were variable. Rogers and Poole (1976) were able to increase the plasma Mg of cows by adding magnesium acetate to the water supply. A disadvantage to this is that during periods of rainfall, cattle and sheep may not need to drink from the water with the supplement in it (Wilkinson and Studemann, 1979). Drenching animals with Mg compounds does not appear to be effective or practical (Bell, 1980).

Rumen alloy bullets have been used as a Mg supplement with varying results. The bullet itself is made up of 86% Mg, 12% Al and 2% Cu and weighted by Fe shot dispensed throughout the matrix of the bullet (Davey, 1968). Some researchers have reported satisfactory results (Davey, 1968; Smyth, 1969), while others have not (Foot et al., 1969; Kemp and Todd, 1970). One of the reasons for this discrepancy is that the decomposition of the bullet appears to have a wide variation among animals, making it a risky method for Mg supplementation (House and Mayland, 1976a).

V. TREATMENT OF GRASS TETANY

When an animal is seen in hypomagnesemic convulsions it is imperative to get a source of Mg into the body that will result in a quick rise in the plasma Mg. The success of the treatment depends primarily on how soon the Mg is administered. A lack of response may be due to the development of irreversible pathological changes and a time delay in repletion of the cerebrospinal fluid, which has been considered to have a role in grass tetany (Littledike and Cox, 1979).

Magnesium solutions may be given as injections intravenously, intramuscularly, subcutaneously or intraperitoneally. In recent years, another method for increasing plasma Mg has been used, that is, a magnesium chloride enema. Two routes will briefly be discussed.

Intravenous Solutions of Magnesium

Since a correlation has been noted between plasma Ca and plasma Mg values, an intravenous injection of Mg and Ca salts is recommended as a treatment. A solution of 200 to 300 ml of magnesium sulfate (20%) and 200 ml of a 50% solution have been used in the treatment of grass tetany (Blood and Henderson, 1960). Another intravenous solution that can be used is 250 g of calcium borogluconate and 50 g of magnesium borogluconate or sulfate added to one liter of water. The boron is added as a preservative. As with any intravenous infusion of Mg, care must be taken not to inject it too rapidly and the effect on the heart rate watched carefully (Merck, 1973).

Magnesium Enemas

It has been shown that Mg is absorbed in the large intestine (Grace *et al*., 1974). Meyer and Busse (1975) attempted to take advantage of this situation by placing a 30% solution of magnesium chloride in the large intestine of cattle and sheep via the rectum. They reported that plasma Mg of normal and hypomagnesemic animals was drastically increased. Bell *et al*. (1978) reported data that substantiates those results. In addition, this same group used the magnesium chloride enema to treat a cow showing symptoms of grass tetany with 0.65 mg Mg/dl plasma. Within 20 minutes the plasma Mg had risen to 2.22 mg/dl and the cow exhibited no outward signs of grass tetany. It was shown that a 35% solution of Epsom salts ($MgSO_4 \cdot 7H_2O$) administered as an enema had no significant effect on plasma Mg (Bell et al., 1978). Reynolds (1981) showed that an enema, as described by Bell et al. (1978), increased plasma Mg of young bull calves fed a semipurified diet and was effective in treating hypomagnesemic tetany in the same group of calves.

VI. METABOLIC MARKERS

In order to carry out metabolism studies with livestock under pasture situations, a method is needed for the indirect determination of dry matter consumption and fecal and urinary outputs. The following is a brief discussion of various metabolic markers which enable those determinations to be calculated.

Fecal

The ideal metabolic marker for fecal output determination should be insoluble in the gastrointestinal tract, indigestible, proceed through the tract at the same rate as ingested feed, have no undesirable physiological effects on the animal and be suitable for chemical analysis. There have been no markers found which meet all of these criteria (Church, 1976). Kotb and Luckey (1972), in a review on the use of markers in nutrition, place markers into three classifications:

elements, compounds and particulates. Elements refers to inert metals (heavy and rare earths), natural isotopes (K^{40}) and artificial isotopes (Ce^{144}). The compound classification is made up of metal oxides (Cr_2O_3) and mineral salts ($BaSO_4$) which are inorganic, plus natural dyes (chromogen), synthetic dyes (methylene blue) and other organic compounds such as cellulose and lignin. Particulates consist of polymers (polyethylene glycol), cells (yeast), charcoal, metal particles and others such as seeds and cotton string.

Some elements of the lanthanide group are advantageous because they appear to be indigestable by mammals (Bell, 1964) and become tightly bound to plant material (Ellis, 1968). The radioisotope that has received extensive attention is cerium-144 (Ce^{144}). It is a fisson product and only small quantities are absorbed from the gastrointestinal tract (Garner et al., 1960). Miller et al. (1972) found that when Ce^{144} was orally dosed in calves, 96% was excreted in the feces, and that the diurnal variation was minimal (Miller et al., 1967). Bell (1964) found only 0.03% of Ce^{144} was absorbed by sheep. Although its long half-life of 285 days makes it useful for short experiments, there is a problem with decontamination of equipment (Kotb and Luckey, 1972). Of the different inorganic compounds, chromium sequioxide has received a good part of the attention of researchers. It seems to closely meet all of the criteria for a good marker except that it has an uneven excretion rate (Brisson et al., 1957). Hopper et al. (1978) have developed equations to characterize these diurnal variations. Organic compounds are not widely used because many are not recovered completely in the feces. Lignin is considered to be indigestible, but it has been shown that losses of lignin occur in the gastrointestinal tract of the ruminant (Porter and Singleton, 1971). Polyethylene glycol is the most widely known and used particulate marker. It has been shown to travel through the ruminant's digestive tract intact and to be satisfactory in estimating fecal output in cattle. As with lignin, the main disadvantage of polyethylene glycol is its difficulty in achieving complete recovery in the feces (Kotb and Luckey, 1972).

Urine

Creatinine is largely the main index material used for the estimation of urinary output. Its use was first suggested by Folin (1905). Creatinine is produced as the end product of phosphocreatine degradation. In the kidney, creatinine is neither absorbed nor secreted against gradients as the glomerular filtrate is concentrated to form urine; therefore, in the normal healthy animal the daily excretion should be constant when fed a similar diet (Lehninger, 1975). Researchers have shown creatinine composition of the urine to be an effective method for the determination of urine volume (Butcher and Harris, 1957; Field, 1964; Kertz et al., 1970).

CHAPTER III

EXPERIMENTAL PROCEDURE

I. GENERAL DESIGN OF EXPERIMENT

A balance trial was conducted during the two years 1980-81 using beef cows in early lactation. Twenty-three cows (10 Herefords and 13 Angus) were used in the first year and 24 Angus cows were used the second. Cows were placed on one of two adjacent tall fescue pastures that had been fertilized and seeded in Fall of 1979. Both pastures were fertilized with N (112 kg/hectare), and P (169 kg/hectare). One pasture received no fertilization of K and the other, 224 kg/hectare (Treatments C and +K, respectively). The balance trials were conducted twice a year during late February and March, 1980 and 1981. Each trial was 14 days in length with 7 to 10 days separating the 2 trials each year.

II. MANAGEMENT AND PROCEDURE

Each year 24 were selected from a herd of 45 cows for this study which was conducted at Holston farm. All were lactating beef cows with calves ranging in age from one to seven weeks at their sides. The average weight for all cows was 466 kg; the average age was 10 years with a range of 5 to 15 years. The cows had been wintered on hay and stockpiled pasture at Holston and Blount farms in the first year and wintered entirely on hay at Holston farm in the second year.

In each trial, six cows were used on each treatment with a stocking rate of 1.25 cows/ha. One cow that had a bad temperament was removed from the control group in trial 2, year 1. Cows were allotted to treatment according to (in decreasing order of importance) plasma Mg, age of dam, weight of dam and age of calf.

Data Collected

Twice a day the cows were stanchioned in a metabolism stall as described by Ritter (1979). In year 1 the cattle were offered a pelleted feed containing 2.13 g of Cr and in the next year 2.00 g of Cr was administered by way of a gelatinous bolus. Since total collections of feces and urine were impractical on grazing animals, indirect measures of dry matter intake, fecal dry matter output and volume of urine excreted were utilized. The total dry matter consumption and total fecal dry matter output of the cows were estimated by the chromium sequioxide, acid-detergent-lignin (external-internal) indicator technique (Linkous et al., 1955). Creatinine ratios were used to determine the urinary volume excreted (Field, 1964). Calves were separated from their dams and allowed to nurse twice daily during a seven-day preliminary and seven-day collection period. During the collection period at 7:30 a.m. and 4:30 p.m., the calves were weighed before and after nursing and approximately 75 ml of milk was sampled midway during the nursing period. The milk was then frozen at -4^{o}C for later analysis. Milk production was determined using the calf-suckle technique. Grab samples of feces and urine were collected after voluntary defecation and urination. When samples were not obtained by that method, a plastic sleeve was used to collect fecal samples and cows were palpated between the udder and vulva to stimulate urination. Collections were made twice daily for the second seven days of the experimental period and then stored similar to the milk samples for analysis. Fecal dry matter output, forage dry matter intake and urine volume were estimated using equations 1, 2 and 3, respectively. Equations 1 and 2 are from Crampton and Harris (1969) and equation 3 is from Field (1964):

$$\text{Fecal DM output (g/day)} = \frac{\text{g Cr in feed X 100}}{\text{\% Cr in feces grab sample DM}} \quad (1)$$

$$\text{Forage DM intake (g/day)} = \frac{\text{(Fecal DM output X Fecal ADL)}}{\text{(\% ADL in forage)}} \quad (2)$$

$$\text{Urine volume (ml/day)} = \frac{\text{50.9 X WT (kg)}}{\text{Concentration of creatinine in grab urine sample}} \quad (3)$$

(50.9 mg of creatinine/kg BW was a constant determined in a previous experiment by Ritter [1979]).

Blood samples were taken via jugular veinipuncture using heparinized syringes and tubes, and the cows were weighed the first week in January and the first week in February to get a baseline prior to the beginning of the collection trials. Samples were taken on days 0, 3, 5, 8, 10 and 12 of the trial, and the blood was centrifuged immediately and plasma harvested. Plasma Mg and Ca were then analyzed. In year 1, plasma K determination was done after centrifuging, and in year 2 the plasma was frozen for subsequent K analysis.

III. CHEMICAL ANALYSIS

Plasma

Plasma samples were diluted to a known volume for stable mineral analysis of Mg, Ca and K. All mineral analyses were run using an Instrumentation Laboratory Model 551 Atomic Absorption/Atomic Emission Spectrophotometer, observing the standard procedure for the preparation of different samples.

Forage and Feces

Forage samples were collected by walking a diagonal through the pastures and sampling small amounts at selected intervals. This was done at the beginning of the preliminary period, and at the beginning and termination of the collection period.

Dry matter determinations (A.O.A.C., 1975) were made on forage and feces. Approximately 1 g of forage and fecal samples were taken and ashed at 600^{o}C for three hours, put into solution with 3 ml of 6 N HCl and diluted to a known volume for stable mineral analysis. Forage was also analyzed for acid-detergent-fiber and acid-detergent-lignin using the method of Van Soest and Vine (1967). Cr analysis was done on feces using the method of Williams et al. (1962). Forage samples were analyzed for N (crude protein) by the Kjeldahl method (A.O.A.C., 1975).

Urine and Milk

Urine and milk samples were thawed at room temperature. Five milliliters of urine or milk was ashed at 600^{o}C for three hours, and then put into solution with 3 ml of 6 N HCl. All samples were then diluted to a known volume for stable mineral analysis. In addition, determination of creatinine concentration in the urine was made using the Hycel Creatinine Test.[1]

All samples were analyzed for stable Mg, Ca and K using the above-prescribed methods. To prevent phosphate interferences in Mg and Ca analysis, .1% Lanthanum trioxide was added to each sample and .1% Cesium Chloride was added in K analysis to prevent K ionization.

IV. STATISTICAL ANALYSIS

The least-squares analysis of variances (Steel and Torrie, 1960) was used to analyze main effects, and treatment means were compared by a multiple range test (Sokal and Rohlf, 1969). A preliminary analysis showed that there was a significant year by trial interaction in the balance data which indicated the an analysis with year in the model was invalid. The model used was:

$$Y_{ijk} = u + t_i + k_j + e_{ijk}$$

where:

Y_{ijk} = dependent variables.

u = theoretical population mean.

t_i = effect of treatment, i = 1-2.

k_j = effect of trial, j = 1-2.

e_{ijk} = random error.

When statistical analysis was done using plasma values as dependent variables, effect of year and age of cow were included in

---

[1]Boehringer Mannhein, Houston, Texas.

the model. In another analysis, the cows were grouped into one of three discrete age classifications and plasma values analyzed.

Plasma mineral levels obtained at the six sampling dates during the 14-day trials were fitted to a trinomial regression on day. The regression equation used was:

$$\hat{Y} = a + b_1(\text{day}) + b_2(\text{day}^2) + b_3(\text{day}^3)$$

where:

$\hat{Y}$ = predicted dependent variables.

a = intercept.

day = day of trial.

b_1, b_2, b_3 = the partial regression coefficients for each dependent variable on the independent variable for day, day^2 and day^3, respectively.

CHAPTER IV

RESULTS AND DISCUSSION

I. BALANCE DATA

Analyses of forage obtained during collection periods are presented in Table 1. Fertilization of the pastures with K did not have an effect on the Mg concentration in the forages. Forage Ca was lower ($P < .05$) and K higher ($P < .01$) in the K-fertilized pasture. N content of the pasture was increased in both year 1 ($P < .10$) and year 2 ($P < .01$) by K fertilization. Acid-detergent-fiber of the pastures was not different between treatments.

Daily Mg balances for cows on each treatment in 1980 and 1981 are presented in Tables 2 and 3, respectively. The intake of Mg by the cows was higher for the control animals in both 1980 ($P < .05$) and 1981 ($P < .10$). Excretion of Mg in the feces and urine of the control cows was higher ($P < .01$) in year 1; while for year 2, there was no significant difference between treatments with respect to fecal excretion of Mg, although the K-fertilized group averaged higher. Urinary Mg excretion was similar to the first year, but the difference was not as great ($P < .05$). There was no significant difference between treatment groups for the excretion of Mg in the milk within year. In 1980, there was no significant difference for Mg balance, and in 1981 the control group had a more positive retention of Mg than the K-fertilized group ($P < .10$).

TABLE 1. FORAGE ANALYSIS DURING COLLECTION PERIODS.

Variable	Treatment: K-fertilized pasture 1980	K-fertilized pasture 1981	Control pasture 1980	Control pasture 1981
Mg[a]	2.35	1.86	2.35	1.97
Ca[ac]	9.66	4.52	12.35	5.16
K[ad]	30.30	23.50	22.62	16.22
CP[be]	22.60	20.07	20.69	17.92
ADF[b]	21.56	22.07	21.16	24.73

[a]Expressed as mg/g DM basis.

[b]Expressed as percent of DM.

[c]Difference between treatments within year (P<.05).

[d]Difference between treatments within year (P<.01).

[e]Difference between treatments for year 1 (P<.10) and year 2 (P<.01).

TABLE 2. MEANS OF DAILY Mg BALANCE IN GRAMS IN YEAR 1 (± S.E.M.).

Item	Treatment: Control pasture	Treatment: K-fertilized pasture
Intake[a]	9.69 ± .54	8.44 ± .46
Excretion		
Fecal[b]	7.88 ± .47	6.11 ± .29
Urinary[b]	.45 ± .05	.20 ± .03
Milk	.30 ± .01	.30 ± .01
Balance	1.05 ± .42	1.82 ± .31

[a]Means within this row are different (P<.05).

[b]Means within this row are different (P<.01).

TABLE 3. MEANS OF DAILY Mg BALANCE IN GRAMS IN YEAR 2 (± S.E.M.).

Item	Treatment	
	Control pasture	K-fertilized pasture
Intake[a]	10.39 ± .56	9.21 ± .33
Excretion		
Fecal	6.37 ± .44	7.11 ± .34
Urinary[b]	1.68 ± .27	1.10 ± .19
Milk	.24 ± .01	.24 ± .02
Balance[a]	2.10 ± .53	.76 ± .57

[a]Means within this row are different (P<.10).

[b]Means within this row are different (P<.05).

Daily Ca balances for cows on each treatment are presented for 1980 and 1981 in Tables 4 and 5, respectively. The Ca intake of control cows was higher ($P < .01$) than Ca intake of the +K group in both years. Fecal excretion of Ca was higher ($P < .01$) for the control cows in year 1, but there was no difference in year 2. In both years, the excretion of Ca in the urine of the +K group was lower ($P < .05$) than that of the controls. There was no difference between treatments within year in the excretion of Ca in the milk. All groups were in a positive retention of Ca, with no differences between treatments in year 1; however, the control cows had a higher ($P < .10$) positive retention of Ca in year 2.

Daily K balances for cows on each treatment are presented in Tables 6 and 7 for years 1 and 2, respectively. The cows on the K-fertilized pasture had higher average intakes of K; this difference was not significant ($P > .10$) in year 1 but was higher ($P < .001$) in year 2. The control cows excreted less ($P < .05$) K in their feces for both years. Urinary K excretion was higher in the +K group. This difference was not significant ($P > .10$) in 1980 but was higher than controls ($P < .001$) in 1981. The amount of K that was lost in the milk was not different between treatments within year. In 1980, the control treatment produced a positive retention value for K, while the K-fertilized pasture treatment had a negative retention value ($P < .05$). In 1981, both groups were in a positive retention of K, and they were not significantly different.

The mean intake of Mg by the cows was within or close to the range reported by Rook and Balch (1958). Although cows on both

TABLE 4. MEANS OF DAILY Ca BALANCE IN GRAMS IN YEAR 1 (± S.E.M.).

Item	Treatment: Control pasture	Treatment: K-fertilized pasture
Intake[a]	48.48 ± 2.67	34.71 ± 2.45
Excretion		
Fecal[a]	33.93 ± 1.76	23.25 ± 1.02
Urinary[b]	.31 ± .04	.22 ± .02
Milk	3.51 ± .14	3.64 ± .17
Balance	10.73 ± 2.12	7.60 ± 1.98

[a]Means within this row are different (P<.01).

[b]Means within this row are different (P<.05).

TABLE 5. MEANS OF DAILY Ca BALANCE IN GRAMS IN YEAR 2 (± S.E.M.).

Item	Treatment	
	Control pasture	K-fertilized pasture
Intake[a]	27.29 ± 1.22	22.36 ± .93
Excretion		
Fecal	17.48 ± .78	17.34 ± 1.04
Urinary[b]	3.61 ± .60	1.82 ± .33
Milk	2.97 ± .13	2.92 ± .16
Balance[c]	3.23 ± .91	.28 ± 1.38

[a]Means within this row are different (P<.01).

[b]Means within this row are different (P<.05).

[c]Means within this row are different (P<.10).

TABLE 6. MEANS OF DAILY K BALANCE IN GRAMS IN YEAR 1 (± S.E.M.).

Item	Treatment: Control pasture	Treatment: K-fertilized pasture
Intake	95.43 ± 3.38	105.61 ± 5.46
Excretion		
Fecal[a]	37.83 ± 4.68	55.12 ± 4.32
Urinary	44.68 ± 5.04	53.74 ± 1.98
Milk	4.64 ± .13	4.61 ± .26
Balance[a]	8.29 ± 4.13	-7.86 ± 3.84

[a]Means within this row are different (P<.05).

TABLE 7. MEANS OF DAILY K BALANCE IN GRAMS IN YEAR 2 (± S.E.M.).

Item	Treatment	
	Control pasture	K-fertilized pasture
Intake[a]	84.36 ± 2.85	116.42 ± 5.18
Excretion		
Fecal[b]	42.34 ± 3.60	55.61 ± 4.14
Urinary[a]	31.07 ± 2.96	52.87 ± 3.80
Milk	2.97 ± .15	3.13 ± .21
Balance	7.98 ± 3.46	4.82 ± 4.21

[a]Means within this row are different (P<.001).

[b]Means within this row are different (P<.05).

treatments in each year were consuming forage containing similar concentrations of Mg, the control cows had higher intakes ($P < .05$). This intake difference in year 1 was due to the fact that control cows consumed larger ($P < .05$) amounts of dry matter. In year 2, the increase was due to the increased Mg content of the control pasture, and to the fact that control cows consumed more dry matter, however neither was significantly higher.

The excretion of Mg in the feces as a percentage of intake is within the range reported by Kemp et al. (1961). The relationship between treatments for fecal and urinary excretion of Mg is similar to results reported by other researchers using sheep fed high K diets (Suttle and Field, 1967; House and Van Campen, 1971; Newton et al., 1972). Those researchers found that high K rations produced increased fecal excretion and decreased urinary excretion of Mg. This relationship was observed in year 2, and in year 1 urinary excretion was lower in the cows on the K-fertilized pasture, but fecal Mg excretion was not increased. Kemp et al. (1961) and Fisher et al. (1978) suggested that the excretion of Mg in the urine is an excellent indicator of the absorption of Mg. The excretion of Mg in the milk was the same for cows on both treatments within year. This agrees with the hypothesis of Rook and Storry (1962), who suggested that the cow will produce milk with the same concentration of Mg regardless of Mg intake. Wilson (1980) has reported results that suggest that an inadequate absorption of Mg will reduce milk production. There were no significant differences in milk production between treatments; although the cows in 1980 produced more ($P < .001$) milk than cows in 1981.

The Mg retention of cows on both pasture treatments was positive. It is difficult to draw conclusions from balance values in this study because all values were estimated from different techniques. The retention values include a summation of all the errors from those calculations.

Ca intake of the control cows was higher than that of cows grazing K-fertilized pasture. This difference was due to an increased ($P < .05$) dry matter intake of control cows in year 1 and increased ($P < .05$) pasture composition of Ca of the control pasture in both years. This increased intake occurred because in year 1 when the pasture was first established, there was a heavy infestation of weeds of the brassica family. These weeds are characterized by a high content of Ca and other minerals (J. H. Reynolds, personal communication).

It appears that K fertilization of fescue pastures in this region causes a reduction in absorption of Mg from the alimentary tract. Based on results in work with sheep, it is felt that the reduced Mg absorption is due to high K intakes by the cows on the K-fertilized pasture; but the higher N intake, and lower Ca and dry matter intake of the +K group must also be considered.

II. PLASMA DATA

Preliminary analysis of plasma data by year indicated that it would be valid to pool the data across years. Changes in plasma Mg levels over time are shown in Figure 1 and Figure 2 for 1980 and 1981, respectively. Day 1 corresponds to the first day the cows

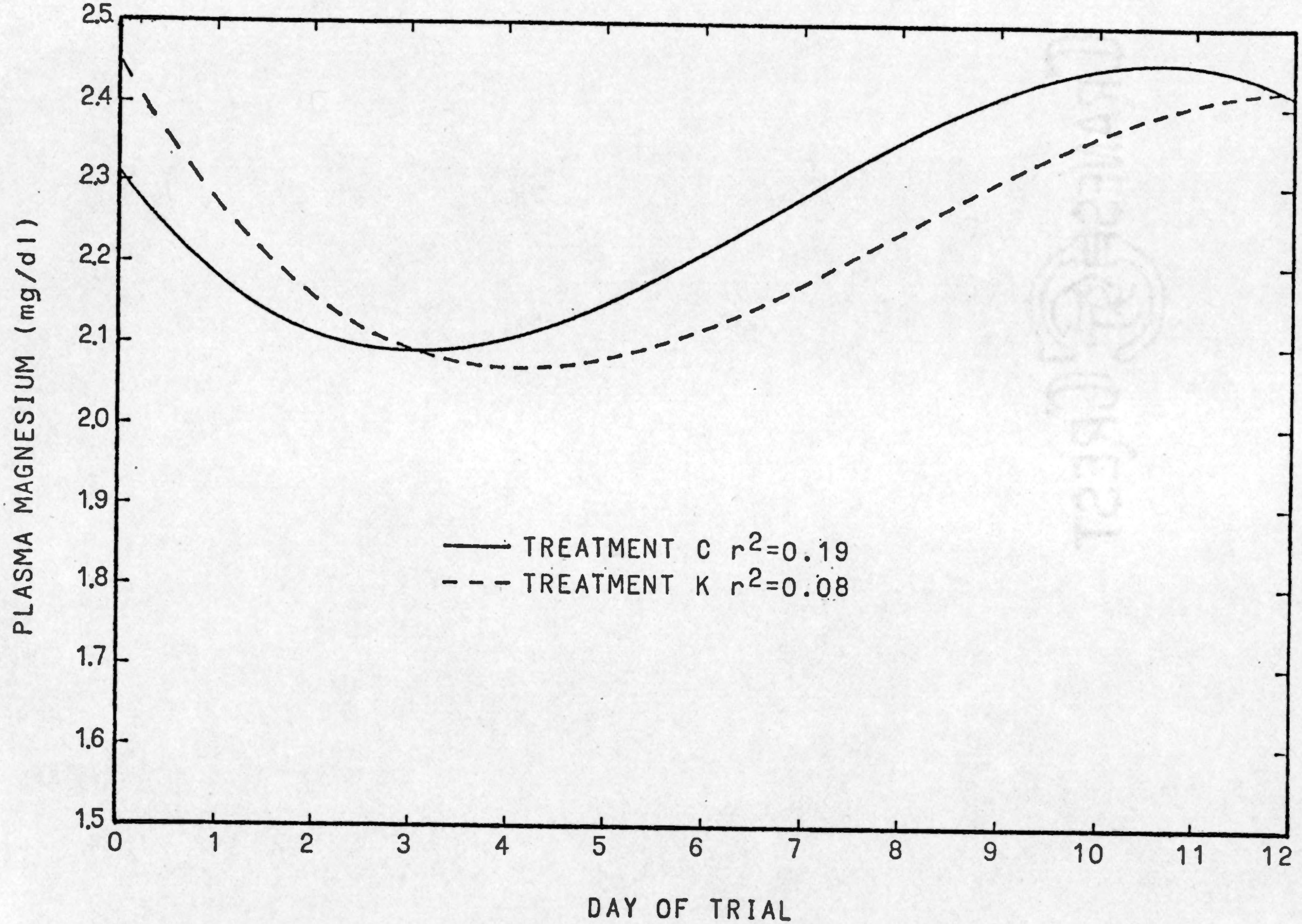

Figure 1. Trinomial regression curves for plasma Mg in year 1. (C = control and K = +K)

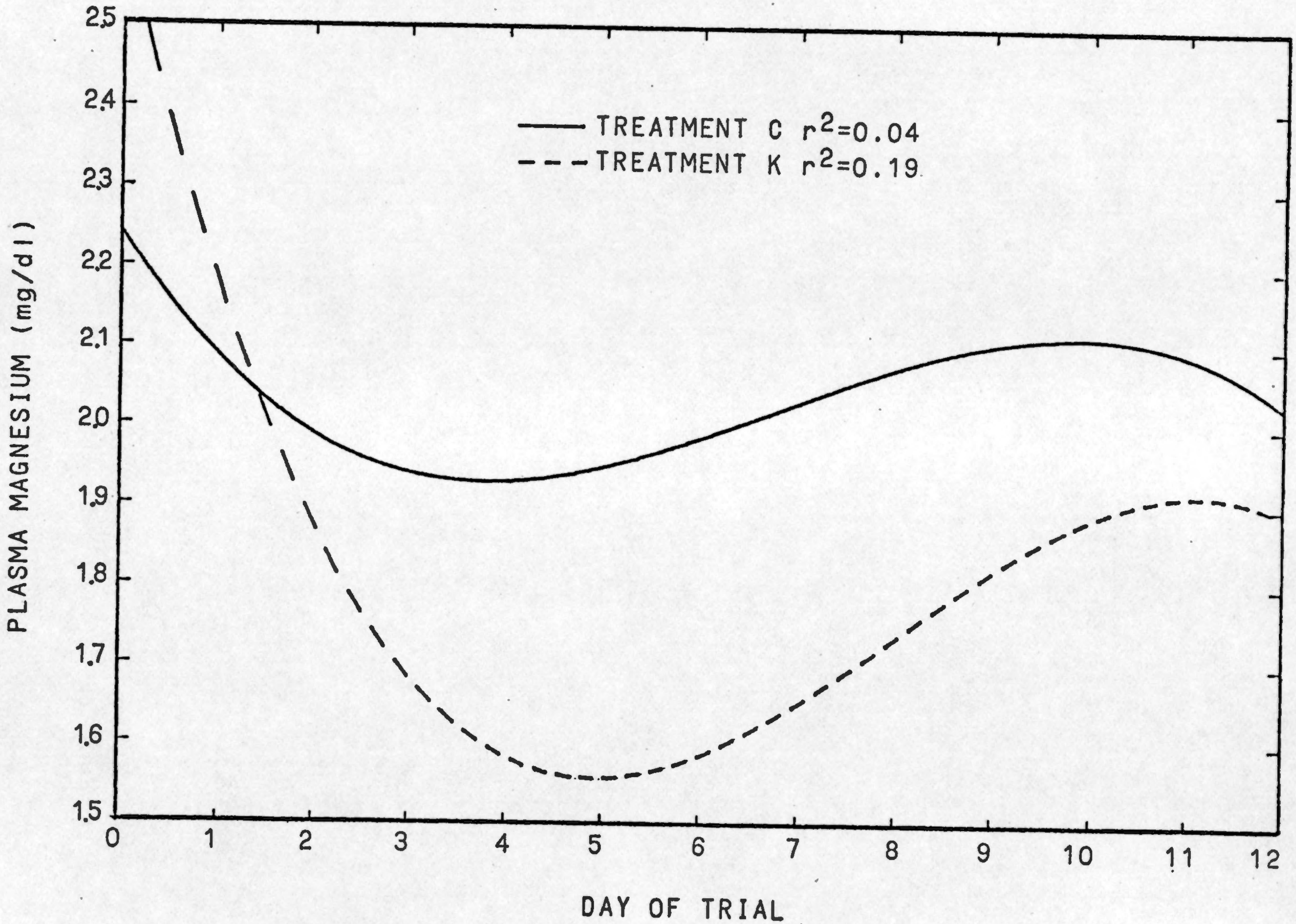

Figure 2. Trinomial regression curves for plasma Mg in year 2. (C = control and K = K+)

were placed on the experimental pastures, and day 12 was the last day of the trial that a blood sample was taken. In both years the predicted plasma Mg values were higher for cows allotted to the K-fertilized pasture than that of cows allotted to the non-fertilized control pasture. Early in both trials, plasma Mg of cows on both treatments dropped with the cows in the +K group reaching the lowest plasma Mg value in both years on day 5 and remained lower than the control group throughout the remainder of the trial. Mean plasma Mg levels are presented in Table 8. These data support what the regression curves show; that is, the cows on the K-fertilized pasture had depressed plasma Mg values compared with cows on the control pasture. These differences were significant on day 5 ($P < .05$) and on day 8 ($P < .10$). Table 9 shows the effect of age of cows on plasma Mg. Cows were divided into three groups which ranged in age as follows: Group 1: 5-9 years, Group 2: 10-12 years and Group 3: 13-15 years. At the start of the trials the older the cow, the lower the plasma Mg ($P < .05$). This was the trend throughout the trial, but the differences decreased as the trial progressed. At no time did mean values indicate that the entire treatment group was hypomagnesemic, although individual animals were.

In year 1 there were four cows considered hypomagnesemic (< 1.50 mg Mg/dl plasma). One cow in the control group had a plasma Mg value of 1.35 mg/dl and two cows in the +K group had values of 1.41 and 1.46 mg/dl. These levels occurred on day 3 of the trial and by day 5 the values had risen above 1.50. The plasma Mg level of the other cow on the K-fertilized pasture dropped to a value of .81 mg/dl

TABLE 8. EFFECT OF K FERTILIZATION ON COW PLASMA Mg (mg/dl).

Pasture treatment	Day 0	3	5[a]	8[b]	10	12
Control	2.15	1.91	2.12	2.26	2.20	2.24
(± SEM)	.05	.07	.08	.08	.06	.07
+K	2.24	1.89	1.80	2.06	2.06	2.18
(± SEM)	.05	.06	.08	.08	.06	.07

[a]Means within this column are different ($P<.05$).

[b]Means within this column are different ($P<.10$).

TABLE 9. EFFECT OF AGE OF COW ON PLASMA Mg (mg/dl).

Age[a]	Day 0	3	5	8	10	12
1	2.46[b]	2.15[b]	2.19[b]	2.17[b]	2.28[b]	2.29[b]
2	2.19[c]	1.81[c]	1.87[c]	2.00[b]	2.08[bc]	2.21[b]
3	1.86[d]	1.74[c]	1.87[c]	2.04[b]	2.00[c]	2.08[b]

[a]Group 1, 5 - 9 years; Group 2, 10 - 12 years; Group 3, 13 - 15 years.

[b,c,d]Means with different superscripts within columns are different (P<.05).

on day 5 and did not rise above 1.50 mg/dl until day 10 of the trial. There were more cows hypomagnesemic in year 2, but most were only borderline with plasma Mg values between 1.35 and 1.50 mg/dl. Four cows on the control treatment had less than 1.50 mg Mg/dl plasma during the trial, compared with six cows on the K-fertilized pasture treatment with low values. Those four control cows had plasma Mg values that ranged from 1.41 to 1.49 mg/dl at the lowest levels. Cows 9758 and 2590, both on K-fertilized pasture, had .64 and .63 mg Mg/dl plasma, respectively, on day 5 of the trial. Both were hypomagnesemic throughout the trial except for the baseline value. At no time were outward symptoms of grass tetany observed in the cows in either year.

Changes in plasma Ca levels over time for year 1 and year 2 are presented in Figures 3 and 4, respectively. The relationship over time is similar to that seen for plasma Mg, that is, plasma Ca values dropped in cows at the beginning of the trial and then increased near the end of the trial. Mean plasma Ca levels are presented in Table 10. There were no significant differences between cows on either pasture treatment. Table 11 shows the effect of age of cows on plasma Ca. The five to nine year old cows tended to have higher plasma Ca levels throughout the trial with differences being higher ($P < .05$) than one or both of the older groups on days 0, 8, 10 and 12 of the trial.

Changes in plasma K levels over time for year 1 and year 2 are presented in Figures 5 and 6, respectively. Table 12 contains the mean plasma K levels. With the exception of day 3, cows on the

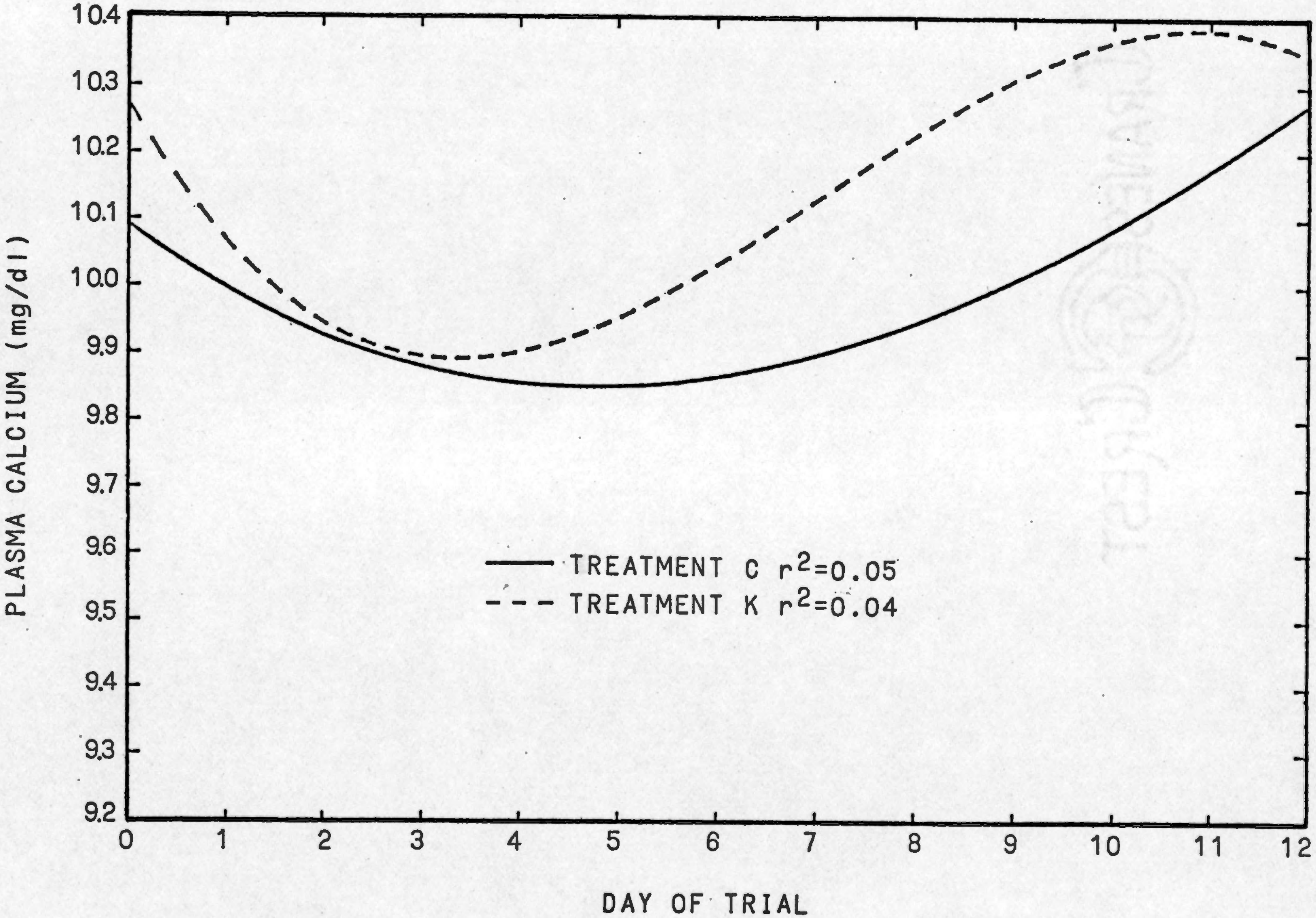

Figure 3. Trinomial regression curves for plasma Ca in year 1. (C = control and K = K+)

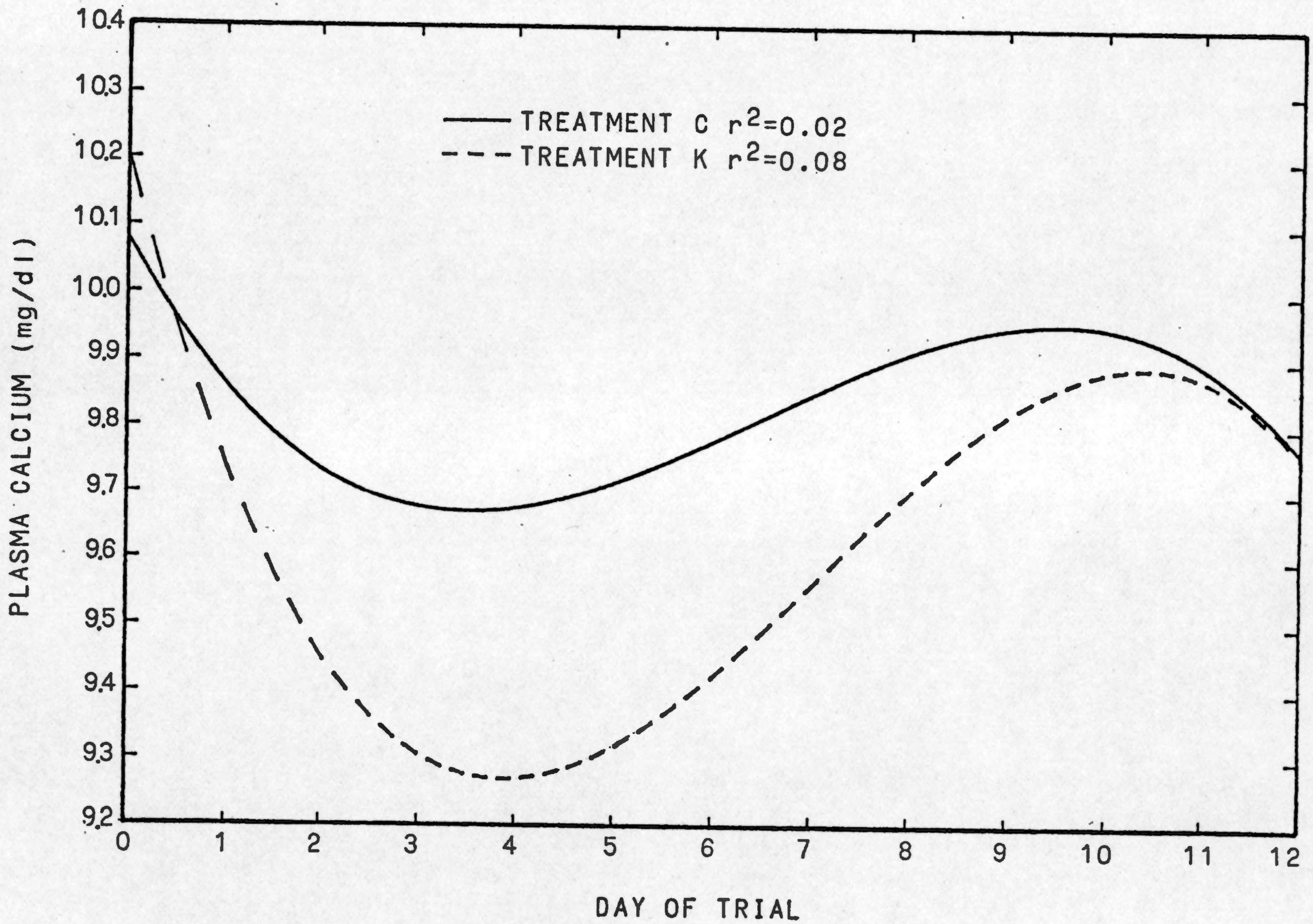

Figure 4. Trinomial regression curves for plasma Ca in year 2. (C = control and K = K+)

TABLE 10. EFFECT OF K FERTILIZATION ON COW PLASMA Ca (mg/dl).

Pasture treatment	Day 0	3	5	8	10	12
Control	9.90	9.83	9.88	9.61	10.34	9.90
(± SEM)	.10	.17	.15	.09	.14	.11
+K	9.88	9.67	9.74	9.59	10.50	9.95
(± SEM)	.10	.17	.14	.09	.14	.10

TABLE 11. EFFECT OF AGE OF COW ON PLASMA Ca (mg/dl).

Age[a]	Day					
	0	3	5	8	10	12
1	10.25[b]	10.04[b]	10.05[b]	9.72[b]	10.59[b]	10.18[b]
2	9.78[c]	9.62[b]	9.73[b]	9.62[b]	10.50[bc]	9.86[c]
3	9.62[c]	9.65[b]	9.65[b]	9.41[c]	10.01[c]	9.71[c]

[a]Group 1, 5 - 9 years; Group 2, 10 - 12 years; Group 3, 13 - 15 years.

[b,c]Means with different superscripts within columns are different (P<.05).

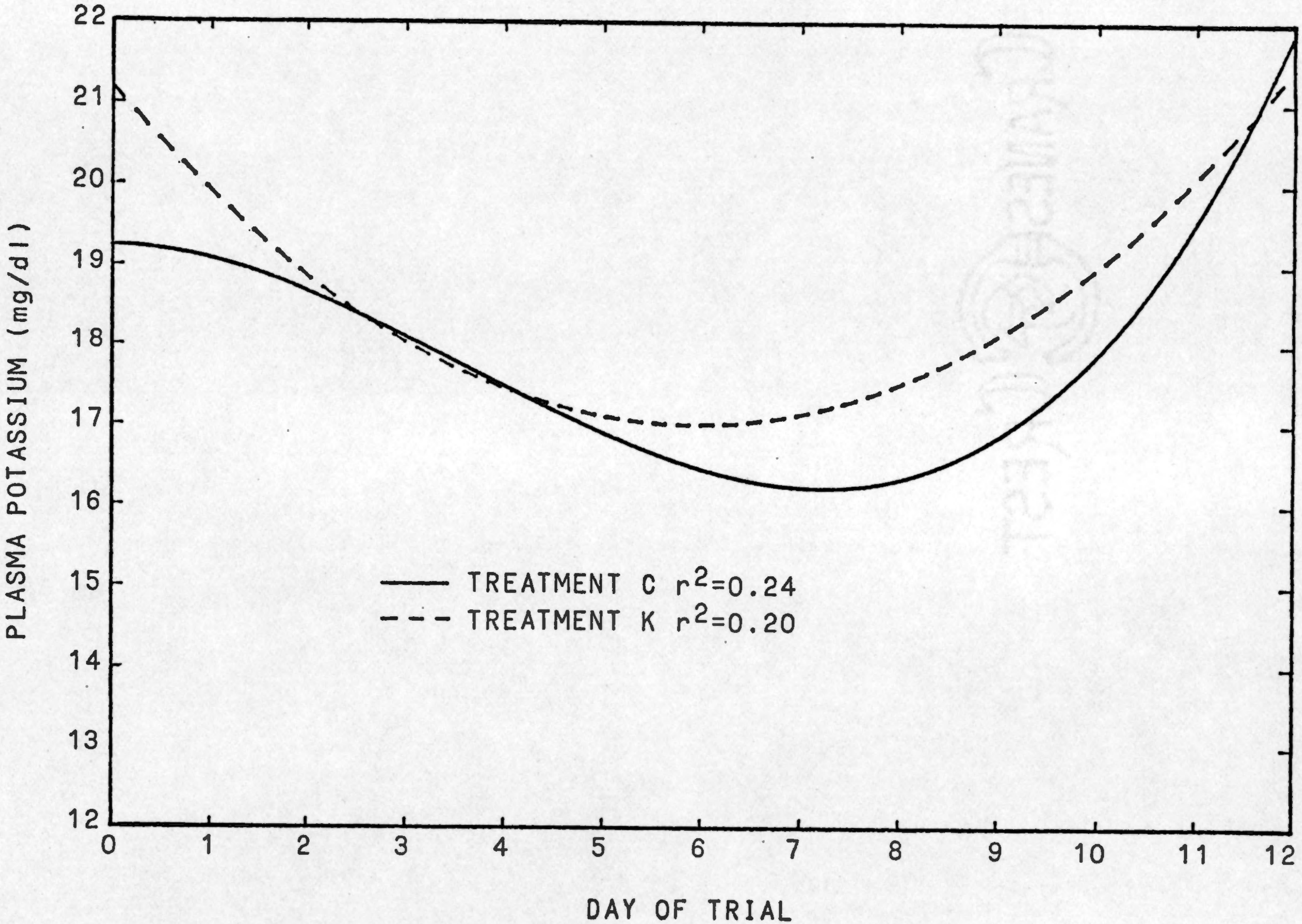

Figure 5. Trinomial regression curves for plasma K in year 1. (C = control and K = K+)

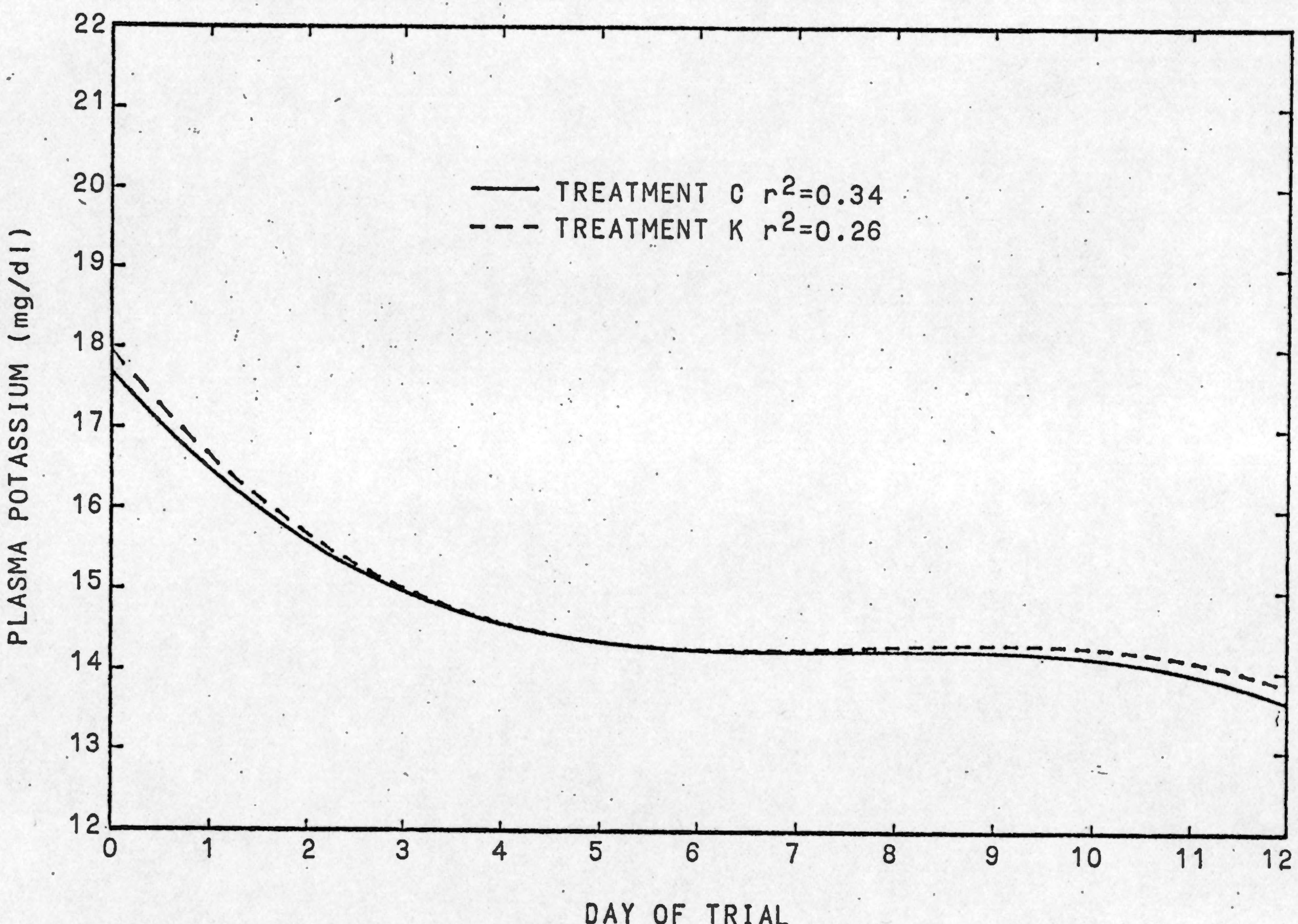

Figure 6. Trinomial regression curves for plasma K in year 2. (C = control and K = K+)

TABLE 12. EFFECT OF K FERTILIZATION ON COW PLASMA K (mg/dl).

Pasture treatment	Day					
	0	3	5	8[a]	10	12
Control	17.89	16.17	15.88	15.49	15.71	17.92
(± SEM)	.64	.42	.34	.28	.31	.68
+K	18.56	15.96	16.00	16.60	15.81	17.94
(± SEM)	.59	.41	.33	.27	.30	.67

[a]Means within this column are different (P<.01).

K-fertilized pasture tended to have higher plasma K values, with the difference being significant ($P < .01$) on day 8. Table 13 shows the effect of age of cows on plasma K.

The depletion of plasma Mg of the cows in each treatment appears to be due to the cows consuming a young, rapidly growing pasture. Ramsey et al. (1979) reported results that agree with this hypothesis. The repletion toward the end of the trial may be due to hormonal readjustment by the cows, in which some are becoming hypomagnesemic. The changes in forage composition that resulted from K-fertilization may have interfered with Mg utilization. Plasma Mg was lower for the +K group and this corresponds with the decreased urinary excretion of Mg by the same group. This decrease in Mg utilization is reflected by the fact that nine cows on the K-fertilized pasture had plasma Mg values of less than 1.50 mg/dl, compared with only five cows on the control pasture.

The younger cows tended to have higher plasma Mg values at the beginning of the trial. Rook (1961) suggests that younger animals have a greater ability to mobilize bone Mg for use elsewhere in the body. The differences due to age were not as great toward the end of the trial. One explanation for this is that if plasma Mg is under hormonal control, the older animals, with lower plasma Mg at the beginning of the trial, could adjust to the lush, spring grasses more rapidly than their younger counterparts, with respect to the content of Mg in their plasma.

The level of plasma Ca for the cows on pasture is within the range reported by Hyde et al. (1977). Plasma Ca was not affected by

TABLE 13. EFFECT OF AGE OF COW ON PLASMA K (mg/dl).

Age[a]	Day					
	0	3	5	8	10	12
1	19.55[b]	16.14[b]	16.79[b]	16.33[b]	16.52[b]	19.16[b]
2	18.16[bc]	16.20[b]	15.65[c]	15.81[b]	15.58[c]	17.39[c]
3	16.84[c]	15.69[b]	15.40[c]	16.17[b]	15.09[c]	17.42[c]

[a]Groups 1, 5 - 9 years; Group 2, 10 - 12 years; Group 3, 13 - 15 years.

[b,c]Means with different superscripts within columns are different ($P<.05$).

the K fertilization of fescue pasture. All plasma K values are within the range reported by Grunes et al. (1970). Since the cows in the +K group were consuming pasture with a higher K content, it is logical that they tended to have a slightly higher content of plasma K.

CHAPTER V

SUMMARY

Balance trials were conducted in late February and March during two years to study the effect of K fertilization of tall fescue pasture on the metabolism of Mg, Ca and K in lactating beef cows. Samples of forage, feces, milk and urine were collected and analyzed. Plasma mineral values of the cows were monitored.

Fertilization of the pastures with K had no effect on the Mg concentration in the forage, but decreased ($P < .05$) Ca concentration and increased ($P < .01$) K concentration. N content of the K-fertilized pasture was increased both in year 1 ($P < .10$) and year 2 ($P < .01$).

Cows on the non K-fertilized control pasture had a higher intake of dry matter in year 1 ($P < .05$) but the difference was not significant in year 2. In year 1, the control group of cows had a higher intake ($P < .05$) of Mg along with increased excretion of Mg in the feces ($P < .01$) and urine ($P < .01$). The cows on the control pasture in year 2 also had higher ($P < .10$) intakes of Mg and urinary Mg was increased ($P < .05$). Results indicate that K-fertilization of fescue pasture causes changes in the composition of the forage which interfere with the absorption of Mg from the alimentary tract.

Ca intake was higher ($P < .01$) in the control group of cows. Fecal excretion of Ca was higher ($P < .01$) for cows on the control pasture in year 1. In both years, excretion of Ca in the urine was lower ($P < .05$) for the cows on the K-fertilized pasture. Results from K analyses were highly variable. Excretion of Mg, Ca and K in the milk maintained constant levels across treatments.

Plasma Mg of the cows on the K-fertilized pasture were depressed throughout the trial. Five cows in the control group became hypomagnesemic (< 1.50 Mg/dl plasma) compared with nine on K-fertilized pasture. Although no outward clinical symptoms of grass tetany were observed, it appears that the application of K to fescue pastures could result in an increased incidence of hypomagnesemic tetany. Plasma Ca was not affected by treatment. The increased K content of the K-fertilized pasture resulted in a trend for higher plasma K values in cows on the aforementioned pasture.

LITERATURE CITED

LITERATURE CITED

Aikawa, J. K. 1971. The Relationship of Magnesium to Disease in Domestic Animals and Humans. Charles C. Thomas, Springfield, IL.

Allcroft, R. 1954. Hypomagnesemia in cattle. Vet. Rec. 66:517.

Allen, V. G., D. L. Robinson and F. G. Hembry. 1980. Aluminum in the etiology of grass tetany. Abstr. from A.S.A.S., Hot Springs, AK.

Ammerman, C. B., C. F. Chicco, J. E. Moore, P. A. Van Walleghem and L. R. Arrington. 1971. Effect of dietary magnesium on voluntary feed intake and rumen fermentations. J. Dairy Sci. 54:1288.

A.O.A.C. 1975. Official Methods of Analysis (12 ed.). Association of Official Analytical Chemists, Washington, D.C.

Baker, R. M., R. C. Boston, T. E. Boyes and D. D. Leaver. 1979. Variations in the response of sheep to experimental magnesium deficiency. Res. Vet. Sci. 26:129.

Barlet, J. P., M. J. Davicco, M. Moncaup and J. Lefaivre. 1979. Foetal plasma magnesium levels during maternal hypo- or hypermagnesaemia in ewes. Br. J. Nutr. 42:559.

Bartlett, S., B. B. Brown, A. S. Foot, M. J. Head, C. Line, J. A. F. Rook, S. J. Rowland and G. Zundel. 1957. Field investigations into hypomagnesaemia in dairy cattle, with particular reference to changes in the concentration of blood constituents during the early grazing period. J. Agri. Sci. 49:291.

Beckmann, G. E. 1977. Magnesium depletion and repletion effects on magnesium, calcium and potassium in bone, muscle, cerebrospinal fluid and plasma of sheep. Master's thesis, The University of Tennessee, Knoxville, Tennessee.

Bell, M. C. 1964. Effect of Ce^{144}-Pr^{144} intestinal irradiation of sheep on Sr^{89} and Ca^{45} metabolism. Proc. 6th Internat. Cong. Nutr., Edinburgh, 1963, Livingstone, p. 529 (Abstr.).

Bell, M. C. 1980. Prevention of grass tetany. Proc. of the John Lee Pratt Internat'l Symp. on Role of Magnesium in Animal Nutrition, Blacksburg, VA (In Press).

Bell, M. C., J. A. Oluokun, N. Ramsey and G. E. Beckmann. 1978. Magnesium treatment of cows for grass tetany. Feedstuffs 50:24.

Ben-Ghedalia, D., H. Tagari, S. Zamwel and A. Bondi. 1975. Solubility and net exchange of calcium, magnesium and phosphorus in digesta flowing along the gut of the sheep. Br. J. Nutr. 33:87.

Blood, D. C. and J. A. Henderson. 1960. Veterinary Medicine. Williams and Wilkins Co., Baltimore, MD.

Bohman, V. R., A. L. Lesperance, G. D. Harding and D. L. Grunes. 1969. Induction of experimental tetany in cattle. J. Anim. Sci. 29:99.

Boling, J. A. and J. M. Evans. 1979. Serum Ca, P and Mg levels in steers injected intramuscularly or intravenously with cholecalciferol. Abstr. from A.S.A.S., New Orleans, LA.

Boling, J. A., T. O. Okolo, N. Gay and N. W. Bradley. 1979. Effect of magnesium and energy supplementation on blood constituents of fall-calving beef cows. J. Anim. Sci. 48:1209.

Brisson, G. J., W. J. Pigden and P. E. Sylvester. 1957. Effect of frequency of administration of chromic oxide on its fecal excretion pattern by grazing cattle. Can. J. Anim. Sci. 37:90.

Brown, R. C., A. D. Care and D. W. Pickard. 1978. Magnesium absorption from the rumen of sheep. J. Physiol. 276:62.

Burau, R. and P. R. Stout. 1965. Trans-aconitic acid in range grasses in early spring. Science 150:766.

Burt, A. W. A. and D. C. Thomas. 1961. Dietary citrate and hypomagnesemia in the ruminant. Nature 192:1193.

Butcher, J. E. and L. E. Harris. 1957. Creatinine as an index material for evaluating ruminant nutrition. J. Anim. Sci. 16:1020.

Butler, E. J. 1963. The mineral element content of spring pasture in relation to the occurrence of grass tetany and hypomagnesaemia in dairy cows. J. Agri. Sci. 60:329.

Care, A. D. 1967. Magnesium homeostasis in ruminants. World Rev. Nutr. Diet. 8:127.

Care, A. D. and A. T. Van't Klooster. 1965. In Vivo transport of magnesium and other cations across the wall of the gastrointestinal tract of sheep. J. Physiol. 177:174.

Chamberlain, C. C. and W. Burroughs. 1962. Effect of fluoride, magnesium and manganese ions on in vitro cellulose digestion by rumen microorganisms. J. Anim. Sci. 21:428.

Chicco, C. F., C. B. Ammerman and P. E. Loggins. 1973. Effect of age and dietary magnesium on voluntary feed intake and plasma magnesium in ruminants. J. Dairy Sci. 56:822.

Chicco, C. F., C. B. Ammerman, W. G. Hillis and L. R. Arrington. 1972. Utilization of dietary magnesium by sheep. Am. J. Physiol. 222: 1469.

Church, D. C. 1976. Digestive Physiology and Nutrition of Ruminants-Volume 1. (2nd ed.). Oxford Press, Portland, OR.

Crampton, E. W. and L. E. Harris. 1969. Applied Animal Nutrition (2nd ed.). W. H. Freeman and Co., San Francisco, CA.

Davey, L. A. 1968. Magnesium alloy bullets for grazing sheep. Vet. Rec. 82:142.

DeGregorio, R. M., S. Kaentrakoon, R. E. Tucker and G. E. Mitchell, Jr. 1981. Renal clearance of magnesium in sheep given citric acid and (or) potassium chloride. J. Anim. Sci. 52:895.

Ellis, W. C. 1968. Dysprosium as an indigestable marker and its determination by radioactive analysis. J. Agri. Food Chem. 16:220.

Erdman, R. A., R. W. Hemken and L. S. Bull. 1980. Effect of dietary calcium and sodium on potassium requirement for lactating dairy cows. J. Dairy Sci. 63:538.

Field, A. C. 1962. Studies on magnesium in ruminant nutrition 4. Balance trials on sheep given different amounts of grass nuts. Brit. J. Nutr. 16:99.

Field, A. C. 1964. Studies om magnesium in ruminant nutrition 5. The indirect determination of the intake of magnesium, calcium and potassium by the grazing cow. Br. J. Nutr. 18:357.

Field, A. C. 1967. Studies on magnesium in ruminant nutrition 7. Excretion of magnesium, calcium, potassium and faecal dry matter by grazing sheep. Br. J. Nutr. 21:631.

Field, A. C. and C. S. Munro. 1977. The effect of site and quantity on the extent of absorption of Mg infused into the gastro-intestinal tract of sheep. J. Agri. Sci. 89:365.

Field, A. C., J. W. McCallum and E. J. Butler. 1958. Studies on magnesium in ruminant nutrition. Br. J. Nutr. 12:433.

Field, A. C. and N. F. Suttle. 1979. Effect of high potassium and low magnesium intakes on the mineral metabolism of monozygotic twin cows. J. Comp. Path. 89:431.

Fisher, D. D., L. L. Wilson, P. C. Lootens and R. W. Scholz. 1978. Grass tetany in beef cows on low magnesium pastures. Sci. in Agri. 25:10.

Fishwick, G. A. and R. G. Hemingway. 1973. Magnesium phosphates as dietary supplements for growing sheep. J. Agri. Sci. 81:441.

Fleming, G. A. 1973. Mineral composition of herbage. p. 529. In G. W. Butler and R. W. Bailey (ed.). Chemistry and Biochemistry of Herbage. Vol. 1. Academic Press, London and New York.

Folin, O. 1905. Laws governing the chemical composition of urine. Amer. J. Physiol. 13:66.

Fontenot, J. P., R. W. Miller, C. K. Whitehair and R. MacVicar. 1960. Effect of a high-protein high-potassium ration on the mineral metabolism of lambs. J. Anim. Sci. 19:127.

Fontenot, J. P. 1980. Magnesium in ruminant nutrition. In Magnesium in Animal Nutrition. National Feed Ingredients Association, West Des Moines, IA.

Foot, A. S., J. Connell, R. A. Allcroft and M. K. Lloyd. 1969. Magnesium bullets. Vet. Rec. 84:467.

Forbes, A. J. 1972. Clinical cases of seasonal grass tetany in lactating beef cows. Aust. Vet. J. 48:444.

Garces, M. A. and J. L. Evans. 1971. Calcium and magnesium absorption in growing cattle as influenced by age of animal and source of dietary nitrogen. J. Anim. Sci. 32:789.

Garner, R. J., H. G. Jones and L. Ekman. 1960. Fisson products and the dairy cow 1. The fate of orally administered cerium-144. J. Agri. Sci. 55:107.

Gerken, H. J. and J. P. Fontenot. 1967. Availability and utilization of magnesium from dolomitic limestone and magnesium oxide in steers. J. Anim. Sci. 26:1404.

Grace, N. D. and J. C. MacRae. 1972. Influence of feeding regimen and protein supplementation on the sites of net absorption of magnesium in sheep. Br. J. Nutr. 27:51.

Grace, N. D., M. J. Ulyatt and J. C. MacRae. 1974. Quantitative movement of fresh herbage by sheep II. The movement of magnesium, calcium, phosphorus, potassium, and sodium in the digestive tract. J. Agri. Sci. 82:321.

Grunes, D. L., P. R. Stout and J. R. Brownell. 1970. Grass tetany of ruminants. Adv. Agron. 22:331.

Hall, R. F. and R. A. Reynolds. 1972. Concentrations of magnesium and calcium in plasma of Hereford cows during and after hypomagnesemic tetany. Am. J. Vet. Res. 33:1711.

Hansard, S. L., F. C. Madsen, G. M. Merriman and J. B. McLaren. 1975. Tennessee grass-fed cattle need supplementary magnesium. Tenn. Farm Home Sci. 93:36.

Hemingway, R. G., N. S. Ritchie, A. R. Rutherford and G. M. Jolly. 1963. Effects of potassium fertilizers, age of ewe, and small magnesium supplementation on blood magnesium and calcium levels of lactating ewes. J. Agri. Sci. 60:307.

Herd, R. P. 1966. Fasting in relation to hypocalcemia and hypomagnesaemia in lactating cows and ewes. Aust. Vet. J. 42:269.

Hiatt, N., M. B. Davidson and G. Bononis. 1972. The effect of potassium chloride infusion on insulin secretion in vivo. Horm. Metab. Res. 4:64.

Hopper, J. T., J. W. Holloway and W. T. Butts. 1978. Animal variation in chromium sequioxide excretion patterns of grazing cows. J. Anim. Sci. 46:1096.

Horst, R. L. and N. A. Jorgensen. 1974. Effect of ammonium chloride on nitrogen and mineral balance in lactating and nonlactating goats. J. Dairy Sci. 57:683.

House, W. A. and H. F. Mayland. 1976a. Magnesium utilization in wethers fed diets with varying ratios of nitrogen to readily fermentable carbohydrate. J. Anim. Sci. 43:842.

House, W. A. and H. F. Mayland. 1976b. Magnesium and calcium utilization in sheep treated with magnesium alloy rumen bullets or fed magnesium sulfate. J. Anim. Sci. 42:506.

House, W. A. and D. Van Campen. 1971. Magnesium metabolism of sheep fed different levels of potassium and citric acid. J. Nutr. 101: 1483.

Hyde, W., J. Kiesey, P. F. Ross, H. M. Stahr. 1977. Analytical Toxicology Methods Manual. Iowa State University Press, Ames, IA.

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

Kemp, A. and J. R. Todd. 1970. Prevention of hypomagnesaemia in cows: The use of magnesium alloy bullets. Vet. Rec. 86:463.

Kemp, A. and M. L. t'Hart. 1957. Grass tetany in grazing milking cows. Neth. J. Agri. Sci. 5:4.

Kemp, A., W. B. Deijs and E. Kluvers. 1966. Influence of higher fatty acids on the availability of magnesium in milking cows. Neth. J. Agri. Sci. 9:134.

Kemp, A., W. B. Deijs, O. J. Hemkes and A. J. H. van Es. 1961. Hypomagnesaemia in milking cows: Intake and utilization of magnesium from herbage by lactating cows. Neth. J. Agri. Sci. 9:134.

Kennedy, G. S. 1968. Trans-aconitate utilization by sheep. Aust. J. Biol. Sci. 21:529.

Kertz, A. F., L. R. Prewitt, A. G. Lane and J. R. Campbell. 1970. Effect of dietary protein intake on creatinine excretion and the creatinine-nitrogen ratio in bovine urine. J. Anim. Sci. 30:278.

Kotb, A. R. and T. D. Luckey. 1972. Markers in nutrition. Nutr. Abstr. Rev. 42:28.

Kunkel, H. O., K. H. Burns and Bennie J. Camp. 1953. A study of sheep fed high levels of potassium bicarbonate with particular reference to indirect hypomagnesemia. J. Anim. Sci. 12:451.

Lehninger, A. L. 1975. Biochemistry. (2nd ed.). Worth Publishers, Inc., New York, NY.

Lentz, D. E., F. C. Madsen, J. K. Miller and S. L. Hansard. 1976. Effect of potassium on insulin in the bovine. J. Anim. Sci. 43:1082.

Linkous, W. N., W. A. Hardison, G. C. Graf and E. W. Crampton. 1955. Fecal chromic oxide concentration in 12 dairy cows as related to time and frequency of administration and to feeding schedule. J. Anim. Sci. 13:1009 (Abstr.).

Littledyke, E. T. and P. S. Cox. 1979. Clinical, mineral, and endocrine interrelationships in hypomagnesemic tetany. In Grass Tetany A.S.A. Sp. Pub. 35:1.

Lomba, F., R. Paquay, V. Bienfet and A. Lousse. 1968. Statistical research on the fate of dietary mineral elements in dry and lactating cows II. Magnesium. J. Agri. Sci. 71:181.

Madsen, F. C., D. E. Lentz, J. K. Miller, D. Lowrey-Hernden and S. L. Hansard. 1976. Dietary carbohydrate effects upon magnesium metabolism in sheep. J. Anim. Sci. 42:1316.

Martens, H., J. Harmeyer and H. Michael. 1978. Magnesium transport in isolated rumen epithelium in sheep. Res. Vet. Sci. 24:161.

Mayland, H. F. and D. L. Grunes. 1974. Magnesium concentration in Agropyron desertorum fertilization with Mg and N. Agronomy J. 66:79.

Mayland, H. F., D. L. Grunes and D. M. Stuart. 1974. Chemical composition of Agropyron desertorum as related to grass tetany. Agronomy J. 66:441.

McAleese, D. M., M. C. Bell and R. M. Forbes. 1961. Magnesium-28 studies in lambs. J. Nutr. 74:505.

McAleese, D. M. and R. M. Forbes. 1959. Experimental production of magnesium deficiency in lambs on a roughage containing diet. Nature 184:2025.

McConaghy, S., J. S. V. McAllister, J. R. Todd, J. E. F. Rankin and J. Kerr. 1963. The effects of magnesium compounds and of fertilizers on the incidence of hypomagnesaemia in dairy cows. J. Agri. Sci. 60:313.

McLaren, J. B., D. W. Saylor, S. L. Hansard and L. M. Safley. 1975. Effects of supplemental magnesium on the incidence of grass tetany in beef cows. Tenn. Farm Home Sci. 94:21.

Merck. 1973. The Merck Veterinary Manual. (4th ed.). O. H. Siegmund (ed.). Merck and Co., Inc. Rahway, NJ.

Metson, A. J., W. M. H. Saunders, T. W. Collie and V. W. Graham. 1966. Chemical composition of pastures in relation to grass tetany in beef breeding cows. N. Z. J. Agri. Res. 9:410.

Meyer, H. and D. W. Busse. 1975. Zur Rekstalen absorption von magnesium biem wiederkauer. Dtsch. tierarztl. Wschr. 82:137.

Miller, J. K., S. C. Perry, P. T. Chandler and R. G. Cragle. 1967. Evaluation of radiocerium as a non-absorbed reference material for determining gastrointestinal sites of nutrient absorption and excretion in cattle. J. Dairy Sci. 50:355.

Miller, J. K., W. F. Byrne and W. A. Lyke. 1972. Comparison of fecal excretions of scandium-46 tagged sand and soluble cerium-144 by calves. Health Phys. 22:461.

Moore, W. F., J. P. Fontenot and K. E. Webb. 1972a. Effect of form and level of nitrogen on magnesium utilization. J. Anim. Sci. 35:1046.

Moore, W. F., J. P. Fontenot and K. E. Webb. 1972b. Effects of level of nitrogen and potassium on magnesium utilization. J. Anim. Sci. 35:271.

Moore, W. F., J. P. Fontenot and R. E. Tucker. 1971. Relative effects of different supplemental magnesium sources on apparent digestibility in steers. J. Anim. Sci. 33:502.

Mosley, G. and D. I. H. Jones. 1974. The effect of sodium chloride supplementation of a sodium adequate hay on digestion, production and mineral nutrition in sheep. J. Agri. Sci. 83:37.

Newton, G. L., J. P. Fontenot, R. E. Tucker and C. E. Polan. 1972. Effects of high dietary potassium intake on the metabolism of magnesium by sheep. J. Anim. Sci. 35:440.

N.R.C. 1975. Nutrient Requirements of Domestic Animals No. 5. Nutrient Requirements of Sheep. National Research Council, Washington, D.C.

N.R.C. 1976. Nutrient Requirements of Domestic Animals No. 4. Nutrient Requirements of Beef Cattle. National Research Council, Washington, D.C.

N.R.C. 1978. Nutrient Requirements of Domestic Animals No. 3. Nutrient Requirements of Dairy Cattle. National Research Council, Washington, D.C.

Odell, D., E. E. Hatfield, W. C. Shrewsberry, M. E. Gibson and R. MacVicar. 1952. Effect of high dietary potassium on sheep. J. Anim. Sci. 11:790.

O'Kelly, R. E. and J. P. Fontenot. 1969. Effects of feeding different magnesium levels to drylot-fed lactating beef cows. J. Anim. Sci. 29:959.

Pearson, P. B., J. A. Gray and R. Reiser. 1949. The calcium, magnesium and potassium contents of the serum of ewes fed high levels of potassium. J. Anim. Sci. 8:52.

Perry, S. C., R. G. Cragle and J. K. Miller. 1967. Effect of ration upon the intestinal distribution of Ca, Mg, Na, K, and N in calves. J. Nutr. 93:283.

Phillipson, A. T. and J. E. Storry. 1965. The absorption of calcium and magnesium from the rumen and small intestine of the sheep. J. Physiol. 181:130.

Pless, C. D., J. P. Fontenot and K. E. Webb. 1973. Effect of dietary calcium and phosphorus levels on magnesium utilization in sheep. V.P.I. and S.U. Res. Rep. 153:104.

Porter, P. and A. G. Singleton. 1971. The degradation of lignin and quantitative aspects of ruminant digestion. Br. J. Nutr. 25:3.

Ramsey, Nancy, J. K. Miller and M. C. Bell. 1979. Hypomagnesemia and insulin in cows overwintered on stockpiled fescue pasture or changed abruptly from stored feed to lush spring pasture. Tenn. Farm Home Sci. 112:16.

Rayssiguier, Y. and C. Poncet. 1980. Effect of lactose supplement on digestion of lucerne hay by sheep II. Absorption of magnesium and calcium in the stomach. J. Anim. Sci. 51:186.

Reid, R. L., G. A. Jung, C. H. Wolf and R. E. Kocher. 1979. Effects of magnesium fertilization on mineral utilization and nutritional quality of alfalfa for lambs. J. Anim. Sci. 48:1191.

Reynolds, C. K. 1981. A study of magnesium metabolism and magnesium depletion and repletion in young calves. Master's thesis, The University of Tennessee, Knoxville, Tennessee.

Reynolds, J. H. 1980. Slurry applications to increase magnesium in fescue forage. Tenn. Farm Home Sci. 113:9.

Ritchie, N. S. and G. Fishwick. 1977. Magnesium phosphate as a dietary supplement for lactating cows at spring pasture. J. Agri. Sci. 88:71.

Ritchie, N. S. and R. G. Hemingway. 1963. Effects of conventional daily magnesium supplementation, breed of ewe and continued potassium fertilizer applications on plasma magnesium and calcium level of ewes. J. Agri. Sci. 61:411.

Ritter, R. S. 1979. Hypomagnesemia effects on magnesium, calcium and potassium balance in lactating beef cows. Master's thesis, The University of Tennessee, Knoxville, Tennessee.

Rogers, P. A. M. and D. B. R. Poole. 1971. Control of hypomagnesaemia in cows: A comparison of foliar dusting with free access to calcined magnesite-molasses mix. Irish Vet. J. 25:197.

Rogers, P. A. M. and D. B. R. Poole. 1976. Control of hypomagnesaemia in cows: A comparison of magnesium acetate in the water supply with magnesium oxide in the feed. Irish Vet. J. 30:129.

Rook, J. A. F. 1961. Rapid development of hypomagnesaemia in lactating cows given artificial rations low in magnesium. Nature 191:1019.

Rook, J. A. F. and C. C. Balch. 1958. Magnesium metabolism in the dairy cow II. Metabolism during the spring grazing season. J. Agri. Sci. 51:199.

Rook, J. A. F., C. C. Balch and C. Line. 1958. Magnesium metabolism in the dairy cow I. Metabolism on stall rations. J. Agri. Sci. 51:189.

Rook, J. A. F. and J. E. Storry. 1962. Magnesium in the nutrition of farm animals. Nutr. Abstr. and Rev. 32:1055.

Ross, J. G. and W. G. Halliday. 1975. Surveys of bovine blood chemistry in Scotland I. Serum magnesium. Br. Vet. J. 131:309.

Scotto, K. C., V. R. Bohman and A. L. Lesperance. 1971. Effects of oral potassium and sodium chloride on plasma composition of cattle: A grass tetany related study. J. Anim. Sci. 32:354.

Sims, F. H. and H. R. Crookshank. 1956. Wheat pasture poisoning. Texas Agri. Expt. Sta. Bull. 842.

Smyth, P. J. 1969. Hypomagnesaemic tetany control in cows: The use of magnesium alloy bullets as a prophylaxis. Irish Vet. J. 23:4.

Sokal, R. R. and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co., San Francisco, CA.

Standish, J. F., C. B. Ammerman, A. Z. Palmer and C. F. Simpson. 1971. Influence of dietary iron and phosphorus on performance, tissue mineral composition and mineral absorption in steers. J. Anim. Sci. 33:171.

Steel, R. G. D. and J. A. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., New York, NY.

Stevenson, M. H. and E. F. Unsworth. 1978. Studies on the absorption of calcium, phosphorus, magnesium, copper and zinc by sheep fed on roughage-cereal diets. Br. J. Nutr. 40:491.

Stewart, B. A., D. L. Grunes, A. C. Mathers and F. P. Horn. 1981. Chemical composition of winter wheat forage grown where grass tetany and bloat occur. Agronomy J. 73:337.

Stillings, B. R., J. W. Bratzler, L. F. Marriott and R. C. Miller. 1964. Utilization of magnesium and other minerals by ruminants consuming low and high nitrogen-containing forages and vitamin D. J. Anim. Sci. 23:1148.

Storry, J. E. and J. A. F. Rook. 1963. Magnesium metabolism in the dairy cow V. Experimental observations with a purified diet low in magnesium. J. Agri. Sci. 61:167.

Suttle, N. F. and A. C. Field. 1967. Studies on magnesium in ruminant nutrition 8. Effect of increased intakes of potassium and water on the metabolism of magnesium, phosphorus, sodium, potassium and calcium in sheep. Br. J. Nutr. 21:819.

Thill, J. L. and J. R. George. 1975. Cation concentrations and K to Ca and Mg ratio of nine cool-season grasses and implications with hypomagnesemia. Agronomy J. 67:89.

Thompson, J. K. and R. L. Reid. 1981. Mineral status of beef cows and sheep on spring pasture fertilized with kieserite. J. Anim. Sci. 52:969.

Todd, A. S., O. T. Fosgate, R. G. Cragle and T. H. Kamal. 1962. Parathyroid action on calcium, phosphorus, magnesium, and citric acid in dairy cattle. Am. J. Physiol. 202:987.

Tomas, F. M. and B. J. Potter. 1976. The site of magnesium absorption from the ruminant stomach. Br. J. Nutr. 36:37.

Valdiva, R., C. B. Ammerman, C. J. Wilcox and P. R. Henry. 1978. Effect of dietary aluminum on animal performance and tissue mineral levels in growing steers. J. Anim. Sci. 47:1351.

Van Soest, P. J. and R. H. Vine. 1967. Use of detergent in the analysis of fibrous feed IV. Determination of plant cell wall constituents. J. Assoc. Agri. Chem. 50:50.

Wilcox, G. E. and J. E. Hoff. 1974. Grass tetany: An hypothesis concerning its relationship with ammonium nutrition of spring grasses. J. Dairy Sci. 57:1085.

Wilkinson, S. R. and J. A. Studemann. 1979. Tetany hazard of grass as affected by fertilization with N, K or poultry litter and methods of grass tetany prevention. In Grass Tetany A.S.A. Sp. Pub. 35:93.

Williams, C. H., C. J. David and O. Iismaa. 1962. The determination of chromic oxide in faeces samples by atomic absorption spectrophotometry. J. Agri. Sci. 59:381.

Wilson, G. E. 1980. Effects of magnesium supplements on the digestion of forages and milk production of cows with hypomagnesemia. Anim. Prod. 31:153.

Wise, M. B., A. L. Ordoveza and E. R. Barrick. 1963. Influence of variations in dietary calcium:phosphorus ratio on performance and blood constituents of calves. J. Nutr. 79:79.

APPENDIX

TABLE 14. MEAN SQUARES FOR Mg BALANCE VARIABLES.

Source	Variable			
	Intake	Feces	Urine	Milk
Treatment	18.31[b]	3.34	2.04[b]	.001
Trial	2.92	.48	1.86[a]	.002
Year	5.78	.91	13.24[b]	.051[b]
Treatment x Trial	4.02	.04	.19	.001
Trial x Year	30.32[b]	6.17	2.28[b]	.001
Treatment x Year	.05	19.04[b]	.33	.001
Error	1.94	1.74	.26	.002

[a]P<.05.

[b]P<.01.

TABLE 15. MEAN SQUARES FOR Ca BALANCE VARIABLES.

Source	Variable			
	Intake	Feces	Urine	Milk
Treatment	1074.37[b]	343.01[b]	10.35[b]	.02
Trial	350.94[b]	9.04	4.45	.33
Year	3384.15[b]	1464.96[b]	70.27[b]	4.60[b]
Treatment x Trial	27.48	3.64	.03	.50
Trial x Year	431.39[b]	.29	4.29	.06
Treatment x Year	253.30[b]	326.01[b]	8.46[a]	.08
Error	24.07	17.22	1.35	.27

[a]$P<.05$.

[b]$P<.01$.

TABLE 16. MEAN SQUARES FOR K BALANCE VARIABLES.

Source	Variable			
	Intake	Feces	Urine	Milk
Treatment	5261.38[b]	2656.09[b]	2873.44[b]	.06
Trial	819.59[a]	98.94	195.54	1.13
Year	.03	61.05[a]	575.34[a]	28.67[b]
Treatment x Trial	1621.79[b]	12.14	194.86	.54
Trial x Year	.03	715.83[b]	1214.42[b]	.73
Treatment x Year	1383.37[b]	37.69	440.76	.08
Error	183.02	200.42	119.18	.42

[a]P<.05.

[b]P<.01.

TABLE 17. INTERCEPT AND REGRESSION COEFFICIENTS FOR PLASMA MINERAL LEVELS.

Mineral	Year[a]	Treatment[b]	Intercept	B_1[c]	B_2	B_3
Mg	1	1	2.452096	-.209387	.034124	-.001407
		2	2.312206	-.161542	.034199	-.001669
	2	1	2.611877	-.501624	.073390	-.003048
		2	2.243806	-.189563	.034518	-.001685
Ca	1	1	10.275788	-.255067	.049820	-.002340
		2	10.092277	-.107975	.013127	-.000239
	2	1	10.203064	-.548625	.096935	-.004524
		2	10.081767	-.266043	.051855	-.002656
K	1	1	21.199886	-1.404962	.116426	.000194
		2	19.239462	-.005914	-.171759	.015887
	2	1	17.961586	-1.501272	.199411	-.008587
		2	17.691601	-1.383515	.183848	-.008070

[a]Year 1 = 1980; Year 2 = 1981

[b]Treatment 1 = K-fertilized pasture; Treatment 2 = Control pasture.

[c]B_1 = Linear regression coefficient for day of trial.

B_2 = Quadratic regression coefficient for day of trial.

B_3 = Cubic regression coefficient for day of trial.

VITA

David Lewis Hodge, son of Robert L. and Joanne C. Hodge, was born in Johnson City, Tennessee on November 24, 1957. He grew up in Upper East Tennessee and attended elementary and secondary schools in Blountville. After attending East Tennessee State University for one year, he transferred to The University of Tennessee, Knoxville, where he received the Bachelor of Science degree in Animal Science in June 1979 and the Master of Science degree in Animal Science in December 1981. His graduate studies were involved with animal nutrition.