History about the NPK fertilization and Mg-deficiency in ruminants (data to the end of 1980s)

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The nutritional value of **nitrogen(N), phosphorus(P), potassium(K), calcium(Ca),magnesium(Mg), sodium(Na)** - has been demonstrated by many investigators and it is generally recognized that its **quantitative variations with microelements** are important factors in animal health. The **use of fertilizers, in general, modifies** the chemical composition of plants. A high association between levels of **K, crude protein(CP) and P, with a high correlation** of "**in vitro dry matter digestibilities" (IVDMD)** was found within the warm season grasses in the **northeast United States** (REID et al.,l988). In the trials conducted with warm season grasses grown on **low P soils** in Pensylvania(MORRIS et al.,l982),a significant **positive correlation was noted between CP and IVDMD concentrations**, but not with P. In the field condition with the NPK fertilization at the level about 254 kg per hectar(N:P:K = l: 0.8: 0.8)- was found **the positive correlation between the CP,P,K and nitrates content** in forages(HLASNY,l990).

Potassium and magnesium relationships

The importance of potassium in agriculture as an essential element for crop growth is well recognized. Although total soil **K reserves are generally large**, K can exist in forms immediately **unavailable for crop** uptake **(McLEAN and WATSON,l985: MARTIN and SPARKS,l985)**. The **three K forms**:water soluble, exchangeable, and nonexchangeable(including mineral and fixed K) give a general representation of soil K availability. Water soluble K is immediately and exchangeable K readily available to plants, but nonexchangeable K, which usually constitues the major proportion of total soil K, can become available only very slowly through soil weathering (MARTIN and SPARKS,l985). The distribution and fixation of K added to a soil, among water-soluble, exchangeable, and nonexchangeable forms, is related to the **surface charge density and degree of interlayering of the clay minerals present** (SHAHIV et al.,l985). In **general, clays with an interlayered structure and high surface and lattice charge** density (certain 2:1 clays, such as micaceous illites, vermiculites, and chlorites) fix K to a greater extent and degree than clays of low negative charge density(such as kaolinites). The fixation of K by clay in a soil can be modified by moisture content through the wetting and drying disruption of clay particles (COOK and HUTCHESON, l960). The **capacity of clays to maintain a given K level** has been quantified as **the K buffer capacity** (**KBC**)of a soil. It is calculated as the slope of K adsorption/desorption isotherm at zero adsorption (BECKETT,l964: LeROUX and SUMNER, l968). It has been suggested that a **high KBC value for a soil is indicative of good K availabilit**y and supply,and that a low KBC suggests a need for frequent K fertilization (KOCH et al.,l970: SPARKS and LIE BHARDT,l98l). Several studies have reported increases in the content of specific K forms after fertilizer K application. For example, SPARKS et al.(l980) and URIBE and COX(l988) measured increases in water-soluble K, HAVLIN et al.(l984) and COPE(l98l) increases in exchangeable K, and WOOD and DeTURK(l94l) increases in nonexchangeable K after K addition to soil. **Potassium chloride has disadvantages** as a fertilizer for grazed pasture. Not only is the K susceptible to leaching on freedraining soils (HOGG and COOPER,l964: HOGG and TOXOPEUS,l970), but, following topdressing, there is **rapid luxury uptake of K by pasture species** (McNAUGHT,l958: SAUNDERS and METSON,l959). On K responsive sites, at normal rates of topdressing with KCl, the **concentration of K in dry matter may rise into the range 3.5-4.0%** (McNAUGHT and KARLOVSKY,l964: McNAUGHT,l958). These concentrations are **well above those of 2.0-2.5% K suggested as optimum levels** for growth of white clover (Trifolium repens,L.) **and ryegrass** (Lolium perenne L.) in the field (CORNFORTH,l984). SAUNDERS and METSON(l959) suggested luxury uptake was a basic cause of the shortlived response to K on yellow-brown loams: the high K content of the eaten herbage hastened the accumulation of fertilizer K into urine and dung patches and stock camps. Luxury uptake, besides being an inefficient use of K fertilizer, **leads to distortion of cation ratios in the herbage: concentration of Na, Mg, and Ca are reduced relative to potassium** (SAUNDERS and METSON,l959: DURING and McNAUGHT,l96l: KARLOVSKY,l964). The increased ratio of K to the other cations has been associated with metabolic problems in cattle (METSON et al.,l966: KEMP and t´HART,l967). METSON and SAUNDERS(l962) experimented with two slightly soluble K compounds, **potassium bicarbonate(KBC) and potassium monophosphate (KMP),** and a calcined feldspar (orthoclasse as a means of reducing luxury uptake. The K from KBC and KMP were taken up by the pasture species as quickly as K from KCl:the K of the mica, although it became more soluble in water after ignition, was not readily available. Coating KCl has been used to control the releaase of K and luxury uptake by crops(ALLEN and MAYS,l974: MIWA et al.,l978). For example, over three crops of corn, **higher total yield was obtained using a sulphur coated KCl** than from uncoated KCl at a high rate of K application. At a lower rate,the uncoated KCl was higher yielding by about 20% indicating that growth may have been limited by a slow rate of release (ALLEN and MAYS, l97l).

Potassium in soils mainly resides in K-bearing minerals. The K-supplying power of a soil depends not only on content and kind of K-bearing minerals in the soil but the rate at which **structural and fixed K becomes available to plants**. The nature of K reserves and rate of K release from minerals are even more important in forest soils where K fertilizers are usually not applied. There are **many factors which affect the rate of K release**. The effect of the nature and particle size of K bearing minerals and soil environments of K-bearing minerals, which plays a very important role in the release of K, includes crystal structure and chemical composition of the mineral, orientation of structural OH ion, location of layer charge alterations in micaceous minerals. **Among the surrounding environmental conditions**, the nature and activity of various ions in soil solution, Eh and pH condition, temperature, wetting, and drying are important factors affecting the rate of K release (HUANG,l977). **Organic acids can facilitate the weathering** of minerals and rocks through the formation of **metalorganic complexes** (KONONOVA et al.,l964: HUANG and KELLER,l970: TAN, l980: KODAMA et al.,l983). Organic acids are produced in soils in the decomposition of plant and animal residues and soil humic substances, microbial metabolism and rhizosphere activities (WANG et al.,l967: RAO and MIKKELSEN,l977), especially in forest soils which usually have a layer of forest litter on top of soil profiles. Besides **humic and fulvic acids, e.g., oxalic, citric, tartaric, fumaric and glycollic acids**, are present in forest litter and soil solutions (SCHWARTZ et al.,l954: KAURICHEV et al.,l963). Some of these organic acids were detected in the rhizosphere of several tree species (SPAKHOV and SPAKHOVA, l970). Among these acids, **oxalic and citric acids are most common and present in a relatively large quantity** (KAURICHEV et al.,l963: STEVENSON,l967).

Fertilization with acid-forming fertilizers results in **increased soil acidity**. Substantial evidence exists that this may result in a **differential loss from the soil of K, Ca and Mg** (ADAMS et al.,l967). In practice, the effect **is enhanced because K losses may be replaced by fertilization whereas Ca and Mg losses may be ignored because of lack of effect on yield.** The increase in soil acidity also results in an increasing quantity of H ions and **high exchangeable Al in certain soils.** LUTZ et al.(l977) illustrated **that N-fertilization**

increased the amounts of Ca, Mg, K, Al and Mn in displaced soil solution. The K content was not as greatly increased in displaced soil solution. The K content was not as greatly increased as Ca and Mg. These increases in concentrations of cations in solution may increase Ca and Mg mobility with percolating waters. GILLINGHAM and PAGE(l965) in a lysimeter experiment showed that the **mobility of Mg was affected by the dominant anion present** with downward Mg mobility decreasing in three following order: **NO_3, Cl, SO_4, PO_4, I.** Residual **acid-N fertilizers (NH_4 and urea sources**) may **enhance Mg-leaching losses**. The effect can be rather large as demonstrated by CLASSEN and WILCOX(l974), who found **that NH_4-N effects were greater than K fertilization effects**. Plant nutrition with **NH_4-N sources also tends to increase the concentration of non-protein N in plant tissue and reduce the soluble carbohydrate fractions in plant tissue**. During spring periods, when soil temperatures are below 3.3 oC, and nitrification of ammonia is inhibited, this may be the major form of N available for plant absorption. FOLLETT et al.(l977) confirmed that high NH_4-N levels did occur in May in North Dacota. However,NH_4-N effects on plant Mg, or the K/(Ca+Mg) ratio **were not strong in bromegrass** (Bromus inermis L.). Based on much greenhouse and controlled environment research, **NH_4-N sources often enhance P and S uptake, whereas NO_3 sources enhance Ca and Mg uptake.** Potassium concentrations appear to be increased by increasing N levels of both forms, unless K is in deficient supply in the root medium.

The relationship between K and Mg in plants and soils has been the subject of several investigations. Some fairly high K concentrations can be found in herbage from soils with low exchangeable K, and it is unlikely that low K concentrations will be found in herbage growing on soils with high levels of exchangeable K. Low Mg content of crops is likely where the soil exchangeable Mg content is low. **However,a high exchangeable Mg content does not guarantee high Mg levels in crops** (McCONAGHY and ALLISTER,l967). ALSTON(1972) attributed a **significant proportion of the variation of Mg concentration in ryegrass** (Lolium perenne L.) to the content of soils. The net relationship between K and Mg in plants is **the result of fluxes between non-exchangeable K and Mg: and exchangeable K and Mg in soil**. A given soil may have large pools of non-exchangeable K that are available to replace exchangeable K as it is depleted, **whereas nonexchangeable Mg may not be readily available to replace depleted exchangeable Mg or vice versa.** The K antagonism on Mg content has been demonstrated for a wide variety of crops, including warm season and cool season species. **The K/Mg effect may be relatively more important in soils with high cations exchangeable capacity(CEC) and clay mineral content.** GEORGE and THILL(l979) found the lowest Mg concentration in bromegrass fertilized with 125 kg K/ha per year, as KCl, and the highest with lanbeinite/2 $MgSO_4$. K_2SO_4/. However, the Mg concentration in bromegrass was higher without K fertilization than with langbeinite. There was no yield response to K fertilization (GEORGE et al.,l979). JONES et al.(l973) demonstrated that broiler litter fertilization tended to produce forage with higher K and higher K/(Ca+Mg) ratios than forage from fields fertilized only with levels increased with increasing N inputs in these studies. JACKSON et al.(l975) demonstrated that the application of broiler litter to Cecil sandy clay loam soil(Typic Hapludult) greatly increased exchangeable Ca and Mg. **Cool season grasses, managed to simulate grazing, require from 2.0 to 3.0% K**(WILKINSON and MAYS,l979). However, many of these values have been determined from field or greenhouse studies designed to maximize yield. Udoubtedly, these values apply to the growth conditions under which they were determined: however, these circumstances have often been with nonlimiting N fertilization and with large removals of K in harvested herbage.

The optimum Ca/Mg ratio for plant growth has not been defined for all plants. However, oats with Ca/Mg ratios less than 0.4

suffer growth reductions. SIMSON et al.(l979) found that varying the Ca/Mg ratio from 0.8 to 5.0 had no effect on corn or alfalfa yields. LIEROP et al.(l979) onion yields were reduced at Ca/Mg ratios less than 0.5. Although having as much Mg as Ca in plant tissue is not normal, **many plants will grow normally over a very wide range of both soil and plant tissue Ca/Mg ratios.** CARTER et al. (l979) reported that the growth of barley may decrease when

Mg/Ca ratio in displaced soil solution of solonetz soils is l.0, or when the proportion of Ca to total cations in soil solution was less than l5%. They suggested that the greater need for Ca may be to maintain the selectivity of plasmalemma against toxicity of other ions. Some diagnostic benefit may be obtained from extending this concept to determine **what proportion of Mg to total cations in soil solution is necessary to achieve "safe" concentrations of Mg in plant** tissue on the soils developed under cool, arid conditions. The **antagonistic effect of Ca on Mg uptake is not as strong as K on Mg**(CARTER et al.,l979). Lime induced depression of corn (Zea mays L.) growth has been attributed to increased Al uptake on certain soils (FARINA et al., l980). However**, Mg concentrations in corn plants were depressed by calcitic limestone when soil pH was near to neutral.**

In Ireland, as in other countries, hypomagnesaemic tetany occurs in cattle and sheep under varying conditions of environment and nutrition. There was found that **treatment with N only or K only did not render the sward more prone to a lowering of blood serum Mg levels**. That the treatment with a **combined dressing of N plus K resulted in a highly** significant rapid decline in cows serum Mg values followed by the onset of tetany. That the application of Mg in addition to N only or N plus K resulted in the **maintenance of blood serum Mg values within the normal range** (SMYTH et al.,l958). Some interesting results have been obtained with the increasing soil rates of potassium chloride. The K levels in the leaf plant tissues increased progresively, Na on the other hand, showed an extraordinary difference in behaviour according to the plant type, Mg uptake in all plants was depressed to a similar extent in five of the six plants (McNAUGHT,l959). **These plants may be classified into two groups**:(a) those which make up for any deficiency of K mainly by increased absorption of Na: for **example brassicas and most grasses**:(b) those which take up increased amounts **of Mg and Ca but make little or no use of sodium:** for example **potatoes and Paspalum dilatatum**. Plants in group(a) utilise Mg and Ca as well as Na, but usually to a less extent than plants in group(b) (McNAUGHT,l959). The role of **potassium as a fertilizer** for grassland has been investigated by many workers including HOLMES and MacLUSKY(l954), REITH et al.(l96l), WIDDOWSON et al.(l969) and CLEMENT and

HOPPER(l968), all of whom considered **effects on dry matter yield**. REITH et al.(l964), SCOTT-RUSSELL(l97l) and SCHAFER et al.(l974) have looked at the effect of applied K fertilizer on a range of herbage mineral constituents. Other investigators, including MENGEL and NEMETH(l97l), have studied the influence of excessive amounts of K in soil **on herbage sodium content**. The conclusion from these experiments has been that **increasing soil K depresses Na content of the herbage**. This is particularly so when growth is stimulated by N fertilizer. There are references in the literature of Western Europe (ROTH and KIRCHGESSNER,l972: ANON,l975) to **excessive herbage K associated with Na levels below that desirable for lactating cows**. Modern fertilizers contain very little Na, and heavy fertilizing of pastures with K may reduce Na uptake (MAFF et al.,l983). A K/Na fertilizer has obvious potential advantages for grassland. It may be that annual additions of Na in rain reported by CAWSE(l987) to be 20 kg per hectar or more, have maintained soil-available Na at a sufficient level to withstand depression by excessive soil K and still be adequate for the satisfactory nutrition of animals grazing grass swards.

About 60 years ago the first data were available on the effects of fertilizing grassland in relation to the **incidence of grass tetany (SJOLLEMA,l932)**. The possible importance was pointed out of the imbalance of **input and output of K and P on tetany- prone farms, the input being much higher than the output.** A comparison of the chemical composition of herbage from"tetany" and "non-tetany" farms drew attention to the higher K, P and crude protein concentrations and the significantly lower contents of Ca and Mg in tetany prone herbage (t´HART,l944). **More recently, grazing experiments** and feeding trials carried out in different countries, mainly in Germany, the Netherlands, New Zealand, Norway, United Kingdom and the U.S.A., resulted in a better understanding of the relationships between fertilizer treatment on grassland and the incidence of hypomagnesemia.**It is now generally accepted, that heavy dressing of N or K may have an adverse effect on the serum Mg concentration in cattle**. Intensification of grassland management by mens of **increasing applications of N-fertilizers will increase herbage production and will change the botanical and chemical composition** of the forage produced. Clover and herbs will be suppressed and the sward will consist mainly of grasses. A **predominately grass sward provides a lower Mg concentration** in the forrage consumed by the animals, even although in a grassy sward heavy N dressing mostly increase the Mg content in the grass slightly. Although the Mg concentrations between grass species may differ considerably, **legumes herbs contain more Mg than grasses** (BAKER and REID,l970: HLASNY,l989). A mainly grassy sward will therefore be more"tetany prone" than a mixed sward. Grazing experiments (BARTLETT,l958) on **pastures containing different amounts of clover** and similarly finding in field conditions (HLASNY,l99l) have shown **higher serum Mg levels** in cows with a higher clover content in the ration. There is probably no information on the availability of Mg from clover and herbs for ruminants. However,it might be possible **that Mg from clover is less available than that from grasses**, because the N concentration in clover is higher than that in grasses, which goes with **higher contents of higher fatty acids-H.F.A**.(MAYLAND et al.,l976). It is likely that higher concentrations of H.F.A. in the forage decrease the availability of feed Ca and Mg by the **formation of insoluble Ca and Mg soaps in the gastrointestinal tract**(WIND et al.,l966; NGIDI et al., l990:).

Magnesium is rarely considered limiting to plant growth. Yet,evidence of **substantial reductions in exchangeable Mg with liming** (SUMNER et al.,l978: SIMS and ELLIS,l983: FARINA et al.,l980: McLEAN and CARBONELL,l972: GROVE et al.,l98l: CHAN et al.,l979) has led to a suggestion that limited Mg availability may be contributing factor in yield reductions commonly observed **when acid soils are limed to near neutrality** (SUMNER et al.,l978: GROVE and SUMNER, l985). **Reductions in exchangeable Mg,** sometimes referred to as **Mg "fixation",** have been reported in many types of soils but have been observed most frequently in **highly weathered Ultisols and Oxisols**(PAVAN et al.,l984). In addition, reductions have been demonstrated with a variety of liming materials and when Mg was applied to the soil either as a lime component or as a soluble salt. There appears to be no unique pH at which lime-induced reductions in exchangeable Mg occur: the **phenomen has been observed at equilibrium pH values ranging from 4.5 to neutrality, but is most commonly reported between pH 6 and 7**. It has been suggested that Mg fixation is directly **related to the exchangeable aluminium (Al) content** of the soil (GROVE et al.,l98l) or to the presence of an ill-defined Al fraction that is extractable with acidified NH4- acetate(NH$_4$ OAc) (FARINA et al.,l980: GROVE and SUMNER, l985). Working with four lime(no lime,pH 5,pH 6,pH 7) and two Mg levels (O and 25% of the cation exchange capacity-CEC) MYERS et al., found reductions in exchangeable Mg with liming over a range of equilibrium pH values, however, the effect was clearly enhanced by increasing the soil pH to neutrality.

Magnesium fertilization

Magnesium fertilization to increase Mg concentration to safe levels has **generally been considered uneconomical for other than coarsetextured soils that are low in K and Ca** (GRUNES et al.,l970). Sufficient evidence exists that Mg fertilization likely will not be effective, and that omitting K fertilizers may increase Mg levels. A high degree of fineness of material, and enough time for reaction with the soil are particularly important for all Mg sources except the soluble sources.For less soluble sources, soil incorporation enhances their effectiveness of grind. MULLER et al. (l976) found that 96 kg Mg/ha as MgCl$_2$ liquor effectively prevented blood serum levels from declining to l.8 mg/lOO ml in cattle grazing ryegrass, rye or cocksfoot. ELKINS et al.(l978) suggested that draining wet areas in pasture would be helpful as a prevention of grass tetany since they showed that soil low in oxygen reduced the plant uptake of Mg in tall fescue both in the greenhouse and in field experiments. When pH soil is neutral or higher, like that of calcareous soils, and liming is not needed, kiesserite is the recommended source, or combinations of acidiforming N fertilizer and Mg. MAYLAND and GRUNES(l974) founf that 600 kg Mg/ha as Epsoms salts was necessary to increase forage Mg to the recommended level of 0.2 on two calcareous Aridisols. They indicated that after 5 years little residual effect of 600 kg Mg/ha on plant Mg was found. Dolomitic limestone is moderately effective in supplying Mg when liming is needed to increase soil pH. AMOS et al (l975) demonstrated that the proportion of ewes with serum Mg below one mg/lOO ml was smaller with dolomite than with calcite, when 4 years of data were combined. They found forage Mg to be significantly higher in dolomite plots early in the season. McINTOSH et al.(l973) **found that magnesian limestone was not as effective as calcined magnesite**, whereas magnesium ammonium phosphate and Epsom salts were similar in their effect. Mg-fertilization may result in in improved retention of plant Mg by lambs as demonstrated by REID et al.(l978).

GUNN(l972) observed that grass tetany is a more serious problem on some farms than others in the immediate area, thereby implicating soil, plant and animal management factors. For **many soils of moderate to high clay content and CEC the omission or reduction of K fertilization may reduce K/Mg an antagonism.** Routine soil testing does not evaluate a soils capacity to supply K, Ca, and Mg although most procedures indicate the relative amounts of these elements available at the time. Recognition of an excessive soil K status is an important part of a soil fertility program. Defining excessive K will vary greatly depending on whether the level is based on yield reductions, stand persistence, or luxury consumption by the plant tissue, and potential K/Mg antagonism. Subsoil contributions to K uptake are seldom considered, which may account for the large uptakes when surface soil K levels are low. Excessive soil K problems may be remedied by cropping with plants that remove large amounts of K by fertilizing with N,or by simply withholding K fertilization to reduce levels over time. **Potassium recycles more effectively in pasture ecosystems than does Mg or Ca.** Even without fertilization, **return of N and K in animal excreta can result in localized areas of grass high in N and K** (WATKIN,l957; JOBLIN and KEOGH,l979). The effect of grazing and recycling through residues (plant and animal) is primarily a conservation effect that is gaining in recognition, with **fertilizer rates** adjusted accordingly for grazed ecosystems. McNAUGHT et al.(l973) calculated the amounts of MgO required to increase plant Mg from 0.l4 to 0.20% Mg and found that ll9 kg MgO per ha was required 34 dollars per ha for materials cost. The **foliar application technique seems successful** for controlling high incidence tetany outbreaks where individual cattle consumption of Mg supplemented-minerals, or concentrates, cannot be assured. Researches at Kentucky (RITTER et al.,l979) have tried a **N-Mg solution spray on a pasture at 4.5 kg Mg per hectar and found that cows sampled 8 days later had 22.3% higher blood levels** than an unsprayed control group.

The main disadvantage is the cost of applying materials. When forage availability is low and rainfall is intense, Mg persistence is short lived and repeat Mg applications may be needed to assure protection.

Nitrogen and magnesium relationships

Over the past **30 years yields of many crops have increased roughly in proportion to the increase in N-fertilizer application (GREENWOOD, l98l**). Nitrogen fertilizer has a **decisive influence on the yields** of most arable crops throughout the world. Nitrogen application, unless it so enhances growth that uptake does not keep pace with yield, **increases N and protein concentrations in plants** (HVIDSTEN et al.,l959). Because of inadequate knowledge of the extent to which mineral elements in plants are digested and absorbed by animals, the effects of N-fertilization on grasses used as mineral sources in ruminant rations must be discussed in terms of their effects on total mineral concentration of the herbage. It was been observed that **application of N fertilizer, which may increase K uptake by plants and/or decrease Mg utilization by livestock, often is associated with the occurence of tetany** (FONTENOT et al.,l973). A **high K/(Ca+Mg) ratio in forage has been suspected with forage having a value higher than 2.2 being dangerous** (KEMP and HART,l957).

WHITEHEAD (l970) and NOLLER and RHYKERD (l974) reviewed the effects of nitrogen on mineral uptake by plants and concluded that results were inconsistent. One frequent response to N-fertilization on pastures is a **change in botanical composition, with loss of the legume** component and a consequent **decline in total herbage concentration of elements such as Ca and Mg.** In general, N fertilization appears to increase the concentrations of P and K in the plant when these elements are in adequate supply in the soil, and to decrease up when soil reserves are low (WHITEHEAD, l970). Form of N may also be significant, through effects of ion competition during absorption by plant roots. Thus the demonstration by van BURG and by van BRAKEL (l965) that **anhydrous ammonia produced herbage with lower concentrations of K, Ca and Mg than herbage treated with equal amounts of N as nitro-lime.** WILCOX and HOFF(l974) have suggested that ammonium absorption by the plant results in a greatly reduced uptake of Ca and Mg,with little change in K,and a depletion of plant carbohydrate and accumulation of amides. This interaction of factors result in an increased susceptibility of the animal to grass tetany. KEMP and GEURING(l978) have also noted that in the Netherlands, where use of nitrogen fertilizer on grassland has **increased from a level of approximetely 50 to 225 kg per ha per year over a 25 year period,nitrate contents in herbage have increased significantly, leading to a possible risk of nitrate toxicity in grazing animals.** On ryegrass(Lolium multiflorum and perenne) - white clover (Trifolium repens L.) pastures in New Zealand, MOLLOY et al.(l978) found that fertilizer N had little effect on concentrations of Ca, K, Mg and P in the mixed herbage, and concluded that the **major implication of N fertilization for animal health lies either in the increased plant concentration of nitrate** or in the increased total N/ total water-soluble carbohydrate ratios. In intensive grassland management N-fertilizer dressings of up to 500 kg N/ha are applied. High rates of N fertilizer **diminish the ensilability of grass by lowering the concentration of fermentable carbohydrates** and increasing the protein concentration and buffer capacity (ALBERDA,l965: WILSON and FLYNN,l979). In **grass nitrate concentrations of l-8 g/kg DM are normally found** under intensive conditions and levels **up to 30 g/kg DM do occasionally occur** (PRINS,l983). In maize the nitrate concentration ranges from l to 4 g/kg DM, exceptionally l0 g/kg DM and more may occur (Van DIJK and WILLEMSEN,l975: HLASNY,l989). Thus heavy fertilization impairs ensilability by changing the chemical composition of the crop but, in addition, the increased nitrate content may influence the ensiling process and the quality of the preserved forage. For instance, when high concentrations of nitrate are preserved in the silage poisoning of the ruminant at feeding may occur by a **reduction of nitrate to nitrite in the rumen** (KEMP et al.,l977), **nitrosamines formation**. The effects of N-fertilization and of environmental factors on nitrate accumulation have been extensively studied (SZWONEK,l986). Subtoxic concentrations of **herbicides have increased nitrate uptake** in some cases (RIES,l980). If herbides were used (**alachlor, pendimethalin, propyzamide**), final level accumulation of nitrates was accelerated, probably inducing a physiological state of maturation. Alachlor and pendimethalin, which are not as selective in lettuce as propyzamide, **reduced carotenes** in the year of heavier rain (GIANNOPOLITIS et al. ,l989).

The growth of plants, their **cation-anion balance**, proton balance and content of various metabolic products are greatly influenced by the form of nitrogen adsorbed. Generally, **NO_3 anions** occurs in a much higher concentration than **NH_4 cations in the soil solution** and is free to move to the roots by diffusion and mass-flow. **Plants, however, tent to prefer NH_4 cations to NO_3 anions** the preference varying with ambient pH and temperature(CLARKSON and WARNER,l979). HEDLEY et al.(l982) observed a steady decline in the uptake of NO_3 by rape, when plants grown in small volumes of soil became extremely P deficient. They suggested that this, together with an increased uptake of Ca cations, was the cause of a higher uptake of cations than of anions in the P deficient plant. SCHJORRING (l986) in an experiment with barley (Hordeum vulgare L.) and buckwheat(Fagopyrum esculentum L.) found that **phosphorus deficiency reduced the rate of nitrate uptake by 58%** when nitrate was the sole N source and by 83% when both nitrate and ammonium were present. **The reduction of nitrate absorption greatly decreased the difference between the uptake of anions and cations**. It is suggested that P deficiency reduced the assimilation of NO_3 anions into proteins, which might cause a negative feedback on NO_3 anions influx and/ or stimulate NO_3 anions efflux.

The increased yield from N-fertilization may also **increase Mg uptake by plant**, particularly throught the growing season. MULDER(l956) demonstrated an antagonistic effect of NH_4-N by roots releases H ions which may be antagonistic to Mg absorption. WILCOX and HOFF(l974) have throughly reviewed the literature which clearly indicates that **NH_4 forms of N may inhibit Mg uptake by plants.**

Increasing amounts of nitrogenous fertilizers applied to grassland result in higher concentrations of N and the same or slightly increased Mg in the forage, if harvested in the same state of growth. **As the herbage grow older**, crude protein (N x 6.25) and Mg decrease, resulting in an **increasing availability of the forage Mg for ruminants**. This relationships **between CP intake and the availability of feed Mg** has been shown in feeding experiments in different countries (KEMP et al.,l96l: REID et al.,l974). To explaine these results it has been suggested that an inadequate absorption of Mg would probably be **associated with high ruminal ammonia production** (HEAD and ROOK,l955). However, the fact that in mature forage diets are accompanied by low Mg availability might not be a direct result of the forage N level. Several metabolism studies in which N was added to the rations in the form of **nonprotein N did not decrease nor Mg absorption** in experimental (FONTENOT et al.,l960: MORE et al.,l972). It is perhaps more likely that the lower utilazation of Mg in ruminants consuming high N forage is **due to a change in the chemical composition of the herbage other than the increase of N content**. In this respect the influence of N application to grassland **on the K and higher fatty acids (HFA) concentration** in the herbage requires attention. Literature data from almost 50 years ago in fact suggested, that **fatty acids might affect Mg and Ca utilization** (BROUWER et al.,l943: BROUWER,l944: DUEL,l955). More recent experimental work confirmed this hypothesis. **Increasing amounts of HFA added to the rations of ruminants resulted in a lower apparent availability or in a reduction of the serum Mg levels** (KEMP et al.,l966: WILSON et al.,l969). Although more information is needed, these results suggested that the adverse effect on N fertilizer treatment of grassland on the Mg utilization may be at least partly explained by an increase in the HFA content of the herbage. The adverse effect of the **formation of insoluble Mg soaps on Mg absorption** is supported by research indicating that the **rumen is an important site of net Mg absorption** (GRACE and MACRAE,l972: GRACE et al.,l974: KEMP et al., l973: TOMAS and POTTER,l976).

It has been shown that it is possible to **predict the uptake of nitrate** (BHAT et al.,l979), P and K (BARBER,l984) by plants growing in controlled environment. On the other hand,ions such as **Ca and Mg, which are often the dominant cations in the soil solutions**, cannot be considered indipendently. Their concentration in the soil solution will be greatly **affected by the total concentration of anions** in solution and by their relative proportions of the exchange complex. In a **fertile soil the nitrate predominates** and tends to fluctuate greatly over a croping period. Hence, the concentrations of Ca and Mg in soil solution also change due to factors other **than plant uptake of these ions**. In addition plant **uptake of Ca and Mg increases** with the **proportion of N supplied as NO_3/NH_4** mixtures (KIRKBY,l969). Thus prediction of Ca or Mg uptake may be **difficult without the close control or knowledge of nitrate levels**. However, if the anion level affects, the uptake of Ca and Mg similarly, then the Ca/ (Ca+Mg) ratio should not be affected by a fluctuating anion concentration in the soil solution, nor should the uptake ratio be greatly influenced by the N status of the plant. The **nutritional quality of forage** is affected by the relationship of Ca to Mg in animal metabolism: **high Ca leads to symptoms of Mg deficiency and high Mg tends** to increase the Ca requirement(MAYNARD et al.,l979). Sometimes both Ca and Mg are low in forages, increasing the likelihood of grass tetany. In wheat pasture tetany, **low Ca in the blood of grazing beef cattle appears to occur more frequently than low Mg** (BOHMAN et al.,l984: LITTLEDIKE et al., l983). The **relationship of forage levels of K,Ca,and Mg** to grass tetany of beef cattle have been studied with wheat(KARLEN et al., l980), and with a wheat-rye mixture(BOHMAN et al., l983, l983). The effects of soil mixture and air temperature on the concentrations of K, Ca, and Mg in wheat forage have also been studied (KARLEN et al.,l978).There also been studies on the effects of K and N fertilization on concentration of Mg, Ca, and K in winter wheat forage grown in solution culture and soil in growth chambers (OHNO et al.,l985). In a field experiment on an acid coarse textured soil in Georgia, LOWREY and GRUNES(l968) found that **fertilization with $MgSO_4$ increased Mg concentration in rye forage, but decreased the Ca concentrations**. In acid soils, the use of **dolomitic limestone** is recommended to avoid grass tetany (MAYLAND and GRUNES,l979).

Concerning the USA, it seems that knowledge of N-fertilization is important with **tall fescue feeding**. The underlying physiological basis for the various effect on tall fescue which result from its **endophyte infection**, and the extent to which the grass and fungus are responsible, are largely unknown. Two lines of evidence suggest that at least N-metabolism is one aspect that may be affected. The first is from green house studies show that high rates of N-fertilization increased the concentrations of one class on endophyte-synthetized N bases, ergoid alkaloids, in endophyte infected tall fescue (LYONS et al.,l986). Second, other classes of nitrogenous metabolites that are insect feeding deterrents are associated with endophyte infection. Furthemore, the expression of cattle toxicoses has been quantitatively related to rates of N fertilization (SIEGEL et al.,l987). Thus in tall fescue, both fungal and host N metabolism may be contributing factors to various characteristics which are pecupiar to the infected plant.In addition, during a field experiment was found that tall fescue generally produced higher yields than ryegrass, however, increasing N-fertilization increased N concentration of tall fescue but did not consistently affect that of ryegrass (COLLINS,l99l). Cows grazing the high N-fertilized fescue, and some extent those grazing the moderate N-fescue, had clinical signs of summer fescue toxicosis comparing with low N-fertilized fescue (STUEDEMANN et al.,l985). Lambs grazing "Kentucky 3l" tall fescue pastures in northern West Virginia had lower average daily gains than lambs grazing perennial ryegrass, orchardgrass, or smooth bromegrass(REID et al.,l978).

Nutrition and magnesium metabolism

Metabolism of the five basic elements

In considering the **relationships of the four basic elements (Ca, P, Mg, K)**, it is fundamental ,importance to recognize, first that a very high percentage of the body **Ca,P,and Mg is located in the bone** and that most of these mineral elements located therein can be mobilized when needed for use in the metabolic events of body tissue. The bone, therefore, serves as a very large reservoir of these mineral elements (LAZZARA et al.,l963). All four elements are closely related to many metabolic events in the body. **Potassium, however, is not stored to any large extent in the bone**: it exists in the body primarily as a cellular constituent. **As the animal ages, the readiness of availability of stored mineral elements in the bone does decrease** (GARCES and EVANS,l97l: HANSARD et al.,l954). Not only can the animal draw on bone reserves, but there is considerable evidence that the animal tissue is able to adapt to varying dietary inorganic elements in such a way as to avoid clinical symptoms of deficiency or insufficiency. A **deficiency of any of these elements leads to reduced voluntary feed consumption** and reduced milk production. Bordeline deficiencies in any one or any combination of these elements are extremely difficult to diagnose. **Dairy farmers simply do not know** a) how much of each mineral element is in their feedstuffs and b)how much of each mineral element should be added to the concentrate mixture fed. Consequently, milk production may unwittingly suffer from mineral deficiency, insufficiency, or toxicity (JACOBSON et al.,l972).

There are a number of published papers on the P (WISE et al.,l958: WISE et al.,l963), Ca or K requirements for ruminants. Many of the dietary relationships among these minerals occur at the absorption rate (ALCOCK and McINTYRE, l962: EWER,l951: KODICEK,l967). **High dietary K impaired intestinal absorption of Na whereas low K increased urinary Na excretion** (SCOTT,l970). Normally, K has no specific effect on Mg requirement. **However, very high K, of the order of about 4 % of the diet, does enhance Mg deficiency** (O´DELL et al.,l960). Apparent **absorption of Mg in rats was reduced by an increase in dietary Ca** from 0.34 to 0.68 or of P from 0.39 to 0.79 % and further reduced by increasinf both. Also, increasing **dietary Ca decreased percent P absorption** (TOOTHILL,l963). High Mg intake increased Ca loss from the body (O´DELL,l960). High-P prevented the Ca loss, and high-K tended to prevent the Ca loss. Magnesium absorption is **enhanced by neomycin** (O´DELL,l960). Vitamin D affects Mg absorption only slightly but Ca absorption quite markedly. **Increased dietary P decreases absorption of Mg**. When the diet **is low in P, excess dietary Mg causes loss of Ca but not when P is adequate**. Vitamin D and bile are required for calcium absorption in the chicks (COATES and HOLDSWORTH,l961) and perhaps also for P absorption in sheeps (EWER,l951).

Some of the relationships in blood minerals include the following: low Mg in the diet and blood did not affect blood Ca or P bone content. **In general, diets low in any of these mineralelements will cause reductions in blood levels** (KENDALL et al.,l968). Low K diets and the consequent low-feed and P intakes lead to reduction in serum P but little change in Na,Ca,or Mg in sheeps (CAMPBELL and ROBERTS,l965). The Ca content of the red blood cells is near zero whereas the K content is high. In cattle, mean serum Ca is l2.9 whereas the diffusable portion is 4.9: inorganic P is 4.9 but total blood P is perhaps 4 times and red cell P approximately l0 times this figure. In man, whole blood Mg is 4.6 ,red blood cell Mg 6.6, plasma 2.7, serum 2.5, and diffusable serum l.9 (mg/l00 ml) (LANE et al.,l968: SCOTT,l970).

SUTTLE and FIELD(l967) showed that **adding K to the diet of sheep resulted in a reduction of the apparent availability of dietary Mg and a fall in the serum Mg** concentration. Similarly, NEWTON et al.(l972) found that the apparent absorption of Mg by young sheep was significantly depressed when the diet contained 4.9 % K (an intake of 40.5 g K/day) compared with one containing 0.6 % K(an intake of 4.8 g K/day),boths diets having a similar Mg content(intakes of 878 and 912 mg Mg/day,respectively). The evidence from grazing trials about the importance of K in the **aetiology of hypomagnesaemia is conflicting.** As HEMINGWAY et al. (l963) have pointed out,different forms, concentrations and combinations of N and K fertilizers have been applied to pastures of differing botanical composition, and sheep and cattle of different physiological states have been used as the test animals. However, other studies have shown that **both the concentration of K and the Na:K ratio in rumen fluid affect the absorption of Mg from the reticulo-rumen** (TOMAS and POTTER,l976: WYLIE et al.,l985). Therefore JOHNSON and POWLEY carried out a balance experiment using four young lactating goats in a Latin square design - **fed with perennial ryegrass from plots that had received 377 kg K**/ha(diet l): 63 kg K plus 377 kg Na/ha(diet 2): l88 kg K plus l88 kg Na/ha (diet 3) or no fertilizer(control diet 4). The apparent **availability of Mg was high in all the grass diets** (0.355-0.469): it was significantly depressed when the intake of K was high(diet l): but was not significantly different when the intake of K was accompanied by a high intake of Na(diet 3):

Diet	Total ash	N	Mg	Ca	Na	K
l	78.5	21.4	l.55	5.67	3.38	27.l
2	73.l	20.9	l.32	4.60	l2.68	l3.7

3	83.3	22.4	l.l6	5.50	8.42	23.0
4	54.6	28.9	l.75	8.27	5.63	9.l

	Diet			
	l	2	3	4
Milk yield	l.31	l.31	l.32	l.27
DM digestib.	0.73	0.73	0.73	0.68
Apparent availability				
Mg	0.36	0.47	0.45	0.47
Ca	0.23	0.l9	0.25	0.30
Na	0.90	0.91	0.91	0.85
K	0.92	0.91	0.93	0.91
Apparently absorbed				
Mg	0.47	0.60	0.59	l.06
Ca	l.28	0.86	l.31	2.73
Na	2.99	l2.56	7.28	5.35
K	24.97	l2.35	20.65	9.46

In their trial, there was a significantly lower apparent availability of Na in diet 4 and a significantly higher apparent availability of K in diet 3. There were no significant differences in the apparent availability of Ca. During the l0 days trial, **the plasma Mg concentration** was not significantly affected by any dietary treatment but did decrease temporarily when diets were changed (on the llth day, the diets were again abruptly changed to hay and concentrates for 6 d. This sequence of grass or hay and concentrates was repeted three more times to complete the Latin square). In addition, there were no significant effects on mineral concentrations in the milk(JOHNSON and POWLEY,l990).

It has been shown that, with (TOMAS and POTTER,l976: GRACE et al.,l988). Studies have **high intakes of K, there is a reduction in the net absorption rate of Mg from the reticulo-rumen** also indicated that this might be a result of the increased potential difference(PD) between blood and rumen fluid (TOMAS and POTTER,l976: BROWN,l980). CARE et al.(l984) showed that in sheep the K:Na ratio affects the absorption of Mg from a solution placed in a rumen pouch. A high K:Na ratio significantly depresses the rate of absorption which is related to the PD across the rumen wall(blood positive) compared with a solution with a low K:Na ratio. It would thus seem **likely that the K:Na ratio in the diet is important in influencing the rate of absorption of Mg from the reticulo-rumen, especially at low concentrations of soluble Mg in the rumen fluid (JOHNSON and JONES,l989).** The observed changes associated with a change in diet of JOHNSON and POWLEY(l990) trial are consistent with those reported in lactating cows, where the mean daily intake of Mg had increased from about l6 g/day on the dry diet to 23 g/ day on frozen spring grass (JOHNSON et al.,l988) and in sheep where diets were kept approximately isomagnesaemic (CARE et al.,l967)

However, an **increase in the intake of K has not always resulted in a fall in plasma Mg concentrations** and it has been suggested that the effect of K on Mg homeostasis depends upon the Mg intake (FIELD and SUTTLE,l979).

JOHNSON and JONES(l989) evaluated the effects of four diets on rumen pH and mineral metabolism in wether sheep.The diets were barley+hay(BH): flaked maize+hay(MH): dried(DG)and frozen(FG)grass:

Diet	BH	MH	DG	FG
Dry matter(g/kg)	821	827	844	l48
Mg (g/kg DM)	2.5	l.9	l.5	2.4
Ca	3.8	3.5	6.5	4.8
P	3.8	2.2	3.3	4.3
Na	l.2	l.0	2.8	l.7
K	8.5	8.5	20.4	33.8
Intake(mmol/d)				
Mg	84.l	71.0	47.9	85.8
Ca	76.3	68.4	l33.8	l02.5

P	l01.9	57.3	84.6	l18.9
Apparent availab.(%)				
Mg	47.3	37.6	27.6	34.9
Ca	-4.l	-4.5	5.8	0.l
P	l2.5	-31.8	l2.0	25.3
Urinary excretion(%)				
Mg	36.3	46.3	26.3	24.9
Ca	9.6	l5.5	0.3	0.9
P	2.6	l.4	3.3	6.4
Retention(mmol Mg/d)	9.4	-5.3	0.5	8.9
Appar.avail.(mmol Mg/d)	40.2	23.0	l3.l	30.2
Urine Mg (mmol/d)	30.8	28.3	l2.6	21.4
Urine pH	8.48	8.50	8.93	8.9

In addition, to the JOHNSON and JONES(l989) trials, the **concentration of Mg in ultracentrifuged rumen fluid was negatively correlated with pH, which was significantly higher at all times on the grass diets**. This relation was also detected in the apparent availability of Mg. The proportion of **absorbed Mg excreted in urine** was significantly influenced by diet as it is seen in above tabl.

A possible explanation for the differences in the apparent rates of release of Mg is the difference in the rates of fermentation of cereal grains and forages in the rumen. Also, there **could be an effect of the form in which Mg is held in plant tissues**. In cereal grains minerals held almost entirely in the aleurone layer, and Mg is present as the salt of inositol hexaphosphoric acid. In vegetative tissues about 70 % of Mg is diffusible and associated with inorganic anions and organic ions such as malate and citrate. It is also associated with indiffusible anions **including oxalate and pectate** (MENGEL and KIRKBY,l982).

Both the concentration of K and the Na:K ratio have been shown to affect the absorption of Mg from the reticulo-rumen(TOMAS and PORTER,l976: WYLIE et al.,l985). It has also been shown that **NH3 reduces Mg absorption, and is additive to the effect of the Na:K**

ratio(CARE et al.,l984). **The concentration of NH3 in rumen fluid was always significantly higher on frozen grass diet(FG) and concentration of Mg was lowest**. Studies have indicated that the **potential difference (PD)** between blood and rumen contents might also affect Mg absorption (TOMAS and PORTER,l976: BROWN,l980). In the above trials was also occured, that the PD was significantly greater on diets FG and DG than on the other two diets which were similar to each other,and that pH values were significantly higher on these both grass diets throughout the day. **Similarly high values have been observed in animals fed on fresh grass**(BRYANT,l964: HORN and SMITH,l978; HLASNY, 1991), but others have reported lower values when animals ate grass than when they ate dry diets (JOHNSON et al.,l988). This apparent anomaly may be a reflection of the amount of grass eaten.

In the experiment of JOHNSON and JONES(l989) the sheep were fed at about maintenance level, whereas the cows were allowed to eat grass ad libit.(JOHNSON et al.,l988). Thus JOHNSON and JONES(l989) concluded that on diet FG the greatest antagonistic effects of the concentrations of NH3 and K, the Na:K ratio, the potential difference (PD) between blood and rumen contents and rumen pH all occured when concentration of dissolved Mg was about at its lowest.

A number of investigators have reported that the ingestion of supplement Na increased urinary Ca excretion in humans (MUL- DOWNEY et al.,l982: BRESLAU et al.,l982: CASTENMILLER et al.,l985: KURTZ et al.,l987) and animals (GOULDING and McINTOSH,l986: GOULDING and CAMPBELL,l984). But these investigators fed NaCl and **ignored the potential importance of dietary anions**. For example, several investigators have shown that **ingestion of sodium bicarbonate decreased urinary Ca excretion** (GOUILDING et al.,l984:LUTZ, l984). There are data on the effects of inorganic anions on Ca utilization. A number of investigators observed **increased urinary excretion of Ca** (LEMANN et al.,l966: LEMANN et al.,l986: JACOB et al.,l983: PETITO and EVANS,l984: KRAUT et al.,l984: KUNKEL et al.,l986: NEWELL and BEAUCHENE,l975) **and often** (PETITO and EVANS, l984: KRAUT et al.,l986: KUNKEL et al.,l986), **but not always**

(NEWELL and BEAUCHENE,l975), **reduced Ca retention in bones** of animals made acidotic by the infusion or ingestion of ammonium chloride. WHITING and COLE(l986) and (GREGER et al.l987: LEWIS et al.,l989: KAUP and GREGER,l990) demonstrated that the **addition of other chloride salts, including NaCl, also increased urinary Ca excretion in rats and humans**. Several investigators noted increased urinary excretion of Ca when **sulfate was generated as a result of catabolism of excess protein or S-amino acids** (ZEMEL et al.,l981: WHITING and DRAPER,l981: GREGER,l989). Furthemore, WHITING and her co-workers (WHITING and COLE,l986: WHITING and DRAPER,l981) demonstrated that the **ingestion of additional inorganic sulfate also increases urinary excretion of Ca**.

GREGER et al.(l99l) examined the Ca,Mg and P utilization in rats fed semipurified **diets supplemented with 0.4 mol Na/kg diet or 0.4 mol K/kg diet** as chloride, sulfate, bisulfate, carbonate or bicarbonate salts in two vivo studies. The **ingestion of supplemental fixed anions** (chloride, sulfate or bisulfate) **increased urinary excretion of Ca,Mg and P**. It made no difference whether the anions were ingested as Na or K salts. Although bone and plasma Ca concentrations were not responsive to these dietary changes, **less Mg was retained in bones of rats fed any of the supplemental salts**. (GREGER et al.,l991). These data indicate that those investigators who have claimed **supplemental Na increases urinary Ca excretion** should consider the importance of these anions administered with the Na. GREGER et al.(l991) suggested that ingestion of supplemental anions **affected Mg utilization** somewhat differently than Ca utilization **in two ways**. First, analyses of the data with stepwise multiple regression analyses indicated that urinary pH and P excretion, unlike Ca excretion, **were important determinants of urinary Mg excretion.** Second, animals fed any of supplemental salts (chloride, sulfate, bisulfate, carbonate, bicarbonate) **retained less Mg in bone**. Previously KAUP and GREGER (l990) observed that ingestion of chloride salts **tended to reduce bone Mg retention**. CHARLTON and ARMSTRONG (l989) observed that the ingestion of varying levels of Na had a quadratic effect on Mg concentrations in muscle and heart. GREGER et al.(l99l) concluded that the potential for large variations in the intake of **inorganic anions in human diets is great**. Thus, the effect on Ca and Mg utilization of variations in anion intake deserves further study, **especially among women with low Ca and Mg intakes.**

Magnesium-potassium and sodium relatioships

Potassium, representing an important fraction of cation contents of the rumen fluid, is important in maintaining a desirable medium for bacterial fermentation. HUBBERT et al.(l958) have shown that **K is essential for cellulose digestion in an vitro system**. Maintenance of osmolarity with plasma is important to maintain a desirable moisture content of the rumen fluid (BALCH and JOHNSON,l950: NICHOLSON et al.,l960). They have shown that a higher moisture content favors cellulose digestion by the cow. They found that the contents of the ventral part of reticulo- rumen had a DM content of 5-6 % on a long-hay diet and about l0 % for ground hay. A similar moisture requirement may exist for cellulose digestion in the colon. It has been suggested that bicarbonate and water are secreted in the ileum to provide a medium for fermentation in the colon (ASCHBACHER et al.,l965).

Differences in physiological and biochemical responses to **different concentrates- forages rations** have been extensively investigated in terms of physical form and crude fiber content of the feed, rate of digestion, and rate of passage. However, one of the most striking differences between high-roughage and high-concentrate rations is that **the K intake may be as much as fourfold higher for animals consuming mostly forage**. Although a strict nutritional deficiency of K probably is seldom a factor, an osmotic deficiency in rumen fluid may be responsible for results attruted to these more commonly considered factors just mentioned.

Sodium and K added as bicarbonates to high-grain rations of dairy cows under experimental conditions have generally tended to **change the rumen pH**, molar ratios of short-chain fatty acids, and milk fat percentage to values obtained when diets containing larger amounts of hay are fed(DAVIS et al.,l964: EMERY et al., l965). However, two papers **indicate no advantage** in feeding Na or K as bicarbonates to fattening steers fed an all-grain ration (LONG et al.,l965: WISE et al.,l965). The usual rationale for feeding bicarbonates is that it will increase the buffering capacity of rumen fluid, which has been lowered because of the decreased salivary secretion associated with consumption of high-grain rations. Perhaps of equal importance to the bicarbonate is the addition of the cation, which increases the osmotic pressure of rumen fluid and tends to maitain a more nearly optimum moisture content in the rumen. If this is the case, then K might be somewhat more effective than Na, because it is more slowly absorbed from the rumen. By the same logic the **divalent cations which are poorly absorbed** (PARTHASARTHY and PHILIPSON, l953) should be even more effective. A report by EMERY et al.(l965), that Mg-oxide is at least as effective as Na-bicarbonate, lends some support to this speculations.

The concentrations of K, like most mineral elements in milk, probably is not influenced appreciably by diet. The **concentration of K in milk is five to ten times that in blood** plasma, whereas the reverse is true for Na. In this respect milk has the ionic composition characteristic of intracellular substances and, since milk is an aprocrine secretion, its composition would be expected to resemble intracellular constituents. WARD(l963) found **significant differences in K concentration in dried milk from different areas** of the United States, and NICKERSON(l960) reported differences between locations within the state of California. **No explanations** have been offered for these differences. One report indicates that high environmental temperatures resulted in a slight decline in the K content of milk(KAMAL et al.,l961). The data of FORBES et al.,(l922) indicate a decline in the concentration as the lactation period progresses. **Colostrum has a lower concentration of K, which gradually increases** as the milk becomes normal (GARRETT and OVERMAN,l940). Potassium was shown to be absorbed through the mammary epithelium more slowly than Na and chloride, when the elements were introduced via the teat as radioactive isotopes(KNUTSON and PERGORAN,l964).

The **possible toxic effects of excessive intake of K by ruminants** has received more attention than K requirements. This is a realistic approach because the ruminant animals, subsisting as they do on a high-roughage diet, may have a K intake throughout their lifespan which is many times their dietary requirement. **Potassium (K), unlike other less available minerals (i.e.;Ca, Mg), is almost completly absorbed** by animals, and the excess excreted principally in the urine. PICKERING (1965) says, "**That the cow normally does not suffer from a permanent hypercalemic acidosis seems to be the result of a fortunate coincidence, that in the herbivorous diet the large amounts of K are part of an excess of inorganic cations which necessitates the excretion of an alkaline urine in order to avoid metabolic alkalosis**". About 200-400 g per day of K would be an average intake for a 500-kg cow fed alfalfa hay **and 500 g or more are probably regularly consumed by cows on fresh pasture or cows fed green-cut alfalfa**. The latter intake would represent over l kg per day of KCl(WARD,l966).

The toxicity of K administered intravenously is well known and widely appreciated. What is not commonly recognized is that K has about equal toxicity, whether administered orally or intravenously because of its rapid and probably nearly complete equilibration with extracellular water. TALBOT and PICHIE(l958) have made the point quite clearly that **there is no difference in effect whether K is administered orally or intravenously**. DENNIS and HARBAUGH (l948) administered 648 g of KCl orally to cows. One died and the **other recovered after treatment with Ca-gluconate**. Two animals received 300 and 400 g, respectively, and manifested no clinical symptoms, whereas a third cow receiving 350 g developed milk fever symptoms and **recovered after treatment with Ca-gluconate**. ANDERSON and PICKERING(l962) administered two liters of one normal KCL by slow intravenous infusion to cows and found no cardiac abnormalities. Plasma K levels increased by l-2 meq/l (from 4-5 to 6-7 meq/l) and remained at that level. Urinary excretion of K rapidly increased to equal rate of infusion. **In the dog, on the other hand, K infusion results in elevated plasma levels unless the dog has been conditioned** by feeding additional K salts (PICKERING,l965). Rats were able to develop a tolerance to oral K when the dose was progressively increased (THATCHER et al.,l947), but **rabbits were progressively less able to tolerate** intraperitoneal injections of K salts (TRUSCOE et al.l953).

The experiences of BERGMAN and SELLERS(l954) indicate that the calf responds more like the dog than the mature cow. The toxicity level of K for calves was reached at a blood plasma level of less than 8 meq/liter. At this levels calves were irritable and urinated every few minutes. Death from cardiac failure resulted at a plasma level of l2.7 meq/l (BERGMAN and SELLERS,l954). ROY et al.(l959) **reported death by cardiac arrest in calves which had localized E.coli infections of the intestinal tract.** They observed increased plasma K levels ,attributed to cellular breakdown associated with loss of weight and consequent release of K from cells. FISHER(l965) reported death attributed to primary cardiac failure of calves with diarrhea. He observed increased plasma K levels as well as increases in blood urea in calves not losing weight. The increased plasma levels **were attributed to renal inefficiency in removal of K via urine**. Another explanation for the source of increased plasma K might be that the abnormal intestinal epithelium allowed absorption of K from the lower intestinal tract, where the concentration is much higher than in plasma. Such calves are **severely acidotic, and this may indicate H ions going into cells and K ions moving out**. **This could result in an increase in plasma K sufficient to produce cardiac arrest** (WARD,l966). It would appear from the studies described that the calf, because of renal insufficiency, **is less efficient in excreting K than the cow,** and the increased levels of blood urea(FISHER,l965) observed in calves add support to this conclusion. **In the cow, severe diuresis did not increase the absolute amount of K excreted in the urine** but, on the other hand, the total loss of Ca,Na,Cl,and PO4 ions was increased (SELLERS et al.,l951). The water demand for urinary excretion of K may be a factor in the water turnover rate, but this has not been investigated. The **water intake and urine excretion volume are directly related to the K intake,** but increases in K intake are also related in most cases to a variety of other factors, such as increases in crude fiber intake (KNOX et al.,l965: LEITCH and THOMSON,l944).

Potassium is required for a variety of body functions. A **deficiency may result in non-specific signs**, including slowed growth reduced feed consumption and efficiency, stiffness, and emaciation. However, there are **unlikely to be K deficiencies in most conventional ruminant diets**. In some regions, it is possible that K deficiencies could arise in view of the decreasing content of this mineral with increasing forage maturity during the extended dry season and the use of NPN, which supplies none of this material. **From 0.5 to 0.9 % of the dietary DM will meet the K requirements of beef cattle**. Grains often contain less than 0.5

% K, and the level may become critical in high-or all-concentrate diets.

Excessive levels of K have been found to interfere with Mg-absorption. High levels of K also interfere with high levels of P, which tend to increase the incidence of phosphatic urinary calculi. However, potassium is unique among the major elements required by ruminants, because **dietary deficiencies of this element are very uncommon if not unknown.** Ruminant animals by comparison with other species, particularly the carnivores and omnivores, **have an uncommonly large intake of K.** The ruminant species are also characterized by a **large fluid volume in the gastrointestinal tract**, necessary for the digestion of a large mass of low energy feed. The literature available does not indicate that the metabolism of K after absorption or at the cellular level is any different in ruminants than in other species. A **specialized exception to this general statement is the K content of sheep erythrocytes.** EVANS and KING(l955) has shown that the large differences between breeds in the K content of a red blood cells of sheep which have been observed are under genetic control, and MEYER(l963) has confirmed this for German breeds of sheep. EVANS and his co-workers have published extesively on this subject and other physiological differences characteristic of the genetically different sheep have been investigated (EVANS,l963). A similar genetic trait has not been detected in cattle (WARD,l966).

Du TOIT et al.(l934) were **the first to investigate K requirements for cattle. They found that a ration providing K as O.32 % of the DM was adequate to maintain milk production of 2 gal per day over a period of 2 lactations**. TELLE et al.(l964) found that O.34 % K in the ration was the minimum for growing finishing lambs and that optimum intake was O.55 % of the ration. ROBERTS and OMER(l965) found that a K level of O.5 to 0.6 % of ration DM was adequate for rapid weight gains in fattening steers. TELLE et al.(l964) made the interesting observation that the **length of rumen papillae was directly related to the amount of K on the skin** increased with supplemental K supplied to deficient sheep. The K content of rumen epithelium has been reported to be higher for sheep with genetically high red blood cell K than for the genetically low K animals (MOUNIB ans EVANS,l960).

The K of the diet is readily absorbed, as indicated by the high percentage of the intake excreted in urine and in the milk of lactating cows. From the data of WARD(l956) it was calculated that **urinary K as a percentage of total K output for nonlactating cows was 86 % and for lactating cows urine represented 75,** feces l3, and milk l2 % of the total. Although the evidence indicates that Na is removed from fluid throughout the entire length of the gastrointestnal (G.I.) tract by a mechanism of active transport, it appears that K enters blood plasma only by flowing down a concentration or electrochemical gradient, **K is absorbed from the rumen** (HYDEN,l961: PARTHASARTHY and PHILIPSON,l953) **and from the omasum** (OYAERT and BOUCKAERT,l96l) although in both organs the **rate of absorption is greater for Na than K**. The K concentration of the fluid fraction throughout the G.I.tract is consistently several times higher than plasma level. On the other hand, the **content of the G.I. tract are generally electronegative**. Thus, the concentration gradient must be sufficiently great to overcome an adverse electrical gradient. The fluid of the G.I.tract tends towards isotonicity with blood: however, rapid increases in ionic concentration are produced by the end products of digestion in the rumen and the small intestine. According to BROUWER(l961) the intestinal contents change from a hypertonic conditions in the small intestine to a hypotonic condition in the colon and fecal water. The **hypotonic condition results from absorption of Na and some organic ions**. At the same time the K concentration becomes progressively greater, reaching a maximum in the fecal water (BROUWER,l961). Despite the relatively increased concentration of K, the **feces is not an important avenue of K excretion for the ruminant** since, as pointed out, it represents only about l3 % of the total K excretion. However, the **percentage of total K output excreted in the feces is higher for herbivores than carnivores** (ALEXANDER:l962, l965). It has been observed that Zebu cattle excreted less K in their feces and more in urine **than Herreford cattle** when both breeds consumed the same ration (HORROCKS and PHILIPS,l964).

Sodium is the most abundant extracellular cation in the mammalian body whilst K and Mg predominate intracellulary. As a result of the functional relation amongst these elements in maintaining osmolality and acid-base balance, nutritional interactions amongst these elements may be anticipated. **Nutritional manipulation of dietary Na,K and Mg** has resulted in altered mineral excretion and tissue composition leading to impaired growth in man and animals (FORBES,l966: DUARTE,l980: RYAN and WHANG,l983). The **interrelatioships between these cations are complex, with reduced Na intake or elevated K intake, or both, decreasing apparent absorption of Mg in the ruminant leading to hypomagnesaemia** (MORRIS and GARTNER,l975); whilst in other species Mg deficiency induces increased Na and decreased K concentrations in muscle and heart EBEL and GUNTHER,l980). In addition, the mineralcorticoid **aldosterone which is stimulated by low Na or high K intakes**, or both, has been demonstrated **to increase Mg excretion in the urine** of rats (HANNA and MacINTYRE,l960:) and sheep (SCOTT and DOBSON,l965) **and to affect the distribution of Mg in the tissues** (DUARTE,l980). So, alterations in Na or K intake, or both, affect the **distribution and excretion of Mg in man and animals**. CHARLTON and ARMSTRONG (l989) were performed the experiments on rats to investigate the effect of varying Na,K or Na+K intakes on Na,K and Mg excretion and plasma and tissue concentrations. **Increasing Na intake in a linear fashion produced a significant quadratic effect on Mg concentration in heart and muscle**, i.e. a decrease followed by an increase as Na intake rose: Na intake did not affect liver or bone Mg concentrations. There were no significant effects of Na intake on plasma Mg,Na or aldosterone-during l8 d testing period, but **plasma K fell significantly as Na intake increased**. The rats fed on the adequate-Na diet had a **significantly higher urinary Mg excretion** than those fed on high-Na diet: Na intake did not affect faecal Mg excretion (CHARLTON and ARMSTRONG,l989). The authors **concluded that lowering the Na itake or increasing the K intake, or both, increases the excretion of Mg in the urine, but any link with aldosterone remains tenuous**. Increasig the K intake had no significant effect on K excretion, **whereas increasing the Na intake increased the excretion of K in urine.** Dietary manipulation of Na,K and Mg produced no conclusive effects on plasma or tissue Na,K and Mg concentrations. The increased excretion of Mg in the urine at low and at high Na intakes may be due to the loss of intracellular Mg from the tissues. **At times of low Na intake, the body tissues act as a**

reservoir for Na, mobilization of which will release not only Na but Mg and K into the circulation (LARVOR,l976: DUARTE,l980: SCHRICKER,l985), which may account for the increased excretion of Mg at low Na intakes. An explanation (CHARLTON and ARMSTRONG,l989) for the increased excretion of Mg in urine at low Na intakes relates to the **ionic exchange of Mg ions for K ions in the kidney tubules**: evidence from previous work (SAMLEY et al.,l960: LEMANN et al.,l970) has suggested that at times of low Na intake, increased amounts of Mg are **excreted in the urine as an ion-exchange for K.** Increasing the K intake produced no natriuries and had no effect on the faecal excretion of Na in trial of CHARLTON and ARMSTRONG (l989)- results which do not concur with those reported by DUARTE(l980). The doubling of K intake produced no significant effect on any K variable **but increasing the Na intake virtually doubled K excretion in the urine**, probably by increasing the secretion of K by late distal tubules and cortical collecting ducts (VALTIN,l983). DUARTE(l980) demonstrated that increasing the K intake of rats produced a kaliuresis and an accumulation of K in heart and bone, **but no similar conclusions were obtained** by CHARLTON and ARMSTRONG(l989).

The ruminant is not only capable of very effective recovery of large amounts of Na from the digestive tract but, **like other species, is capable of conserving body Na by action of the kidney.** The combination of the two processes can reduce Na excretion to nearly zero. On the other hand, there is an **obligatory excretion by cattle of K, both in the feces and urine** (CAMPBELL and ROBERTS,l965).

Some K excretion is probably **necessary to prevent severe alkalosis, because K ions are exchanged in the kidney for H ions and vice versa** (PICKERING,l965). STACEY and BROOK(l964) observed that the urine volume of penfed sheep was reduced as well as the total output of Na and K when their daily feed was given. At the same time the hydrogen ion output in the urine increased. This was interpreted to mean that the secretion of large quantities of saliva created a drain on the Na and bicarbonate of the blood plasma, **which initiated an aldosterone response to conserve Na and eliminate K.**

KAY(l963) reviewed the subject of **salt concentration** and its effect on **the osmotic pressure**

of rumen fluid and made the point that little attention has been given to this relationship. The concentration of Na in the rumen fluids exceeds K by a factor of l.5 to 3.0. **Whereas the major source of ruminal K is the diet, Na is introduced into the rumen primarily by saliva.** BAILEY (l96l) investigated a variety of diets and found K values in saliva of 4-70 and in rumen fluid of 24-85 meq/l. Comparable values for Na were 74-l66 and 83-147 meq/l. The ionic composition of rumen fluid is closely related to the rate of salivary secretion, and the **chemical composition of saliva can vary, particularly in K concentration**. The sodium status of the animal has a profound effect on the composition of saliva. A **Na deficiency stimulates increased production of aldosterone, with the cosequence that K largely replaces Na in saliva.** This subject has been studied intensively and reviewed in detail by BLAIR-WEST et al.(l965) and DOBSON(l965). He reports an interesting situation in which a **change from a high to a low K intake resulted in an apparent Na deficiency**. He found that in sheep a change from grass providing an intake of 0.7 mole of K to hay and meal providing O.25 mole of K per day **produced an aldosterone-like response**. Sodium retention was greatly increased and the concentration of K in saliva increased and Na decreased. Na concentration in the rumen at the same time increased from 55 to 9O mmoles per liter. The author postulates that this sequence of events is due to removal of Na from extracellular water to the gut, to maintain the ionic concentration of the fluid which otherwise would be markedly reduced because of the lower K intake. This exchange reduces the concentration of Na in extracellular water, which serves as the stimulus for increased aldosterone output. Increasing aldosterone output has the effect of increasing K output in saliva as a mechanism for conserving Na (BLAIR-WEST et al.,l965). **This may explain the Na diuresis found by HIX et al.(l953) when potassium bicarbonate was added to the diet of sheep.**

Considerable variation exists between the mineral content of grass species and variaties of the same species, **particularly in regard to sodium** (LEHR,l960: GRIFFITH et al.,l965). The sodium content of different grasses grown on the same site may, for example, vary from O.O2 % for varieties of timothy to nearly l % for varieties of cocksfoot or perennial ryegrass (GRIFFITH and WALTERS, l966). However, **high levels of Na ingestion may well be**

detrimental to animal performance: for example, JACKSON et al.(l971) have reported a linear decrease in weight and energy gain of lambs when the level of dietary Na was increased from O.7 to 3.0 %.

Therefore MOSELEY and JONES(l974) aimed at investigating the effects of **high levels of Na intake on the metabolism of wethers**. They found that DM intake, dry organic matter intake and digestible OM in DM(DOMD) were significantly reduced at the highest Na intake. There were **no consistent or significant changes in the serum concentrations of Na or K following NaCl supplementation, but serum Ca and Mg levels were significantly lowered as a result of NaCl supplementation.** NaCl supplementation improved the apparent availability of Na,K,Mg and Ca but reduced that of P and N. The retention of Na,K,Mg,P and N was lower at the highest Na intake but Ca retention was higher. **Urine volume and excretion of Na,K,Mg Ca,P, and N increased with NaCl intake**.

Effect of increasing dietary Na levels on changes in serum mineral concentrations was evaluated by MOSELEY and JONES (l974). They found an **increasing urinary output with higher dietary NaCl levels.** The increase in apparent availability the retention of Mg decreased by 65 % while that of Ca did not significantly differ from the control. For both Ca and Mg, however, the retention was positive at the higher levels of salt intake. Thus the **depression in serum levels of Ca and Mg cannot be explained on the basis of a negative balance** (MOSELEY and JONES,l974).

However,the control diet (0.46 % Na), with ad libitum feeding of herbage, provided an intake of 3.85 g Na/day, while the published recommended requirements (for examp. ARC,l965) for these sheep suggest an intake of 0.75 g Na/day (0.092 % in the diet). The herbage of the control diet, therefore, supplied a more than adequate Na intake, while the NaCl supplemented diets containing l.66, 2.46 and 3.09 % - were considerably in excess of requirements. There is much evidence **to show that a high concentration of NaCl in the diet will limit feed intake** (WEIR and MILLER,l954: WEIR and TORRELL l953: CHICCO et al.,l971: WILSON and DUDZINSKI,l973), and this concept has been used to a practical end in controlling intake of concentrate feed in feedlot cattle (RIGGS et al.,l953: KROGER and CARROLL,l964). JACKSON et al.(l971) found that increasing Na in the diet linearly decreased weight and energy gain, and claimed that this was due mainly to the interference of Na on fat deposition (KROMANN and RAY,l967). This was confirmed by WALKER et al. (l971) who showed by carcass analysis that sheep **given l.3 % NaCl in the drinking water had lower body weights, lower fat content, but higher protein than sheep given tap water.** MOSELEY and JONES(l974)observed the following changes in urinary excretion and retention of minerals- observed with increasing dietary Na on minerals (g/day):

	control	l.7% Na	2.5% Na	3.0% Na
		Sodium		
Intake	3.73	l4.22	20.49	24.72
Availability(%)	32.7	74.3	77.4	83.9
Urine	l.3	8.0	l0.9	21.6
Retention	-0.l8	2.6	5.0	l.0
Urine(% intake)	33.6	56.l	53.2	87.2
		Potassium		
Intake	l9.0	l9.5	l8.33	l7.l
Availability(%)	69.6	75.l	76.5	84.0
Urine	9.8	8.8	l0.l	l8.9
Retention	3.6	6.0	3.9	-4.5
Urine(% intake)	51.3	44.9	54.9	ll0.4
		Magnesium		
Intake	l.2	l.206	l.l34	l.053
Availability(%)	55.2	54.3	56.2	61.7
Urine	0.129	0.l93	0.219	0.477
Retention	0.533	0.463	0.417	0.l86
Urine(% intake)	l0.8	l6.0	l9.3	45.3
		Calcium		
Intake	2.86	2.92	2.75	2.55

Availability(%)	-4.2	-10.5	-0.6	+1.0
Urine	0.003	0.007	0.011	0.016
Retention	-0.12	-0.31	-0.04	0.01
Urine (% intake)	0.1	0.2	0.4	0.6
		Phosphorus		
Intake	2.577	2.643	2.514	2.369
Availability(%)	-1.6	-6.2	-10.1	-8.4
Urine	0.008	0.024	0.029	0.101
Retention	-0.05	-0.19	-0.29	-0.30
Urine(% intake)	0.3	0.9	1.2	4.3

According to these authors the **increase in the urinary excretion of minerals was mainly explained by an increase in water through- put and glomerular filtration rate in the kidney, leading to a reduced percentage reabsorption of minerals.** This urinary loss of minerals would largely explain the decrease in retention, although the decrease in intake would also affect the overall balance. The changes in apparent availability of minerals between groups are largerly nonsignificant but, except P, there is a trend towards increasing availability with increasing dietary Na.

MOSELEY and JONES(1974) **observed also the following effect of increasing levels of dietary Na** on water intake and urine volume output (l/day):

Groups	Water intake	Urine output	Difference
control	1.90	0.41	1.49
1.66 % Na	2.75	1.17	1.58
2.26 % Na	3.38	1.78	1.60
3.01 % Na	4.83	3.33	1.50

The authors concluded that it is clear from the results presented that **high Na levels** (i.e. those containing above 1.7% Na) have a **detrimental effect** on intake, live-weight gain, feed utilization, and **serum Ca and Mg level**. It is therefore possible that by supplementing a herbage diet on the basis of a low Na content the dietary concentration of Na may rise to well above l % . This approaches the level of dietary Na concentration (l.7 % Na) at which significant reductions were observed in serum Mg and Ca concentrations and also in N retention. It follows that **indiscriminate Na supplementation without due regard to herbage Na levels may be detrimental to the health and production of stock.**

Magnesium, calcium and phosphorus relationships

In ruminants, a high percentage of the Ca and P excreted is via the gut. **More than half of the Mg excreted is via the gut**. On the other hand, urinary excretion accounts for 90 % of the total K excreted and large quantities may be easily excreted via this route (SCOTT,l970). Urinary Mg excretion was between l and 3 g per cow per day. **There is an obligatory excretion of these elements which continues even when animals are fed diets completely devoid of each mineral element**(SCOTT,l970). Dietary K has little influence on Ca excretion: **however PTH increases Ca excretion.** A high Mg intake decreases the percent of bone ash, and increases bone Mg content and **decreases manganese (Mn) retention.** Acidosis or an acid diet, leads to increased renal excretion of P, though the urine is not a major pathway of P excretion, usually of the order of 2-8 % of the intake of sheep and cattle on roughage diets. Insulin causes a reduction in plasma inorganic P. **Urinary exretion of Ca seems to be related to urine pH** (SCOTT,l970). Bone is the probable source of the Ca, as fecal excretion in these studies remained constatnt.

Calcium metabolism has been studied by several workers in a number of species including the ruminants. Animals adapt to low-Ca diets by a reduction in fecal excretion and increased absorption of Ca. **Older animals take longer to adapt than younger ones.** Calcium retention was 25 % on a low-P diet but 96 % on a high (HENRY et al.,l960) phosphorus diet, suggesting that **retention of Ca, even though it may be quite available in the diet, is dependent upon the concurent availability of P**. In sheep(SMITH and LAURENT, l970) adaptation to low intakes of Ca can be accomplished by increasing the efficiency of Ca absorption. This efficiency is reported to be due in part to the formation of a greater amount of specific protein in the intestinal mucosa that binds and transports Ca**. Vitamin D is required for its formation.** The adaptation is quickly acquired and quickly lost and is partial rather than complete. Much has been said about the proper dietary Ca to P ratio (WISE et al.,l963). Holstein steers gained faster on either a 4:l or l:l Ca to P ratio diet with P held at National Research Council recommended amounts than those on a 8:l ratio (RICKETTS et al.,l970). For milk production most authors orefer a Ca to P ratio between l:l and 2:l.

In cows, urinary excretion of Ca ios between l and 2 g daily, relatively constatnt, and indipendent of diet. A report involving many diets states that"**it should be possible to kept lactating cows in Ca balance, not by high dietary Ca** but by including appropriate feed in the diet"(PAQUAY et al., l968). The endocrine regulation of Ca metabolism has been adequately reviewed by COPP (l970), COPP et al.(l962). Some of the more significant points include the following: the **two hormones that regulate Ca are PTH and calcitonin(CT).** The secretion rates of these two hormones may be mediated by changes in the Ca concentration of the perfusing blood without mediation by the pituitary or the central nervous system. **Increased Ca increased CT secretion, and decreased Ca decreased CT secretion- whereas increased Ca decreased PTH secretion and decreased Ca increased PTH secretion.** If plasma Ca was kept constant, changes in P did not affect PTH. **However, with constant Ca concentrations, lowered plasma Mg stimulated secretion of PTH and high Mg inhibited it.** This mechanism provides a highly efficient **negative-feedback control**. Both 3´,5´cyclic adenosin monophosphate (cAMP) and glucagon stimulate release of CT from pig thyroid (CARE et al.,l970). **Administration of PTH to dogs and humans caused a rise in plasma Ca and a fall in plasma P** which began within 30 to 60 min and continued from l2 to 24 hr. Calcitonin normally loweres both plasma Ca, and P. The target organ of CT is bone.PTH stimulates whereas CT inhibits bone resorption.

Parathyroidectomy depressed Ca absorption from the gut in the rat whereas administration of parathyroid extract restored or enhanced Ca absorption. CT had no effect on absorption of Ca, Mg, or P from intestinal loops in dogs but did not cause increased excretion of P in the urine. Parathyroid extract increased urinary excretion oh P and seemed to enhance tubular reabsorption of Ca. PTH enhances uptake of Ca by monkey kidney cells by 3 to 60-fold. It has been **proposed that PTH activates adenyl cyclase and that the resulting**

increase in cAMP increases the permeability of the cell membrane to Ca ions. PTH tended to increase total Ca absorption but net absorption was unchanged in ^{47}Ca studies (JACOBSON et al., l972). **Calcitonin secretion or release is increased** by :

> a)glucagon, b) porcine pancreozymin, c)dibutyryl cyclic AMP which is enhanced by theophyline, d) adrenaline in the presence of alpha-adrenergic blocade with phentolamine, e) increased Ca, f) to a lesser degree by increased Mg, and depressed by progesterone (JACOBSON et al.,l972).

Calcitonin is low or undetected and PTH high in the blood of parturient cows (CARE,l968: ANDERSON,l970), though there is normally a basal secretion rate. Cows in advanced pregnancy are more hypocalcemic than either milk-fever-prone or normal lactating cows when subjected to experimental hypocalcemia (PAYNE,l963). **Cows with milk fever often have reduced blood serum Ca, inorganic P and increased blood serum Mg** (HIBBS et al.,l946). Inorganic P decreases from about 6 to perhaps l.5, Ca down from l0-ll to 5 and Mg up from 2 to possibly 3.5 mg %. **Lactating cows are frequently in negative Ca and Mg balance** (LOMBA et al.,l968: PAQUAY et al.,l968). In attemps so far, parathyroid extract has not usually been effective in treating cows with early symptoms of milk fever (HIBBS et al., l947: MAYER,l968). The role of parathyroid hormone on Mg metabolism is not defined so clearly as it is for Ca and P (MILLER et al. ,l972; FONTENOT,l980).

A number of studies in animals, using a variety of in vivo and in vitro techniques, have indicated that there is direct **competition between Ca and Mg for intestinal transport**(BEHAR,l975: CARE et aal.,l984: ALCOCK and MacINTYRE,l962: SCHACHTER and ROSEN, l959). BEHAR, using an in vitro technique, reported that increasing the Ca concentration from 2 to 4 mmol/L in the incubation medium significantly reduced Mg transport in rat ileum at all Mg concentrations studied. Work by other investigators with rats, however, **indicates that the interaction between Ca and Mg is not always predictable**. In the everted gut sac, HENDRIX et al.(l963) found that Ca and Mg are taken up preferentially in different portions of the intestine and that their interaction varied throughout the intestine. **Specifically, Ca inhibited Mg transport in the ileum but not the**

duodenum, whereas Mg inhibited Ca transport primarily in the duodenum. ALDOR and MOORE(l970) concluded that Mg transport was depressed by increases in luminal Ca from O to l or 5 mmol/L in the colon, but not in the small intestine. O´DONNELL and SMITH (l973)investigated the interaction of Ca and Mg by studying short -term uptake in rat duodenal mucosa. Mg significantly inhibited the time dependent uptake of Ca, but Ca did not significantly reduce uptake of Mg. PETITH and SCHEDL(l977), however, found that Ca absorption from the cecum and colon was depressed in Mg-deficient rats as compared to controls, but Ca deficiency had no effect on Mg absorption. More recently, KARBACH and EWE(l987) reported that increasing the Ca concentration from l.25 to l0 mmol/L in in vivo intestinal perfusate has no effect on Mg absorption in the colon of rats. Likewise, increasing the Mg concentration from l.25 to l0 mmol/L had no effect on Ca absorption under similar conditions. When KARBACH and EWE examined Ca and Mg interactions further in the descending colon of the rat using "Ussing" system", however, they found that Mg had a significant effect on net Ca absorption. Specifically increasing the Mg concentration to l.25 mmol/L decreased the mucosal-to-serosal flux of Ca by 50 % and abolished net Ca absorption. The effect was due to a depression of the voltage-dependent component, that is, the paracellular pathway. Increasing the Ca concentration from O.l25 to 5 mmol/L had no effect on Mg transport. This **study does not rule out that Ca at lower concentrations may significantly alter Mg absorption.**

Much of the evidence for intestinal interactions between Ca and Mg has come from studies in which transport of one nutrient was studied in the absence of dietary intake of the other nutrient (BEHAR,l975: ALCOCK and MacINTYRE,l962: PETITH and SCHEDL,l977). This approach **does not represent the situation of an animal consuming a normal diet.** The deficient animals are often sick, and changes that alter cell permeability may occur. Indeed,KRAWITT (l972) found that whereas Mg-deficient animals absorbed more Ca than rats fed ad libitum, they absorbed the same amount of Ca as pair-fed controls. **Another problem in interpreting these studies is that absorption of Ca and Mg was studied primarily in isolated segments rather than in the intact animal**.

The results of the studies discussed previously do not exclude an adaptive effect of Ca upon Mg transport in the intestine. **Ca may indirectly affect Mg absorption through changes in serum concentrations of Ca-regulating hormones**. Alterations in serum Ca concentrations are known to affect not only l,25 dihydroxycholecal- ciferol but also parathyroid hormone(PTH). Although the effect of vit.D on Mg absorption is not fully elucidated, **PTH increases absorption of Mg in both humans and animals** (EBEL and GUNTHER,l980: WALSER,l967: SEELIG,l964: WILKINSON, l976: ANAST and GARDNER,l981). The precise manner by which PTH affects Mg absorption, however, is uncertain. Although the involvement of l,25-dihydroxycholecalciferol and PTH in mediating interactions between Ca and Mg in the intestine cannot be ruled out, these hormones are probably more important in the long-term adaptation to dietary Ca and Mg levels rather than in mediating short-term fluctuations. In addition, the in vitro evidence does suggest that there is interaction between Ca and Mg in the intestine indipendent of these hormones.

Increased inorganic phosphorus (P) in the diet has been reported to depress Mg absorption, presumably by **complexing with Mg to form an insoluble salt**. 0´DELL et al.(l960)showed that increased dietary P, **even more than Ca, increased the Mg requirement** for maximal growth in the both the guinea pig and the rat. TOOTHILL (l963) observed a **significant decrease in Mg absorption when P was increased** from 0.39 to 0.79% in l0-wk-old rats. This decrease was further reduced when both Ca and P were increased in the diet. Other investigators, **however, have not observed any effect of P on Mg absorption** (CLARKSON et al.,l967: CLARK and RIVERA-CORDERO,l974)
Later authors found in older rats that increasing P in the diet had no effect on Mg absorption and that there was no correlation between Mg absorption and P intake. BUNCE et al.(l965)reported that the effect of P on Mg absorption depended on the amount of Mg in the diet of weanling rats. High intakes of P (l%) lowered Mg absorption in the presence of high dietary Mg(O.l%), **but P improved Mg absorption when Mg was limiting in the diet** (O.Ol %). High Mg intakes, likewise, depressed P absorption to a greater extent the higher the P intake.

CLARK(l968) has also reported that the **effect of Mg on P absorption in rats depends on P intake**. Dietary Mg had no effect on fecal P at a P intake of O.2 %, significantly decreased it at an intake of 0.4 %, and significantly increased it when the P intake was 0.8 % and Ca intake was low(0.2 %). Analysis of variance indicated that dietary Mg alone had no effect on fecal P but **rather it was the interaction between Ca and Mg that significantly altered P absorption**. In studies **in humans, HEATON et al.(l964) showed** that increasing dietary P decreased Mg absorption. Conversely, BRISCOE and RAGAN(l966) observed a substantial decrease in P absorption when Mg was increased in the diet, although P balance did not appear to be significantly affected. GREGER et al.(l981) reported that subjects(males) lost significantly more Mg in the feces when they consumed a high P diet (2443 mg/d) rather than a moderate P diet(843 mg/d). The apparent absorption of Mg dropped from 43 to 34 % on the high P diet: however, urinary Mg also decreased on the high P diet, so that overall retention of Mg was unaffected by P intake. Both SPENCER et al.(l980) and LEICHSENRING et al.(l951) **observed no effect of P on Mg metabolism in men or women regardless of the Ca or Mg intake**.Studies on the interaction between P and Mg absorption are subject to the same concerns as the studies on Ca and Mg interactions. However,the data do suggest that the interaction between P and Mg in the intestine is complex and dependent on several variables, such as age, luminal contents, as well as the dietary intake of Mg and P.

Magnesium and aluminium in ruminants

A/ Soil-forages- ruminants; relatioships

Legume crops, that produced the highest dry matter yield accumulated the least amount of Al from spoils, whereas the reverse was true for those that produced the lowest yields and **exhibited Al toxicity effect** /TAYLOR et al.,l991/. **Aluminium is the most abundant metal and the third** most abundant element on the earth /MARTIN,l988/. No **evidence of essentiality** has been established for Al in the animal system. However, it may have **adverse effects** on animal performance and health **when it is consumed in excessive amounts.** Excessive intake of **antacids containing** appreciable amounts of Al may have adverse effects on human health /PERL,l988/. **Aluminium may interact with essential elements, namely P, Ca, Mg, and F** and adversely affect their metabolism by animals /ALLEN,l984/. The mechanism by which Al interferes with Mg metabolism are not defined so clearly as the effect of Al on P availability /ALLEN,l984/. Al does not form insoluble complexes with Mg in vivo /ALLEN and FONTENOT,l984/, as it does in vitro /ALLEN and ROBINSON,l980/. Aluminium is the most important yield-limiting factor in many acid soils /FOY,l988/. **Inhibition of root growt is a primary effect of Al toxicity** /CLARKSON,l965/.

One of the nutrient elements apparently affected by Al to a

great extent is Mg. Exposure to Al results in **decreased Mg concentration and total Mg content in plants** /CLARK,l977/. This may be due to decreased Mg ions absorption brought about by reduced root growth or to a direct Al inhibition of Mg ions uptake. The suggestion was put forward **that Al directly affected Mg ions absorption** in oats /GRIMME,l983/, sorghum /KELTJENS,l988/, **and ryegrass** /RENGEL and ROBINSON, l989/. Increasing evidence suggests that Al, previously considered to have little effect on animal life /McCOLLUM et al l928/, influences the metabolism of several minerals and **may play a role in hypomagnesemic tetany in ruminants** /DENNIS,l971/. In addition, Al may play a role in neurological disorders and bone disease in man /ALFREY,l983/. DENNIS/l971/ **found 500 to l,000 ug/g Al, dry-basis, in oat and wheat pasture** forage in Texas where grass tetany outbreaks occured. In Louisiana**, Al concentrations in forage samples from tetany-prone pastures ranged from 2,000 to more than 8,000 ug/g Al**, air-dry basis /ALLEN and ROBINSON,l980/. Ruminal contents of Al in cows that died from grass tetany averaged 2,373 ug/g,air-dry basis. KAPPEL et al. /l983/ found **higher Al in ruminal contents of hypomagnesemic cows** exhibiting symptoms of grass tetany than in asymptomatic hypomagnesemic cows and normomagnesemic cows /3,382 vs l,442 and l,666 ug/g, dry basis/, but found no relationship between changes in serum Mg and ruminal Al concentration over a 51-d period. CHERNEY et al./l983/found a **positive correlation among Al, Fe and Ti in forage samples and concluded that high Al concentrations** reported in forage and ruminal content samples probably resulted from soil contamination. While large quantities of Al in forage samples can be due to surface contamination with soil, a plant-accumulated fraction does occur /MUCHOVEJ et al.,l986). Meadow voles /Microtus pennsylvanicus/ **fed ryegrass** /Lolium multiflorum,Lam./ **containing 485 ug/g Al** had increased Al absorption, increased urinary Ca concentration, **and decreased serum Mg,** compared with voles fed forage containing l87 ug/g Al /TERRIL,l984/. Perhaps the plant-accumulated form/s/ Al have **more potential for affecting mineral metabolism in animals** than Al in soil. As little as 2 mg Al/kg body weight as Al-nitrilotriacetate resulted in **necrosis of proximal tubular cells, metabolic acidosis, atrophy of nerve cells in cerebrum and demyelination of the brain stem in rats** /EBINA et al.,l984/. WALLACE and ROMNEY /l977/ reported **30 mg Al/kg as a threshold value in soybean leaves for Al toxicity.** They observed significant reductions in soybean growth with Al leaf concentrations of 70 mg/kg. In study of TAYLOR et al. /l992/, all the **legume clover crops accumulated large amounts of Al,** with crimson clover having the greatest(259 mg/kg) and cowpea the smallest amounts (ll7 mg/kg).

The reduction in exchangeable Mg was positively **correlated with several soil Al fractions** including exchangeable, organically chelated, and poorly crystallized inorganic species: however, exchangeable Al produced the best correlation supporting the hypothesis that Mg "fixation" is **due to the occlusion or coprecipitation of Mg with Al upon liming** (MEYERS et al., l988).

MAYLAND and GRUNES(l979) summarized the literature on the effects of soluble, or **exchangeable Al on the uptake of Mg** by plants or in interfering with Mg absorption by the animal. METSON et al.(l979) studied the seasonal variations in pasture herbage of Al and Mg and concluded that **highest levels of Al in herbage samples were associated with soil contamination** as indicated by Fe levels and by limited verification with titanium analyses. There is evidence that existing grass germplasm has the ability to accumulate Mg concentrations of 0.20-0.25% without reducing yield. Corrective fertilization to achieve the desired plant composition may require one or more of the following increased Mg uptake, decreased K uptake, reduced N accumulation, reduced Al concentration.

B/ Forages- ruminants; relatioships

Aluminium (Al) is abundant in the environment of animals and humans. **Ruminants ingest Al from soil, plants, feed and water contamination and feed additives** (ALLEN,l984). Soil Al sources generally are low in solubility: this source of Al ingestion by ruminants has not been shown to present a toxic hazard (ROBINSON et al.,l984: ALLEN et al.,l986). **Large amounts of Al in forage samples have been associated with outbreaks of grass tetany** in beef cows (ALLEN and ROBINSON,l980: KAPPEL et al.,l983), although Al in these samples may have been due largely to soil contamination. More soluble Al sources have impaired metabolism of P,Mg, and Ca in ruminants (ALLEN and FONTENOT,l984: ALLEN et al.,l986). Aluminium induced Mg deficiency is one of the causes of forest decline. **High concentrations of Al in the soil solution of acidified soils "impede" Mg uptake by the plants**, thus leading to Mg deficiency, with secondary failure in chlorophyll production and reduced photosynthesis, provoking leaf loss. On the agricultural sector **Al-induced Mg deficiency is no problem in Central Europe, but it plays an important role in the Tropics where large areas are covered with acid soils** (GRIMME and HUTTL,l990). With a solution culture experiment, added Al depressed concentrations of Mg and Ca in shoots of wheat, thus producing forages on which grass tetany of animals would be more likely (OHNO et al.,l992).

Exposure to Al results in **decreased Mg concentration and total Mg content in plants** (CLARK,l977).DENNIS(l97l) found 500 to l,000 ug/g Al, dry basis, in oat and wheat pasture forage in Texas where grass tetany outbreaks occured. **Al directly affected Mg absorption** in oats (GRIMME,l983), sorghum (KELTJENS,l988) and **reygrass** (RENGEL and ROBINSON,l989). CHERNEY et al.(l983) found a positive correlation among Al, Fe and Ti in forage samples. Meadow voles (Microtus pennsylvanicus) fed reygrass (Lolium multiflorum,Lam.) containing 485 ug/g Al had increased Al absorption, **increased urinary Ca concentration, and decreased serum Mg**, compared with voles fed forage containing l87 ug Al (TERRIL,l984). Perhaps the plant-accumulated form of Al have more potential for affecting mineral metabolism in animals than Al in soils. As little as 2 mg Al/kg body weight as Al-nitrilotri acetate resulted in necrosis of proximal tubular cells, atrophy of nerve cells in cerebrum and demyelination of the brain stem in rats (EBINA et al.,l984).

However, Al ingestion has **had no consistent effect on Mg absorption and retention** in research reported by ALLEN (l987). VALDIVIA et al.(l982) found no effect of 2,000 ppm Al as AlCl3 on apparent Mg absorption. ALLEN and FONTENOT(l984) observed a trend toward increased apparent Mg absorption by wethers administered 2,OOO ppm Al of the diet as chloride, sulfate or citrate via ruminal cannula for lO d. In the other experiment (ALLEN et al.,l990) Mg absorption was depressed only during the first 5 d, suggesting that adaptation had occured. They explained, **that the effect of Al on serum Mg cannot be explained by decreased apparent Mg absorption but could be related to increased serum Ca** (FONTENOT et al., l989).

Magnesium absorption in animals

Intestinal Mg transport has been studied under a variety of conditions in the past 25 years. However, there was still uncertainity about the major intestinal sites of Mg absorption, transport saturability, dependence on metabolic energy, interactions with Ca or P and the influence of vitamin D (EBEL and GUNTHER,l980: WALSER l967: SEELIG,l964: WILKINSON,l976: ANAST and GARDNER,l981). In several studies the **major site for Mg absorption (in rats…) was shown to be the colon** (CHUTKOV,l964: CHUTKOV,l966: MENEELY et al.,l982), whereas others demonstrated that the **greatest rate of Mg absorption occurs in the duodenum** (ALDOR and MOORE,l970: URBAN and SCHEDL,l969). Intestinal Mg transport has been reported to occur by diffusion, solvent drag and/or a saturable process that may (MEENELY et al., l982: BEHAR,l974) or may not (ROTH and WERNER,l979) **require energy**.

CHUTKOV in l964 reported that the **major site of Mg absorption was the colon** in both Mg-deficient and Mg-replete young rats. Mg absorption was based on either fecal recovery of Mg after injection into various sites along the intestine or on the amount of 28Mg recovered in carcass (without the gut) and urine following orogastric feeding of Mg. Using both techniques, CHUTKOW demonstrated that up to70 % of^{28}Mg absorption **occured in the colon**. Specifically, he found that absorption of Mg was not significantly lower when Mg was injected into the cecum vs. when Mg was injected into the stomach or the duodenum. Moreover,only 8 % of total^{28}Mg absorption occured in the first 75 cm of the small intestine when absorption was based on^{28}Mg activity recovered in the carcass and urine.

Others investigators, however, have demonstrated significant absorption of^{28}Mg **in the small intestine as well as the colon**. MENEELY et al.(l982) using in vivo intestinal perfusion found that the net transport rates of^{28}Mg in the colon were equal to or greater than those in either the jejunum or the ileum of weanling and adult rats. BEHAR(l974) demonstrated net Mg absorption of similar magnitude from both the ileum and the colon of the rat in vivo. ROSS(l962) in rats found that^{28}Mg was transported more efficiently in the ileum than in the jejunum in the everted gut sac. HENDRIX et al.(l963) reported that both the rate uptake and the total uptake of Mg was greater in the jejunum, ileum and colon than in the dupodenum of rats. ALDOR and MOORE(l970) and URBAN and SCHEDL(l969) found that the amount of Mg transported per unit weight decreased progressively through the gut in the rat. Based upon segment length or weight, therefore, their data **indicate that Mg absorption predominates in the distal segments of the intestine.**

In sheep **rumen, the major site of net Mg absorption, an active saturable component of Mg absorption has been reported** (SCOTT,l965: CARE and KLOOSTER,l965; MARTENS and BLUME,l986: MARTENS and HARMEYER,l985: MARTENS,l985: CARE et al.,l984; GAEBEL et al.,l987). MARTENS and colleagues reported that the mechanism of net Mg transport was saturable in the rumen when Mg concentration of the bathing solution was elevated from l.25 to 5 mmol/L. SCOTT(l965) found no correlation between Mg absorption and luminal Mg concentration in jejunal or ileal loops from sheep. His data **indicate that no more than a small fraction of Mg absorption occurs by simple diffusion in the small intestine.**

It is well known that there is a fall in the plasma Mg con- centration of cattle and sheep immediately **following a change of diet from forage and concentrates to young grass**. This occurs even when diets are isomagnesaemic (CARE et al.,l967). More recently, JOHNSON et al.(l988) have shown a fall in plasma Mg concentration when lactating Jersey cows were **changed from a diet of hay and concentrates to one of frozen grass(ad lib.)**, even though the daily intake of Mg increased by approximately 44 % on the grass diet. The concentrations of ultrafiltrable Mg and Ca in rumen fluid varied inversely with pH. There were also changes in water intake, rumen volume, dilution-and outflow-rates associated with the diets. Using grass from the same harvest but conserved by ensiling, by arteficially drying or by deep-freezing, POWLEY and JOHNSON(l977) showed in ewes that the extent of the fall in plasma Mg concentration was **influenced by the method of herbage conservation.** The apparent bioavailability of forage Mg also varied with the method of conservation.

Tolerance time of blood Mg,i.e., time required after Mg loading to return to normal, decreased in goats fed extra K : this also means increased cellular uptake and retention of Mg since urinary excretion was lowered and endogenous fecal excretion was expected to be depressed (HOUSE and BIRD,l975). Mg concentration in blood plasma was not changed by the K feeding in goats, although this had been reported by workers for sheep (HOUSE and BIRD,l975). **Intravenous Mg loading decreased blood Ca in goats**: treatments to cure hypomagnesemia **should contain both Mg and Ca** so as not to confound a tetany problem. During underfeeding of Mg (238 mg Mg per day to 2-yr-old goats for ll days), milk yield and urinary excretion decreased markedly, and total Mg output was reduced. While Mg contents of milk did not change, urine contents first decreased, later increased with low volume, and those of blood plasma increased approximately l0 % (RAZIFARD,l972).

Although **vitamin D is an important regulator of Ca** transport in the intestine, the **importance of vitamin D for Mg absorption remains unknown** (LEVINE et al.,l980: HANNA,l96l: KREJS et al.,l983: MEINTZER and STENBOCK,l955: ANAST,l967:WILZ et al.,l979: HODGKINSON et al.,l979: BRICKMAN et al.,l975: KARBACH and EWE,l987). In several studies in vitamin D-replete rats, large doses of cholecalciferol and l,25-dihydroxycholecalciferol increased absorption of Mg (HANNA,l961: KREJS et al.,l983). A similar effect on Mg absorption was not observed at lower doses of l,25 dihydroxy- cholecalciferol in the colon of vitamin D-replete rats (KARBACH, l989).

However,STILLINGS et al.(l964) found that **supplemental vit. D increased the apparent availability and retention of Ca and Mg in animals consuming low-nitrogen(N) containing forage**, but had no effect when given to Merino wether sheeps consuming **high N-containing forage**. In addition, studies have indicated that cholecalciferol increases Mg absorption in vitamin D-depleted animals. LEVINE et al.(l980) observed **augmentation of intestinal absorption of Mg in vitamin D-deficient rats given** fysiological levels of various vitamin D sterols. In particular, Mg absorption was very sensitive to l,25-dihydroxycholecalciferol with a maximum effect observed with only 2O pmol/d after 9 d. Interestingly,they also observed that increasing dietary Mg from O.O3 to O.2 % depressed percent net absorption of Mg in vitamin D-deficient rats after 3 d(LEVINE et al.,l980). Why Mg absorption was depressed by increases in dietary Mg in these vitamin D-deficient rats is unclear.However,these studies do **suggest that there may be at least two intestinal transport systems for Mg**: one that is vitamin D-dependent and another that is independent of vitamin D and exhibits adaptation to dietary Mg.

In vitamin D and Mg-replete animals, **pharmacologic doses of vitamin D markedly influence Mg absorption.** KARBACH and EWE(l987), using in vivo intestinal perfusion documented that lOO ng/d of l,25 dihydroxycholecalciferol given subsutaneously for 4 d markedly stimulated net Mg absorption in the colon of rats. This effect was independent of net water, Na or Cl movement. However, when lower doses of vit.D were given to rats and Mg fluxes were studied under voltage-clamp conditions, vit.D had no effect on Mg transport(KARBACH,l989).

Magnesium deficiency in ruminants

Magnesium deficiency has been discussed and reviewed on numerous occasions. **Hypomagnesemic tetany is quite distinct from hypocalcemic tetany** (KEMP,l966: KEMP and GUERINK,l967: KEMP and TODD, l970). The **two distinctive symptoms** of Mg deficiency across species are **hyperiritability and metastatic calcification**. Of particular interest have been the observations of the group at Missoury that **on a low-Mg diet exostosis, soft tissue calcifications and stiffness in the hind limbs occur in guinea pigs** (O´DELL,l960).

Tissue mineral concentration changes associated with Mg deficiency are numerous (FORBES,l966: MARTINDALE and HEATON,l964). The requirement for Mg (in mg per l00 g of diet) is for rats 20, guinea pigs 80, and calves 200 (O´DELL,l960). **Why should guinea pigs and cattle have a much higher requirement for Mg than rats and other monogastric species?** The cattle requirement for Mg is lO to l5 mg per kg body weight (O´DELL,l960). The Mg requirement is increased as dietary Ca alone or dietary Ca and environmental temperature are increased (VOISIN,l963). **Kidney calcification on low-Mg diets may result in an eleven-fold increase in kidney Ca while kidney Mg is unchanged** (McALEESE and FORBES,l961). Keeping both Ca and P high, as opposed to either high, or more effective in accentuaating Mg deficiency (PACKETT and HAUSCHILD, l963).

Signs of hypomagnesemic tetany are encountered in both grazing ruminants and calves reared too long on milk without access to other feeds. **Susceptibility to grass tetany is increased in older ruminants because of the decreased ability to mobolize skeletal Mg with increasing age**. Grass tetany generally occurs during **early spring or a particularly wet autumn among older cattle** grazing grass or small-grain forages in cool weather. Clinical tetany is endemic in some countries, **affecting only a small proportion of cattle (l % to 2 %)!** However, individual herds may report tetany as high as 20 %. Although not characterized by death, incidence of non-clinical hypomagnesemia is far greater than clinical tetany, and economic consequences of lowered production are substantial. **Grass tetany may be prevented by Mg fertilization, adding Mg to feed or salt blocks and avoiding high K fertilizers.** The majority of the commercial Mg-containing mineral supplements are often of little value because: (1) they contain inadequate quantities of Mg to protect against tetany during susceptible periods and (2) provision of such supplements to normal animals during non-susceptible periods is useless as a prophylactic measure since additional Mg will not provide a depot of readily available Mg for emergency use. In southeastern United States, a complete mineral mixture with 25 % MgO (l4 % Mg) has been effective in preventing grass tetany in beef cattle (CUNHA,l973).

A tetany related to low serum Mg was **first described SJOLLEMA (l928)** as a disease "**grass tetany**". Because of the low serum or plasma Mg of afflicted animals, it is also known as "**hypomafnesemic tetany**". In New Zealand, it has been called "**grass staggers**" and when it occurs with animals on low Mg hays, it is known as "**winter tetany**" (GRUNES et al.,l970). CROOKSHANK and SIMS(l955) described a similar condition in cattle as "**wheat pasture poisoning**".

HORVATH and TODD (l968), GRUNES et al.(l970), GRUNES(l973) **suggested that the ratio of soil Mg:K** should be at least 2.0. HOOPER(l967) and GRUNES(l973) reported that the soil Mg:K ratio should be l.2 or higher to obtain 0.2 % Mg in the forage. HORVATH and TODD(l968) recommended that the Ca: Mg ratio in the soil should be about 5:l (not higher), from the standpoint of Mg needs of grazing cattle. **HORN(l983), in his review on wheat pasture poisoning, noted that the protein concentration(N x 6.25) of wheat pasture DM ranged from l5 to 34 %. BELYEA et al.(l978) found similar levels. In fact, the levels have been high enough that ammonia toxicity has been postulated in grazing animals (HORN et al.,l977: HORN,l983), but blood ammonia did not reach toxic levels in those studies.** In addition, total lipids and K were high in the cereal plants initially and again at tetany. The **high values for plant K concentrations reflect the high soil K levels, but plant K varied greatly during season** (BOHMAN et al.,l983). FONTENOT(l979) reviewed the effect of dietary N and combinations of dietary N and K on the absorption of Mg from the digestive tract of experimental animals. He **concluded that N by itself or with K did not decrease Mg absorption, but dietary K was involved. Extra dietary K lowered plasma Mg.** BOHMAN et al.(l969) added extradietary K and **lowered plasma Mg, but without any mesureable effect on plasma Ca**. Some investigators noted a positive relationship between K and N in forages (MILLER,l939: METSON et al.,l966). MOLLOY et al.(l973) found that **higher fatty acids (HFA) in the herbage of New Zealand grass-clover pastures were positively correlated with plant N.** Forage N and total lipids were highly correlated in the study of BOHMAN et al.(l983). KEMP et al.(l966) and WILSON et al.(l969) also found a close relationship between the HFA content of grasses and CP. WILSON et al.(l969) postulated that the decreased availability of Mg in high N pasture and consequent **lower plasma Mg may be caused by the formation of insoluble soaps of Mg and Ca, which are excreted in the feces**. The addition of dietary fat (animal fat or peanut oil) further decreased

Mg availability, plasma Mg levels and increased the amount of fecal soaps.

Ash alkalinity is an indirect measure of total organic acids in plant material. In rye, aconitic, malic and citric acid predominanted (MAYLAND and GRUNES,l979). Aconitic acid is high in wheat (MAYLAND et al.,l976). For two species of crested wheatgrass, Agropyrum desertorum and Agropyron cristatum, the organic acid concentrations were appreciably higher under a high K regimen (PRIOR et al. l973). STOUT et al.(l967) suggested that plants with l % or more of organic acids could be potentionally toxic as related to tetany. The sodium citrate decreased the concentration of Mg in the blood serum, when compared to the effect of NaCl. **So, certain Krebs cycle organic acids appear to be involved in the grass tetany.** Because tetany in cattle involves many factors, several investigations have used ratios and other calculations to develop a more precise estimate of the tetany-proneness of forage. MAYLAND et al.(l974) have **compared the ratio of plant N with total water soluble carbohydrates** (TWSC). When the ratio exceeded 0.3,the incidence of tetany increased. They also emphasized the importance of the rapid increase in the ratio just before tetany. The most **commonly used ratio is the equivalents of K divided by the sum of the equivalents of Ca and Mg - K/(Ca+Mg).** This ratio is of value unless the concentrations of **Ca are high, as occurs in many legumes**. If this **ratio is equal to or greater than 2.2, the forage is rated as tetany prone** (KEMPP and t´HART 1957; METSON et al.,l966: GRUNES et al.,l970). BUTLER and METSON(l967) compared nineral contents of fodder sampled from pasture in several different parts of the Europe:

Type of pasture %	Mg %	Ca %	K %	Na %	P	K^{++} / Ca + Mg	Ca^{+} / P
		KEMP and ´t HART(Netherlands),l957					
T	0.l70	0.52	3.67	0.l6	0.48	$2.4^{++}5.3^{+}$	$l.l^{+}$
NT	0.l90	0.64	3.03	0.25	0.41	$l.6^{++}3.6^{+}$	$l.6^{+}$
			LARVOR and GUEGEN(France),l963				
T	0.ll7	0.60	3.33	0.l8	0.39	$2.2^{++}4.6^{+}$	$l.5^{+}$
NT	0.l40	0.54	3.02	0.l3	0.32	$2.0^{++}4.4^{+}$	$l.7^{+}$

BUTLER et al.(Scotland),l963								
T	0.l45	0.63	3.39	0.l2	0.48	2.0^{++}	4.4^{+}	l.3^{+}
NT	0.l65	0.69	3.02	0.l9	0.48	l.6^{++}	3.5^{+}	l.5^{+}

$^{+}$ / percent values to calculate K/(Ca+Mg) and Ca/P

$^{++}$/ milliequivalents per kg were used to calculate K/(Ca+Mg)

T / tetany- prone pastures

NT/ non-tetany pastures

KEMP and t´HART(l957) indicated that when the ratio of **K/(Ca+Mg) in forage was less than 2.2, there were very few tetany cases(0.77 % of 4658 animals**):however, **with a value greater than 2.2, the frequency of tetany increased (6.66 % of l908 animals).** The mineral composition of the forage is related to weather conditions, so that K/(Ca+Mg) ratios greater than 2.2 are **more common in spring and autumn than at any time of the year**. Magnesium is lower in forage from the "tetany" pasture. Calcium is also low in some of these tetany-prone pastures. However,in their rewiev article, ALLCROFT and BURNS(l968) suggested that the hypocalcemia that develops concomitantly with hupomagnesemia is independent of the Ca content of the diet. **BUTLER and METSON(l967) indicated that K concentrations were higher in forage from the "tetany"** pastures. Pastures should not to be low in K , since deGROOT (l966) indicated that below 2.l % K the growth of grass begins to suffer. **In Holland the K/(Ca+Mg) ratio does not appear to have any particular significance in relation to the occurence and severity of hypomagnesaemia but significant correlations have been found between serum Mg levels and the concentrations of Mg and K in the pasture, the former correlation being negative and the later positive** (KEMP,l960: KEMP et al.,l960). SMYTH et al.(l958) **on the other hand could find no relationship between hypomagnesaemia and the Mg or K content of the pasture in Ireland.** The results **obtained in Britain** have also been conflicting. ROOK and WOOD(l960) could find no general relationship between the degree of hypomagnesaemia and the concentration of any particular element. Of the various indices and **ratios they examined only the alkaline-earth alkalinity, namely Ca+Mg-P, showed a consistent variation with**

the degree of hypomagnesaemia and only then for a given sward as it varied through the season. STORRY(l961) also reported that there was no correlation between the development of hypomagnesaemia and the K/(Ca+Mg) ratio in the pasture in his experiments. BIRCH and WOLTON(l961), however, found highly significant correlations between serum Mg levels and the Mg and K levels in pasture, the results being very similar to those obtained in Holland.

In the field conditions **the K/(Ca+Mg) and WSC/DCP ratios,** water soluble carbohydrates (WSC), digestible crude protein (DCP), Ca, Mg, P, K contents of forages were evaluated – when in 53 dairy feed rations were used (HLASNY, 1991). It was found, that the **level of potassium(K) eaten did not influence acid-base balance and magnesaemia**. It is important to know; both values of the K/(Ca+Mg) and WSC/DCP (or WSC/CP) in dairy ration; to predict metabolic disturbances. It was found; **if the sum of K/(Ca+Mg) and WSC/DCP** ratios **exceeds the value 4** (four), the dairy rations are acido- prone. On the other hand; if this sum falls **below 2 (two), alcalogenic impact** can be expected. It was concluded that exists the **synergism between the acidosis and subclinical hypomagnesemia in the summer fresh forage feeding period**- in connection with blood urea nitrogen decrease. By computor evaluating the biochemical parameters and K/(Ca+Mg), WSC/DCP values in fed forages it was found that the **values of these ratios highly negetively related with blood Mg-urea, and pH urine of dairy cows.** Also, the K/(Ca+Mg) slightly negatively related with the pH of urine. HLASNY (1991) also found that **increasing blood urea nitrogen is accompanied by the increasing pH of the urine**. Using the equation y =(a . x) + b it can be for example predicted that; if the pH of dairy cow urine is 8.0 then the level of blood urea is:(l.773 x 8)+ (-9 x 602)= 4.582 mmol/l etc…(HLASNY, 1991).

It can be concluded that these results are very important for the initition of hypomagnesemia and acid-base disturbances in dairy cows. Many experimentators, **using only potassium salts to initiate hypomagnesemia in cattle, did not recognize the simultaneously effect of K, CP, P and WSC** about hypomagnesemia occurrence, under field conditions.

In l954 (BLAXTER et al.), it was suggested that the nutritive failure of **calves given whole milk for long periods was related to a deficiency of Mg**. DUNCAN et al.(l935) estimated that 30 to 40 mg/kg body weight(BW) or about 2,000 ppm Mg were necessary to maintain normal plasma Mg when supplement was given as Mg salts. Only l2 to l5 mg Mg/kg BW from natural feedstuffs were sufficient when feeding synthetic milk diets containing from O.5 to 24 mg Mg per l00 ml diet to calves l to 2 weeks old. **BLAXTER et al.(l954) noted clinical signs of Mg deficiency in calves after blood serum Mg was reduced to below 0.7 mg per l00 ml**. This occured when the diet contained 0.5 to l.6 mg Mg/lOO ml. One calf in tetany increased its serum Mg spontaneously, possibly from tissue release. If this is typical, blood samples from cows after tetany may not indicate pre-tetany levels. **In these studies no calcification of tissues was observed: however, bone Mg was reduced to l/3 normal.** Bone depleted of Mg may or may not have an increased Ca content. Most researches employing **low-Mg diets have observed calcification of the soft tissues** (DUCKWORTH,l938).

Rectal infusion of Mg solutions can be a very effective way to help cattle that are down with grass tetany to replenish their blood Mg levels**. Calves 6 weeks of age were given MgCl2 solutions by oral or rectal administration while fed diets containing either 0.04% (very deficient) or 0.24% Mg** (BACON et al, 1990). Plasma Mg of deficient calves was maximized within 10 minutes following rectal infusion compared to 160 minutes after oral dosing. However, **plasma levels were sustained longer following oral dosing**. While plasma levels of both oral and rectal treatment groups were increased by dosing, those of deficient calves were increased by a much higher percentage (16% or 47% in Mg adequate calves vs 48% or 124% in deficient calves).

Hypomagnesemia is the common symptom of grass tetany and **usually is associated wit hypocalcemia**. Potassium should be considered **in any investigations of the etiology of this syndrome, because those cases associated with lush pasture involve K concentrations much higher than found in stored feed.** The influence of high dietary K intake on blood Mg levels has been considered by a number of workers (DANIELS et al.,l952: DENNIS and HARBAUGH,l948). However, PEARSON et al.(l949) and STORRY(l96l) **did not find a**

depression in blood Mg associated with increased K intakes. On the other hand KUNKEL et al.(l953) and FONTENOT et al.(l960) found with increases in K intake a reduction in blood Mg, and the latter showed an increased fecal excretion of Mg. CURME et al.(l949) found a **reduced Ca retention associated with increased K intake**, but Mg analyses were not included. DeGROOT(l962) found that **increases in K intake decreased blood Mg levels** and also increased plasma and red cell levels of K. He reviewed a nuber of experiments performed with cattle and, **although the results were conflicting**, he **concluded that K intake was very important in explaining hypomagnesemia.**

An hypothesis to explain certain aspects of the pasture-induced hypomagnesemia is suggested by the above data and much of the evidence has been discussed by DeGROOT(l962). The hypothesis assigns two basic actions to K, the first that increased K intake is responsible through mass action for reducing the absorption of Ca and Mg from the gut. Thus, if the animal is temporarily unable to mobilize sufficient amounts of these elements from body stores then a hypocalcemia and hypomagnesemia would result. In support of this idea it is of interest **that blood serum Mg levels increased in sheep fed low K diets** (TELLE et al.,l964). The other key role assigned to K in the hypothesis is that a rapid change to a much greater dietary intake of K per se could result in tetany or death. The interference for this is from the discussion above toxicity. On the other hand, it must be considered that PEARSON et al.(l949) fed up to 5 % K and DANIELS et al.(l952) fed 7.7 % KCl in rations with little or no effect on sheep. It is possible that the sheep in these experiments were slowly **introduced to these high levels of K, in which case the kidneys could probably accommodate to the increased K load** (PICKERING,l965). This is not the situation, however, in grass tetany and wheat poisoning cases, which usually occur when an animal on winter feed is **suddenly changed to grass on high K content.**

Magnesium deficiency in man

In humans, several laboratories have reported that increasing Ca in the diet significantly depresses Mg absorption (NORMAN et al.,l981: CLARKSON et al.,l967). NORMAN et al.(l981)fed healthy humans a low (300mg/d) or a high (2000 mg/d) Ca diet for 4 wk and perfused jejunal and ileal segments in vivo with solutions that contained no Ca and 5 mmol/L MgCl2. They found a **significant decrease in Mg absorption in the ileum of subjects fed the high Ca diet**. SPENCER et al.(l980), however, fed diets containing 200 - 2000 mg Ca/d for 29 to 43 d and saw no significant effect on fecal Mg. LEICHSENRING et al.(l951) also observed no correlation between fecal Ca and fecal Mg when Ca was increased from 300 to l200 mg/d in the diet of healthy women. Increasing Mg in the diet has been reported to significantly decrease fecal Ca in humans (CLARK,l969: LEICHSENRING et al.,l951).BRANNAN et al.(l976), however, found in an intestinal perfusion study that **increasing the concentration of Mg in the lumen decreased Ca absorption in the jejunum.** Direct intestinal perfusion with various concentrations of soluble Mg or Ca salts in an isolated segment, however, may not reflect what is actually occuring in vivo. AMMANN et al.(l986) found significantly absorption of^{45}Ca when the^{45}Ca was injected directly into the colon of rats. After an oral dose of Ca, however, net^{45}Ca absorption in the colon was negligible. The data suggest that Ca arriving in the colon from the small intestine is unavailable for absorption because of **binding of Ca to complexing agents found in the intestine, such as oxalate or fatty acids**. It is possible that Mg also binds to these complexing agents. The quetion is therefore raised whether interactions between Ca and Mg that are observed in isolated segments actually reflect what is occuring in the intact animal.

Although there are conflicting results in studies with humans (BRANNAN,l976: CLARKSON et al.,l967: SPENCER et al.,l980), all but one study (CLARK,l969) **in rats** have demonstrated that net **absorption of Mg in vivo is depressed by a high Ca intake** (AMMANN et al. l986: HARDWICK et al.,l987: ALCOCK and MacINTYRE: PETITH and SCHEDL, l977: KRAWITT,l972: O´DELL et al.,l960: TOOTHILL,l963: O´DONNELL and SMITH,l973). The **machanism by which Ca and Mg interact**, however, has not been welldefined. Several possible mechanisms have been proposed. These include competition for a common carrier system (ALCOCK and MacINTYRE,l962), a Ca induced change in membrane permea- bility to Mg (LEICHSENRING et al.,l951), and modulation of a specific Mg carrier by Ca (WALSER,l967).

Several studies provide evidence that Mg deficiency affects lipid metabolism

(RAYSSIGUIER and GUEUX,l989). They previously reported that Mg-deficiency in weanling rats produces **hypertriglyceridemia and that the type of dietary carbohydrate plays a role in the expession of Mg deficiency**, based on our observations of more severe hypertriglyceridemia in Mg-deficient rats **fed sucrose than in those fed starch** (RAYSSIGUIER et al.,l98l). They reported that total plasma cholesterol was not significantly modified by the deficiency, but free cholesterol was increased and esterified cholesterol was diminished. Mg-deficient rats had decreased levels of stearic acid, increased levels of oleic and linoleic acid and decreased levels of arachidonic acid in total plasma lipids (RAYSSIGUIER et al., l986), and Mg deficiency produced dyslipoproteinemia characterized by an increase of VLDL and LDL and a decrease of HDL. Recently, these changes were shown to be involved in the modification of the erythrocyte membrane fluidity that occurs during Mg deficiency (TONGYAI et al.,l989: RAYSSIGUIER et al.,l989). In proposed mechanisms explaining hyperlipemia, a defect in the removal of triglyceride-rich lipoproteins has been reported (RAYSSIGUIER and GUEUX,l983), but more studies are needed to assess the role of Mg on the complex system of plasma lipid transport. The defect that produces hyperlipemia may occur within a tissue or in the lipoprotein particle itself and cause the partcle to interact poorly with a lipase or receptor (GRUNDY,l984). However, no studies have reported the compositional changes of lipoproteins in deficient animals. A recent study (RASMUSSEN et al.,l989) found that **oral Mg supplementation reduced plasma concentrations of triglycerides, VLDL and apolipoprotein B in patients with ischemic heart disease.** Several observations indicate that patiets with ischemic heart disease are often Mg-deficient and that Mg-deficiency, together with several other factors, may be involved in the development of ischemic heart disease (RASMUSSEN et al.,l989).

In **humans the results of experiments** on the effect of **vit.D on Mg absorption have been conflicting**. KREJS et al.(l983)noted that jejunal, but not ileal, Mg absorption was enhanced by a week of pharmacologic oral doses of l,25-dihydroxy- cholecalciferol(vit.D). ANAST et al.(l964)reported an increase in Mg when large doses of calciferol were given to a patient with vit.D-resistant rickets. WILZ et al.(l979), in contrast, noted **no relation between Mg**

absorption and plasma vit.D concentrations in humans. Moreover, significant quantities of Mg were absorbed in the absence of detectable plasma vit.D. HODGKINSON et al.(l979) orally administered pharmacologic amounts of ergocalciferol, 25-hydroxy- ergocalciferol,or l,25-dihydroxycholecalciferol for l to 6 mo to patients with various disorders of Ca or bone metabolism. These treatments all enhanced Mg absorption but also increased urinary Mg so that Mg balance was unaffected. Likewise, BRICKMAN et al.(l975) observed a similar decrease in fecal Mg and rise in urinary Mg when large doses of cholecalciferol were given, resulting in no change in Mg balance. Other investigators, however, have reported that high doses of vit.D greatly enhance urinary Mg and actually lead to a substantial decrease in Mg retention in both animals and humans (HANNA,l961: HEATON and PARSON,l961: LIFSHITZ et al.,l967). RICHARDSON and WELT(l962), however, reported that the hypomagnesemia associated with ergocalciferol administration occured with no changes in urinary or fecal Mg excretions in Mg-deficient rats.

The available data,therefore,suggest that a significant amount of Mg absorption is vit.D-independent because it persists under conditions of vit.D deficiency. Repletion of vit.D is, however, associated with increments in Mg absorption. In vit.D-replete animals and humans, pharmacologic doses of vit.D appear to increase Mg absorption whereas spontaneous fluctuations in circulating levels of vit.D have little effect on Mg transport. The importance of vit.D- -stimulated Mg absorption on overall Mg homeostasis remains uncertain, particularly in light of the dramatic increases in urinary excretion of Mg that have been associated with vitamin D administration.

Magnesium has been particularly involved in atherosclerosis. Increased dietary Mg decreases lipid deposition (sudanophilia) of the aorta of rats on atherogenic diets. High-Mg diets exert an "anti-sudanophilic" effect. The addition of thyroxine definitely reduced the sudanophilia (NAKAMURA et al.,l965). On low-Mg diets sudanophilia increased after 6 to l2 months, and several animals showed grossly visible aortic intimal plaques (NAKAMURA et al., l965). Increased dietary K has reduced the mineralized aortic Ca in dogs (BUNCE et al.,l962). Rats and monkeys fed diets low in Mg developed high blood cholesterol and were susceptible to athero- sclerosis by cholesterol feeding. Additional reports discuss the relationship between Mg and atherosclerosis (BHATTACHARYYA and MULLICK,l963: BUNCE et al.,l962: KNIERIEM et al.,l968: LIKAR and ROBINSON,l966: McKINSTRY et al.,l969: NAKAMURA et al.,l960: SKOLD et al.,l967: VITALE et al.,l957: VITALE et al.,l959).

Studies have shown that **phytic acid(PA) and insoluble carbohydrate (fiber)** may be possible causes for depressed mineral bioavailability from plant-based diets (as **compared to animal-based diets**), even after accounting for the **lower protein quality of most plant-based diets** (ERDMAN,l979). CHERYAN et al.(l983) reported that the Mg-PA complexes were soluble below pH 5 at molar ratios studied (0.5-l2). Above pH 5 solubility decreased rapidly. The higher the Mg:PA molar ratio, the lower the pH at which the solubility drop was observed. At Mg:PA ratios of 4 or less, phytate-P was relatively more soluble than Mg at pH > 5. However,at Mg:PA ratios greater than 6, the Mg was more soluble than phytate. Their data suggest that the penta-magnesium form of PA probably predominates when Mg is in excess (CHERYAN et al.,l983).

JACKMAN and BLACK (l951) were **probably the first to report on the solubility characteristics of Mg-PA as a model system for soils.** OBERLEAS and MOODY (l981)determined the amount of precipitate formed in a reaction mixture containing a l:l molar ratio of Mg:PA in the pH range of 3-9. TANGKONGCHITR et al.(l982) reported solubility of PA-phosphorus using a 3.9:l molar ratio at pH 5-8 to demonstrate the possible role of Mg-PA complexes in fermenting wheat doughs. EVANS and PIERCE(l981) determined the composition of the precipitate at pH 6.0 using a 6:l molar ratio in the reaction mixture. However, the above study (CHERYAN et al.,l983) covered a much wider range of Mg:PA molar ratios (0.5-l2) and a pH range of 2-9 , because most food products, ingredients, raw materials, diets, or processing procedures used should fall within these ranges.

Magnesium dietary sources in ruminants

Knowledge of magnesium in animal nutrition has progressed considerably during the 1970s-1980s. Absorption of Mg in ruminants occurs throughout the digestive tract but primarily in the rumen and reticulum, provided the Mg source is readily soluble. Non-ruminants absorb Mg primarily from the small intestine. Dietary factors which limit Mg utilization include excessive K levels, added fat and an imbalance of other minerals, especially Ca and P. Supplementing with Ionophores appears to improve Mg utilization in ruminants. Also, the animal's ability to mobilize Mg from body reserves decreases with age.

Continued research shows that Mg bioavailability varies among supplemental Mg sources, even among different sources of the same compound, such as magnesium oxide. Mg sources which are more soluble in acid solution and in the rumen are more efficiently utilized. Readily bioavailable Mg sources include MgO, Mg(OH)2 and MgSO4.

Buffers containing MgO along with sodium bicarbonate and sodium sesquicarbonate continue to be more effective than a single buffer/alkalizer in ruminants. Recent research shows that rumen buffers restore depressed butterfat levels in part by reducing the formation of trans-fatty acids in the rumen. **Building upon the extensive buffer research of the early 1980's, recent researchers continue to show the benefits of feeding magnesium oxide along with sodium bicarbonate to lactating dairy cows.** MgO acts as an alkalizer to raise the pH or decrease the acidity in the digestive tract that results from feeding a high concentrate or high energy ration. Following are some prominent examples of this research.

Various methods were used to measure the biological availability of Mg. One experiment **compared three commercial feed grade magnesium oxides** with different reactivities and different particle sizes by measuring soluble Mg in acid solution and rumen fluid. The **finer, more quickly reactive MgO (MAGOX) was more readily soluble** in both acid solution and rumen fluid than less reactive and coarser products (XIN, et al, 1988). Rumen fluid Mg contents were 157.26, 128.08 and 86.01 meq/l**, respectively for fine (Magox), medium and coarse sizes.**

The effects of feeding an excess of Mg were described in three reports. In the first, 24 finishing steers were fed diets containing calculated levels of 0.3, 1.2, 2.4 or 4.8% total Mg (dry basis, from MgO) for 130 days (CHESTER-JONES, et al, 1988). Control steers gained 20 pounds while other groups lost 11, 59 and 65 pounds, respectively. **Steers fed the two higher levels became lethargic and developed severe diarrhea, with intermittent diarrhea** in group 2. Other effects were **decreased feed intake, increased Mg absorption and serum Mg levels (up to 9.04 mg/dl).**

The same research group (CHESTER-JONES, et al, 1989) studied **the feeding of excessive Mg levels to lambs.** Four Mg levels in the complete ration were 0.2% (basal), 0.6, 1.2 and 2.4% with MgO supplying the supplemental Mg. Reduced feed intake occurred only in one animal fed 2.4% Mg. **Diarrhea occurred within 24 hours in lambs fed the two higher levels,** those fed 2.4% Mg having the most severe form. Other effects were reduced dry matter digestibility and decreased P and Ca utilization. There was little effect of feeding 0.6% Mg and the authors suggest **that the "maximum tolerance" level of 0.5% Mg is acceptable with a narrow margin of safety.**

Finishing steers were fed one of four Mg levels ----0.3, 1.4, 2.5 or 4.7% ----in a feedlot ration for 130 days (CHESTER-JONES, et al, 1990). Supplemental Mg was supplied by MgO. Steers fed the two higher levels refused some feed so their daily intakes were 2.4 and 3.7% Mg. **Severe diarrhea and a lethargic appearance occurred at the two higher Mg levels**. There was noticeable damage to rumen papillae of steers fed 1.4% Mg, although not as severe as found at the two higher Mg levels. Utilization of P, Ca and dry matter was decreased at the higher Mg levels. **A safe level appeared to be something below 1.4% Mg**. **The authors conclude that accidental over-consumption of Mg, although debilitating, is unlikely to cause fatal toxicosis under practical circumstances.**

Buffer consisting mainly of MgO (30 g/day) and sodium bicarbonate (100 g/day) was fed for 8 months to groups of 92 cows with depressed milk fat. **Milk fat increased from 3.06% (pre-treatment) to 3.68% at 4 months and 3.71% at 8 months**. The number of rumen protozoa increased from 2.85 x 105/ml pretreatment to 9.61 x 105/ml at 8 months with an increase in acetate production (SHIMADA, et al, 1989).

Magnesium mica was compared to MgO and MgSO4 in lambs. Diet treatments were control (.08%Mg), Mg-mica (.27% Mg), MgO (.27% Mg) and MgSO4 (.24% Mg). Fecal Mg excretion was highest with Mg-mica while plasma Mg was highest with MgO and MgSO4, **indicating greater availability for the latter two sources (JACKSON, et al, 1989).**

Another in vitro experiment compared Mg solubilities of various commercial MgO sources in ruminal conditions for 48 hours then in abomasal conditions for another 2 hours. **MAGOX from Premier Chemicals was more soluble than the nearest competitive product** (22.6 vs 14.6 %) in the ruminal stage and in the abomasal stage (51.1 vs48.2 %) (BEEDE, et al, 1989).

One experiment compared magnesium hydroxide and MgO for bioavailability in beef cattle fed free-choice supplements. Daily Mg intakes were similar (7.4 and 7.7 g, respectively) and plasma Mg levels were similar, **suggesting the two sources had similar bioavailabilities** (DAVENPORT, et al, 1990).

Five feed grade MgO's were compared to reagent grade MgSO4 in another experiment with lambs. One MgO source was derived from seawater and the others were calcined magnesite products. Based on urine excretion, the seawater source was 85.3 to 86.3% as available reagent grade MgSO4 while magnesite sources ranged from 77.5 to 81.8% (Van RAVENSWAY, et al, 1991). Raw, uncalcined magnesite ore had a biological availability of zero when the Mg content of the basal diet was considered.

First lactation dairy goats were fed concentrates and alfalfa (70:30) supplemented with 2.5% bicarb alone, 2.5% bicarb + 0.5% MgO or 0.5% MgO alone. **Feeding MgO increased fat and solids content and had an additive effect on milk fat.** Also, feeding the combination increased milk fat and rumen fluid butyrate content (LEE and HSU, 1991).

Mostly, in this study citated literature sources I obtained from the „**Evansdale Library**". (http://www.libraries.wvu.edu/evansdale/) (http://www.libraries.wvu.edu/evansdale/images/map.gif) There I participated as a „Visiting Research Fellow" for the period April 1 to December 31, 1991 (Division of Animal and Veterinary Sciences; director- professor P.E. LEWIS) (http://www.caf.wvu.edu/avs/faculty/lewis.html).