**Chapter 1 - Literature Review**

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Chapter 1 - Literature Review

1.1 Introduction

Grass tetany is a nervous disorder occurring when the level of Mg in the cerebrospinal fluid surrounding the brain and spinal cord falls below a critical level. The tetany is preceded by hypomagnesaemia, or lower than normal Mg in the blood (Caple & Allworth 1987; Caple 1992, pers. comm.).

Many variations of diet and physical circumstances can lead to reduced Mg in the diet, blood and cerebrospinal fluid, first producing hypomagnesaemia, which can be followed by grass tetany. This is usually triggered by physical factors such as climate, activity or body functions (t'Hart 1961; Morton 1984; Greene et al 1989; Hardt et al 1989; Elliott 1991).

Treatment of affected cattle at the onset of tetany convulsions with commercially available Cal-Mag intravenous solutions can prevent deaths. However, since most beef cattle are out in the paddocks (or out on the range) and therefore out of sight, a high mortality rate in beef cattle has been estimated. These estimates are based on the knowledge that many beef producers accept losses of 1 to 3 beef cows each year without reporting them to a conventional official reporting mechanism such as NSW Vetlink (Locke 1991, pers. comm.; Whittaker 1991; Caple 1992, pers. comm.).
Inaccurate reporting is made even worse because deaths from tetany are easily mistaken for deaths from bloat and pulpy kidney (Elliott 1991; Johnson 1991, pers. comm.; Locke 1991, pers. comm.; Whittaker 1991, pers. comm.).

Rural Lands Protection Board (RLPB) veterinary inspectors estimate NSW losses to be as high as $A10 million each year, with $A3 to $A5 million each year occurring on the southern tablelands and south west slopes of NSW. These estimates were based on a value of $A500 for each cow (1999 valuation) and may be conservative.

Short-term preventative measures, both in south east Australia and overseas, are based on the supply of Mg usually (in Australia) in the form of MgO directly to the affected animal. However, even though this is the "best available" treatment it is time consuming and the MgO is unpalatable. In many circumstances, this treatment takes 3 days to take effect (Marshall & Elliott 1983; Morton 1984; Caple & Allworth 1987; Morton 1991, pers. comm.).

Longer term measures are extremely difficult to determine and there are no current recommendations in world literature. Even though Mg is the element responsible for the hypomagnesaemia which can lead to death, the uptake of Mg into the body of a cow is affected by many factors (Caple 1992, pers. comm). However, it is known that Mg levels remain fairly constant in pasture species, as do Ca levels (Conyers 1991, pers. comm.), and studies of the levels of these elements in pasture species have been carried out in relation to outbreaks of grass tetany.

For many years the ratio of K/Mg + Ca in pasture species has been studied in connection with grass tetany in many parts of the world, and in many species of animals (Pott et al. 1987;
Grass Tetany in NSW


The K component of the K/Mg+Ca ratio varies greatly because of soil type, balance of grass/legume, fertiliser used and N concentrations.

1.2 Causes and development of grass tetany in cattle

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In ruminants, a reduction in the concentration in the ventricular cerebrospinal fluid of magnesium below 0.5 mmol/L leads to hyperexcitability, muscular spasms, convulsions, and death from hypomagnesemic tetany. The disorder occurs following a decrease in plasma magnesium concentration when absorption of dietary magnesium is unable to meet the requirements for maintenance and lactation in cows, ewes, and does fed on either lush grass pastures or young green cereal crops of oats, barley, or wheat. Lactating ruminants are most susceptible owing to loss of magnesium in milk (120 to 170 mg/L), but occasional losses are recorded in nonlactating cows and also bulls and stockier calves.
HYPOMAGNESEMIC TETANY IN CATTLE

Hypomagnesemic grass tetany in lactating cattle often appears as a complex disorder owing to the variety of circumstances that can lead to a reduction in magnesium absorption. Throughout the world, there are several types of hypomagnesemic tetany syndromes, which can be diagnosed according to the ages of cows affected and the etiologic factors inducing the fatal nervous disorder. In beef herds, cows older than 6 years, if they are overfat at calving (body condition scores 4 to 5 on a 1-to-5 scale), and lose liveweight (up to 1 kg/day) during lactation, are more commonly affected with grass tetany than younger cows. Younger cows, two- and three year-olds, may also be affected in herds with more complex types of grass tetany syndromes associated with low magnesium and high potassium intakes, and low sodium and phosphorus nutrition. Determining which factors are likely to be important in reducing magnesium absorption in ruminants at a specific location enables recommendation of cost-effective management strategies to prevent hypomagnesemic tetany.

Hypomagnesemic tetany also occurs in young calves fed for several months on whole milk or milk-replacer diets, which provide inadequate magnesium for their requirements for maintenance and growth.
OCCURRENCE

Hypomagnesemic tetany occurs when lactating cows graze lush green pastures or cereal crops with magnesium concentrations less than 0.2 per cent magnesium, calcium less than 0.3 per cent, sodium (Na) less than 0.15 per cent magnesium, and potassium greater than 3.0 per cent on a dry matter (DM) basis. The disorder occurs more frequently when pastures have been fertilized with potassium and nitrogen and when soils are naturally high in potassium (K) and low in sodium. Young green cereal crops, and short rotation ryegrass pastures used for winter grazing by cattle and sheep often contain low magnesium (<0.2 per cent DM), low calcium (<0.2 per cent DM), and high potassium and nitrogen (N) concentrations (up to 5.0 per cent DM).

In countries where cattle are housed during winter, grass tetany occurs most commonly when lactating cows are turned out to graze lush, grass dominant pastures in spring. The disorder has occurred in lactating dairy and beef cows fed indoors mainly on silage containing less than 0.1 per cent magnesium DM basis and minimal amounts of concentrates were fed.

The occurrence of hypomagnesemic tetany is seasonal, and its prevalence varies from year to year, depending largely on climatic conditions, pasture availability, the proportion of dry residues in winter pastures, and the clover and grass composition of green herbage. Inclement weather and management procedures such as yarding and transport, which result in reduced magnesium intakes, predispose lactating cows to the disorder. Commonly, hypomagnesemic tetany occurs when cattle recommence grazing lush pastures or cereal crops after being fed on hay during inclement weather.
Hypomagnesemic tetany also occurs when low herbage availability (less than 1000 kg DM per hectare [ha] for lactating cows and less than 600 kg DM/ha for lactating ewes) results in liveweight losses during lactation. Essentially no magnesium is obtained from body tissues mobilized during loss of liveweight to support lactation.

Deaths from hypomagnesemic tetany may be as high as 50 per cent in groups of lactating cows on farms. In southeastern Australia losses of 0.5 per cent of cows in dairy herds, and 3 per cent of cows in beef herds have been recorded on a district basis in grass tetany seasons.

**Etiology and Pathogenesis**

The normal plasma magnesium concentration in ruminants ranges between 0.75 and 1.3 mmol Mg/L. There are no hormonal systems directly controlling plasma magnesium concentrations, and magnesium homeostasis depends on a continual absorption of magnesium from the gut to provide the amounts lost in milk, faeces, and urine. Magnesium absorbed in excess of requirements is excreted in the urine.

Cerebrospinal fluid (CSF) magnesium concentrations are maintained in relative constancy despite wide variations in plasma magnesium concentrations. Plasma magnesium concentrations below 0.4 mmol/L may result in a decrease in the concentration of magnesium in CSF below 0.5 mmol/L and lead to hyperexcitability, muscular spasms, convulsions, and death from hypomagnesemic tetany. More commonly, sudden decreases in plasma magnesium and calcium (Ca), and an increase in plasma potassium concentrations precipitate the disorder by causing a rapid decrease in CSF magnesium concentrations.
In ewes, clinical signs of hypomagnesemic tetany do not occur unless there is a concomitant hypocalcemia (plasma Ca < 2.0 mmol/L). In sheep, lowering both the concentration of magnesium and calcium in the CSF produces more severe convulsions than reducing magnesium concentration alone.

Lush pastures and green cereal crops that have an excess of fixed cations over anions (Na\(^+\)+K\(^+\)-Cl\(^-\)) > 500 mEq/kg diet dry DM predispose older cows and ewes to metabolic alkalosis and decreased bone mobilization, thereby increasing the risk of hypocalcemia and hypomagnesaemia in late pregnancy and early lactation.

There are differences between animals in their ability to absorb magnesium, and the absorption of magnesium from different diets is extremely variable. Most of the variation is due to changes in absorption from the rumen, the main site of absorption in adult ruminants. There is net secretion of magnesium into the small intestine, and this increases as plasma magnesium increases in the normal range. Magnesium is absorbed from the large intestine, but the amounts absorbed are only significant on high magnesium intakes.

The main factors controlling magnesium absorption from the reticulorumen are its concentration in the liquid phase of the digesta and changes in the rate of active magnesium transport through the rumen wall caused by factors such as potassium. Increasing potassium concentrations in the reticulorumen from 10 to 30 mmol/L in cattle and from 30 to 60 mmol/L in sheep reduces magnesium absorption by increasing the transcellular potential difference across the rumen wall. Intraruminal potassium concentrations increase following ingestion of herbage with high potassium (greater than 0.3 per cent DM), and low sodium (less than 0.15 per cent sodium DM) concentrations when cattle are deficient in sodium and when the diet is
changed from hay or dry feed to lush pasture and salivation and sodium entry into the rumen decreases.

High intraruminal ammonium ion concentrations (30 to 70 mmol/L) also reduce magnesium absorption, and this effect is additive and independent of that of potassium. High intraruminal ammonium ion concentrations occur following ingestion of herbage with high nitrogen (4 per cent nitrogen DM) and low soluble carbohydrate concentrations).

Low magnesium concentrations (0.5 to 1.5 mmol/L) in ruminal fluid associated with low magnesium intake, high potassium concentrations (greater than 30 mmol/L), and high rumen ammonium ion concentrations (greater than 30 mmol/L) are more important in restricting magnesium absorption from most herbage diets than binding of magnesium to organic moieties in the rumen contents.

The important etiologic factors in grass tetany include:

1. Low magnesium intake, which can arise simply through a reduction in food intake when cows are grazing short grass dominant pastures containing less than 0.2 per cent magnesium (DM basis).

2. High potassium and low sodium intakes, which have important implications for magnesium absorption from the rumen. Soils naturally high in potassium or fertilized with potash and low in sodium are high-risk areas.
3. The cow's ability to maintain calcium homeostasis. Most cows with hypomagnesaemia (less than 0.65 mmol magnesium/L) do not develop grass tetany until blood calcium levels decrease below 2.0 mmol/L. Hay feeding is an important control measure in herds in which hypocalcemia precipitates hypomagnesemic grass tetany in older hypomagnesemic cows. Phosphorus deficiency and low intraruminal phosphorus concentrations exacerbate the effects of high potassium intakes on magnesium absorption from the rumen.

Other epidemiologic factors in hypomagnesemic tetany include grazing management, provision of shelter, and husbandry procedures that involve a reduction of food intake in high risk cows. The incidence is usually higher in thin and fat cows than in cows in moderate body condition. Fat cows maintain higher milk yields through loss of liveweight in early lactation. Thin cows with chronic hypomagnesaemia due to underfeeding are more susceptible to tetany during inclement weather.

Clinical Signs

In the initial stages, cows and ewes appear to become restless, separate themselves from the herd or flock, and stop grazing. They seem unusually alert and may suddenly walk or run for no apparent reason. When affected animals are disturbed, they may walk with a high-stepping action of the forelimbs and bellow continuously. They may either attempt to run away or attack when approached. The animal runs with a stiff gait, becomes uncoordinated, staggers, and falls with the limbs showing tetanic spasms interspersed with bouts of clonic convulsions. During convulsions, the eyeballs appear distended with retraction of the eyelids, and eye movements are erratic and indicative of nystagmus. Fine muscle trembling is present with champing of the jaws and fine frothy saliva around the mouth. The violence of the muscular
activity is associated with a very rapid heart rate up to 150 beats/min, and the force of the beats may make the heart sounds audible up to 2 meters away from the cow. The respiratory rate is increased, up to 60/min, and the rectal temperature may be elevated up to 40.5 °C with the increased muscular activity. Between convulsive episodes, the animal often relaxes in lateral recumbency, but stimulation such as the insertion of a hypodermic needle for therapy may trigger another bout of tetanic and clonic convulsions. It is not uncommon for cows to die suddenly during a convulsion.

When cows are found dead from hypomagnesemic tetany at pasture, there are usually signs of scuff marks on the ground around the cow caused by her legs and feet during the tetanic convulsions.

**Subacute Hypomagnesemic Tetany.** The subacute form resembles the initial stages of an acute attack and is commonly seen in dairy herds yarded for milking after grazing pastures fertilized with potassium and nitrogen. It may also be observed with potassium and nitrogen. It may also be observed in beef cows during mustering. Signs include frequent urination and defecation and flinching around the head, with the animal acting as though it is going to be struck. Animals may be aggressive during this stage. The pulse and respiratory rates are rapid, and ruminal movements are reduced. Unless affected animals are treated and herds are supplemented with magnesium, losses from clinical hypomagnesemic tetany can be expected.

**Chronic Hypomagnesaemia.** The chronic form is associated with a vague change in temperament and a loss of appetite and body condition. The mean serum or plasma magnesium concentration in 10 randomly selected cows from affected herds is usually less
than 0.65 mmol/L. Affected dairy herds show increases in milk fat production following oral supplementation of magnesium oxide. It has been observed that hypomagnesemic cows in herds tend to be less aggressive, and their reduced production has been attributed to reduced grazing activity.

**HYPMAGNESEMIC TETANY IN EWES AND GOATS**

The clinical signs of hypomagnesemic tetany in sheep is almost identical to the disease in cattle. Lactating ewes grazing young green cereal crops are most susceptible. When cases occur on grass pastures, hypomagnesaemia is usually associated with undernutrition (herbage availability less than 600 kg DM per ha) when grain supplementation ceases following the first rains of autumn.

Older, twin-rearing ewes in better body condition and producing the most milk are most at risk.

In goats, clinical signs are similar to those reported in cattle, and acute, subacute, and chronic forms of the disease have been recorded.

**Clinical Pathology and Lesions**

*Plasma or serum magnesium concentrations less than 0.65 mmol/L indicate hypomagnesaemia, and animals with concentrations of less than 0.4 mmol/L are at risk to tetany. There may be concomitant hypocalcemia (<2.0 mmol ca/L), and hyperkalemia (>7*
mmol K/L. Following tetany there is a transient increase in serum aspartate aminotransferase (AST) and creatine phosphokinase (CPK) activities.

Ventricular cerebrospinal fluid magnesium concentrations less than 0.5 mmol/L are associated with hypomagnesemic tetany and are reliable indicators for up to 12 hours after death. Vitreous humor magnesium concentrations of less than 0.4 mmol/L are associated with hypomagnesaemia, and the concentrations provide a reliable indication for up to 48 hours after death, provided that environmental temperatures do not exceed 23°C after 24 hours.

Urine concentrations provide better information on magnesium status and magnesium supply of cattle than blood plasma or serum concentrations. Correction for the variation in urine water excretion is made by dividing the urine magnesium concentration by urine solute concentration (osmolality) or creatinine concentration. When an osmometer or creatinine assays are unavailable, urine solute concentration can be assessed from urine specific gravity measured with a refractometer. The equation

\[
\frac{\text{urine mineral concentration (mmol/L)}}{\text{Specific gravity - 1.000}} \times 0.03
\]

gives similar values to using osmolality measurements on urine samples with specific gravities greater than 1.010.

Urine values > 2 μmol Mg/mOsm or 1.5 mmol Mg/mmol creatinine indicate adequate magnesium status, since cattle with these levels are usually in positive magnesium balance. In cattle with hypomagnesaemia (plasma Mg < 0.65 mmol/L), urine magnesium concentrations are often undetectable. A commercial kit (Equipment: Magnesium in Bovine Urine, no. 1105) is available to measure urine magnesium.
Urine samples are also used to assess the sodium status of cattle, because sodium deficiency can predispose cattle to hypomagnesaemia. A mean urine sodium concentration less than 10 μmol sodium/mOsm from 10 to 20 cows indicates the herd is in negative sodium balance. Sodium deficiency can be confirmed from samples of parotid saliva having a Na:K ratio of less than 5.

Dairy cows in herds with mean blood magnesium concentrations of less than 0.6 mmol/L have shown increases in milk production when supplemented with magnesium. Low plasma concentrations in cows lead to a reduction in the amounts of calcium that can be mobilized in response to hypocalcemia and may predispose milk fever in cows around parturition.

Diagnosis

A history in which lactating cows or ewes grazing lush grass dominant pasture or green cereal crops have died suddenly after showing signs of tetany and convulsions is suggestive of hypomagnesemic tetany. Recovery of clinically affected animals following treatment with combined solutions affected animals following treatment with combined solutions of calcium and magnesium and no deaths after Mg supplements are fed may provide confirmatory evidence.

When losses continue despite magnesium supplementation, low sodium nutrition should be suspected, particularly when potassium fertilizers have been applied to sandy soils. Potassium fertilization results in decreased sodium uptake by plants, and dairy cows can develop sodium deficiency after about a month of grazing on pastures containing less than 0.1 per cent sodium DM. The possibility of sodium deficiency should be considered when water is
provided from surface storages and streams rather than from bores and when no salt supplements are provided. With sodium deficiency, sodium in saliva decreases and potassium concentrations in rumen fluid become elevated and reduce magnesium absorption.

In cattle, acute lead poisoning produces clinical signs similar to those of hypomagnesemic tetany, but there is usually a history of access to lead, and there may be blindness and mania. Rabies usually includes ascending paralysis, anesthesia, and absence of tetany. Nervous ketosis is characterised by ketonuria and absence of convulsions and tetany. Lightning strike, plant poisoning, and meningitis need to be considered, but the acute clinical case of hypomagnesemic tetany is fairly easy to recognise. Paspalum staggers (Claviceps paspali) poisoning is a fairly important differential diagnosis but occurs only when cattle have access to ergots.

When a dairy herd grazing winter and spring pasture shows suboptimal production, hypomagnesaemia must be considered. Other diseases causing similar signs include inadequate available herbage, mastitis, parasitism, and deficiencies of copper and cobalt.

Treatment

In clinically affected animals, combined solutions of magnesium and calcium salts are administered by slow intravenous injection. Intravenous injection of magnesium plus calcium reduces the likelihood of inducing cardiac irregularities, medullary depression, and respiratory failure, all of which may occur when magnesium salts alone are administered intravenously. Since relapses often occur after about 6 hours when intravenous calcium and magnesium therapy is given, it is advisable to administer solutions of magnesium sulfate...
subcutaneously as well. As a guide, 350 ml of a combined solution of calcium borogluconate (25 per cent wt/vol) and magnesium hypophosphite (5 per cent wt/vol) is given intravenously, and 100 to 200 ml of a 50 per cent solution of magnesium sulfate is injected subcutaneously.

To prevent relapses in cows treated under range conditions, we also administer orally a slurry of 100 g magnesium oxide, 100 g dicalcium phosphate, 60 g calcium carbonate, and 50 g sodium chloride. Alternatively, 60 g magnesium chloride (MgCl₂) or magnesium sulfate (MgSO₄) in 200 ml water can be given as an enema. The herd is supplemented with hay at the rate of 4 kg/cow/day, and magnesium oxide (MgO) (50 g daily or 120 every second day) is added to the hay.

For parenteral therapy, sterile solutions of 10, 20 and 50 per cent wt/vol magnesium sulfate are available from a number of sources. Also available are combined solutions of either calcium borogluconate (25 per cent wt/vol), dextrose (25 per cent wt/vol) with magnesium chloride (4 per cent wt/vol), or hypophosphite (5 per cent wt/vol), or simply calcium borogluconate (25 per cent wt/vol) and (MgCl₂) (4 per cent wt/vol). Other combinations include magnesium as the citrate and varying combinations of ingredients. Packaging is 100 ml for sheep and goats and includes 200-, 300-, 350-, 500-, and 1000- ml sizes for cattle.

Response to therapy is variable and is related to the interval between the onset of tetany and the commencement of therapy. Most cattle respond within an hour, the delay in response being related to the time taken to restore CSF magnesium concentrations.
Care should be taken to avoid unnecessary disturbance of clinically affected cows while they are being treated. In cows at risk of severe injury from continuous convulsions, the use of sedatives and tranquilizers has been recommended.

Prevention

Since there is no readily available store of magnesium in the body, supplementation has to be given daily to animals at risk of hypomagnesemic tetany. Most magnesium salts are quite unpalatable, and an important practical aspect in supplemental feeding is combining magnesium with other palatable ingredients such as molasses, concentrates, and hay.

Feeding hay alone may be all that is required to prevent hypomagnesemic tetany in some herds in which only old cows are affected. Other herds may require the addition of magnesium, sodium, and phosphorus. Correction of sodium deficiency aids prevention of hypomagnesemic tetany, but provision of salt to cows receiving adequate sodium intakes may be detrimental.

There are several ways of providing magnesium supplements for ruminants, including individual drenching, treatment of hay, pasture topdressing, water trough treatments, and magnesium licks. It is desirable that the magnesium supplement be readily soluble in the rumen liquor and be sufficient to prevent the development of hypomagnesaemia in any individual animal in a herd.

Individual dairy cows may be drenched daily with 20 MgO or 100 g MgSO₄·7H₂O or 100 g MgCl₂·6H₂O to provide 10 g magnesium. Micronized (<300 mesh) magnesium oxide can be
suspended in water and 20 g can be administered by drenching guns provided it is constantly mixed to maintain the suspension.

Magnesium oxide may also be added to hay at the rate of 50 g MgO/cow/day.

Pastures may be dusted with magnesium oxide (calcined magnesite, 60 mesh) at the rate of 500 g/cow just prior to grazing. One treatment at weekly intervals usually suffices, but if rainfall exceeds 40 to 50 mm within 2 to 3 days of dusting, the pastures will require re-dusting.

Addition of magnesium chloride or magnesium sulfate to water is usually an unreliable method of supplementing cows, because water intake by cows is generally low when they are tetany-prone through grazing lush pastures.

Magnesium licks are considered unreliable for 100 per cent protection, because some cows are not good lickers, and licking behaviour may be intermittent. More cows accept licks if they have been exposed to licks as calves. Homemade recipes for extensive grazing situations include 1:1 magnesium oxide:molasses, 5:3:2 salt:molasses:magnesium oxide, and 2:2:2:2 salt:calcium carbonate:dicalcium phosphate (DCP):molasses:magnesium oxide. Most commercial magnesium licks and blocks contain up to 80 per cent molasses. Licks and blocks should be placed near watering points or stock camping areas. Crusts that develop on licks should be removed, and licks should be moistened before cows are allowed access.

Intraruminal magnesium devices (Sire Sign Magnesium Capsules - Manufactured by Cheetham Rural, Australia, under license from CSIRO), which release about 1.5 g Mg/day for 90 days after a stabilizing period of 1 week are marketed as an aid to grass tetany prevention
in cattle. Magnesium alloy boluses (Rumbul bullets - Pitman-Moore Animal Health Ltd, New Zealand), weighing 100 g and containing 86 per cent magnesium have also been used. Usually these intraruminal devices do not increase serum magnesium concentrations above those of untreated cows. It is recommended that cattle receiving these devices be also fed hay and the devices be used as an alternative to adding magnesium oxide to the hay.

Magnesium fertilizers are useful in increasing herbage magnesium concentrations on acid, sandy soils with low cation exchange capacity but are not recommended for fine-textured soils of high-cation exchange capacity or calcareous soils. When magnesium fertilizers are contemplated for prevention of hypomagnesemic tetany, trials should be done to assess their effectiveness in increasing herbage magnesium.

Older lactating cows should not be grazed on short green pastures or paddocks that have been fertilized with potassium fertilizers.

HYPMAGNESEMIC TETANY IN MILK-FED CALVES

In young ruminants, magnesium is absorbed from the small intestine, whereas in adult ruminants the small intestine is a site of net magnesium secretion. The rumen becomes the major site of absorption once it develops; the large intestine is also a site of net magnesium absorption, although of lesser importance than the rumen. Magnesium is absorbed efficiently (0.9) from milk by young calves. The coefficient of absorption decreases rapidly with age, and in calves fed milk on fibrous bedding, the values decrease to 0.12 at 14 weeks of age. Calves fed milk diets deficient in magnesium for extended periods show poor growth, calcification of soft tissue, increased irritability, tetany, and convulsions.
Hypomagnesemic tetany in calves must be differentiated from acute lead poisoning, tetanus, strychnine poisoning, polioencephalomalacia, and enterotoxemia caused by the toxin of Clostridium perfringens. Analysis of bone calcium and magnesium provides a useful aid to diagnosis. Normal bone has a ratio of calcium:magnesium of 70:1, and in hypomagnesemic calves this ratio may exceed 90:1.

Affected calves should be treated with 100 ml of 10 per cent wt/vol magnesium sulfate solution subcutaneously and should be given oral treatments of magnesium oxide. Suggested dosages are 1, 2 and 3 g magnesium oxide daily for calves up to 5 weeks, from 5 to 10 weeks, and from 10 to 15 weeks of age, respectively. Provision of good quality legume hay and a starter ration from 2 weeks of age prevents the disorder.
The following is an extended review based upon Leaver (1972).

1.3 Mineral requirements

When considering an outbreak of grass tetany, it is essential to look at anything that might affect the animals’ input and output of Mg. The Agricultural Research Council (ARC) has established detailed requirements of sheep and cattle for the major minerals Ca, phosphorus, Mg, K and Na (Agricultural Research Council 1965).

These requirements were assessed by measuring the least amount of mineral needed for maintenance, production and endogenous loss (ie the amount of each element lost through urine and faeces when none of that element is ingested). Then, having established this quantity, the net requirement of the mineral in food was calculated by measuring the availability of the mineral to the animal (ie the amount that is actually absorbed from the gastrointestinal tract).
Figure 2 shows the various pathways of Mg metabolism for a 500 kg cow producing 10 kg of milk. The availability of dietary Mg is shown as 20 per cent and the endogenous loss as 1.5 g. In this example, Mg input equals output. If dietary supply of any mineral exceeds the net requirement the animal is said to be in positive balance. If the reverse is true the animal is in negative balance and the body tends to become depleted of that mineral.

Figure 2. Mg status of a 500 kg cow producing 10 kg of milk. The values in brackets represent the approximate pool of total magnesium in each tissue (Agricultural Research Council, 1965).
When an animal is in negative balance for a particular mineral, the concentration of that mineral in blood plasma and body fluid usually falls. In the cases of Ca, (Anderson 1970) and Na, (Denton 1969), the animal has special mechanisms that enable it to conserve the mineral and/or to draw on body reserves to maintain the blood plasma concentration at the normal value. Nevertheless, with Ca and sometimes with Na, the imbalance between intake and output may be so great that there is a breakdown in regulation, and disease occurs.

With P, (Underwood 1966) and Mg (Rook 1969), although the animal has an extensive store of these minerals in bone and although the metabolism of these elements is to some extent dependent on Ca, the immediate effect of any dietary deficiency is a fall in the plasma concentration which in the end tends to stabilise at a lower value (Leaver 1972).

1.3.1 Calcium and magnesium and production

When individual animals are just in positive balance for Ca and Mg (Figure 2) little Ca and virtually no Mg is excreted in the urine. The main loss of these minerals is in the milk and as endogenous secretion into the gastrointestinal tract (Aikawa & David 1969; Rook 1969).

Endogenous loss depends on body weight. Therefore, for an individual of constant body weight, a change in milk production is the main factor tending to alter Ca and Mg balance. Consequently, as milk production increases, it is theoretically possible to establish whether the extra food that is eaten to meet the increased energy requirements also provides enough minerals to meet the increased loss in the extra milk.
The relationship between these variables has been constructed for Ca and Mg (Figure 3) using ARC requirements for a 500 kg cow at maintenance (dry, non-pregnant), and secreting 10 and 20 kg of milk. Availability of Ca and Mg was taken as 45 and 20 per cent respectively and the food has been specified as containing 3 Mcal of metabolisable energy, 6 g of Ca, and 2 g of Mg per kg of dry matter (Leaver 1972).

Where the mineral content of grass or the availability of minerals differs from the values used in Figure 3, the slope of the lines will not alter but the lines will shift to higher or lower values.

Figure 3. Ca and Mg requirements of a 500 kg lactating cow and Ca and Mg provided by grass (0.6% Ca, 0.2 Mg, 3.0 Mcal metabolisable energy per kg (DM) (Agricultural Research Council 1965).
For example, if the Mg grass line were redrawn for pasture containing 0.15 per cent Mg in the dry matter, then the cow would always be in negative balance. If the Mg content remained as stated (20 per cent) but the availability increased from 20 to 30 per cent, the requirement line would be shifted to a lower value and the animal would always be in positive Mg balance (Leaver 1972).

Two other important aspects of mineral metabolism may be established by considering how differences in the animal's physiological status affect the relationships shown in Figure 3.

Firstly, at any level of production, the more efficient producer - the cow that produces most milk from least energy - will be more likely to be in negative balance than its average or less efficient counterpart.

Secondly, because soft tissue has a much lower Mg content than grass, (Field et al 1968), an animal that maintains production partly by using body reserves is more likely to be in negative balance for Mg than one maintaining production just from eating pasture (Swan & Jamieson 1956a).

1.4 Seasonal and regional occurrence

In Australia, losses from grass tetany have been reported in north east, western and southern Victoria (Herd et al 1965; Caple 1992, pers. comm.); south east NSW (Newman et al 1962; Elliott & Dunlop 1989; Elliott 1991; Locke 1991, pers. comm.; Caple, I. 1992, pers. comm.; Tasmania (Jolley 1972); and the south east of South Australia (Lewis &
Grass Tetany in NSW

Sparrow 1991; Lewis & McFarlane 1993). The disease is rare in Western Australia, but the Causmag Ore Co. is distributing Mg to both Western Australia and Queensland for grass tetany control.

In these regions and in New Zealand, outbreaks are mainly in winter and early spring, and it seems that temperature and pasture quality and quantity may be the primary factors that limit the disease to these times.

1.5 Temperature

Grass tetany usually occurs when temperatures are low (Caple & West 1993; Kemp 1958). In Holland, 95 per cent of all cases occurred when the mean temperature was between 8°C and 16°C (46-57°F) (Grunes et al 1970; t'Hart 1961). The association seems to go deeper than the general restriction of the disease to the colder months (Huxley 1959). Within these months, grass tetany cases seem to be more frequent during cold, wet and windy weather (Allcroft & Burns 1968; Marshall & Elliott 1983; Morton 1984; Caple & West 1993; Elliott 1991; Grunes et al 1992). This suggests that low temperatures affect, and in some way predispose, the animal to grass tetany as well as having an indirect effect through the slower pasture growth.

Swan and Jamieson (1956b), and Allcroft and Burns (1968) suggested that cold weather alters some physiological function in the animal, for example thyroid secretion, thus making the animal more susceptible to the development of hypomagnesaemia and grass tetany. Several hormones do influence Mg metabolism, and plasma Mg in sheep exposed to a temperature of 8°C fell by 12 per cent within two hours (Sykes et al 1969). Another indirect affect of
cold and windy weather is that it reduces grazing time and therefore lowers the total intake of both pasture and Mg (Arnold 1964). These various studies further support the thesis that the aetiology of grass tetany is not only multifactional, but that the various factors may be closely interlinked.

1.6 Pasture quality

Environmental conditions also influence pasture quality and quantity, and it may be that a grass tetany "period" simply reflects a certain stage of pasture growth. Grass tetany is frequent when pasture is in short supply and also when it is growing rapidly in the early spring. In America, it commonly occurs in cattle grazing small-grain forage crops (Grunes et al. 1968).

The relationships between Ca and Mg supply, animal requirements and milk production, shown in Figure 3, were established for a rapidly growing young pasture with a high energy value (digestibility) and a low fibre content. As the grass matures, the digestibility will decrease and the crude fibre will increase (Table 1) and the animal will have to consume more to meet its energy needs (Aikawa & David 1969).

Table 1. Metabolisable energy of dried rye-grass S23 at different stages of growth (Agricultural Research Council 1965).

<table>
<thead>
<tr>
<th>Stage of growth</th>
<th>Crude protein % DM</th>
<th>Crude fibre % DM</th>
<th>Metabolisable energy Meal/kg DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young leafy</td>
<td>18.50</td>
<td>21.20</td>
<td>3.07</td>
</tr>
<tr>
<td>Late leafy</td>
<td>15.20</td>
<td>24.80</td>
<td>2.75</td>
</tr>
<tr>
<td>Flowering</td>
<td>13.80</td>
<td>25.80</td>
<td>2.78</td>
</tr>
<tr>
<td>Seed Set</td>
<td>9.6</td>
<td>31.2</td>
<td>2.38</td>
</tr>
</tbody>
</table>
Provided the Ca and Mg content of the grass stays constant as it matures, this increased consumption will mean a bigger total intake of these minerals and a lower chance of the animal being in negative balance.

Table 2. Nutrient requirements of an adult dairy cow (500 kg) walking 1 mile per day (Agricultural Research Council 1965).

<table>
<thead>
<tr>
<th>Production and requirement</th>
<th>Energy concentration of diet (Mcal/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.8</td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
</tr>
<tr>
<td>DM</td>
<td>6.50</td>
</tr>
<tr>
<td>Ca (% DM)</td>
<td>0.39</td>
</tr>
<tr>
<td>Mg (%DM)</td>
<td>0.12</td>
</tr>
<tr>
<td>Producing 10 kg milk</td>
<td></td>
</tr>
<tr>
<td>DM</td>
<td>15.90</td>
</tr>
<tr>
<td>Ca (% DM)</td>
<td>0.30</td>
</tr>
<tr>
<td>Mg (% DM)</td>
<td>0.09</td>
</tr>
<tr>
<td>Producing 20 kg milk</td>
<td></td>
</tr>
<tr>
<td>DM</td>
<td>14.30</td>
</tr>
<tr>
<td>Ca (% DM)</td>
<td>0.52</td>
</tr>
<tr>
<td>Mg (% DM)</td>
<td>0.14</td>
</tr>
</tbody>
</table>

1.7 Energy requirements of grazing animals

The validity of the quantitative relationships shown in Figure 3 depends to a large extent on the accuracy of the ARC assessment of energy requirements (Table 2), although similar relationships could be established for any other set of energy requirements. Only limited information is available for the actual intake and energy requirements of beef cattle at pasture in Australia (Blaxter et al 1960) and New Zealand (Stillings et al. 1964). For
dairy cows, these requirements have been calculated in an extensive series of investigations at Ruakura in New Zealand (Wallace 1961; Hutton 1962; Hutton 1963; Hutton 1971).

In Australia, pasture fed animals appeared to be eating very large amounts compared to the feed requirements calculated overseas (Wallace 1961). Experiments with much higher stocking rates and more intensive grazing management systems showed that results are closer than had been thought at first (Hutton 1971). The difference between USDA standards and ARC standards between actual and estimated intakes was as small as 1.1 Mcal of metabolisable energy per day.

In Victorian work, where intake was estimated simply by assuming that all the food available was eaten, the energy intake of lactating cows during July and August was lower than estimates from ARC standards.

When pasture is limited in quantity but of high nutritive value, lower-producing animals at maintenance would be in negative Mg balance and this could explain why lactating beef cattle are susceptible to grass tetany even though they may be producing only 7 kg of milk a day (Caple 1992, pers. comm.).

This leads to two related factors. Firstly, the animal needs even more energy on the lower-quality feed because more must be used in the process of digestion. Secondly, the Mg in mature grass seems to be more available to the animal than that in young grass (Grunes et al. 1984; Grunes & Welch 1989; Grunes et al. 1992).
Grass Tetany in NSW

All these trends combine to give a sound nutritional explanation of why hypomagnesaemia and grass tetany are most common in winter and early spring, when grass is immature and has a low fibre content and high energy value (Grunes et al 1970).

1.8 Magnesium status of pasture

Composition

Grass tetany is most common on pasture swards comprised predominantly of grasses, particularly when the grasses are perennial species such as ryegrass. It is also observed when wheat, rye, and oats have been used as green pasture (Grunes et al 1970).

Even in full growth, these species might not provide the Mg needed to keep animals healthy. In fact, the Mg level of any pasture species seldom falls below the level of 0.1 %, which is accepted as limiting to plant growth (McNaught 1970). In a series of trials Mg fertilisers did not produce any growth responses in pasture (Grunes et al. 1985).

Mg levels in the plant depend on both plant and soil factors, and usually remain fairly constant at a given site. It appears to be linearly related to the logarithm of the soil Mg concentration. This underlying logarithmic relationship may be shaped by plant physiological processes whereas soil factors, such as those affecting soil:solution relationships, may account for the different Mg levels of particular plant species on different soil types (Lewis & Sparrow 1991).
Table 3. Mineral content of pasture constituents from seven grass tetany "prone" properties in Victoria (Jolley 1972).

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Ca % of DM</th>
<th>Mg % of DM</th>
<th>Na % of DM</th>
<th>K % of DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>0.74</td>
<td>0.20</td>
<td>0.17</td>
<td>2.03</td>
</tr>
<tr>
<td>September</td>
<td>1.06</td>
<td>0.25</td>
<td>0.22</td>
<td>2.32</td>
</tr>
<tr>
<td>Grass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>0.42</td>
<td>0.18</td>
<td>0.12</td>
<td>2.79</td>
</tr>
<tr>
<td>September</td>
<td>0.46</td>
<td>0.21</td>
<td>0.16</td>
<td>3.21</td>
</tr>
</tbody>
</table>

The Ca, Mg, Na and K content of the grass and clover in swards from tetany-prone regions of Victoria are shown in Table 3. In both July and September, the clover had higher levels of Ca and Mg than the grass, and other evidence shows that winter cereal forage crops can be particularly low in these two minerals.

Since legumes (eg clover) contain more Mg than grass, the amount of Mg that will be ingested depends on the proportion of clover in the sward. It is significant that clover content of most swards increases in spring, when the incidence of tetany falls (Brougham 1959; Todd 1966) and this is coincident with a reduction of the K/Mg + Ca.
Grass-clover relationship

In southern Australia, the development of productive grass-legume pastures has been based on applying superphosphate to improved species of grasses and legumes. At first the sown grass responds less to the superphosphate than the clover, due to shortage of N.

Once the clover has fixed N in the soil the grass responds and, if superphosphate is kept up, legume dominance is succeeded by non-legume (usually grass) dominance (Trumble & Donald 1934; Anderson & McLachlan 1951; Rossitter 1964; Wolfe 1971).

Improving pasture in this way has dramatically increased animal production without the need to use expensive inorganic N. In some situations though, pasture improvement has raised hazards for the grazing animal. For example, animal production can be limited by clover infertility in sheep (Bennetts et al 1946), and bloat in cattle (Wolfe 1971), during the clover-dominant phase and by grass tetany during the grass-dominant phase (Jolley 1972).

Irrespective of the method used to increase soil fertility, clover will be suppressed as N in the soil builds up. This is caused partly by the direct effect of N on grass growth (Stern & Donald 1962 a, b) and partly by an indirect effect of grass on clover growth.

The grass suppresses the clover by competing for light and, therefore, under grazing will accentuate grass dominance (Donald 1963). Heavy grazing generally favours clover growth even though the grasses may benefit from the greater recycling of nutrients at higher stocking rates (Donald 1963; Wolfe 1971).
As a result of pasture improvement or under grazing or both, most pasture swards on grass tetany-prone properties in Victoria consist mainly of grass, even in the spring (Table 4).

Table 4. Composition of pasture from seven grass tetany ‘prone’ properties in Victoria (Jolley 1972).

<table>
<thead>
<tr>
<th>Time of year</th>
<th>Clover</th>
<th>Grass % of green sward</th>
<th>Weed</th>
</tr>
</thead>
<tbody>
<tr>
<td>July</td>
<td>13</td>
<td>73</td>
<td>14</td>
</tr>
<tr>
<td>September</td>
<td>24</td>
<td>70</td>
<td>6</td>
</tr>
</tbody>
</table>

Chemical composition of the pasture

The occurrence of hypomagnesaemia is related firstly to the total amount of Mg ingested, and secondly to the proportion of ingested Mg that is actually absorbed (the available Mg) by the animal. However, these are not the only factors. Other chemical components of the pasture also affect the incidence of grass tetany such as a high K and N content and a low Na content which will also increase the likelihood of tetany occurring (Sjollema 1932; Bartlett et al. 1954; Ender et al 1957; Smyth et al 1958; Kemp 1960; Butler 1963a).

Ca may be important too, since most clinical cases of grass tetany involve hypocalcaemia as well as hypomagnesaemia (Allcroft 1947; Storry 1961; Forbes 1972). Also, some surveys of the relationship between mineral content of the pasture and the incidence of hypomagnesaemia and tetany have revealed positive correlations between the K/Ca + Mg ratio. A critical ratio of above 2.2 has been established (Allcroft 1947; Lewis & Sparrow 1991; Lewis & McFarlane 1993).
Many investigations have been made into how K and N affect the absorption of Mg from the gastrointestinal tract (Grunes et al. 1984; Grunes et al. 1985; Grunes & Welch 1989; Grunes et al. 1992) since the first proposal of this association between tetany and fertilisers.

1.9 Magnesium status of animals

Absorption of magnesium

While early thinking was that most Mg was absorbed in the small intestine (Stewart & Moodie 1956; Care & van t'Klooster 1965; Scott 1965), it seems that in both sheep (Grace 1970; Pfeffer et al 1970), and cattle (Rogers & van t'Klooster 1969), most absorption happens in the stomach region. The rumen epithelium is relatively impermeable to both Ca and Mg, but a small movement of Mg from the omasum to the blood has been demonstrated in in vitro preparations (Harrison 1971). Hence the omasum may be the most important site for Mg absorption.

It seems that the factors that influence Mg absorption in the omasum need to be carefully studied, especially as such digestion would occur before the digesta is exposed to the acid environment of the abomasum.

Despite this, some Mg is likely to be absorbed in the intestine. Sheep can be fed solely on a liquid diet infused into the abomasum and show no ill effects. It has been suggested (Smith 1969) that they must be absorbing some Mg, the amount probably depending on the concentration of Mg in the digesta.
Grass Tetany in NSW

Fortunately, the lack of precise information about the mechanism and sites of Mg absorption has not impeded work on many other aspects of Mg metabolism. As well, a lot of information has been collected from carefully balanced studies done on the whole animal.

1.10 Nitrogen and protein

Nitrogen fertilisers have apparently increased the incidence of grass tetany in grazing animals (Whitehead 1970). There are two possible reasons for this effect. The first is the increase in grass dominance mentioned earlier. The second is an increase in the crude protein content of the fertilised herbage.

In one experiment cattle were fed two herbagens, one containing 14 per cent protein and the other 26 per cent. The availability of Mg in these herbagens was 20 per cent in the low-protein herbage and 10 per cent in the high-protein herbage (Kemp et al 1966). Grass in a grass-clover sward can have a high protein content without any N fertiliser, and absolute crude protein content of the pasture, regardless of how it is achieved, could be another important factor in reducing Mg absorption (Metson et al 1969).

Theories explaining how a high protein level could reduce Mg absorption have not, so far, been satisfactorily supported by experimental evidence (Whitehead 1970). Furthermore, the situation has been clouded by work with sheep (Grace and McRae 1972). Sheep were fed a basic dry grass diet, which was supplemented with casein to give crude protein levels from 16.5 to 21.5. There was no effect on the availability or net absorption of Mg. It may be that the effect is due to other associated factors that change as the protein level changes.
One factor closely associated with protein level is the concentration of higher fatty acids in fresh grass (Kemp 1960; Wilson et al. 1969). When these acids were added to cattle feed, the availability of Mg declined from 20 per cent to less than 10 per cent.

Another piece of circumstantial evidence is that the plasma Mg concentration of cattle grazing ryegrass decreased with peanut oil supplements but increased with starch supplements (Wilson et al. 1969).

It has been suggested that the fatty acids may act by forming an insoluble Mg soap in the abomasum. Paradoxically though, the immature cows, which were less affected by the supplements than the mature cows, had a higher concentration of faecal fatty acids and insoluble soaps. It is possible that the soaps interfered with the absorption of Mg in the omasum but were then absorbed in the small intestine of the mature cows (Caple & West 1993). Again, this hypothesis is not supported by experimental evidence.

In a second trial where the general levels of Mg intake and of plasma Mg were higher, the response was much less (Wilson et al. 1969). The inconsistency may, therefore, simply be due to either a higher Mg intake or a lower Mg excretion (in the case of young calves) which masks the effect of the peanut oil.

This important notion - that Mg intake must be at a marginal level before any interference will be reflected in the concentration in the plasma - was first clearly demonstrated in sheep for the interaction between K and Mg (Suttle & Field 1969).
1.11 Potassium

Grass tetany appears to be more frequent where K fertiliser has been used. Overseas it has also been suggested that a sudden increase in K intake when cattle are first permitted to graze spring grass after being over-wintered indoors may contribute to development of higher incidences of grass tetany (Suttle & Field 1969; Grunes et al. 1984; Grunes & Welch 1989).

In one experiment, the availability of Mg to sheep fed a hay/concentrate diet was reduced when the K concentration was raised to the level found in pastures conducive to the development of grass tetany in grazing animals (Suttle & Field 1969). Although availability of Mg was lowered, hypomagnesaemia was not observed, confirming the results of many earlier experiments that also failed to show any direct effect of K on circulating serum Mg concentrations (Pearson et al 1949; Eaton & Avampato 1952; Odell et al. 1952; Blaxter et al 1960; Dua et al. 1988).

These negative results are not entirely unexpected for it has been observed that serum Mg concentrations in cattle do not reflect changes in Mg intake when the presence of this element in the diet exceeds requirements.

When the effect of K on plasma Mg of sheep was carefully re-examined, using diets with a range of Mg levels, it was found that the sheep receiving low Mg and high K not only had lowered plasma Mg, but four out of eight also developed grass tetany (Suttle and Field 1969). In that work there appeared to be a clear interaction between K and Mg in the development of hypomagnesaemia and grass tetany.
1.12 Sodium and calcium

The effects of Ca and Na on development of hypomagnesaemia and grass tetany are not clear cut, but neither seems to be very important in Australia. Low Na levels in pasture are common in some grass tetany areas in Victoria (Blair-West et al. 1968b; Jolley 1972), and it is known that Na stimulates Mg absorption in the small bowel in rats (Ross 1961), and sheep (Care et al. 1967). However, the evidence is that hypomagnesaemia in cattle is independent of the amount of Na in the diet (Rook 1969) and applying it to pasture will not stop hypomagnesaemia (Kemp 1964).

Furthermore, sheep with chronic Na deficiency apparently do not develop hypomagnesaemia. It may be that in cases of chronic deficiency any effects that the absence of Na could have on Mg metabolism are masked by the excess of Mg.

A common transport system for Ca and Mg absorption has been proposed (Alcock & MacIntyre 1960), and excess Ca can reduce the absorption of Mg in rats (Clark 1969), and sheep (Stillings et al 1964). However Ca content of most Australian and New Zealand pastures is low by overseas standards and here the main problem with Ca metabolism is to explain the common occurrence of hypocalcaemia and hypomagnesaemia.

1.13 Organic acids

Some organic acids, such as citric and transaconitic acids, may also be associated with the development of hypomagnesaemia. Both citrate and aconitate can chelate Ca and Mg and thus
could interfere with the metabolism of either element in the animal (Burt & Thomas 1961; Burau & Stout 1965; Grunes & Welch 1989). Some species of grass contain quite a lot of organic acids (Burau & Stout 1965; Stout et al. 1967). The way in which these compounds actually influence hypomagnesaemia is open to debate. Results about their effects on the animal have been conflicting.

For example, when heifers were fed a diet that contained one per cent of Na citrate, serum Mg concentration was reduced. Some cattle that were given oral doses of K chloride and either transaconitic acid or citric acid developed tetany (Bohman et al. 1983a). However, diets containing up to 6 per cent transaconitate have been fed to sheep and guinea pigs without any effect on health and without depressing the serum Mg concentration (Kennedy 1968; Wright and Wolf 1969).

Perennial ryegrass (*Lolium perenne*) is a dominant component of many grass tetany pastures in Australia and New Zealand. It has a low transaconitate content but a relatively high citrate content (Jones & Barnes 1967). Citric acid is rapidly broken down by rumen microflora, except in the presence of high concentrations of K (Power et al. 1970). It is thus possible that citric acid contributes to the development of hypomagnesaemia when the K intake is high and can inhibit the normal breakdown of the citrate in the rumen.

### 1.14 Body reserves of magnesium

When lactating ruminants develop hypomagnesaemia the Mg content of their milk is not reduced and, if they cannot take in enough Mg from the gut, they must draw on their body reserves to maintain plasma concentration.
There is a considerable amount of Mg in the soft tissue and in the bone (Figure 2). Experiments have shown that these reserves are reduced when young rats (Smith & Nisbet 1968) and calves (Blaxter & Rook 1954), are fed Mg-deficient diets for prolonged periods. Such reduction in the skeletal Mg of young animals has been taken as supporting evidence for the theory that the skeletal Mg provides animals with a labile reserve. However, it may only mean that the growing animal deposits bone with a low Mg content (Duckworth & Godden 1941).

The evidence is more clear cut with adult rats (Smith & Nisbet 1972), and rabbits (Agricultural Research Council 1965). On Mg-deficient diets, both species showed a decrease in skeletal and soft tissue Mg. The rats continued to excrete Mg at a constant rate, but lower than reference values (Smith 1966).

Sheep were depleted of Mg by peritoneal dialysis, and blood Mg reduced to about 0.8 mg per 100 mL, and stayed at about this level. This result again indicated the existence of a reservoir of Mg capable of meeting some of the demands imposed by depletion.

Selective removal of skeletal Mg has also been reported in some adult sheep grazing on hill farms in Scotland. Other ewes on the same property had hypomagnesaemia during the same period (October-November) in four successive years (Field et al. 1968).

Some mobilisation of body reserves, therefore, does occur, especially in the long term. However, it appears that it is usually not enough to maintain the plasma Mg concentration of ruminants in the face of high milk secretion and a Mg-deficient diet. In this situation, the
limited reserves of plasma and extra-cellular fluids are soon depleted and plasma Mg concentration falls sharply (Rook 1969).

1.15 Hormones and magnesium

Several hormones are known to influence Mg metabolism. Administering aldosterone decreases the availability of dietary Mg (Hanna and MacIntyre 1960; Care and Ross 1963). It was therefore logical to suspect that hypomagnesaemia and grass tetany might be associated with increased secretion of aldosterone.

Intramuscular injections of thyroidectomized sheep with tri-iodothyronine also reduced plasma Mg concentration (Care 1969). Apparently tissue turnover was increased and absorption from the intestine decreased. Plasma Ca concentration was also increased. This evidence and the association mentioned earlier between the occurrence of grass tetany and cold, wet, windy weather, led to the suggestion that the thyroid may be involved in inducing hypomagnesaemia. So far there have been no direct measurements of the relevant concentrations of the plasma hormones - tri-iodothyronine and tetraiodothyronine - in cattle or sheep with hypomagnesaemia.

Parathyroid hormone (PTH) raises the concentrations of plasma Ca and Mg by stimulating absorption from the intestines and resorption from the bone and renal tubules (Care 1969; MacIntyre & Robinson 1969), and by reducing the amount of Ca secreted in the milk.

Using a specific radioimmunoassay for PTH, inverse relationships between the rate of PTH secretion and the concentration of plasma Ca and Mg have been demonstrated for ruminants.
(Care et al. 1966; Buckle et al. 1968; Sherwood et al. 1968). Also, when PTH was measured in clinical cases of parturient paresis (milk fever) the circulating PTH concentration was higher than in cows with a normal plasma concentration (Mayer et al. 1969). In milk fever, the parathyroid glands appear to respond in a normal manner and a similar response apparently occurs in animals with hypomagnesaemia (Care 1969).

In contrast to parturient paresis, where plasma Mg is elevated (Willoughly et al. 1970), cattle with grass tetany usually have a low level of both serum Ca and Mg (Schuster et al. 1969; Forbes 1972). A possible explanation is provided by the finding that PTH could not mobilise Ca from in vitro bone preparations when there was not Mg in the culture media (MacManus et al. 1971).

Grass tetany often occurs in cows in oestrus (Allcroft & Burns 1968), when the concentration of circulating oestrogen is high. Similar high levels are found at birth (Challis 1971), when milk fever occurs. It is known that a high concentration of circulating oestrogen does inhibit bone resorption in some species (Lindquist et al. 1960; Orimo et al. 1970), but this effect has not yet been documented in ruminants. It may be that the main effect of oestrus on grass tetany is simply to initiate behavioural changes that reduce the food and Mg intake of some animals on the day of oestrus.

1.16 Breed differences

Serum Mg levels vary considerably between individuals but only a small percentage of animals with low levels develop grass tetany (Kemp 1958). This suggests that some animals may also be more susceptible to the induction of hypomagnesaemia and grass tetany. An
important question, with far reaching implications for tetany control, is whether these differences among individuals are inherited and can be affected by breeding (Wiener & Field 1971).

Recent work suggests that breed differences do exist. Angus and its derivations are the most susceptible with *Bos Indicus* the most resistant (Greene *et al.* 1989a; Greene *et al.* 1989b; Elliott 1991). Earlier Australian work identified shorthorn cattle as being extremely susceptible to grass tetany (Harris *et al.* 1983).

Differences in the incidence of milk fever have been demonstrated between animals of different breeds kept in separate herds and also within the same herd. For grass tetany, the differences have only been demonstrated for breeds kept on the same property. Any breed differences could be confounded with environmental and managerial differences (Wiener & Field 1971).

Estimates of the genetic basis of Mg concentrations in the blood of sheep and cattle have put the contribution of the breed to total variation at 20 per cent for sheep (Field *et al.* 1969; Wiener & Field 1971), and up to 58 per cent for cattle, (Wiener & Field 1971).

Similar but more restricted studies with monozygotic twins also showed a hereditary basis for the concentration of Ca, P, Mg, Na, and K in cows' milk (Field 1970; Field 1971).

This suggests some genetic variation in disorders of mineral metabolism and in the mineral levels in animal tissues and fluids. However, the amount of genetic variation, and whether the
variation shows up equally in different environments and at different levels of nutrition, remains unknown.

1.17 Induction of tetany

Only a small percentage of hypomagnesemic cattle and sheep develop clinical tetany. Similar results are found with rats. Most deficient rats show some signs of increased nervousness, but few actually develop spontaneous convulsions (Chutkow & Meyer’s 1968). A possible explanation is that most animals can adapt to lower blood and extra-cellular Mg levels, but are reduced to an unsteady state. If Mg levels are lowered still further, or if other factors intervene, convulsions can develop. Convulsions have indeed been brought on by sudden exposure to noise in Mg-short rats for instance (Chutkow & Meyer’s 1968).

These convulsions are not properly understood, which is complicated by the fact that Mg is known to be involved in many intracellular biochemical reactions (Wacker 1969). There is evidence that the cell membrane may play an important role in Mg depletion leading to grass tetany. Extracellular Mg levels may fall steeply within a few days whereas the intracellular level falls only marginally over a much longer period (Allcroft & Burns 1968). Hence, in hypomagnesaemia the major change is in the ratio between the intracellular and extracellular Mg concentrations (Woodward & Reed 1969), and this ratio operates across the cell membrane.

The effect on the central nervous system is also unclear. We still do not know whether the change in Mg concentration in peripheral extracellular fluid is transmitted to the fluid...
compartment of the brain. Relatively large experimental fluctuations in the Mg concentration of extracellular fluid seem to have little effect on the level of Mg in the cerebrospinal fluid (Davison 1956; Oppelt et al. 1963; Ames et al. 1964; Pallis et al. 1965; Woodward & Reed 1969). However, in one experiment with rats, convulsions appeared at the same time as the cerebrospinal fluid Mg decreased (Chutkow & Meyer's 1968). In the same experiment brain intracellular Mg also decreased, but to a smaller degree, Therefore it seems that convulsions and death in the Mg-deficient animal could be due to the effect of Mg on the generation and propagation of nerve impulses in the peripheral and the central nervous systems.

It is now known that generation and propagation of nerve impulses depends on the intra and extracellular concentrations of K and Na and on the ability of the nerve cell membrane to make rapid changes in its permeability to these two ions when it is stimulated (Katz 1966). The nerve impulse also depends on extracellular concentrations of Ca and Mg. When these concentrations are reduced, the properties of the cell membrane are changed, so that a single brief stimulus produces a volley of impulses rather than one single impulse. The effects of Ca and Mg are additive and the volley of impulses appears to result from an oscillating change in the permeability of the nerve cell (Gordon & Welsh 1948; Huxley 1959). If this physiological change is the basis for the convulsions, it would also explain why tetany occurs so often in animals that are both hypocalcaemic and hypomagnesemic.

Ca and Mg are also involved in the neurosecretion process at the synapse (the junction between nerve cells) and at the neuromuscular junction (Katz 1966). If the physiology of the process at the synapse is the same as at the neuromuscular junction, then Mg deficiency in the presence of normal Ca would not enhance neurosecretion. At the neuromuscular junction a Ca
deficiency or an excess of Mg tends to stop neurosecretion and thus the passage of the nerve impulse across the junction (Hubbard et al. 1968).

There is a high mortality rate in animals affected by grass tetany. Sudden death associated with convulsions arising from any cause is usually due to either respiratory failure or heart failure. Cardiac and electrocardiograph abnormalities have been reported in some Mg-deficient animals of other species (Seelig 1969), but it is not known whether heart failure is the ultimate cause of death in grass tetany.

1.18 Prevention of grass tetany

Preventing grass tetany in the Australian beef industry will involve management changes in the whole industry, as well as in the scale and number of individual farms. Many more cattle are now at pasture in tetany-susceptible areas in southern Australia, with much of the increase being brought about by pasture improvement and more intensive stocking. Both these factors can increase the risk of grass tetany.

With higher stocking rates in enterprises based only on pasture, animals will inevitably be under greater nutritional stress during the winter. Although cattle can overcome this stress by using fat to supply energy, they cannot, at least in the short term, get all the Mg that they will need from the body or the pasture.

Grass tetany can only be prevented in this situation by increasing the amount of Mg the animal digests and absorbs, or by reducing relative amounts of pasture high in K.
1.19 Fertiliser use

Pasture improvement in Australia has been largely the result of using phosphate fertilisers and legumes (Williams 1970). So far, N and K fertilisers have not been widely used. Their frequent use overseas been associated with a rise in grass tetany (Allcroft & Burns 1968; Grunes et al. 1985; Grunes & Welch 1989; Grunes et al. 1992). Increased use in southern Australia could well lead to similar problems.

Nitrogen

Despite Australian soils being relatively low in N, the high cost of bag N has restricted its use. Although legumes will successfully fix N in some parts of southern Australia, where winter temperatures are too low for satisfactory clover growth and where appreciable amounts of soil N are mineralised, N fertilisers are being used to increase winter grass growth (Newman et al. 1962; Collins 1967). Responses have ranged from as high as 28 kg DM per kg of N at harvest in September for applications of up to 92 kg N per hectare, down to 12 kg DM per kg N. Lower responses have been said to be due to low temperatures and short days (Collins 1967), or to lower-than-average autumn rainfall.

Profitable responses to N applied in winter have also been recorded on dry and irrigated grass-clover dairy pastures (Strang & Broue 1958; Newman et al. 1962; Crofts 1965; Collins 1967; Landy 1970), and on winter cereal crops used as supplementary feed for dairy cows. The use of N in these situations seems to be increasing (Landy 1970). In any tetany-prone area, the implications of N dressings need to be examined in terms of the effect on the incidence of grass tetany, as well as the effect on total pasture production.
Grass Tetany in NSW

The links between heavy N dressings and grass tetany are still poorly understood (Whitehead 1970), so it would seem unwise to apply more than 92 kg N on unirrigated land. A further safeguard would be to manage any N-dressed pastures to keep clover content as high as possible (Conyers 1991, pers.comm.).

Potassium

One hundred and forty thousand tonnes of fertiliser K are used annually in south eastern Australia. When K is deficient, pasture production drops and pasture content changes. Grasses can scavenge for and extract K more efficiently from deficient soils than clovers, and so the clover content of K deficient swards will fall.

Obviously, where K is limiting plant growth, K fertiliser will increase pasture and animal production, and the Mg status of the sward by encouraging the clovers (McNaught 1958; Hosking 1967). It is known that grass grows best when K content reaches 2 per cent of dry matter (McNaught 1970). Hence, with continued or heavy applications of K fertiliser grasses can indulge in luxury uptake, and the “within plant” K content can reach as much as 4 or 5 per cent, which favours grass tetany. In one experiment at Ellinbank Dairy Research Station, annual dressings of 100 kg K per hectare between 1967 and 1971 increased the K content of the pasture throughout the period and, for the first time on the station, cattle grazing this pasture developed grass tetany.

The indiscriminate use of K fertilisers should be discouraged, and it would be wise to monitor K levels in pastures in tetany-prone areas. If the level of K rises to 3 per cent of plant content or higher in the spring, next year’s application should be foregone and any further applications
should be decided by the measured status of the pasture. Optimum rates of K fertilisers should be used (McNaught 1958), as excess rates might induce grass tetany.
1.20 Control of grass tetany by management

The essence of control is to ensure that the animal absorbs enough Mg from its gastrointestinal tract to maintain plasma Mg concentrations. This can be done in several ways, which can be used alone or in combination.

Pasture management

Because clover contains more Mg and Ca than grass, its content in the sward should be increased, particularly in late winter. This can be done by heavy grazing in spring and autumn to stop the grass overshadowing the clover and restricting its light. This does not always work because in some areas clover makes little growth in winter even when light is not restricted.

Fertiliser N can be used to increase grass growth in late winter but, as already explained, the advantage of having more forage and therefore more Mg may be outweighed by the disadvantages of grass dominance and the possible increase of a factor(s) in grass that reduces Mg absorption.

At the farm level, any tetany prone paddocks should be grazed in winter by the less-susceptible dry stock and first calf heifers. The "safe paddocks" should be used for the more susceptible older milking cows. In studies where it has been possible to check graziers’ observations by pasture analysis, the sward in a "safe" paddock contained much more clover and had a higher Mg and Ca content than the sward in a tetany-prone paddock (Jolley 1972).
Magnesium fertiliser

The magnesium (Mg) content of some pastures can be increased by dressings of Mg fertiliser (Bartlett et al. 1954; Hooper 1967; Allcroft & Burns 1968).

Obviously, a single application of fertiliser would be the ideal control method. Unfortunately, fertilising with Mg is often not effective or economic. On many soils it is very difficult to raise the Mg content of the pasture to the 0.2 per cent thought to be safe for animals. The difficulty is that this level is much higher than the level required for optimum pasture growth, and as far as the plant is concerned, is within the luxury uptake range (McNaught 1970). Nevertheless, heavy applications of calcined magnesite to certain soil types in New Zealand, England and Ireland have either significantly increased pasture Mg or effectively controlled grass tetany or both (Bartlett et al. 1954; Parr & Allcroft 1957; Todd 1965; McNaught & Ludecke 1967; Allcroft & Burns 1968).

In New Zealand the only responsive soil type was a yellow brown pumice, and in England (Allcroft & Burns 1968), and Ireland (Todd 1965), the best response was obtained with light sandy soils with pH below 6. Responses were poor on medium heavy loams with a pH of 6.6. A contrasting report from Holland claims that, provided K is not a complicating factor, pasture Mg concentration content can be increased by applying Mg fertiliser (Dryeere 1932).

Mg fertilisers have been tested against grass tetany in Victoria and South Australia. In South Australia, the Mg content of the treated pasture had increased significantly by the end of the first year of the experiment (Jolley & Leaver 1974).
Grass Tetany in NSW

Part of the grass tetany-prone area in Victoria has soil of light texture and low pH that should in theory respond to Mg fertiliser (Conyers 1991, pers. comm.). Whether the treatment is an economical proposition will depend on how long the effect lasts and on whether other cheaper Mg fertilisers, such as dolomite, are as effective as calcined magnesite (Grunes et al. 1968; Grunes et al. 1970; Grunes et al. 1985).

Magnesium feed supplements

The levels of serum Mg in cattle can be raised by oral doses of Mg compounds. The minimum effective dose is about 56 g (2 oz) of Mg oxide every second day (Allcroft & Burns 1968). On small properties or dairy farms calcined magnesite can be fed to cattle either mixed with concentrates or sprinkled on silage (Allcroft & Burns 1968). However, this procedure is not suitable for extensive beef cattle properties.

Most beef producers in south eastern Australia conserve pasture hay in late spring and feed it out in the following winter. Without any modification, this will improve the Mg status of cattle because it transfers Mg to a time of shortage.

More important is the modification of spraying the hay with calcined magnesite. With rates adjusted so that each cow gets 112 g (4 oz) of magnesite every second day, grass tetany can be completely controlled (Eaton & Avampato 1952). In the preliminary studies, a small quantity of hay was treated with a fairly concentrated magnesite spray and fed to the cattle before the main portion of hay. Subsequently, some producers found that they could simplify the procedure by incorporating magnesite into the hay at baling (Caple & Allworth 1987).
Grass Tetany in NSW

Licks made of equal weights of molasses and calcined magnesite may also be effective. In one trial in Ireland, twenty-seven cows each consumed between 36 and 56 g of Mg per day from licks. The one cow that would not take to the lick developed tetany (Todd et al. 1966). Other formulations have also proved palatable (Allcroft & Burns 1968), and Mg chloride has been added to drinking water (Blaxter et al. 1960). Further trials with licks are warranted because licks are less troublesome than spraying hay with magnesite. In regions such as north eastern Victoria, where the pastures are low in Na as well as Mg, it may be possible to take advantage of the Na-deficient animals' appetite for salt and simply incorporate Mg oxide into a salt lick (Blair-West et al. 1968b; Jolley 1972).

Mg bullets given orally can also be used to increase levels of Mg. In some studies, these bullets have controlled grass tetany (Smyth 1969; Ritchie & Hemingway 1986); whilst in later trials the bullets failed to stop the development of hypomagnesaemia (Kemp & Todd 1970). Mg bullets are now commercially available in Australia.

Technology developed for other purposes may also be useful in monitoring Mg levels in cattle. A device that allows the slow, long-term release of anti-bloat agents into the rumen has controlled bloat in the field (Laby 1970) and could perhaps be adapted for the release of Mg. This device is administered orally and changes shape in the rumen so that it is too large or too awkward to regurgitate. A similar but alternative device has already been developed to release Mg in the rumen. In effect, the device is an electric cell which releases Mg at a uniform rate of 2.4 ± 0.2 g per day for seven to nine weeks (Caple 1992, pers. comm.). The release rate is considerably higher than can be obtained by diffusion, and the duration of release coincides well with the normal grass tetany period of about nine weeks in southern Australia.
Grass Tetany in NSW

An important problem in any method of control is when to start and when to stop supplementing with Mg. Unfortunately, there is no general answer, for conditions vary so much from year to year and region to region. Any decision must take into account both weather and pasture conditions. The onset of cold, wet, windy conditions should be the signal to start feeding supplements.

In contrast, when pasture is plentiful and conditions are mild in early winter, supplementation can be delayed. At the other end of the season supplements can be stopped when temperatures rise in the spring (Marshall & Elliott, 1983; Morton 1984; Caple & Allworth 1987; Greene et al. 1989b; Elliott 1991).

Husbandry

The incidence of grass tetany can be reduced by correct management (Lowe & Allo 1965; Morton 1984; Caple & Allworth 1987; Elliott 1991). As an extreme measure, sheep can be substituted for cattle, or dry cattle for lactating cattle. Losses among lactating animals can be reduced by not calving older cattle in the winter. Either spring or autumn calving is preferable, but there is some evidence from the Hamilton Research Station that autumn-born calves can be finished at an earlier age in western Victoria than those born in spring (Vivian 1970). Similar considerations apply to favour autumn calving in south west NSW.

Moving cattle in winter, particularly over long distances, can also cause stress and increase the likelihood of tetany. When moving cannot be avoided, cattle should be fed Mg supplements for the week before the move.
Providing shelter and shelter belts of trees may also be of some benefit, for the incidence of tetany seems to increase during spells of harsh weather (Allcroft 1947; Caple & West 1993; Caple & Allworth 1987; Elliott 1991; Caple 1992, pers. comm.).

### 1.21 Plant and soil factors

The relationship between grass tetany and the mineral content of pastures has been examined in a very detailed way.

In Australia, limited studies such as Jolly and Leaver (1974) found that pastures likely to lead to grass tetany contain less Ca and Mg than safer pastures. Kemp and t'Hart (1957) proposed that K divided by the sum of Ca and Mg (K:Ca + Mg) gives a critical ratio of 2:2. It appears that this critical ratio in tetany prone pastures is always higher, as verified by Butler (1963a) and Meinson et al. (1966).

Other factors such as temperature (Grunes et al. 1968), low Mg concentrations (Kubota et al. 1980), plant species (Thill & George 1975), soil type (Kubota et al. 1980) and breed type (Greene et al. 1989b) all play critical roles in the development of hypomagnesaemia, leading to grass tetany.

Recent soil, plant and animal interactive studies in South Australia by Lewis and McFarlane (1993) were presented to the J S Davies Beef Research Forum and showed positive correlations between soil type and plant K/Ca + Mg ratio (Table 5).
Although the ratios of K:Ca + Mg in perennial grass samples collected in October were still high (for all soils), no grass tetany was observed in that study. The author suggested that this may be due to rising air temperatures in the spring and an increased clover component in the pasture. European work (Kemp & t'Hart 1957; Butler 1963b; Meilson et al. 1966) suggests the average maximum temperature must be below 14°C for at least 5 days for grass tetany to occur, and studies on grass tetany in the United States of America suggest that a diurnal range between 8°C and 16°C is a critical factor (Grunes et al. 1984).
Table 5. Effects of soil type on the mean mineral concentrations (%) and mean K/(Ca + Mg) ratios for pasture components sampled in July and October (Lewis and McFarlane 1993).

<table>
<thead>
<tr>
<th></th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>K/(Ca+Mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Legume</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solodised solonetz (12)</td>
<td>1.98</td>
<td>0.44a</td>
<td>0.23a</td>
<td>1.24a</td>
</tr>
<tr>
<td>Rendzina (4)</td>
<td>2.17</td>
<td>1.00b</td>
<td>0.33b</td>
<td>0.73b</td>
</tr>
<tr>
<td>Siliceous sand (5)</td>
<td>1.58</td>
<td>0.81c</td>
<td>0.27c</td>
<td>0.62b</td>
</tr>
<tr>
<td>Significance</td>
<td>n.s.</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td><strong>Perennial Grass</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solodised solonetz (10)</td>
<td>2.96</td>
<td>0.27</td>
<td>0.24</td>
<td>2.26a</td>
</tr>
<tr>
<td>Rendzina (5)</td>
<td>2.46</td>
<td>0.32</td>
<td>0.26</td>
<td>1.72b</td>
</tr>
<tr>
<td>Siliceous sand (2)</td>
<td>2.75</td>
<td>0.30</td>
<td>0.31</td>
<td>1.78b</td>
</tr>
<tr>
<td>Significance</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>**</td>
</tr>
<tr>
<td><strong>Annual Grass</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solodised solonetz (8)</td>
<td>3.14</td>
<td>0.36a</td>
<td>0.22a</td>
<td>2.39a</td>
</tr>
<tr>
<td>Rendzina (1)</td>
<td>2.00</td>
<td>0.56b</td>
<td>0.33b</td>
<td>0.93b</td>
</tr>
<tr>
<td>Siliceous sand (4)</td>
<td>2.81</td>
<td>0.39a</td>
<td>0.26c</td>
<td>1.76c</td>
</tr>
<tr>
<td>Significance</td>
<td>n.s.</td>
<td>*</td>
<td>**</td>
<td>***</td>
</tr>
</tbody>
</table>

| **Legume**         |          |      |       |           |
| Solodised solonetz (12) | 2.18a | 0.83a| 0.24a | 0.19a     |
| Rendzina (4)       | 2.33a | 1.42b| 0.30b | 0.65b     |
| Siliceous sand (5) | 1.27b | 1.37b| 0.29b | 0.36c     |
| Significance       | **      | ***  | ***   | ***       |

| **Perennial Grass**|          |      |       |           |
| Solodised solonetz (10) | 2.84  | 0.24 | 0.18  | 2.75      |
| Rendzina           | 2.84  | 0.29 | 0.18  | 2.53      |
| Siliceous sand (2) | 2.63  | 0.20 | 0.24  | 2.26      |
| Significance       | n.s.  | n.s. | n.s.  | n.s.      |

| **Annual Grass**   |          |      |       |           |
| Solodised solonetz (8) | 1.97  | 0.28a| 0.15  | 1.94      |
| Rendzina (1)       | 2.48  | 0.37b| 0.14  | 2.10      |
| Siliceous sand (4) | 1.96  | 0.36b| 0.19  | 1.48      |
| Significance       | n.s.  | *    | n.s.  | n.s.      |

* = P < 0.05;    *** = P < 0.0001;  ** = P < 0.01;  n.s. = not significant

Note: Number of sites is in parentheses. Within nutrient and pasture component, values followed by the same letter are not significantly different at P = 0.05.
Grass Tetany in NSW

Table 6. Mean pH values and extractable cation concentrations for the three soil types sampled in July. (Lewis and McFarlane 1993).

<table>
<thead>
<tr>
<th>Soil type and Number of sites</th>
<th>Ph (mg/kg)</th>
<th>P (Cmol(+)</th>
<th>Ca (Cmol)</th>
<th>Mg (Cmol)</th>
<th>K/ (Cmol(+)</th>
<th>(ca+Mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solodised Solonet (12)</td>
<td>6.45a</td>
<td>36a</td>
<td>0.40a</td>
<td>4.0a</td>
<td>0.73a</td>
<td>0.100a</td>
</tr>
<tr>
<td>Rendzina (5)</td>
<td>7.55b</td>
<td>41a</td>
<td>2.90b</td>
<td>43.4b</td>
<td>8.08b</td>
<td>0.058b</td>
</tr>
<tr>
<td>Siliceous sand (5)</td>
<td>6.80c</td>
<td>17b</td>
<td>0.09a</td>
<td>3.1a</td>
<td>0.45a</td>
<td>0.025b</td>
</tr>
<tr>
<td>Significance</td>
<td>***</td>
<td>**</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>

** = P < 0.01;  *** = P < 0.001

Note: Within rows, values followed by the same letter are not significantly different at P=0.05.

The ratio of K/Ca + Mg in the top 10 cm of soil is also higher in solodised solonet soils (Table 6). As these values were closely correlated to the plant ratios, it may be possible to use soil sampling to diagnose potential grass tetany paddocks. The recommendation made to South Australia producers by works such as Lewis and Sparrow (1991) are very similar to those in Victoria by Caple and West (1993). These recommendations were to test both soil and plant samples for respective K/Ca + Mg levels before fertilising or grazing cattle.

Development of powerful databases has allowed analysis of the CALM Soil Database System to check if the NSW grass tetany prone districts in the southern tablelands and south west slopes areas have a soil K/Mg + Ca ratio similar to the levels reported by Lewis and Sparrow (1991) in South Australia. They determined that the critical lower level of the K/Ca + Mg ratio is 0.07 - 0.08.
Grass Tetany in NSW

NSW Soil Conservation Service estimates are that an area subject to four consecutive days from 8°C to 16°C would trigger variations in the plant levels of K, Mg and Ca., provided that the soil temperature was 6° - 7°C or less for about one week.

From the review of the literature it is clear that a number of factors are involved in predisposing beef cattle to grass tetany. Each of these factors will be looked at separately and in combination in the following sections to determine if the factors predisposing beef cattle to grass tetany can be more accurately determined.
Chapter 2 – Introduction to Plant Studies

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Chapter 2 - Introduction to Plant Studies

2.1 Introduction

It is clear from the literature review that further analysis of soil, plant, climate and animal interactions need to be carried out in Australia to better understand the aetiology of grass tetany and provide a list of warning signals to beef cattle producers.

Most of the research conducted in Australia has concentrated on the association between Mg availability to the animal and susceptibility to grass tetany. However, most research in the past has concentrated on clinical manifestation of grass tetany and treatment of affected animals. Given that there appear to be many interacting factors, this study was established to examine the animal/plant/soil/weather/management complex so graziers can more easily predict when outbreaks might occur.

2.2 Mineral analysis of common pasture species

Introduction

It has long been suspected that Mg absorption in the animal is inhibited by K. Limited studies in Australia have concentrated on Mg and Ca in soils and pastures, and on how these minerals behave in the animal system.
Grass Tetany in NSW

European work (Kemp and t'Hart 1957a; Butler 1963b; Meilson et al. 1966) proposed that K divided by the sum of Ca and Mg represented in the formula K/Mg+Ca produced a ratio that could be used to indicate pastures associated with outbreaks of grass tetany. A critical plant ratio of 2.2 was proposed. Pastures with a lower than 2.2 K/Mg + Ca ratio were considered safer. To test this proposal under Australian conditions, it would be necessary to do plant mineral analysis for areas prone to grass tetany. Fortunately, in NSW, a single data bank of plant mineral analysis existed at NSW Agriculture Rydalmere Research Institute where, for many years, a large scale mineral analysis of plants had been done across NSW.

Materials and Method

The samples were collected by district agronomists who had been trained to collect and prepare pasture samples for analysis in a standardised way. The collection and sample handling procedures are described in Appendix 3 (Cresswell 1994; pers.comm.).

Most of the samples were collected between 1982 and 1986. For this study, the K/Mg + Ca ratio was worked out for each species of oats, phalaris, rye grass and clover for these years.
Results

Figure 4 demonstrates that in line with the Kemp and t’Hart (1957a) data sub clover is the safest species for grass tetany, followed by rye grass, phalaris and oats.

Figure 4. Observed ratio by crop from samples analysed from over NSW (summary of all Rydalmere data years 1982 to 1986). No. of samples representing each species shown in brackets.
Since some minerals can behave differently in wet years, compared with dry years, a wet year (1986) and dry year (1982) analysis was done to see if the K/Mg + Ca ratio differed (Kelleher 1996, pers.comm.). No significant effect on K/Mg + Ca ratios was observed over a large range of samples. The point of this analysis shows that if the K/Mg + Ca ratio does not vary with wet and dry year effects, then it must be other factors which create grazing conditions conducive to the onset of grass tetany.

Discussion

Nearly all oat samples taken are above the 2.2 K/Mg + Ca ratio accepted in the industry. It is known that even though grazing oats can be a grass tetany hazard, many cattle graze it without developing hypomagnesaemia or dying of grass tetany.

Air and soil temperature variations were shown to influence K/Mg + Ca ratio by Miyasaka and Grunes (1990). Under a controlled experiment, winter wheats in the US developed a rising K/Mg + Ca ratio as a result of air temperature being varied between 8°C and 16°C. This in turn caused the cold soil temperatures to rise.

The rising soil temperatures affected the uptake of K, Ca and Mg through the root system. K in particular was taken up by the plant roots in large quantities causing the K/Mg + Ca ratio in the leaves of the winter wheat to increase. Grunes et al. (1984) suggested that this may pose a grass tetany hazard.
2.3 Field observation of K/Mg + Ca ratio in relation to temperature conditions

Introduction

The data bank results from Rydalmere Research Station (Figure 4) and the work done by Miyasaka and Grunes (1990) poses the question, “Does the K/Mg + Ca ratio change in different species of cereals other than winter wheats?”.

Materials and Method

Temora Research Station in south western NSW has been involved in oat variety breeding for NSW Agriculture. Since oats is a common grazing crop and a controlled supply was available, surplus oat cuts were taken weekly over the period 16 June 1995 to 15 September 1995 for K/Mg + Ca analysis to see if there was a ratio variation. At the same time, air and soil temperatures were taken. Soil temperatures were measured at a depth of 10 cm.

The oat plants were dried at 70°C in a plant dehydrator for 24 hours. Samples were then sent to Wagga Agricultural Research Institute for analysis according to the method by Johnson and Ulrich (1959). Data produced was then converted to K/Mg + Ca ratio and plotted against the minimum/maximum air temperatures and soil temperatures at the time of the harvest.

Results

The data for K/Mg + Ca ratio from oats grown at Temora (New South Wales) are shown in Figure 5. The data indicates that the K/Mg + Ca ratio varies proportionally to air and soil temperatures.
Figure 5. Summary of Temora oat samples taken over time. Summary shows the variation in K/Mg + Ca in plant leaves as air and soil temperatures vary (Temora Research Station, 1995).

Data in Figure 5 data show that the K/Mg + Ca ratio varies proportionally to air and soil temperatures.

Discussion

Air temperature varies according to changes in weather conditions; soil temperature changes according to changes in air temperatures under normal conditions (exceptions are volcanic activity and other naturally occurring geological phenomena).

From the Temora study it can be observed that the K/Mg + Ca ratio changes which are proportional to air and soil temperature variations, are similar to the work of Miyasaka and
Grunes (1990) experiments with winter wheats, except for one major difference. This difference is that whereas the K/Mg + Ca ratio for wheat was delayed seven days from when air temperatures were between 8° and 16°C, which in turn caused the soil temperature to rise, the oats K/Mg + Ca ratio rose proportionately to the rise of air and soil temperatures.

While the different response mechanism to mineral uptake in the plant, is not the subject of this thesis it should be acknowledged that different responses exist and have relevance to the potential development of grass tetany in the grazing animal. From field observations it is known that cattle can graze on oats at high K/Mg + Ca levels without exhibiting hypomagnesaemia or grass tetany (see Figure 5). The danger of cattle developing grass tetany therefore becomes apparent with the rise of the K/Mg + Ca ratio due to air and soil temperatures increasing from about a 6° - 7°C level that has been constant for around four to six days.

An explanation of this phenomenon is that with leafy grass species, such as oats, which are under the influence of cool soil temperatures, the active mineral uptake mechanism of plant roots (which is energy dependent) shuts down and is replaced by a passive (or slower) uptake mechanism of minerals including K, Mg and Ca. Potassium, in particular, will gather around the root zone but the passive uptake mechanisms in the roots will stop it being taken up by the plant when soil temperatures approximate <6° - 7°C or lower. If soil temperature rises (as influenced by air temperature) enough energy is available for the plant to switch into an active uptake mechanism through normal xylem and phloem activity (Helyar, pers. comm, 1998).
This switch results in a surge of nutrients into the plant and leaves. Under such conditions, K would be taken rapidly into the leaves causing the K/Mg + Ca ratio to rise significantly. The amount and rate of rise will vary under different conditions but it should be noted that the leafy grasses should, in theory, react in a similar way.

In May 1995, cattle deaths were reported in the Wagga Wagga area of southern New South Wales, Australia. These cattle were grazing oats, phalaris and cocksfoot dominant pastures. Table 7 shows temperature recordings during the period of reports of cattle deaths to the Rural Land Protection Board during this episode. Temperature varied for five days between at least 16°C maximum day temperatures followed by 8°C or less minimum night temperatures, after an extended cold period of less than 6-7°C, which is consistent with observations by t'Hart (1961).

<table>
<thead>
<tr>
<th>Date</th>
<th>Max °C</th>
<th>Min °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th</td>
<td>16.4</td>
<td>6.9</td>
</tr>
<tr>
<td>6th</td>
<td>18.0</td>
<td>4.8</td>
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</tr>
<tr>
<td>9th</td>
<td>18.2</td>
<td>8.9</td>
</tr>
</tbody>
</table>

These data led to the need to test the proposition that diurnal temperature fluctuations within a certain range, and over several consecutive days, were a component of the onset of grass tetany.
2.4 Experiment 1

*University of Western Sydney Hawkesbury and NSW Agriculture, April to July 1996*

2.4.1 Aim

This experiment was conducted to test the hypothesis that K levels in plants, expressed as a ratio of K/Mg + Ca, are temperature sensitive, creating grazing conditions that can lead to grass tetany in cattle. The aim was to simulate grazing and environmental conditions thought to be associated with the occurrence of grass tetany.

Ambient temperature below 8°C was thought to be critical for the selected grass species, based on similar work in wheat in the USA (Miyasaka & Grunes 1990) and field observations made by extension officers within the NSW Department of Agriculture. Although there is little evidence in the literature that "lush" uptake of K was associated with the onset of grass tetany in cattle, the association between ambient temperatures ranging between 8°C night and 16°C day over a number of consecutive days, followed by cold snap weather conditions, had been suggested to alter the K/Mg + Ca ratio (Caple & West 1993). Replication of field observations in the laboratory would assist in unravelling the association between K/Mg + Ca ratio and the occurrence of grass tetany in cattle.
2.4.2 Materials and method

Two plant species commonly grazed by cattle in areas prior to the development of grass tetany were used in this experiment. The two species, Cooba oats (Avena sativa) and Holdfast phalaris (Phalaris aquatica) were grown under glasshouse condition, but with no temperature control, prior to commencement of treatments. A 2 x 2 factorial design comprised of 32 pots (5 plants per pot) of each species (16 with lime added to the soil at a rate equivalent to 2000kg/ha, and 16 without lime was used.

Soil

A light sandy soil known to be low in nutrients was collected at the University of Western Sydney - Hawkesbury, and treated with a complete mix of fertilisers. Apart from the lime added to half of the treatment groups as previously described, all pots had nitrogen, phosphate, sulphur and potassium added to the soil at the following equivalent rates:

- Nitrogen (Nitram) - 300kg/ha
- Phosphate and Sulphur (Superphosphate) - 200kg/ha
- Potassium (Potash) - 100kg/ha

As well, lime was added to the pots of the equivalent of 1 t/ha, to determine if directly adding Ca would have an effect on the K/Mg + Ca ratio.

Plant Growth

Plants were sown in April 1996 and allowed to grow to 30cm for oats and 20cm for phalaris, measured by the largest leaf, for five weeks. This experiment was conducted at this time of
year to simulate field conditions for growth of these plant species. Water was added to all pots
daily to simulate field conditions for growth of these plant species, at the rate of 320g, which
was field capacity.

Experimental Treatments

After five weeks of growth all pots were exposed to minimum and maximum daily
temperature variations that were thought to be critical to the development of high \( \text{K/Mg + Ca} \)
ratios in these plant species, as follows:

i) Plants were taken from their outdoor glasshouse and placed in a darkened, refrigerated
room for 12 hours, to shut down the active nutrient uptake mechanism within the plant
(Mulholland, pers. comm. 1996). Experimental treatments and harvests were then
applied. For each treatment four replicate pots were harvested, each time a harvest
took place.

ii) Before any further temperature treatments were applied, one plant per pot, in each of
four pots for each of the treatment groups, was harvested for mineral analysis (harvest
1). The plants were harvested 10 cm from the root crown area to simulate grazing by
cattle, and dried at 70°C in a plant dehydrator for 24 hours, before storage for mineral
analysis.

iii) Experimental harvest 2: Following the initial harvest at 5 weeks, plants were grown at
8°C for two weeks (ie weeks 5 - 7 of growth), before one plant from each pot was
again harvested as described in point (ii) above.

iv) Experimental Harvest 3: Following harvest 2, plants were subjected to 8°C (night) for
12 hours and 16°C (day) for 12 hours, for a period of 1 week. One plant from each pot
was then harvested as for harvests 1 and 2.
v) Experimental Harvest 4: Following harvest 3, plants were moved back to a constant 8°C temperature environment for a period of 2 weeks, and then sampled again as previously described.
Plant Analysis

The dried material from each harvest and for each of the treatments was analysed for K, Mg, Ca and the K/Mg + Ca ratio according to the method described by Johnson & Ulrich (1959).

2.4.3 Analysis of data

Residual maximum likelihood (REML) was used in the Genstat 5 statistical package. REML was used because of the treatment effects being confounded by not being able to replicate the glasshouses.

Dry weights for the elements were calculated by multiplying the measured total dry matter by the percentage contents of the elements.
2.4.4 Results

There was no significant difference in the pattern of Calcium (Ca) uptake for either of the plant species tested (Figure 6). However, it appears that Ca levels in phalaris and oats were slightly elevated as a consequence of having added lime during the period when maximum and minimum temperatures simulate the temperature ranges suspected to cause nutrient uptake changes leading to a critical K/Ca + Mg ratio associated with clinical grass tetany (Caple & West 1993).

![Graph showing Ca uptake](image)

Figure 6. The proportion (%) of Calcium in Cooba Oats with and without lime (■ and □ respectively) and Holdfast Phalaris with and without lime (▲ and △ respectively) for harvests 1 to 5 (left to right). (Standard Error + or − 5%)
Figure 7. The proportion (%) of Magnesium in Cooba Oats with and without lime (■ and respectively) and Holdfast Phalaris with and without lime (▲ and △ respectively) for harvests 1 to 5 (left to right). (Standard Error + or − 5%)

There were also no significant differences in magnesium (Mg) uptake over the test period. The inconsistent response to both temperature and lime application is evident over the course of the trial, although Mg levels in the phalaris and phalaris + lime groups changed slightly more than the response in the oats and oats + lime groups.
Figure 8. The proportion (%) of Potassium in Cooba Oats with and without lime (■ and respectively) and Holdfast Phalaris with and without lime (▲ and △ respectively) for harvests 1 to 5 (left to right). (Standard Error + or − 5%)

An elevation of K at harvest 2 for oats grown in soil supplemented with lime, in combination with a decrease in Ca (Figure 6) and negligible increase in Mg (Figure 7) has significantly increased the K/Ca + Mg ratio (Figure 9) to simulate the "at risk" field condition postulated to be associated with outbreaks of grass tetany.
Figure 9. The ratio of K/Mg + Ca in Cooba Oats with and without lime (■ and □ respectively) and Holdfast Phalaris with and without lime (▲ and △ respectively) for harvests 1 to 5 (left to right). (Standard Error + or – 5%)

In one of the experimental groups a marked change occurred in the K/Mg + Ca ratio. The K/Mg + Ca ratio changed in the oats + lime group of plants at harvest 2 to a point where a grass tetany risk may be expected. The higher K levels and decrease in Mg and Ca levels were responsible for the rise in the ratio in this group at harvest 2. In other groups no significant rises and falls in the K/Mg + Ca ratio were observed.
2.4.5 Discussion

Whilst the mechanism for physiological changes in uptake of Ca, Mg and K are poorly understood, it is apparent that the field response that this experiment set out to duplicate occurred between harvest 1 and harvest 2 in the oats + lime group of plants.

While the experimental glasshouse was assumed to be even in temperature, the possibility exists that the oats + lime group was situated nearer to the end of the glasshouse which may have received more heat energy from solar radiation than the other groups. If this occurred, then it is possible that the group of plants in these pots reacted differently compared with the other treatment groups. This response was not envisaged when the trial was set up.

The above inconclusive result suggests the need to duplicate the experiment, with greater control over temperature factors. Air temperature was assumed to be even, but the only way to establish this was to measure both the soil and air temperature in and around the pots.
2.5 Experiment 2

*University of Western Sydney, Hawkesbury and NSW Agriculture, 1996 to 1997*

2.5.1 Aim

Based on outcomes from Experiment 1, and possible deficiencies in experimental design alluded to in that work, a further experiment was developed to test the hypothesis that K levels in plants expressed as a ratio of K/Mg + Ca are temperature sensitive, creating conditions that can lead to grass tetany in cattle (similar to that observed by Miyasaka and Grunes 1990).

The work described by these authors also highlighted a possible additive effect of soil temperature below 6-7°C in combination with diurnal temperature fluctuations between 8°C and 16°C as precursors to development of the critical K/Mg + Ca ratio thought to pose a grass tetany hazard in beef cattle.

2.5.2 Materials and Method

Three grazing species were selected for this experiment. Cooba oats (Avena sativa), Paterson wheat (Triticum aestivum) and Seaton park clover (Trifolium subterraneum) were selected because oats is commonly used for grazing in autumn; the new wheat has been suggested for grazing and clover is known to be safer in terms of grass tetany risk (see Figure 4). Clover was used instead of phalaris in this experiment because it is more commonly used in grazing areas affected by grass tetany.
A randomised grouping of 120 pots was divided into 3 groups of 40 pots and each group of 40 labelled A, B and C. Four pots of each species were selected for a base harvest to establish a base point for the minerals K, Mg and Ca.

The remaining 36 pots for each species were randomly selected and divided into 3 groups of 12 as replications. Therefore, each group of plant species was broken into 3 equal replication groups labelled A₁, A₂ and A₃ (similarly for groups B and C).

- Group A would be grown at a constant 8°C
- Group B would be grown at a constant 16°C
- Group C would be subject to experimental variation of 8°C - 16°C

Table 8 describes the overall design showing the simulated paddock conditions expected to cause grass tetany and the harvest of the three species of plants to be analysed for K, Mg and Ca levels.

**Table 8. Representation of trial.**

2 weeks’ acclimatisation → 5 days warming → expected risk period 7 days → physio check 7 days
ie. at cool temperatures

<table>
<thead>
<tr>
<th>Harvest 1</th>
<th>Harvest 2</th>
<th>Harvest 3</th>
<th>Harvest 4</th>
<th>Harvest 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 pots each species</td>
<td>8 pots each species</td>
<td>12 pots each species</td>
<td>12 pots each species</td>
<td>4 pots each species</td>
</tr>
</tbody>
</table>
Plant Growth

Each group of 40 (15 cm height) pots were sown with Paterson wheat (Triticum species), Cooba oats (Avena species) and Seaton Park clover (Trifolium species) on 19 June 1997, with 12 seeds, and thinned to 7 plants per pot after germination. The plants were allowed to grow in a non-temperature controlled glasshouse to reach at the largest leaf, wheat 25 – 40 cm, oats 40 – 50 cm and clover 10 – 15 cm (see plates 1, 2, 3 and 4). Water was added to field capacity (200 g including pot) for the duration of the trial.

Plate 1. Seaton Park clover, Patterson winter wheat and Cooba oats grown naturally in glasshouse.
Plate 2. Seaton Park clover before harvest.

Plate 3. Patterson winter wheat before harvest.
Plate 4. Cooba oats before harvest.

Plate 5. Cooba oats showing insulation and icing for extra temperature control.
Plate 6. Treatment pots showing soil temperature monitoring.
Soil

Soil used in pots in the trial was collected from a paddock with a known grass tetany history at Goulburn, in the southern tablelands of New South Wales.

Soil samples were collected from a diagonal transect across a 16.5 ha paddock at regular intervals. The extremely dry soil was placed in 8 x 50 litre bins and trucked to the University of Western Sydney (Hawkesbury Campus) where the bins were combined and mixed into a composite sample. This composite soil sample was then sieved (2 mm sieve) and weighed (1,600 g/pot) into lined 15 cm pots. Water holding capacity of the soil was calculated to be 21 per cent. A sample of soil was collected at the beginning and end of the trial for analysis of K, Mg and Ca using the method described by Gilman and Sumpter (1986) (see Appendix 5). See results in Table 9 - Mineral Soil Results.
Treatments and Harvests

The three groups of plants were placed in temperature controlled glasshouses on 1 August 1997 with Group A at a constant 8°C and Group B at a constant 16°C. Four pots from each group were harvested (Harvest 1) to establish K, Mg and Ca levels. (Cut plants were dried in a dehydrator at 70°C for 24 hours and samples labelled.)

Harvest 2 was carried out after two weeks of constant temperature plus five days of treatment of 8°C night and 16°C day temperatures for the Replicate 1 group for each species (see Table 8). The constant 8°C group and 16°C group were also harvested. After Harvest 2, all remaining pots were treated with DAP to ensure an adequate nitrogen and phosphorus level for healthy plant growth.

All Group C plants were placed in sand covered in ice (see Plate 5) to attempt to keep the soil temperature down. The soil thermometers (see Plate 6) were showing that adequate soil temperature control was not achieved until Harvest 3 took place on 27 August 1997. All cut plants were dried and labelled.

Harvest 3 was carried out in Rep 1 Group C plants that had been subjected to five days of 8°C night and 16°C day temperatures, expected as the precursor to potential grass tetany conditions. Rep 2 of groups A and B at constant temperatures were also harvested, dried and labelled.

Harvest 4 took place on 2 September 1997, similarly to Harvest 3, to check the expected risk period for grass tetany. Rep 3 plants in Group A and B, plus Rep 2 plants for Group C, were harvested, dried and labelled.
Grass Tetany in NSW

Harvest 5 was carried out on 10 September and consisted of Group C Rep 3 plants plus the remainder of the pots in Groups A and C. The harvested samples were dried and labelled.

Plant Analysis

The dried material from each harvest and for each of the treatments was analysed for K, Mg and Ca and the K/Mg + Ca ratio according to the method in Johnson and Ulrich (1959). [Analytical Method for Use in Plant Analysis, Calif. Agr. Exp. Ats. Bull 766, 26-28 and Reuter & Robinson (1986), Plant Analysis and an Interpretation Method, Globe Press, Brunswick, Victoria.]

2.5.3 Measurements

Base plants were harvested 1 August. After the conditioning period subsequent harvests were carried out as follows:

- Harvest 1 - 1 August 4 plants from each species to set averages or base point
- Harvest 2 - 22 August Rep 1 plant in groups A and B
- Harvest 3 - 27 August Rep 1 plant of Group C, Rep 2 of groups A and B
- Harvest 4 - 2 September Rep 3 of groups A and B, Rep 2 of Group C, 2nd C of Rep 1 Group
- Harvest 5 - 10 September Rep 3 of Group C and baseline second cuts

Plants were dried at 70°C in plant dehydrator for 24 hours. Samples were then sent to Wagga Wagga Agricultural Research Institute for analysis.
2.4.5 Analysis of data

Data from the temperature-controlled cabinet were confounded by not replicating the
glasshouse conditions. As a result, a different method of analysis was used because of the
understandable inability to replicate a number of similar glasshouses.

Therefore residual maximum likelihood (REML) was used in the Genstat 5 statistical
package. REML was used because of the treatment effects being confounded by not
replicating the glasshouses.

Dry weights for the elements were calculated by multiplying the measured total dry matter by
the percentage content of the elements. To maintain correct methodology each individual
sample was analysed for dry matter weights and K, Mg and Ca percentages at the Chemical
Analysis Laboratory, Agricultural Research Institute, Wagga Wagga.

The raw data was examined as individual elements of dry matter production and converted to
the K/Mg + Ca ratio. Biometrical analysis was done using Genstat 5 and data was transformed
to stabilise variance (Genstat 5) (Coombes 1993-1998, pers. comm.) (see Appendix 1).

2.4.5 Results

The results from experiment 2 for K/Mg + Ca ratio, controlled air temperatures and soil
temperatures for the duration of the trial, are duplicated in Figure 10. After a conditioning
period of 5 days with air temperatures controlled between 8°C and 16°C the K/Mg + Ca ratio
reached expected high levels between 5 and 6 for wheat and oats, but below 2 for clover.
Following rapid cooling of soil and air temperatures to < 6°C and 7°C respectively to simulate
field conditions, the K/Mg + Ca ratio fell in oats and clover, but continued to rise in wheat for a period of seven days.

![Graph showing temperature variations and K/Me ratio changes over time.](image)

**Figure 10.** Changes to the K/Mg + Ca ratio in response to changes in air and soil temperatures, from oats, wheat and clover grown under experimental conditions.

In response to temperature variation the concentration of Mg and Ca in each of the plant species only changed to a minor degree (Figures 11 and 12). However, the concentration of K in each of the plant species changed markedly in response to temperature change (Figure 13). The influence of the marked change in K concentrations in response to temperature changes was shown to be the major determinant of change to the K/Mg + Ca ratio (Figure 10).
Figure 11. The concentration of Mg as a percentage (%) of dry matter (DM) in oats, wheat and clover from harvests 3 – 5.

Figure 12. The concentration of Ca as a percentage (%) of dry matter (DM) in oats, wheat and clover for harvests 3 – 5.
Figure 13. The concentration of K as a percentage (%) of dry matter (DM) in oats, wheat and clover for harvests 3 – 5.

Figure 14. 8°C to 16°C treatment dry matter (g) comparison.
The response of K in clover is more marked than the oats or wheat (see Figure 13), but when placed in the K/Mg + Ca ratio, the relatively higher Mg and Ca levels keep the K/Mg + Ca ratio at a low level below 2 (see Figure 10). The percentage of dry matter from oats and wheat ranged between 3% and 4% of herbage mass throughout the trial and clover increased from 2% to 2.3% of herbage mass (see Plates 2, 3 and 4) (see also Figure 14).

2.6 Individual Plant Species Results

2.6.1 Discussion

This experiment showed that the K/Mg + Ca ratio observed under field conditions can be reproduced experimentally. Plant uptake of K in relation to the concentration and rate of uptake of Mg and Ca is the critical point to note, inducing the potentially dangerous K/Mg + Ca ratio described in the literature predominantly by the work of Grunes’ and others in the USA and observation in the field (see Figure 5, Temora Research Station).

Adequate temperature control of both the soil and ambient temperature was critical to outcomes in this experiment. The behaviour of the 8°C plants and 16°C plants is not the subject of this experiment, although it is interesting to note that the 8°C group of oats had higher K/Mg + Ca than the 16°C group. The results for plant mineral uptake, as in Experiment 1, indicated that at 8°C temperature the active mineral uptake mechanism was still working.

This was explained when the soil and air temperatures were examined in what was intended to be constant 8°C night and day temperature. Day temperatures did rise as did soil temperature,
thereby leading to the conclusion that enough energy was available to the oats and wheat to keep K, Mg and Ca being actively taken up.

This followed the acclimatisation period where the icing and insulation of the soil would have kept the soil temperature at 6°C-7°C, thereby shutting down the active uptake mechanisms and only having passive uptake available to the plants (Milham 1997, pers. comm.). Adequate soil temperature control was achieved after Harvest 3 by icing and insulation procedures (see Figure 6).

The critical period of experimental observation occurred between Harvest 3 and Harvest 5 for the 8 to 16°C temperature variation group, referred to in the following sections.

Wheat (Paterson winter wheat)

A similar result was observed to that of Miyasaka and Grunes (1990), whereby after being subjected to variable temperatures of 8°C night and 16°C day for four days, wheat K/Mg + Ca ratio peaked 7 days after these climate conditions. This may pose a grass tetany risk seven days after the sustained 8°C to 16°C temperature variation occurred.

Oats (Cooba)

From field observations at Temora Research station (1995) (see Figure 5), there is a proportional rise and fall of K/Mg + Ca to air and soil temperature. The experimental data shows a peak in these levels at Harvest 3 in Figure 10 which is proportional to the soil and air temperature. As both the soil and air temperature fall, so does the K/Mg + Ca level. Field data (see Figure 5), leads to the conclusion that the experimental fall of K/Mg + Ca proportional to soil and air temperature would be approximately equal to the rise of the K/Mg + Ca in response to rising soil and air temperature.
In terms of grass tetany risk, after a sustained four days of 8 to 16°C conditions, the K/Mg + Ca ratio rises proportionately to soil temperature rise and may pose a grass tetany risk.

Clover (Seaton Park)

The levels of Ca and Mg in clover were much higher than in either wheat or oats. The higher Ca and Mg in clover results in clover being safer for cattle to graze, because of the relatively higher Mg and Ca levels compared to K and the consequent effect on K/Mg+Ca ratio. The response of K is more marked in clover but balanced by the relatively higher Ca and Mg concentrations in terms of grass tetany risk for livestock.

Conclusions

1. All Ca, Mg and K absorption in plants is temperature sensitive due to the ability of the plant to absorb Ca, Mg and K from the soil but it is the maximum point that the levels reach compared to the plant’s normal levels of Ca, Mg and K that is critical to grass tetany.

2. Under variable temperature conditions (8 to 16°C), Mg and Ca absorption slows down more noticeably in wheat than in oats or clover.

3. Potassium levels appear to be critical. In both oats and clover K levels tend to peak, proportionate to the temperature level of the soil. Wheat had slightly higher levels of K than oats, but these levels were reached 7 days after the variable temperature conditions, consistent with the US results of Miyasaka and Grunes (1990).
4. Although Mg levels vary slightly, these do not change as much as Ca or K levels. This leads to the conclusion that adequate levels of Ca are more important than Mg in allowing legumes to establish on high K/Mg + Ca soils (See section B3, “NSW study of available soil test data”). Mg levels need only to be adequate for plant growth.

5. The rate of rise of the K/Mg + Ca ratio may be more critical to the onset of grass tetany once the 2.2 ratio is exceeded.

From field observation, cows can graze oats at higher K/Mg + Ca ratios in relative safety. However, once the variable 8°C to 16°C temperatures are experienced, it is apparent that the rise in K/Mg + Ca may be the danger factor, when soils have been subjected to temperatures of less than 8°C for approximately four days.
Chapter 3 – Soil and Weather Studies

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Chapter 3 - Soil and Weather Studies

As they relate to development of K/Mg + Ca ratios in pasture species.

3 Introduction to Soil and Weather Studies

Lewis and Sparrow (1991) indicated that there was a relationship between outbreaks of grass tetany in beef cattle in South Australia and particular soil types. The soil relationship alluded to in that study did not fully explain how this relationship occurred. It has also been postulated that weather is implicated in outbreaks of grass tetany (Lewis and Sparrow, 1991) and experimental outcomes from trials described in Chapter 2 support these views. It was therefore considered necessary to superimpose weather patterns in various cattle producing regions in New South Wales on soil maps of the same areas.

Data from Rydalmere Research Station (Figure 4 - Observed ratio by crop from samples analysed from over NSW) and field studies at Temora Research Station (Figure 5 – Summary of Temora oat samples taken over time) suggest that cereal and grass species eaten by cattle have potentially higher K/Mg + Ca ratios than the critical 2.2 level stated in the literature (Caple and West, 1993).

Four separate studies were deemed necessary, as follows:

3.1 Survey of Rural Lands Protection Board (Figure 15 - RLPB) districts in NSW to ascertain actual cattle losses. This data was then to be compared to the Rydalmere Research Station plant data collected in 1994, to determine if there were any relationships between cattle losses and plant K/Mg +Ca ratios.
3.2 NSW incidence study of areas experiencing 8°C night temperatures to 16°C day temperatures by a historical search for the last 25 years conducted by NSW Bureau of Meteorology. The above data was then mapped by GIS techniques of NSW Agriculture, to determine the incidence of suspected weather conditions associated with grass tetany.

3.3 NSW study of available soil data, converting chemical analysis to prescribed K/Mg + Ca ratios, broken down to potential hazard zones, then mapped by GIS techniques by NSW Agriculture, to determine areas in NSW of soil K/Mg + Ca ratios associated with grass tetany in cattle.

3.4 Combining the data from (1), (2) and (3) above to determine if a cross match of the previous results correlated with grass tetany prone areas of NSW.

3.1 Survey of Rural Land Protection Boards - NSW

3.1.1 Introduction

In March/April 1994 a state-wide survey was designed, to determine cattle lost to grass tetany.

3.1.2 Materials and Method

Each district veterinarian was requested to randomly select fifteen cattle producers in each district (sometimes one district veterinarian covers more than one district) and ask each producer the following three questions:
Grass Tetany in NSW

- What was the number of cattle lost to grass tetany in the last 5 years?
- What is the total number of cows in the herd?
- What is the size of your farm?

The survey data were collected by all district veterinarians in May 1994 and analysed on a farm by RLPB district basis. These were sent to all district veterinarians in May 1994. The survey return rate by January 1995 was 85%.

For each RLPB district the number of cattle lost and herd size was averaged over the farm. Total losses and total herd numbers were also calculated for each RLPB district and an average rate of loss per thousand cattle calculated. An alternative rate was calculated by obtaining a rate of loss for each farm surveyed and averaging this loss over each RLPB district.

A ratio of K/Mg + Ca had to be calculated for each RLPB district. Data from Rydalmere Research Station recorded percentage content of K, Mg, Ca and P in farm crop types, i.e. oats, phalaris, ryegrass and sub clover. It was clear from the summary plots of data that the K/Mg + Ca ratio in oats was much higher than that observed in sub clover. To try to eliminate bias in the calculated average value for each RLPB district a linear model was fitted. This model was based on the following:

- ratio = RLPB effect + crop effect.
- RLPB effect is the difference between RLPB mean and the overall mean of the K/Mg + Ca ratios.
- crop effect is the difference between the crop mean and the overall mean. To obtain the value of each crop at each RLPB district, add the overall mean to the RLPB effect of the K/Mg + Ca ratios.
The Rydalmere Research Station data were selected for four years (1982-1986), when there was a maximum number of 236 samples. The subtotals were as follows:

- oats 133 samples
- phalaris 24 samples
- ryegrass 47 samples
- sub clover 32 samples.

Note. Wet year and dry year analysis showed no significant variation in the K, Mg and Ca minerals.

From this model a ratio value was predicted for each RLPB combination, assuming there was no RLPB crop interaction. In other words, there was an overall average level of the ratio for each crop and this level was adjusted by a constant amount for each RLPB district.

**Example:** Average K/Mg + Ca ratio from a number of plant species collected at Albury NSW, adjusted by a selected constant, which in this case was the average ratio for plant species at Bathurst, NSW.

- Oats 8.2322 - 1.1273 = 7.1049
- Phalaris 5.9441 - 1.1273 = 4.8168
- Ryegrass 5.1134 - 1.1273 = 3.9861
- Subclover 2.8765 - 1.7492 = 1.1273
- Average 5.5416 - 1.1273 = 4.4143

These average data for each RLPB were then plotted as a K/Mg + Ca ratio against cattle deaths from grass tetany in NSW (Figure 15).
3.1.3 Results

Figure 15. Losses of cattle in NSW related to plant K/Mg + Ca ratio for the surveyed Rural Land Protection Boards in NSW (+ or −5%).

From the data available this is the only way of estimating comparable ratios at each RLPB.
3.1.4 Discussion

If the threshold $K/\text{Mg} + \text{Ca}$ ratio is considered to be 2.2 (Caple and West 1993) then total losses of cattle in NSW related to predicted $K/\text{Mg} + \text{Ca}$ shows that in most centres cattle would be susceptible to grass tetany (Figure 15). However, the field data also shows that cattle can be grazing on pastures with relatively high $K/\text{Mg} + \text{Ca}$ ratios and not suffering grass tetany. Centres such as Goulburn and Gundagai have a higher incidence of grass tetany than Young and Forbes yet the latter centres have a higher risk in terms of the plants that have been sampled. This observation therefore suggests that other factors may also be operating to trigger the outbreaks of grass tetany, eg weather and soil factors, combined with plant species, breed susceptibility and management practices.

3.2 NSW incidence of $8^\circ\text{C}$ night and $16^\circ\text{C}$ day temperatures extending to 6-day intervals

3.2.1 Introduction

Climate and especially temperature conditions have been well documented in the literature where grass tetany has been associated with cold, wet and windy conditions, particularly with the incidence of $8^\circ\text{C}$ night and $16^\circ\text{C}$ day temperatures.

The above temperature range is considered to be relatively mild. Combined with observations at Temora Research Station (1995), (see Figure 5) it was shown that a sustained daily temperature range of about $8^\circ\text{C}$ in the night and $16^\circ\text{C}$ in the day for five days produces enough energy for the colder soil (in late autumn winter) temperature to increase, giving a rise in the
K/Mg + Ca ratio of plants. This observation has also been confirmed in the work by Grunes et al. (1992) for winter wheats in the US.

3.2.2 Methods

A study of the incidence of sustained temperatures conditions approximating 8°C nights and 16°C day over a number of consecutive days was made in 1995 (see Figure 5 – Summary of Temora oat samples taken over time).

How long sustained 8°C night and 16°C conditions took to cause the temperature of a cold soil (6-7°C) to rise ranged from 4 to 6 days depending on the view and experience of soil conservation officers of the NSW Soil conservation Service.

The NSW Bureau of Meteorology was commissioned to search all weather stations in NSW, Victoria and South Australia for 8°C night, 16°C day temperatures, sustained for six days at any time during the last 25 years. Raw data generated was sorted into incidence areas. To do this the data was loaded into Excel 5.0 with one work sheet for each file received.

Subtotals were calculated using data: subtotal: count function and new files saved showing only location and frequency of occurrence. Latitude and longitude for each location were added one at a time from the CSIRO weather analysis program, Metaccess. Data was then amalgamated into one file and frequency classes allocated into approximately equal numbers for each class (See Table 9).
Table 9. Frequency class allocations where each class represents the number of times that 8°C minimum to 16°C maximum temperatures sustained for six days occurs in a given year or years period. The frequency of the temperature events are shown for each time period for each class nomination.

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<thead>
<tr>
<th>Class</th>
<th>Temperature event Occurrence</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 &gt; 10 years</td>
<td>1,2</td>
</tr>
<tr>
<td>2</td>
<td>1 &gt; 5 years</td>
<td>3,4,5</td>
</tr>
<tr>
<td>3</td>
<td>1 &gt; 2 years</td>
<td>6 to 12</td>
</tr>
<tr>
<td>4</td>
<td>1 to 2 years</td>
<td>13 to 30</td>
</tr>
<tr>
<td>5</td>
<td>Greater than 1 per year</td>
<td>&gt;30 (max 2337)</td>
</tr>
</tbody>
</table>

Each of the classes represents an area of land that experiences 8°C minimum to 16°C maximum diurnal temperatures sustained for six consecutive days at various frequencies in discreet time periods.

- Class 1 experiences 8°C minimum to 16°C maximum diurnal temperature range sustained for six consecutive days, up to twice in a ten year period.
- Class 2 experiences 8°C minimum to 16°C maximum diurnal temperature range sustained for six consecutive days, up to five times in five years.
- Class 3 experiences 8°C minimum to 16°C maximum diurnal temperature range sustained for six consecutive days up to twelve times in two years.
- Class 4 experiences 8°C minimum to 16°C maximum diurnal temperature range sustained for six consecutive days from twelve to thirty times in two years.
- Class 5 experiences 8°C minimum to 16°C maximum diurnal temperature range sustained for six consecutive days occurring more than thirty times in one year.

This file was then saved as a CSV file and converted to a Arc/Info coverage. Arcview is NSW Agriculture standard software. Data was then plotted using Arcview.
3.2.3 Results

The following Figures 16 to 23 are the result of the process described.

Figure 16. Areas of south east Australia where Class 1 temperature events occur. Class 1 is where 8°C min - 16°C max diurnal temperature sustained for 6 consecutive days occurs up to twice in 10 years.

Figure 17. Areas of south east Australia where Class 2 temperature events occur. Class 2 is where 8°C min - 16°C max diurnal temperature sustained for 6 consecutive days occurs up to 5 times in 5 years.
Figure 18. Areas of south east Australia where Class 3 temperature events occur. Class 3 is where 8°C min - 16°C max diurnal temperature sustained for 6 consecutive days occurs up to 12 times in 2 years.

Figure 19. Areas of south east Australia where Class 4 temperature events occur. Class 4 is where 8°C min - 16°C max diurnal temperatures sustained for 6 consecutive days occurs from 12 up to 30 times in 2 years.
Figure 20. Areas of south east Australia where Class 5 temperature events occur. Class 5 is where 8°C min - 16°C maximum diurnal temperatures sustained for 6 consecutive days occurs greater than 30 times in a 1 year period.

Figure 21. Amalgamated Temperature Frequency Class Areas. Class 1, 2 and 3 have been amalgamated into a single area. Class 4 and 5 remain as discreet areas. A 50 km radius was created around each area (clipped to the coastline) so that the temperature events of 8°C min - 16°C max diurnal temperatures sustained for 6 consecutive days, can be visually interpreted on the geographical area of south east Australia.
Class 5 (see Table 9) tended to be coastal areas extending in some areas into lower coastal valley areas. Cattle grazing areas in the high frequency zone tended to be more in Victoria and South Australia although some areas of the NSW South Coast and into the Hunter Valley of NSW were included.

Class 4 areas include Class 5 but do extend into cattle grazing areas where known high grass tetany events occur. Class 1, 2 and 3 areas include the above but also approximate where grass tetany is considered less of a risk. The less risky areas will be considered in section 3.4.

### 3.2.4 Discussion

The necessary temperatures do occur throughout south east Australia often enough to be a vital ingredient in the occurrence of grass tetany. It should be noted that the mapped regions indicate the occurrence of 6 consecutive days with 8°C night - 16°C day temperature, compared with field observations which suggest that 4 to 5 days with this temperature range may be enough to trigger grass tetany.

However, it appears that the temperature event alone is not always enough to trigger grass tetany in cattle.

There is also evidence that plants growing in higher K status soils are more likely to be affected by temperature changes, and the combination of plant type and temperature range perhaps magnifies the risk of grass tetany. It was therefore considered necessary to look at the distribution of soil types in grass tetany prone areas so that K availability for plants could be evaluated.
3.3 NSW study of available soil test data

In several Australian studies (Lewis & Sparrow 1991; Lewis & McFarlane 1993), soil type in the south east of South Australia has been linked to the occurrence of grass tetany in sheep and cattle.

The findings of Lewis and Sparrow (1991) confirmed that a relationship existed between soil K/Mg + Ca and plant K/Mg + Ca ratios.

Other studies, implicating soil type (Kubota et al. 1980), temperature (Grunes et al. 1968) and plant studies (Kemp & t’Hart 1957a; Kemp 1960; Grunes et al. 1970) have all linked soil type to the occurrence of grass tetany. It would therefore seem appropriate to develop a farming system model that took account of these key factors of soil type, plant species type, climate, time of year and variations in management, to assist with predictability of outbreaks of grass tetany.
3.3.1 Discussion in relation to UWS Hawkesbury and NSW Agriculture trial (1997)

From experimental data derived from laboratory experiments (Section 2.4), it was shown that potassium uptake by plants often exceeds mineralisation, suggesting that random soil tests would have to be done often to get an accurate soil level for K. These data were confirmed by testing at an independent laboratory. Both tests gave a K/Mg + Ca ratio of approximately 0.14, which according to previous studies indicated that the soil was in a dangerous category for grass tetany (Lewis and Sparrow, 1991).

Table 10. Mineral soil results - sub sample of test soil.

<table>
<thead>
<tr>
<th>Cations (soluble and exchangeable)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CALCIUM (Ca)</td>
<td>49.0 %</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>36.7 %</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>2.1 %</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>12.4 %</td>
</tr>
</tbody>
</table>

**Giving soil ratio**

K/Mg + Ca

0.14 %

TEXTURE = SAND CLAY LOAM

PH = 6.4

STANDARD ERROR ± 5%

Table 11. Changes in soil minerals (c.mol/kg) (+ or - 5%). Concentrations of calcium, magnesium and potassium, and the K/Mg + Ca ratio before and after plant growth, in soil collected from a paddock where clinical cases of grass tetany have been observed.

<table>
<thead>
<tr>
<th></th>
<th>Paddock soil</th>
<th>After plant growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>10.5</td>
<td>10.7</td>
</tr>
<tr>
<td>Magnesium</td>
<td>4.63</td>
<td>4.95</td>
</tr>
<tr>
<td>Potassium</td>
<td>1.60</td>
<td>1.07</td>
</tr>
<tr>
<td>K/Mg + Ca</td>
<td>0.11</td>
<td>0.07</td>
</tr>
</tbody>
</table>
From Table 11 it can be seen that mineralisation in the soil exceeded plant uptake with both Ca and Mg, the converse situation to that of K. However, differences between rates of mineralisation of K, Mg and Ca, and the rate of uptake of these elements by plants, is probably an important key to K/Mg + Ca ratios in soil.

Soil influence on grass tetany in NSW has been suspected (Conyers, pers. comm. 1997), however little data on a large scale in relation to K/Mg + Ca ratio was available.

Maps of soil K/Mg + Ca ratios would give an image of the extent of soils considered dangerous in other studies such as that by Lewis and Sparrow (1991).

### 3.3.2 Soil mapping

**Method**

From 1982 to 1990 over 25,000 soil samples were tested for exchangeable cations over NSW. The variability of K levels at different times of the year (see Table 11) would be solved by averaging a large database such as the 25,000 tests available. This database was considered large enough to handle random distribution over the year (Conyers, pers. Comm. 1997).

2,500 samples contained information complete with K, Mg and Ca tests. The database was averaged and broken into K, Mg and Ca classes by the GIS Section, NSW Agriculture at Orange, then converted to K/Mg + Ca ratios. The method is similar to that used to create the weather maps detailed in Section 3.2.2.

Using known data from Conyers, pers. comm. (1997) and referring to the Lewis and Sparrow (1991) work a decision was made to break the soil K/Mg + Ca ratios into hazard categories (See Table 12).
Table 12. Proposed K/Mg + Ca soil classes to classify soils as a component of overall grass tetany risk.

<table>
<thead>
<tr>
<th>K/Mg + Ca ratio</th>
<th>Soil class</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; .06</td>
<td>Less hazardous</td>
</tr>
<tr>
<td>.06 - .07</td>
<td>Marginal</td>
</tr>
<tr>
<td>.07 - .08</td>
<td>Critical</td>
</tr>
<tr>
<td>.08 - .09</td>
<td>Hazardous</td>
</tr>
<tr>
<td>&gt; .09</td>
<td>Dangerous</td>
</tr>
</tbody>
</table>

A similar procedure to that used to plot the temperature data (see Section 3.2) was used, resulting in the Figures 22 to 26.

Results – Figures 22 to 26

Figures 22 to 26 are the GIS maps resulting from breaking up the soil data into the categories nominated in Table 12.

Figure 22. Areas of NSW where soil sample analysis showed the K/Mg + Ca ratio to be < .06 and less hazardous as a factor in assessing grass tetany risk.
Figure 23. Areas of NSW where soil sample analysis showed the K/Mg + Ca ratio to be .06 - .07 and marginal as a factor in assessing grass tetany risk.

Figure 24. Areas of NSW where soil sample analysis showed the K/Mg + Ca ratio to be .07 - .08 and critical as a factor in assessing grass tetany risk.
Grass Tetany in NSW

Figure 25. Areas of NSW where soil sample analysis showed the K/Mg + Ca ratio to be .08 - .09 and hazardous as a factor in assessing grass tetany risk.

Figure 26. Areas of NSW where soil sample analysis showed the K/Mg + Ca ratio to be > .09 and dangerous as a factor in assessing grass tetany risk.
3.3.3 Discussion

The results from the soil mapping in terms of the soil contribution to grass tetany risk is very clear where large tracts of discreet soil types are present such as the dryland western areas of the state. However where dense population areas exist with larger numbers of smaller holdings, the soil results indicate that potentially hazardous soils are in a very close proximity to soils with lower K/Mg + Ca ratios.

Contributing to this situation will be the natural K/Mg + Ca ratio of the soil type, the type of crop or pasture grown, intensity of grazing by animals and the application of fertilisers such as lime and potash. The timing and interpretation of any soil test should keep the above factors in mind, as an interpretation of a single soil test without taking in the above factors could lead to misleading conclusions.

Although helpful, this data does not by itself explain the potential incidence of grass tetany surveyed in Section B1, though the RLPB areas do fall into the hazardous soil zones (see Figure 27).

Concentrations of dangerous soil types tend to occur in known high risk grass tetany areas but also in other areas of NSW where grass tetany does not occur (see Table 12 and Figures 22-26). Therefore weather and soil types combined were examined.
3.4 Combining soil and weather data

*With Rural Land Protection Board (RLPB) surveys for cow losses attributed to grass tetany.*

The overall effects on the K/Mg + Ca level available to grazing cattle are partly explained by individual, soil and weather studies. It is more likely that a combination of effects bring on grass tetany in cattle. Using the data created in the maps for sections 3.2 and 3.3 for suspect weather conditions and soil types respectively, it was necessary to combine that data with the results of the RLPB losses of cows attributed to grass tetany.

3.4.1 Method

Utilising the GIS methodology in sections 3.2 and 3.3, an overall perspective of the effects of suspect weather conditions and the effect of soil types combined with surveyed RLPBs for grass tetany cow losses was created by overlaying the maps created in sections 3.2, 3.3 and superimposing the surveyed RLPBs in section 3.1.

3.4.2 Results

![Map depicting grass tetany potential showing the overlap between high grass tetany cattle loss Rural Land Protection Board areas, dangerous soils of K/Mg + ca ratio > .07 and weather conditions where suspect 8°C minimum to 16°C maximum temperatures were sustained for 6 days, occurs at least once between 2 – 10 years and up to 12 times in 2 years (see Table 9).]
Figure 28. Grass tetany potential showing the overlap between high grass tetany cattle loss Rural Land Protection Board areas, dangerous soils of K/Mg + Ca ratio > .07 and weather conditions where suspect 8°C min - 16°C max sustained for 6 days, occurs at least once between 2 – 10 years and up to 12 times in 2 years.

Figure 29. Grass tetany potential showing the overlap between high grass tetany cattle loss Rural Land Protection Board areas, critical soils of K/Mg + Ca ratio > .07 and weather conditions where suspect 8°C min - 16°C max sustained for 6 days, occurs from 12 to 30 times in 2 years to more than 30 times in 1 year.
Figure 30. Grass tetany potential showing the overlap between high grass tetany cattle loss
Rural Land Protection Board areas, critical soils of K/Mg + Ca ratio > .07 and weather
conditions where suspect 8°C min – 16°C max sustained for 6 days, occurs at least once
between 2 – 10 years and up to 12 times in 2 years.

A much clearer picture developed in NSW when the known grass tetany weather conditions
and soil K/Mg + Ca hazard areas were superimposed on areas of known high grass tetany cow
loss areas.

Temperature Class 1, 2 and 3 areas (i.e. 8°C minimum - 16°C maximum temperature events for
6 days occurring at least once between 2 to 10 years and up to 12 times in 2 years) overlap the
critical soils over much of NSW (see Figure 30).

All high grass tetany loss RLPB boards fit this particular model with the exception of Hay
RLPB board.
3.4.3 Discussion

In Chapter 2 mention was made to the length of 8°C minimum to 16°C max temperatures to increase soil temperatures to a point where the active mechanism of plants could take up high levels of K and pose a grass tetany risk.

Postulations from the NSW Soil Conservation service varied between 4 to 6 days of sustained 8°C minimum - 16°C maximum temperatures were needed to raise cold soil temperatures from 6-7°C.

Figures 27 to 30 are 6-day sustained events, therefore a 4- or 5-day sustained event will occur more often. This thesis suggests that Hay RLPB will fit the model if the lower weather frequency is accepted.

The other feature of the maps is that hazardous soils and necessary weather conditions also occur in the northern and coastal areas of NSW, which appear to have lower incidence of grass tetany based on current reporting mechanisms. Therefore another factor that affects the incidence of grass tetany could be calving time in NSW beef herds combined with soil temperature.

High Mg loss via the milk is experienced by dairy cattle mainly along the coastal strip in NSW. Grass tetany does occur occasionally in this area but is more related to animal physiology than to external conditions.

Soil temperatures would also be expected to be higher in this zone. This means that there is not a big effect of the change from passive nutrient uptake (K uptake low levels) to active nutrient
uptake (K uptake lush levels) in pasture, as soil temperatures last for long periods below 6-7°C, then have sudden bursts of warming temperatures (Helyar 1997, pers. comm.). Legumes containing higher levels of Ca and Mg would also be more available in the coastal areas.

Furthermore, the upper Hunter Valley region and northern areas of NSW have a different calving time to the southern areas of NSW.

Earliest calvings in beef herds in the upper Hunter occur in the spring time on native pastures containing trefoil species, which would be expected to contain higher levels of Ca and Mg than other legumes. Further north, calving mainly occurs later in spring on improved pasture containing more legumes. Again, more Ca and Mg would be available from the legume plants, reducing grass tetany risk. The only grass tetany reported in the north has been induced grass tetany where inappropriate applications of K fertilisers have been used.

3.4.4 The Causes of Grass Tetany

This thesis suggests that a naturally occurring set of circumstances, ie a combination of soil, weather, pasture and cattle factors must act in a prescribed manner to bring about the condition called grass tetany.

For grass tetany to be expressed the factors mentioned appear to operate in the following manner:

- Soil: $\text{K/Mg + Ca Ratio} > 0.07 - 0.08.$
Grass Tetany in NSW

- **Weather:** Cold soil temperatures <6°C - 7°C followed by air temperatures of 8°C night and 16°C day for 4 to 6 days to warm the soil.

- **Plant:** Grass or cereal pastures with little or no legumes. Warming soil causes roots to uptake lush levels of K (K).

- **Cattle:** Usually milking cows under additional stress such as cold weather, mustering or first oestrous after calving. Angus and Angus-derived cattle are the most 'at risk' breed types.

The above conditions occur mainly in autumn and winter, but can also occur in spring. Given that these conditions can occur widely across the year, development of a matrix of predictability to assist farmers to recognise danger periods from the occurrence of grass tetany will assist in minimising economic and genetic loss from this condition, as well as enhancing animal welfare for free ranging beef cattle.

Cattle can graze on pastures with quite high K/Mg + Ca ratios (see Figures 3 and 4) without developing grass tetany, and these levels can be well above the 2.2 K/Mg + Ca ratio mentioned in the literature. However, when air temperatures of 8°C night and 16°C day for 4 to 6 days on soils with temperatures from 6°C to 7°C are sustained for at least a week, grassy plant (grasses and cereals) roots change from passive absorption of K to an active absorption of K causing high levels of K to then become available in plant leaves (described previously as lush uptake of K). There is evidence from field observations in the present study that this set of conditions can lead to outbreaks of grass tetany in beef cattle in some areas of NSW.

It should be noted that the same K uptake occurs in legumes, but the K/Mg + Ca ratio does not rise as dramatically because the legumes have naturally higher levels of Ca and Mg.
Grass Tetany in NSW

From the available literature, and based on field observations throughout this study, cattle under stress from milking, mustering or first oestrous during cold weather after warm weather need a critical amount of Mg to sustain normal physiological living functions. Under the right predisposing conditions (described above) cattle will ingest the plants containing high levels of K, which will effectively cut Mg absorption in the rumen, leading to an acute Mg deficiency which in turn leads to death from grass tetany.

However, it is acknowledged that other circumstances can induce grass tetany, such as the inappropriate application of K fertilisers, which supplies high levels of K to the leaves of plants, causing a similar effect on cattle as described above.

Only one incident (Dewes 1995) has referred to hypomagnaseamia being induced by high Na levels, and this extremely rare event occurred after cyclonic winds deposited salt long distances inland in the Waikato and Taranaki districts of New Zealand. High Na levels are therefore regarded as an unlikely contribution to grass tetany outbreaks in south east Australia. The short term implication for beef producers is that they need to learn to recognise the interacting environmental conditions that are associated with outbreaks of grass tetany, and take appropriate management measures to minimise the possibility of physiological K imbalance.

Longer term measures coincide with best practice already adopted by leading producers. These measures include:

- establishing balanced pastures containing legumes
- using lime to create legume friendly soils
- conserving fodder containing legume based silages and hay
- adopting grazing management practices that encourage legumes
- identifying “at risk” weather conditions
- strategic feeding of “at risk” cattle at this time
- using legume based storages.

For example, bulls, steers and dry cattle will be less at risk than milking cows. Therefore, if fodder is in short supply the legume-based fodder can be fed preferentially to the milking cows.
## Chapter 4 – Factors for Producer Management of Grass Tetany

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Chapter 4 – Factors for Producer Management of Grass Tetany

4.1 Conclusion from this study

The economic impact of grass tetany at a time of reduced returns to producers cannot be underestimated. Losses (cattle deaths) of between $A5 to $A10 million worth of cows occur annually in NSW. Losses resulting from grass tetany are so common in southern areas of Australia that producers accept them as a normal risk, and often do not report these losses. From the data analysed in this study it is apparent losses could be reduced by a grazier alert constructed from the identified factors causing grass tetany.

One of the key findings from this study is that the attributed factors of soils within a K/Mg + Ca ratio of > .07, and weather conditions where 8°C - 16°C sustained for four to six days on soils with temperatures < 6-7°C, do occur with enough frequency to be assumed to be a precursor to potential grass tetany. Furthermore, soils with naturally low Mg and Ca can be treated with fertiliser to assist in combating high K levels. Weather conditions occur naturally and are not able to be controlled in free range situations. The weather can be monitored by producers. Soil temperature changes as influenced by atmospheric temperatures need to be incorporated into an overall management strategy by producers in grass tetany prone areas.

However, the key factor to controlling grass tetany is management. Cattle breed type and the type of feeding of cows and calves, type of crop or pasture grown, intensity of grazing, fertilisers used and animal activity such as mustering, changing paddocks, will all have an influence as to whether the cattle will develop grass tetany.
Dissemination of this information by scientific publications as well as farmer, professional, advisory, industry and commercial organisations will help grass tetany to be managed more effectively, thereby increasing profitability of beef cattle farming in areas affected by the condition.

A further addition to extension of this information to a more practical level would occur if producers could be educated to accurately predict at risk conditions and whole regions could then be alerted by a grass tetany alert system on regional radio stations.

4.2 High risk conditions for grass tetany

4.2.1 Soils

Identify: High Risk Soils > 0.07 - 0.08 K/Mg + Ca ratio.

Recommend: Soil pH optimum for legume growth. Use lime-based fertilisers.

4.2.2 Weather

Identify: 8°C minimum - 16°C maximum diurnal temperatures for 4 to 6 consecutive days, where soil temperatures are likely to be < 6°C-7, usually in autumn and winter

Recommend: Graze grass-legume based pastures. Do not move or muster livestock in these weather conditions.
4.2.3 Pastures

Identify: Grassy species with nil legume (especially phalaris and cocksfoot). Grass pasture species with nil legume. Cereals with no legume, (especially oats and winter wheat).

Recommend: A balance pasture mix, with ideally 55% initial legume, until the nitrogen cycle establishes, to drive the grass phase. Over time, 20% - 40% legume is acceptable. Do not graze milking cows on oat or winter wheat crops in the high-risk weather conditions. Be aware of livestock needs and grazing management practices, consistent with production objectives.

4.2.4 Cattle types

Identify: Susceptibility of breeds:

Most susceptible
- Angus
- Murray Grey
- Angus Crosses
- Shorthorn
- Hereford
- Jersey
- Friesian (Holstein)

Most resistant
- Brahman

Recommend: Depending on the breed of livestock, adjust feeding and husbandry.
4.2.5 Management

Identify: All factors – soils, weather, pastures, cattle types and specific needs, air and soil temperatures.


In high risk conditions minimise mustering and any change of paddock feeds. Preferentially feed cows and calves legume based feeds.

4.3 Community Action

The data presented in this thesis provides the basis for decreasing the incidence of grass tetany in prone areas of Australia. Based on these findings, large scale producer education could now be undertaken to assist in recognising "at risk" conditions. A flow chart depicting the key areas of analysis required to be undertaken by beef cattle producers is shown in Figure 31.
GRASS TETANY

Many Decisions For More Live Cattle

WEATHER
Forecast: Temperature
Recent Weather: Rainfall / Temperature

SOIL ANALYSIS
Test Results
Fertilizer History

MANAGEMENT
Assess and Assimilate
Weather
Livestock and Pasture Management

SOIL TEMPERATURE
Records
Trends

PASTURE
Species
Check Grass Dominance
Check Grass Legume Balance

CATTLE
Susceptibility of Breed Type
Livestock Feeding
Handling and Movement

Figure 31. Producer management of grass tetany
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Grass Tetany in NSW


Grass Tetany in NSW


Lewis, D.C., and McFarlane, J.D. (1993), *Implications of soil type, pasture composition and mineral content of pasture components for the incidence of grass tetany in the South East of South Australia*, SA Department of Primary Industries, Naracoorte, SA.


Grass Tetany in NSW


Grass Tetany in NSW


Appendix 1  REML Variance Components Analyses

Ratio = log (K/Mg + Ca) analysed in tables 14, 15 and 16. This method was discarded in favour of % analysis.

Table 9. Predicted means for K (log ratio K/Mg + Ca).

<table>
<thead>
<tr>
<th>Species type</th>
<th>Harvest Temp</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td>0.386</td>
<td>0.191</td>
<td>0.270</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>0.533</td>
<td>0.502</td>
<td>0.500</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>0.478</td>
<td>0.294</td>
<td>0.531</td>
</tr>
<tr>
<td>Clover</td>
<td>8</td>
<td>1.793</td>
<td>1.641</td>
<td>1.488</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>1.566</td>
<td>1.473</td>
<td>1.326</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>1.731</td>
<td>1.549</td>
<td>1.505</td>
</tr>
<tr>
<td>Oats</td>
<td>8</td>
<td>1.729</td>
<td>1.734</td>
<td>1.698</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>1.579</td>
<td>1.372</td>
<td>1.451</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>1.606</td>
<td>1.753</td>
<td>1.606</td>
</tr>
</tbody>
</table>

Standard error of differences: 0.06798

l.s.d.: 0.13526

Response variate: K
Table 10. Predicted means for Ca (log ratio K/Mg + Ca).

<table>
<thead>
<tr>
<th>Species type</th>
<th>Harvest Temp</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover</td>
<td>8</td>
<td>2.818</td>
<td>2.445</td>
<td>2.610</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>3.122</td>
<td>2.820</td>
<td>2.955</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>3.125</td>
<td>2.288</td>
<td>2.875</td>
</tr>
<tr>
<td>Oats</td>
<td>8</td>
<td>2.697</td>
<td>2.470</td>
<td>2.218</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>2.660</td>
<td>2.530</td>
<td>2.410</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>2.740</td>
<td>2.170</td>
<td>1.860</td>
</tr>
<tr>
<td>Wheat</td>
<td>8</td>
<td>2.735</td>
<td>3.005</td>
<td>2.183</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>2.485</td>
<td>2.383</td>
<td>2.427</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>2.932</td>
<td>2.772</td>
<td>2.383</td>
</tr>
</tbody>
</table>

*Standard error of difference:* 0.1623

*l.s.d.:* 0.3229

*Response variate:* Ca
Table 11. Predicted means for Mg (log ratio K/Mg + Ca).

<table>
<thead>
<tr>
<th>Species Type</th>
<th>Harvest Temp</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover</td>
<td>8</td>
<td>1.1790</td>
<td>1.2191</td>
<td>1.1787</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>1.1618</td>
<td>1.1335</td>
<td>1.1391</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>1.1703</td>
<td>1.1200</td>
<td>1.1065</td>
</tr>
<tr>
<td>Oats</td>
<td>8</td>
<td>0.5448</td>
<td>0.5512</td>
<td>0.5407</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>0.5949</td>
<td>0.5974</td>
<td>0.6074</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>0.5405</td>
<td>0.5428</td>
<td>0.5290</td>
</tr>
<tr>
<td>Wheat</td>
<td>8</td>
<td>0.5829</td>
<td>0.5872</td>
<td>0.6018</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>0.5978</td>
<td>0.6183</td>
<td>0.6264</td>
<td>*</td>
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<td></td>
<td>8-16</td>
<td>*</td>
<td>0.6123</td>
<td>0.5612</td>
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</table>

Standard error of differences: 0.02004

l.s.d: n.s

Response variate: Mg
Table 12. Predicted means for dry matter.

<table>
<thead>
<tr>
<th>Species Type</th>
<th>Harvest Temp</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover</td>
<td>8</td>
<td>0.7228</td>
<td>0.7318</td>
<td>0.7758</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>0.6943</td>
<td>0.6498</td>
<td>0.7035</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>8</td>
<td>0.7481</td>
<td>0.6685</td>
<td>0.6182</td>
</tr>
<tr>
<td>Oats</td>
<td>8</td>
<td>0.3839</td>
<td>0.4166</td>
<td>0.4554</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>0.4497</td>
<td>0.4663</td>
<td>0.5214</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>0.4383</td>
<td>0.4053</td>
<td>0.3634</td>
</tr>
<tr>
<td>Wheat</td>
<td>8</td>
<td>0.3785</td>
<td>0.4299</td>
<td>0.3904</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>0.3932</td>
<td>0.4660</td>
<td>0.4183</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>0.4608</td>
<td>0.4060</td>
<td>0.3967</td>
</tr>
</tbody>
</table>

*Standard error of difference*: 0.01772

*I.s.d.* 0.03526

*Response variate*: $dm = dry\ matter\ weight$
Table 13. Predicted means for K % .

<table>
<thead>
<tr>
<th>Species</th>
<th>Type</th>
<th>Harvest Temp</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover</td>
<td></td>
<td>8</td>
<td>1.432</td>
<td>1.467</td>
<td>1.285</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16</td>
<td>2.675</td>
<td>3.535</td>
<td>4.005</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8-16</td>
<td>*</td>
<td>1.797</td>
<td>2.003</td>
<td>2.359</td>
</tr>
<tr>
<td>Oats</td>
<td></td>
<td>8</td>
<td>2.934</td>
<td>4.271</td>
<td>4.200</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16</td>
<td>3.984</td>
<td>4.908</td>
<td>5.204</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8-16</td>
<td>*</td>
<td>3.805</td>
<td>3.393</td>
<td>4.694</td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td>8</td>
<td>2.556</td>
<td>3.077</td>
<td>2.763</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16</td>
<td>3.321</td>
<td>4.012</td>
<td>3.998</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8-16</td>
<td>*</td>
<td>3.324</td>
<td>3.478</td>
<td>3.455</td>
</tr>
</tbody>
</table>

Standard error of differences: 0.2502

l.s.d. 0.4978

Response variate: $Kdm = K\% \times \text{dry matter weight}$
# Table 14. Predicted means for Ca %.

<table>
<thead>
<tr>
<th>Species Type</th>
<th>Harvest Temp</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover</td>
<td>8</td>
<td>4.054</td>
<td>3.573</td>
<td>3.287</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>8.348</td>
<td>9.955</td>
<td>11.844</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>5.611</td>
<td>4.572</td>
<td>6.807</td>
</tr>
<tr>
<td>Oats</td>
<td>8</td>
<td>7.973</td>
<td>10.454</td>
<td>9.261</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>10.579</td>
<td>12.389</td>
<td>12.561</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>10.388</td>
<td>7.371</td>
<td>8.700</td>
</tr>
<tr>
<td>Wheat</td>
<td>8</td>
<td>6.983</td>
<td>9.224</td>
<td>7.761</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>8.258</td>
<td>9.516</td>
<td>9.693</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>9.728</td>
<td>9.653</td>
<td>8.257</td>
</tr>
</tbody>
</table>

*Standard error of differences: 0.7643*

*l.s.d. 1.5207*

*Response variate: Cadm = Ca% * dry matter weight*
Table 15. Predicted means for Mg %.

<table>
<thead>
<tr>
<th>Species Type</th>
<th>Harvest Temp</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover</td>
<td>8</td>
<td>1.988</td>
<td>2.152</td>
<td>1.790</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>3.614</td>
<td>4.539</td>
<td>5.193</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>2.452</td>
<td>2.518</td>
<td>2.878</td>
</tr>
<tr>
<td>Oats</td>
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<td>0.871</td>
<td>1.289</td>
<td>1.224</td>
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</tr>
<tr>
<td></td>
<td>16</td>
<td>1.409</td>
<td>1.749</td>
<td>1.920</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>1.111</td>
<td>1.004</td>
<td>1.314</td>
</tr>
<tr>
<td>Wheat</td>
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<td>0.869</td>
<td>1.062</td>
<td>1.002</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>1.187</td>
<td>1.533</td>
<td>1.566</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>*</td>
<td>1.245</td>
<td>1.095</td>
<td>1.102</td>
</tr>
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</table>

*Standard error of differences:* 0.1896

*l.s.d.* 0.3772

*Response variate:* \( Mg_{dm} = Mg\% \times \text{dry matter weight} \)
Table 16. Predicted means for K/Mg + Ca %.

<table>
<thead>
<tr>
<th>Species Type</th>
<th>Harvest</th>
<th>Temp</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
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<td>0.7488</td>
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<td>0.7707</td>
<td>*</td>
</tr>
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<td>16</td>
<td></td>
<td>1.2899</td>
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<td>1.9842</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td></td>
<td>*</td>
<td>0.9990</td>
<td>0.9003</td>
<td>1.0918</td>
</tr>
<tr>
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<td>0.4308</td>
<td>0.7339</td>
<td>0.8695</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td></td>
<td>0.8041</td>
<td>1.0662</td>
<td>1.4097</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td></td>
<td>*</td>
<td>0.7290</td>
<td>0.5565</td>
<td>0.6209</td>
</tr>
<tr>
<td>Wheat</td>
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<td></td>
<td>0.3719</td>
<td>0.5697</td>
<td>0.4212</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>16</td>
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<td>0.5167</td>
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<td>0.7011</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td></td>
<td>*</td>
<td>0.7064</td>
<td>0.5757</td>
<td>0.5462</td>
</tr>
</tbody>
</table>

*Standard error of differences:* 0.08726

*I.s.d.:* 0.17362

*Response variate:* $K/Mg + Ca$
Appendix 2  Plant Data Analysis

Dr G C Cresswell
Appendix 3  

Plant Tissue Analysis: Collection and Sample Handling

Dr G Cresswell, Senior Chemist,

Biological and Chemical Research Institute, Rydalmere

Plant tissue analysis is a valuable and versatile tool used in the management of a wide range of agricultural pursuits. A common misconception amongst users of the technique is that what happens in the laboratory is more important than what happens during sampling. I suspect this attitude comes from our overoptimistic faith in technology. However, where tissue analysis is concerned, careless sampling will always result in an unreliable diagnosis, regardless of how Highett the laboratory operation. The purpose of these notes is to raise your awareness of this fact, so that you may benefit more from tissue analysis in the future.

The importance of following the sampling procedure which has been established for a crop is not really clear unless you understand how plant analysis works. Then it becomes obvious how poor sampling can lead to an incorrect diagnosis.

Plant analysis and soil analysis are complimentary techniques. They provide different information about the nutritional conditions available to a crop and so cannot replace one another.
Soil analysis

Soil analysis is a predictive technique used mainly to anticipate whether soil nutrient reserves are sufficient to satisfy the needs of a crop during development. Soil fertility is estimated by measuring the quantity of a nutrient, which can be chemically extracted from a sample of soil in the laboratory. A difficulty with this approach is that variations in the chemical extracted and the method of extraction will lead to different results. Plants also differ considerably in how efficiently they absorb nutrients from soil. This raises two important questions about soil analysis.

1. Which chemical extraction procedure is most appropriate?

2. How can one procedure be representative of crops which have different abilities to obtain nutrients from soil?

Plant analysis

Plant analysis does not have these problems because it is calibrated for individual crops. With this technique, nutrient availability is estimated from the amounts of nutrients which the crop has been able to accumulate in its tissues. Instead of guessing what will be available to the crop, chemical procedures are used to actually measure what the crop has absorbed from the soil. Plant analysis obviously cannot be used to predict nutritional problems in new ground. The adequacy of supply is determined by comparing the nutrient content of a target plant tissue, usually leaves, with a standard for the crop. The standard normally specifies the range in tissue concentrations found in high producing plantings and plantings which have been affected by deficiency or toxicity.
Many non-nutritional factors also influence the nutrient composition of plant tissue and these reduce the sensitivity of plant analysis. The purpose of sampling is to minimise their impact.

**Sampling for tissue analysis**

There are four main aspects of sampling which influence the chemical test result and therefore the conclusions drawn from a tissue analysis report.

1. **Field sampling strategy**

   How many plants must be sampled to estimate the average nutrient status of a crop?

   Which plants do you take?

   The purpose of any sampling strategy is to cover plant to plant variation. One plant is obviously too small a sample and sampling all plants is clearly impractical.

   The minimum sample size is determined by the uniformity of the planting and the quantity of material needed to perform the analytical tests. Recommendations for uniform plantings of individual crops can be obtained from the Plant Analysis Manual edited by Reuter and Robinson, Inkata Press. For a full range of tests, the laboratory will require around 200 g of fresh material.

   Samples should be collected from plants distributed evenly throughout the area of interest in the crop. The selection strategy adopted is really a matter of convenience but should be systematic. A zig zag path through the crop, a diagonal transect or simply
moving up and down rows are all equally valid, so long as they cover the variation in the planting. If this variability is large, it may be better to sample different parts of the crop separately. For example, samples could be taken from sections where the problem is severe, mild and healthy.

All plants selected for sampling should be at a similar stage of maturity. Plants which are obviously in poor health because of disease, insect damage or some other non-nutritional problem should not be sampled. These factors influence tissue composition and so may mislead a diagnosis based on tissue analysis.

Only one species of plant should be sampled to find the nutrient status of a pasture. Pasture species can differ markedly in their nutrient composition, even when plants are growing side by side. The chemical test results for a mixed pasture sample can, therefore, owe more to the proportion of each species present in the sample than the availability of nutrients in the soil. Do not sample plants growing in urine patches.

If areas of quite good growth occur alongside areas of poor growth in a crop, it is often useful to sample both. A comparison of tissue analysis results for the two samples may help the laboratory identify the crop.

2. Time of sampling

As plants mature, the nutrient composition of their tissues change. For example, concentrations of nitrogen and potassium are highest in very young plants. These nutrients become diluted by subsequent growth and so are lower in mature plants. Plant maturity can, therefore, complicate the tissue analysis interpretation. The effect is
minimised by restricting sampling to a specific developmental stage, generally when
tissue composition is most stable. This is usually around early flowering for most crops.
When samples are collected from a crop which is not at the recommended stage of
maturity, the plant standards cannot be applied directly. Most diagnostic samples fall into
this category. Problems rarely occur at a time which suits the diagnostician. When
samples are collected at the wrong time, two things can be done to make the
interpretation more meaningful.

a. The laboratory should be informed of the crops stage of maturity (i.e. seedling,
   vegetative, flowering and harvest) so that they can make allowances in the
   interpretation.

b. Samples from poor and healthy plants should be collected. This provides a type of
   living tissue standard which can be used to identify nutritional abnormalities in the
   poorer plants.

3. Sample tissue

For most crops, tissue analysis is conducted on a sample of leaves or petioles. Because
the nutrient composition of leaves changes with physiological age, position on plant (i.e
height, aspect) and relationship to developing fruit or grain, the age and location of the
leaf targeted for sampling is usually clearly specified. The tissue analysis laboratory
should be able to provide details of the correct sample tissue for most of the crops grown
in this state. Information is also available in the Plant Analysis Manual edited by Reuter
and Robinson.
If the appropriate sample tissue is not known, it is customary to sample only recently mature leaves, avoiding leaves which are very young or very old. At this stage of development, the nutrient composition of a leaf is relatively stable and is most directly influenced by the current nutrient status of the plant. Young leaves are less satisfactory for plant analysis because their nutrient composition changes very rapidly as they expand. This can obscure the changes which are due to supply. Age and the extent of nutrient retranslocation to other plant tissues, have a greater influence on the nutrient composition of old leaves than does nutrient supply. This makes them unacceptable for tissue analysis.

If symptoms are prominent on some leaves, it is usual to sample them for tissue analysis. This provides the diagnostician with another basis for identifying the problem.

4. Handling and packaging

Plant material will begin to deteriorate soon after sampling in the field. Nutrient composition can be altered by decomposition, respiration or with whole plant samples, by nutrients moving out of the target leaves to the developing fruit or grain. If these processes go too far, they will effect the interpretation. Sample deterioration may also hide useful diagnostic symptoms.

The following action can be taken to minimise this source of error.

a. Get samples to the laboratory as soon as possible. Make sure that they do not arrive on weekends or on public holidays when the laboratory is closed. Samples may be stored in a refrigerator until they can be despatched.
b. Package the samples so that they do not deteriorate rapidly. Fresh plant material should be loosely packed into a paper bag and, if possible, placed into a box or stiff envelope. Plastic bags encourage sweating and should not be used unless the sample is kept cool. Samples may be dried prior to dispatch if there is no need to send the sample fresh (this is usually only when monitoring or for trials). This can be done by spreading samples in the sun or even using a micro-wave oven but it is only advisable under special circumstances.

Chemical residues on the plant at sampling or picked up during packaging are another source of error in tissue analysis. Such things as foliage sprays containing trace elements, fungicides, dust and soil. Occasionally samples are contaminated after sampling because the plant tissue has come in contact with a fertiliser bag or soil in the boot of the car. These residues can be reduced by rinsing but this must be done when the sample is still fresh. Special washing procedures are described in the Plant Analysis Manual. These have been developed principally for the laboratory and are generally too involved for field use.

If large amounts of residue are present on the sample, some may be rinsed off with clean water or in the case of soil removed by brushing, shaking, or wiping off. Samples which have been wet in this way are more likely to rot and so should be blotted dry before packaging. In any event, the laboratory should be informed of the presence and nature of any residue on a tissue analysis sample. This is because washing, no matter how sophisticated the technique, does not remove all contamination and so the chemical interference must be accounted for in the interpretation.
PLANT TISSUE INTERPRETATION

G H Price, Agricultural Services Supervisor
Incitec Ltd. Brisbane

The intention of determining the plant's total nutrient content is to assess how well the plant has obtained its nutrients from the soil supply.

This thesis covers aspects of interpreting the results from the analysis of the total acid digest of plant material.

Other analytical procedures can be used to analyse:

i. the nutrient content of sap in petioles (nitrate) or leaves;
ii. biochemical reactivity of enzymes in various tissues; and
iii. nutrient content of product (grain, fruit, fibre).

The interpretation procedure suggested can be taken in stepwise progression to simplify it.

1. Determine the grower's real reason for sampling. You need to ask "Is he trouble-shooting or monitoring?"

Trouble shooting is the process of determining why one plant or one area is performing better than another. Because there is a comparison, two samples MUST be taken at the same time.
If the grower is monitoring, then we need to have a previous set of results from the same area to follow progress with treatments and resultant plant growth or response.

2. Consider the field information provided. Field information includes past soil/paddock history, past cropping history, current and past fertiliser history (including product and rate use). This information provides an insight into the management practices of the grower and nutrient inputs provided to the crop.

3. Using interpretation standards related to the plant part sampled, assess each nutrients' status.


Determine if the nutrient is deficient, low, optimum (or adequate), high or excessive (or toxic). If the nutrient is outside the optimum range, the fertiliser use programs may have to be adjusted.

If low or deficient, increase rate of application. If high or excessive, reduce rate of application or apply other product(s) to aid reduction in uptake by the plant.

4. Determine the appropriate fertiliser products and application rates.

The fertiliser recommendation should be provided in terms of the product (name or analysis), rate, timing and placement. This should allow for modification to the
current or previous fertiliser rates based on the needs determined by the plant analysis.

Additional information may be used, especially if good yield records are kept, so crop nutrient removal can be determined, if soil test results are available and nutrient input (fertiliser) rates are known.

The use of both soil testing (provides information on soils' ability to supply nutrients) and plant analysis is suggested for fertiliser needs of tree crops.

5. The best way to become proficient at interpreting analytical results is to continually practice. Hence the remainder of this segment will be taken up in practising the interpretation of plant analysis results.

Examples have been chosen from crop types grown in this area.
Appendix 4  Plant Sample Information Form

NSW Agriculture

Please see following pages 173 and 174
# Plant Sample Information

**Purpose of analysis:**
- Diagnostic
- Fertilizer programme
- Survey

**Date of dispatch:**

**FOR LABORATORY USE ONLY**
- Date received
- Lab. Nos
- CN

### Sample Information

<table>
<thead>
<tr>
<th>Sample</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

**Problem or symptom:**

**Severity:**
- Serious
- Potentially serious
- Minor

**Affecting:**
- Most plants
- Groups of plants
- Scattered plants

**Area of crop:** Yield reduction (per cent)

**Crop:**

**Variety:** Rootstock

**Maturity:** Date sown

**Cropping history:**

**Soil:** Type... Depth (cm)

**Irrigation type/frequency:**

**Drainage:**

**Weather conditions:**

**Fertilizer - This crop:**
- Last year
- Earlier

**Nutrient sprays:**

**Other sprays:**

**Other comments, earlier analyses etc. (give BCRN Lab. No.)**

**Plant preparation:**

**Elemental Analysis:**

- CI
- N
- P
- K
- Ca
- Mg
- Na
- S
- Si
- Mn
- Cu
- Zn
- Fe
- Al
- Fe
- NO₃-N
**Grass Tetany in NSW**

**HOW TO TAKE A LEAF SAMPLE**

**DO'S AND DON'TS**

- Don't take samples from plants suffering from root injury, disease, waterlogging, soil compaction or other obvious causes of restricted nutrient uptake.

- Adequately sample the crop. For a uniform block of fruit trees take samples from at least 12-20 trees. For crops such as maize or vegetables take leaves from 15-20 plants. With large leaves submit only a strip 8-10 cm wide taken across the middle of each leaf.

- If the aim of the analysis is to diagnose an apparent deficiency or toxicity, or if a problem is seen at other than the optimum sampling time (see table below), submit a sample of healthy leaves of the same age as the affected sample, for comparison.

- Don’t enclose soil or dirty roots within the leaf sample container.

- Don’t use plastic bags for leaf samples unless samples are kept on ice during transit. Pack loosely in a small cardboard box or a paper bag.

**CHOICE OF LEAVES AND SAMPLING TIME**

**GENERAL RULE.** Where no specific procedure is recommended, choose the most recently fully matured leaf, at early flowering stage.

**SPECIFIC CROPS.** Individual sampling instructions for a representative selection of crops are tabulated below.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Tissue</th>
<th>Sampling time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple and pear</td>
<td>Mid-shoot leaves</td>
<td>Jan. - Feb.</td>
</tr>
<tr>
<td>Avocado</td>
<td>Spring flush leaves from non-fruiting shoots, 4-5 mo. old</td>
<td>Jan. - Feb.</td>
</tr>
<tr>
<td>Banana</td>
<td>Leaf strips on each side of the midrib from the centre of the third youngest leaf</td>
<td>Jan. - Feb.</td>
</tr>
<tr>
<td>Orange</td>
<td>Spring flush leaves from non-fruiting wood, 4-7 mo. old</td>
<td>Late Jan. - early March</td>
</tr>
<tr>
<td>Grapevine</td>
<td>Leaf from base of a shoot and opposite a fruit bunch</td>
<td>Jan.</td>
</tr>
<tr>
<td>Stone fruit</td>
<td>Mid-shoot leaves from first main flush</td>
<td>Jan. - Feb.</td>
</tr>
<tr>
<td>Pecan nut</td>
<td>Pairs of middle leaflets from midway along terminal shoot bearing fruit</td>
<td>Jan. - Feb.</td>
</tr>
<tr>
<td>Cabbage and lettuce</td>
<td>Wrapper leaves at or near head maturity</td>
<td>Jan. - Feb.</td>
</tr>
<tr>
<td>Potato</td>
<td>Fourth (first fully expanded) leaf at early bloom</td>
<td>Aug.</td>
</tr>
<tr>
<td>Wheat, oats, barley, etc.</td>
<td>First fully developed leaf at late tillering stage</td>
<td>Aug.</td>
</tr>
<tr>
<td>Maize</td>
<td>Leaf opposite and below lower ear at full tassel</td>
<td>Aug.</td>
</tr>
<tr>
<td>Lucerne</td>
<td>Mid-stem leaves at beginning of flowering</td>
<td>Aug.</td>
</tr>
<tr>
<td>Clover</td>
<td>Leaflets plucked from the pasture at early flowering stage</td>
<td>Aug.</td>
</tr>
<tr>
<td>Soybean</td>
<td>Upper fully expanded leaves prior to or during early flowering</td>
<td>Aug.</td>
</tr>
</tbody>
</table>
Appendix 5  Test Procedure for Cation Exchange Capacity and Exchangeable Cations

Please see pages 176 to 181
Test Procedure for Cation Exchange Capacity and Exchangeable Cations

DETERMINATION OF CATION EXCHANGE CAPACITY AND EXCHANGEABLE CATIONS BY SILVER THIOUREA

Abbreviated Name: CEC and exchangeable cations
Test Number: C5
Test Method Type: A

THIS VERSION

Version Number: 4
Date Adopted:
Date Terminated

1. SCOPE

This method for the simultaneous measurement of Cation Exchange Capacity and Exchangeable Cations is based on the very high affinity of the Silver-Thiourea complex ion for occupying exchange sites on soil colloids.

The method consists of a single saturation of a one gram soil sample with 0.01 M Silver-Thiourea solution. CEC and Exchangeable Cations are measured by analysing the extract for Silver, Calcium, Magnesium, Potassium, Sodium and Aluminium.

2. SPECIAL APPARATUS

* Atomic Absorption Spectrophotometer with Hollow Cathode lamps to measure Ag, Na, K, Ca Mg and Al.

* Diluter/Dispenser. (Brand Diluette® Cat. No. 7046 54)

3. REAGENTS

General Reagents

See reagents in Test C5 A/3

Working Standard Solutions
Silver

Pipette 25mL of 0.01 M Ag-Thiourea reagent into a 200mL volumetric flask and bulk to volume with 0.75 g/L Thiourea solution.

concentration - Ag = 134.8 mg/L

Prepare a range of calibration standards using the Diluter/Dispenser and the following table as a guide.

Table 1. Preparation of calibration solutions of Silver.

<table>
<thead>
<tr>
<th>Standard No -------&gt;</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms. 134.8 mg/L</td>
<td>0.05</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>Ag. Std. Soln.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ms. 0.075 g/L</td>
<td>4.95</td>
<td>4.90</td>
<td>4.80</td>
<td>4.70</td>
<td>4.60</td>
<td>4.50</td>
</tr>
<tr>
<td>Thiourea Soln.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Concentration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of Ag (mg/L)</td>
<td>1.35</td>
<td>2.70</td>
<td>5.39</td>
<td>8.90</td>
<td>10.78</td>
<td>13.48</td>
</tr>
</tbody>
</table>

Sodium, Calcium, Magnesium

Transfer by pipette, 20mL of 1000mg/L Na, 25mL of 1000 mg/L Ca, and 25mL of 1000 mg/La Mg, into a 500mL volumetric flask and make to volume with deionised water.

concentrations:-

\[
\begin{align*}
    \text{Na} & = 20\text{mg/L} \\
    \text{Ca} & = 50\text{mg/L} \\
    \text{Mg} & = 5 \text{ mg/L}
\end{align*}
\]

Prepare a range of calibration standards using the Diluter/Dispenser and the following table as a guide.
Table 2. Preparation of calibration solutions of Na, Ca & Mg.

<table>
<thead>
<tr>
<th>Standard No -----&gt;</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mis. Na, Ca &amp; Mg Working Std.</td>
<td>0.05</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>Mis. 20 000 mg/L Potassium Soln.</td>
<td>4.95</td>
<td>4.90</td>
<td>4.80</td>
<td>4.80</td>
<td>4.70</td>
<td>4.50</td>
</tr>
<tr>
<td>Final Concentration of ion (mg/L) Na</td>
<td>0.20</td>
<td>0.40</td>
<td>0.80</td>
<td>1.20</td>
<td>1.60</td>
<td>2.00</td>
</tr>
<tr>
<td>Ca</td>
<td>0.50</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
<td>4.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Mg</td>
<td>0.05</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Potassium

Pipette 10mL of 1000mg/L Potassium Std. into 500 mL volumetric flask and make to volume with deionised water.

Concentration - K = 20 mg/L

Prepare a range of calibration standards using the Diluter/Dispenser and the following Table as a guide.

Table 3. Preparation of calibration solutions of Potassium

<table>
<thead>
<tr>
<th>Standard No -------&gt;</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mis. 20 mg/L K Std. Soln.</td>
<td>0.05</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>Mis. 1500 mg/L Sodium Soln.</td>
<td>4.95</td>
<td>4.90</td>
<td>4.80</td>
<td>4.70</td>
<td>4.60</td>
<td>4.50</td>
</tr>
<tr>
<td>Final concentration of K (mg/L)</td>
<td>0.20</td>
<td>0.40</td>
<td>0.80</td>
<td>1.20</td>
<td>1.60</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Aluminium

Pipette 20 mL of 1 750 mg/L Aluminium Std. into a 250 mL volumetric flask and make to volume with deionised water.
Prepare a range of calibration standards using the Diluter/Dispenser and the following table as a guide.

Table 4. Preparation of calibration solutions of Aluminium

<table>
<thead>
<tr>
<th>Standard No ————&gt;</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms. 140 mg/L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al Std. Soln.</td>
<td>0.05</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>Ms 20 000 mg/L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium Soln.</td>
<td>4.95</td>
<td>4.90</td>
<td>4.80</td>
<td>4.70</td>
<td>4.60</td>
<td>4.50</td>
</tr>
<tr>
<td>Final Concentration of Al (mg/L)</td>
<td>1.40</td>
<td>2.80</td>
<td>5.60</td>
<td>8.40</td>
<td>11.20</td>
<td>14.0</td>
</tr>
</tbody>
</table>

4. PROCEDURE

Removal of Soluble Salts

See salt removal in Test C5 A/3

Extraction for Cation Exchange Capacity & Exchangeable Cations

Add 50 mL of 0.01 M Ag-Thiourea and shake for 4 hours at 15 rpm

Filter through a Whatman No 42 Filter paper.

Retain the filtrate in a sealable glass container.

Measurement of Cation Exchange Capacity

Dilute the unknown sample by 100 with 0.075 g/L thiourea solution

Set up the atomic absorption spectrophotometer to measure Ag in accordance with the manufacturer's instructions. Measure the absorption of each of the standard solutions and diluted unknown samples.

Measurement of the Exchangeable Na, Ca Mg, Al

Dilute the unknown sample by 10 with 2 000 mg/L Potassium solution

Set up the atomic absorption spectrophotometer to measure Sodium in accordance with the manufacturer's instructions. Measure the absorption of each of the standard solutions and diluted unknown samples.
Cary out the measurement of Ca, Mg and Al concentraiton in the same manner. a dilutionation of 50 is suggested for Calcium and Magnesium, and a dilution ratio of 3 for aluminium.

Measurement of Exchangeable K

Dilute the unknown sample by 10 with 1 500 mg/L Sodium solution.

Set up the atomic absorption spectrophotometer to measure Potassium in accordance with the manufacturer’s instructions. Measure the absorption of the standard solutions and diluted unknown samples.

3. CALCULATIONS

Cation Exchange Capacity

From the working standards draw a calibration curve of absorption versus Ag concentration. Read the Ag concentration of the unknown sample extract from the graph.

Calculate the Cation Exchange Capacity. (CEC)

\[ \text{CEC (meq/100 soil)} = \frac{53940 - (A \times DF \times 50 \text{ ml})}{B \times 10788} \]

Where:
- \( A \) = Ag concentration in diluted extract from graph (mg/L)
- \( B \) = Oven-dry weight of sample (g)
- \( DF \) = Dilution factor

Exchangeable Cations

From the working standards draw a calibration curve of absorption versus cation concentration. Read the cation concentration of the unknown sample extract from the graph.

Calculate Exchangeable Cations.

\[ \text{Cation (mg/kg)} = \frac{A \times DF \times 50 \text{ mL}}{B} \]

Where:
- \( A \) = Cation concentration in diluted extract from graph (mg/kg)
- \( B \) = Oven dry weight of soil sample. (g)
- \( DF \) = Dilution factor

\[ \text{Cation (me/100g)} = \frac{Cation (mg/kg)}{E} \]
Where: \( E = \) Equivalent Weight of cation \( \times 10 \)

\[
\begin{align*}
\text{Na} & = 229.9 \\
\text{K} & = 391.0 \\
\text{Ca} & = 200.4 \\
\text{Mg} & = 121.6 \\
\text{Al} & = 89.9
\end{align*}
\]

6. **REPORTING OF RESULTS**

Report the CEC to one decimal place and Exchangeable Cations to one decimal place for meq/100 g or to the nearest whole number for mg/kg.

7. **REFERENCES**


8. **NOTES**

1. The volume of 0.01 M Ag-Thiourea prepared should be adjusted according to the amount required for extraction and use in standar solutions.

2. The driving time is reduced if the final wash is done with Water/Ethanol mixture (36 mL deionised water/964 mL Ethanol).

3. If the concentration in the samples is greater than that of the standards carry out a further dilution with Na, Ca, Mg diluting solution. Take 25mL of 0.01M Ag-Thiourea, 25mL of 20000mg/L K and dilute to 250 mL with deionised water.

4. If the concentration in the samples is greater than that of the standards carry out a further dilution with K diluting solution.

K diluting solution: Take 25mL of 0.01 M Ag-Thiourea, 25mL of 15 000 mg/L Na and dilute to 250ml with deionised water.
Appendix 6  Grass Tetany in Cattle

NSW Agriculture Advisory Bulletin

Please see pages 183 to 185
Grass tetany in cattle—the disease

M. G. Elliott
District Livestock Officer (Beef Cattle)
Wagga Wagga

It has been estimated from meetings with Rural Lands Protection Boards and NSW Agriculture & Fisheries in the Wagga Wagga, Albury and Gundagai districts that losses of cattle can be $3–5 million yearly. The cost to producers is greater than this, as many different forms of prevention are used, sometimes with ineffective results.

The disorder is prevalent on the northern, central and southern tableland and slopes but it has also occurred elsewhere.

Most veterinary texts define grass tetany as a deficiency of magnesium (Mg). Though grass tetany is expressed as a Mg deficiency, the reasons for this expression are complex and varied.

Grass tetany (Caple and Allworth, 1987)
Grass tetany is a disorder in cattle when the level of Mg in the cerebro-spinal fluid which surrounds the brain and spinal cord, decreases below a critical level. In the development of grass tetany, the level of Mg in the blood decreases before the level in the cerebro-spinal fluid. Hence, the analysis of Mg level in the blood is a guide to the disorder.

Grass tetany may not always arise from a simple deficiency of Mg. The disorder can be quite complex and different circumstances can lead to a reduction in Mg concentration in the blood and cerebro-spinal fluid, thus, producing signs of grass tetany, as follows:

- Simple form: A deficiency of Mg
- Complex form: Potassium (K) is the most important factor which interferes with Mg absorption from the rumen.

K concentrations in the rumen increase when:
- cattle graze pastures on natural soils high in K
- cattle graze pastures fertilised with potash
- cows are deficient in salt (sodium)
- the diet is changed from hay or dry feed to lush pasture.

Symptoms (Morton 1984)
For most farmers, the first sign of an outbreak of grass tetany is finding dead cows. Usually, there is froth from the mouth and nose and the ground is rubber where the animal’s legs moved violently before it died. Excitement and muscular spasms (tetany) are the most common symptoms.

In the mildest form of the disorder, the cow may have an abnormally low level of Mg in the blood and yet show no symptoms. All may be well for days or even weeks until she is stressed by yarding, mustering, trucking, etc. after which symptoms may show.

In the intermediate form of the disorder, the cow is wild, her front legs “goose step”, she does not like being driven, the tail is held a little bit high and she may appear blind. A few recover at this stage but without treatment, the condition of most of them will worsen and they will die.

Excitement, galloping, bellowing and staggering are common in the worst form of the disorder. The cow soon goes down on its side with its legs outstretched, stiff and thrashing backwards and forwards (leg paddling). The head arches back slightly and she froths at the mouth. If the animal is down and has survived an attack, any disturbance (especially touching it) may start a new attack of leg paddling. The animal may die within minutes of being seen staggering, especially if she is driven or stressed in any way.

Initial signs of the disorder include twitching of the face and ears, a wary appearance and a stiff gait. Often, these early warning signs are missed and the only sign a producer sees is dead cows.

Why grass tetany usually occurs in late autumn/winter
Grass tetany usually occurs in late autumn/winter because:
- The seasonal change in southern and tableland pastures alters the chemical composition of pasture ingested by cows that are calving and thus they are under physiological and environmental stress at this time. Extra stress will enhance potential grass tetany disorders.
- Tetany-prone pastures (Caple and Allworth, 1987)
Pastures which have low:
- Mg concentrations <2 g/kg dry matter
- Ca concentrations <3 g/kg dry matter
- Na concentrations <1.5 g/kg dry matter
and have high:
- K concentrations >20 g/kg dry matter
- N concentrations >50 g/kg dry matter
tend to be prone to grass tetany.

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Note: These pastures are usually grass dominant or cereal crops, for example, grazing oats. These conditions equate to acid soils in the south-west of the state. Tableland and coastal soils do not have naturally high K concentrations but this is offset by the addition of K fertilisers. Clovers tend to contain higher concentrations of Mg and Ca.

**Magnesium absorption in the animal**
The cow requires a constant intake of Mg. The maximum level of dietary absorption is about 35% of intake directly from the rumen. There is only a small reserve of Mg in the body fluids and bone metabolism is often insufficient to meet increased Mg requirements when demand is increased. Lactating cows are more prone because of milk production. Higher milk producers can be more prone to grass tetany (see Figure 1).

**Phosphorus and calcium effects** (Caple and Allworth, 1987)
The concentration of phosphorus in the rumen is also important, with higher levels of phosphorus favouring Mg absorption. Cows grazing phosphorus-deficient pastures may have low concentrations of phosphorus in the rumen and Mg absorption may be further impaired. On these farms, we may expect to see two- and three-year-old cows affected with grass tetany and milk fever.

Ca concentration in the blood also plays a role in the development of grass tetany in some cows. If it decreases, the concentration of Mg in the cerebro-spinal fluid falls more rapidly when Mg in the blood decreases as absorption is insufficient. The ability of cows to absorb Ca from pasture usually decreases after the autumn break and increases again when the pastures mature in spring. Feeding high quality legume hay to cows is one way of ensuring they absorb sufficient Ca to maintain the Ca level in their blood. On many farms, it is an essential step in the prevention of grass tetany.

**Effects of age of the cow**
- A cow's milk production tends to rise to four years of age, then it stabilises.
- In older cows, the absorption rates of Mg decrease with age.
- Some cows are just poor Mg absorbers.
- Older cows lay down more fat. Fat cows are more prone to grass tetany because they have less available Mg in their body fluids.
- Lean cows have more body fluids on a weight basis than fat cows.

**Effect of breed**
In the specialist NSW Agriculture & Fisheries publication, *Cattle breeding topics*, January 1991, from US data at Texas A. and M. University, comparisons were made of the susceptibility of various breeds of cattle to grass tetany. This study compared Angus, Hereford, Brahman, Holstein, Jersey cows and their crosses over four years. Angus and Angus crosses were more susceptible than Hereford, Jersey, Holstein and Brahman, in that order.

Further studies showed that part of these differences were probably due to the ability of Brahman to better digest and absorb Mg and differences in the milk production.

**High production demand**
Selection based on high growth rate and more muscle increases the demands on the metabolic ability of the cow.

---

Figure 1. Flow and excretion of Mg in the cow (Caple and Allworth, 1987).
Some genetic lines of cattle as well as individuals within a line cannot cope with the increased biochemical demands. Therefore as production demands increase pressure on the cow, the incidence of metabolic disorders such as grass tetany will increase.

Starvation and interference from other elements
Sudden starvation of fat cows or heifers can lead to reduction in available Mg to the body system. Cow or heifer fatteness should be controlled over a period of time to prevent over-fatteness or if over-fat, the cow should be put under a careful diet and not starved. In the soil, plant and animal elements such as Na, K, chlorine and Mg can interfere with the amount of Mg a cow will be able to obtain. Positive correlations exist between K : Ca + Mg ratio, that is, a high K fertiliser and/or soil will depress the Mg level.

Other factors contributing to the risk of grass tetany
- Time of calving—May/August calving cows are the most susceptible to grass tetany.
- Autumn/winter calving cows will be more susceptible to grass tetany than spring calving cows.
- Stress
  - Any additional stress on the cow at the critical time may be enough to trigger grass tetany.
  - Some of the more common stresses are:
    - Wind, rain and exposure
    - Sudden change of feed and feed quality
    - Sudden lowering of temperature
    - First oestrus after calving
    - Mustering
    - Transport—do not transport cows in the last six weeks of pregnancy.

Facts to note
- Cattle exhibiting hypomagnesaemia may not develop grass tetany.
- Blood sampling alone may not establish cattle that will develop grass tetany.

- Certain body hormones contribute to grass tetany notably from the thyroid gland and ovaries.
- Genetic variation means some cattle are more susceptible than others.
- High fat and protein in the diet can depress Mg absorption.
- Up to now, the most effective supplement is hay treated with MgO.
- The period of supplementation will vary between regions and between seasons in the same region.

Notes on supplementation
- Feed out in as long a trough as possible so that each animal can obtain the required Causmag dose.
- Causmag daily requirements for cattle: 60 g/head/day (up to 100 g/head/day may be necessary in some circumstances).
- After you start feeding it takes two to three days before the stock is protected.
- Protection ceases immediately supplementation ceases.

References
AMRC Review: October 1972, Grass tetany of cattle and sheep.

Edited by Lee-Ling Sim
Division of Agricultural Services
Appendix 7  Grass Tetany – Treatment and Prevention

Please see pages 187 to 189
Grass tetany - treatment and prevention

Grass tetany is a metabolic disease of cattle responsible for cow losses amounting to $3-5 million annually in the Albury, Wagga and Gundagai Rural Lands Protection Board areas.

The disease is prevalent on the northern, central and southern tablelands and slopes areas, but also occurs elsewhere.

Grass tetany is defined in another publication, Advisory Bulletin Grass Tetany in Cattle.

Grass tetany may not always arise from a simple deficiency of magnesium. Straight magnesium supplements are therefore sometimes ineffective as a sole treatment. The disorder can be quite complex, with many factors contributing:

* Older cows with young calves are most vulnerable
* Feeding on grass dominant pastures and/or early crops
* Acid soils in South Western N.S.W.
* High potassium soils and/or soils treated with potassium fertilisers
* Environmental effects such as: Wind, rain and exposure. Sudden lowering of temperature.

TREATMENT

A veterinarian will usually inject calcium and magnesium intravenously (into the vein) followed by a subcutaneous (under the skin) injection of magnesium. Injecting these solutions intravenously requires extreme caution, as an injection given too quickly, or at too large a dose, will kill the cow.

Farmers will often have to treat their animals themselves, such is the seriousness of the situation. If you have to do this, do not disturb the animal until you are ready to start the treatment. Generally, calcium and magnesium solutions from one to two commercially available plastic packs are injected under the skin, followed by 60 to 200 ml of 50 per cent magnesium sulphate solution, also injected under the skin.

Warm the plastic packs to body heat (approximately 38°C) in a bucket of hot water. This makes the solution easier to administer, causes less upset to the cow and gives a quicker uptake of calcium and magnesium.

Needles should be sterile, and the two solutions injected into different sites. Follow-up injections of magnesium sulphate (20 to 60 ml of 50 per cent solution) are often required for a day or two.

Sixty grams of magnesium oxide (Causmag®) should be fed daily after recovery to ensure that the cow’s magnesium requirements are met (see section on prevention below).

PREVENTION: SUPPLEMENTATION OF MAGNESIUM (MG)

The most effective supplement is hay treated with magnesium oxide (Causmag).

Daily Causmag requirement for cattle is 60gm/head/day, but up to 100g/head/day may be necessary in some circumstances.

After you start feeding it takes 2 - 3 days before stock are protected. Protection ceases as soon as this supplementation is stopped.

Too much Causmag is expensive and can cause scouring.

Magnesium blocks

Blocks are not recommended because of their high cost ($850/tonne, or $5,300/tonne of Causmag) and the difficulty in ensuring that all animals get the correct dose. However, there are blocks available containing around 16% Causmag.
Loose licks and homemade recipes

Variable consumption of loose licks by cows leads to insufficient levels of magnesium in some animals. However, in situations where no more effective means can be employed to deliver the Causmag, they can be of some use.

Recipes are as follows:

Mix no. 1 - Looselick

- Causmag 30%
- Salt 30%
- Lime 20%
- Molasses 20%

Salt supplies sodium (Na) and counteracts the effects of potassium (K).

Lime (stock grade) supplies calcium which is also involved in counteracting grass tetany.

Some recipes include epsom salts (magnesium sulphate) instead of Causmag; however, this is 2 to 3 times the price of Causmag and contains less magnesium.

Mix no. 2 - Homemade Block

- Molasses 40%
- Causmag 15%
- Salt 10%
- Lime 10%
- Meal or grain 25%

The objective is to get cows to consume around 120g of Causmag every 2 days. This means 200g/head/day of lick No. 1, and 400g/head/day of block No. 2.

Increase the salt level in the mixes if cattle are consuming too much, and reduce the level if they are consuming too little.

Causmag costs around $500/tonne bagged, and less in bulk. Mixes 1 and 2 will cost around $280 and $240/tonne respectively, compared with $850/tonne for commercial preparations. At recommended rates these mixes cost 5.5 cents and 9.5 cents/head/day respectively. Mix No. 2 will also provide some protein if cottonseed meal or lupins are used, and this will be advantageous to lactating cows.

Causmag Treated Grain

Work at Rutherglen Research Station in Victoria suggests that this is an easier, cheaper and more effective method of supplementing cattle to prevent grass tetany.

Rations - oats is used as the carrier medium and is mixed in both rations in a concrete mixer. Both rations will provide a supplement for 100 cows for one day.

Ration A
- 35 kg oats
- 6 kg causmag
- 2 litres water
- 3 kg molasses

Make a slurry of water and molasses; add the Causmag, then the oats. This will keep for at least 10 days.

Ration B (useful where higher grain supplementation is necessary):

- 120 kg oats
- 6 kg Causmag
- 10 litres water

This ration must be fed the day it is mixed, as the Causmag dries and separates from the grain.

Causmag Treated Hay (the slurry is the same as Ration A and B, above, but without the oats)

Mix a slurry of Causmag, molasses and water. The slurry of the prepared Causmag can be administered by pouring the mixture onto the bichis or rolled out bale.

Causmag is abrasive, so don’t pump the mix; pour with a container.

Dampen hay bales with water, then shake dry Causmag onto the cut bale face.

Feed out hay with Causmag already introduced to baled hay. Some work has been done with this technique but again the Causmag is abrasive on the bale parts and bearings.

OTHER METHODS OF ADMINISTERING MAGNESIUM

Magnesium bullets

These are relatively expensive but provide protection for 80 to 90 days. The bullets are about 5 cm in diameter, 15 cm long and weigh about 250 g. They need to be installed at least a week before the high risk period starts. The release rate is 2g/day which is only a marginal supplement of doubtful efficiency. The requirement of a cow producing 20 litres of milk 15g/day (a recommended daily allowance takes into account the requirement and the availability of magnesium from feeds). Magnesium bullets may not give sufficient protection when magnesium absorption is being affected by high dietary K.

The cost of the bullets is just under $9 each (10 to 11 cents/head/day).

Medicated water troughs

Providing soluble magnesium salts (magnesium sulphate (epsom salts) or magnesium chloride) in water troughs
at a rate of 3g/litre can be effective. This solution is not appropriate where surface water is available to cows.

High magnesium feed supplements

Causmag International is now producing a pellet in trial stages that will distribute the Causmag to cattle in a palatable form, with none of the waste and mess of other methods. The pellet has the additional property of staying together in wet weather, the usual conditions when feeding out occurs.

Millmaster Feeds at Tamworth will also be producing a feed pellet containing Causmag.

MANAGEMENT STRATEGIES

In the longer term, producers must look to soils and pastures to prevent acidification as it is evident that acid soils and high potassium (K) levels are synonymous with grass tetany incidence (see publication - Grass Tetany the Disease).

Beef cattle management

Following is a summary of management strategies that can alleviate potential problems.

Time of calving. Spring calving cows will be less susceptible than autumn-winter calving cows.

Mustering and transport. Keep to a minimum and never transport cows in the last six weeks of pregnancy. Do not run or stress animals.

Sudden changes of feed and feed quality. Leave the gate open to a fresh paddock so animals can move quietly to the new pasture or oats but are able to return to their old grazing till they get used to the new pasture.

Keep hay for the cows and calves, and give the steers the green crop. The best hay is legume hay because legumes supply nutrients which help reduce grass tetany.

Starving of fat cows and heifers. Sudden starvation can lead to a reduction of magnesium available to the body system.

If body condition is to be reduced, it should be carried out well before calving and the cattle dieted, not starved.

Other stresses. Any stress on the cow at the critical time may be enough to trigger grass tetany, such as:

- first oestrus after calving;
- unnecessary handling and movement;
- high fat and protein in diet can depress Mg uptake.

SUMMARY

Grass Tetany is probably one of the least understood metabolic diseases.

Many factors contribute to this most complex disease. Good cattle management is essential to combat grass tetany but sometimes is not enough to stop cows dying. This publication gives an outline of the available technology to assist producers in the treatment and prevention of grass tetany.

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Grass Tetany of Cattle in New South Wales

By Malcolm Gordon Elliott

A thesis submitted to Faculty of Environmental Management and Agriculture
University of Western Sydney – Hawkesbury
for fulfilment of the requirements for the degree of

Master of Science (Hons)

Faculty of Environmental Management and Agriculture
University of Western Sydney – Hawkesbury
PLEASE NOTE

The greatest amount of care has been taken while scanning this thesis,

and the best possible result has been obtained.
This book is dedicated to the love and support from my best friend Alexa May Elliott.
Grass Tetany
in New South Wales

DEATH AND THE PLOUGHMAN
Drawing by Holbein (1497-1543)

M.G. Elliott
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<tr>
<td>ARC</td>
<td>Agricultural Research Council</td>
</tr>
<tr>
<td>AST</td>
<td>aminotransferase</td>
</tr>
<tr>
<td>Ca</td>
<td>calcium</td>
</tr>
<tr>
<td>CALM</td>
<td>NSW Department of Land and Water Conservation</td>
</tr>
<tr>
<td>CPK</td>
<td>creatine phosphokinase</td>
</tr>
<tr>
<td>CSF</td>
<td>cerebro-spinal fluid</td>
</tr>
<tr>
<td>GIS</td>
<td>geographic information system</td>
</tr>
<tr>
<td>K</td>
<td>potassium</td>
</tr>
<tr>
<td>Mg</td>
<td>magnesium</td>
</tr>
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<td>N</td>
<td>nitrogen</td>
</tr>
<tr>
<td>Na</td>
<td>sodium</td>
</tr>
<tr>
<td>P</td>
<td>phosphorus</td>
</tr>
<tr>
<td>PTH</td>
<td>parathyroid hormone</td>
</tr>
<tr>
<td>REML</td>
<td>residual maximum likelihood</td>
</tr>
<tr>
<td>RLPB</td>
<td>Rural Lands Protection Board</td>
</tr>
<tr>
<td>USDA</td>
<td>United States Department of Agriculture</td>
</tr>
<tr>
<td>UWS</td>
<td>University of Western Sydney</td>
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CERTIFICATE OF ORIGINALITY

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institute of high learning, except where due acknowledgment is made in the text.

Malcolm Gordon Elliott
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ABSTRACT

Over the last 60 years, grass tetany has been recognised as a significant lethal condition in sheep and cattle. In NSW, veterinary estimates of economic losses to the State vary between $A5 to $A10 million of cows lost in the cattle industry annually. Losses in some years will sometimes be more severe than in others, but it appears that losses are so common that producers often do not report them as they consider them a normal annual condition.

Outcomes from the current study include documentation of the likely precursors to grass tetany, ways to recognise these precursors, and long term practices that will enable producers to minimise livestock deaths.

This study was comprised of a series of investigations to identify factors associated with outbreaks of grass tetany in beef cattle and to see how these factors coalesce to cause conditions likely to lead to deaths. The linkage between each individual stage was established and common factors examined.

For grass tetany to occur the factors mentioned above must operate in the following manner:

- **Soil:** Potassium(K)/Magnesium(Mg) + Calcium(Ca) ratio > 0.07 - 0.08.
- **Weather:** Soil temperatures between 6°C - 7°C followed by air temperatures of 8°C (night) and 16°C (day) for 4 to 6 consecutive days to warm the soil.
- **Plants:** Grass or cereal pastures with few or no legumes. Warming soil causes roots to take up high levels of K which dramatically changes the K/Mg + Ca ratio.
• Cattle: Susceptibility increases in lactating cows under additional stress such as cold weather, mustering or first oestrous after calving.

These conditions occur mainly in autumn and winter but can also occur in spring time in eastern Australia.

The accepted K/Mg + Ca ratio danger level is approximately 2.2, although cattle can graze pasture where the ratio of K/Mg + Ca is higher than 2.2 without developing grass tetany. In the current study there was an association between the occurrence of grass tetany and the rate of rise of K compared with Mg + Ca in grass species, not the absolute ratio of K/Mg + Ca per se.

It is postulated that this rapid rise occurs when air temperatures of 8°C (night) and 16°C (day) last for 4 to 6 consecutive days on soils where temperatures of 6°C to 7°C have been sustained for at least a week. Under these conditions plant roots (grasses and cereals) change from passively absorbing to actively absorbing K. As a result, high levels of K become available in the leaves of the plants. The same process occurs in legumes, but the K/Mg + Ca does not rise as dramatically because the legumes have naturally higher levels of Ca and Mg.

Cattle under stress from lactation, mustering or first oestrous during cold weather immediately after warm weather need critical amounts of Mg to sustain normal physiological functions. Cattle can ingest plants containing high levels of K, which will effectively cut Mg absorption in the rumen, leading to an acute Mg deficiency, which in turn may lead to death from grass tetany.
It is suggested that a naturally occurring set of circumstances in south east Australia described in this thesis, which involves interaction between climatic conditions, animal susceptibility, plant physiology and species, and soil type will be the main cause of deaths from grass tetany in beef cattle herds. The benefit of this research to beef producers is that the environmental circumstances thought to be associated with outbreaks of grass tetany have been identified, along with remedial action that can be taken to prevent deaths occurring.

Recommendations to industry on best practice to be adopted by leading producers to minimise outbreaks of grass tetany include:

- establishment of pastures that contain legumes
- using lime to create less acid soils
- conserving fodder containing legume in either silages or hay
- adopting grazing management practices that encourage maintenance of legume species
- identification of “at risk” weather conditions and strategically feeding “at risk” cattle at this time, using legume based storages. "At risk" weather conditions exist when soils are below 6° - 7°C for over one week, then are subject to warm weather of 4 to 5 days of 8°C minimum and 16°C maximum temperature. "At risk" cattle are usually lactating cows.

Bulls, steers and dry cattle are less likely to be affected by grass tetany than lactating cows. Therefore if fodder is in short supply, legume based fodder can be fed preferentially to lactating cows.
This study provides an alternative strategy for the management of grass tetany in beef cattle, to the more clinical approaches previously recommended. It is suggested that losses from this economically important metabolic disease can be minimised if management practices of beef cattle producers in eastern Australia can incorporate a more holistic approach to farm management, which takes account of the soil/plant/animal/climate inter-relationships.
Introduction

The baffling condition of grass tetany has been recognised for over 60 years throughout the world in the cattle and sheep industries.

Understanding of grass tetany has been represented by a key (Figure 1) that unlocks weather and soil factors, which, in turn influences plant and cattle factors. All of these factors then combine to cause the condition of grass tetany. Figure 1 shows the linkages between various individual studies that have been carried out over seven years as part of this study.

Figure 1. The grass tetany jigsaw. A representation of the processes used in this study. (Elliott 1998).
Rural Lands Protection Board figures in NSW suggest that between $A5 to $A10 million worth of cows die annually from grass tetany (Elliott 1993). Producers tend not to report losses as they consider the condition an expected occurrence. Cow losses were valued at $A500 per cow.

This study examines the proposition that grass tetany in beef cattle is the result of a combination of interlinked factors, and that no one factor on its own can be responsible for this lethal metabolic disease. Included in the analysis are suggested methods for predicting when outbreaks may occur and how they might be controlled.

An extensive campaign to educate farmers on the causal relationship between the various factors is also suggested. Recognising the factors causing grass tetany will result in more timely implementation of control measures leading to greater profitability for beef cattle farms in affected areas.