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Magnesium deficiency in crops and its relevance to arable farming in New Zealand - a review

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Background

Magnesium (Mg) losses from the soil include those from crop removal (of plant material and through animal grazing and resultant nutrient transfer), leaching, erosion and soil fixation. The predominant cropping soils of New Zealand, Southern and Central Yellow Grey Earths (or Pallic soils) and their associated Recent and Gley soils, have been developed under weak to moderate leaching. Most have medium or medium to high exchangeable Mg levels, 1-7me./100g and have medium to high reserves of Mg, 7-30me./100g, (Metson and Brooks 1975). Hence, historically Mg fertiliser has not been required for crop production. Canterbury is the major cropping area of New Zealand and most QTMg (MAF quick test) values range from 15-60 (0.7-3me./100g). Most of the Yellow Grey Earth's of the Canterbury Plains tend to fall at the lower end of this range (QTMg 15-30 or 0.7-1.5me./100g), however in some areas such as near Methven these soils can have QTMg < 10 and some as low as 3-4 have been found (Craighead and Martin 2001). It is now common to see symptoms of Mg deficiency in cereal and brassica seed crops in some seasons.

Historically Mg deficiency has not limited dry matter production of New Zealand pastoral soils with the exception of some of the coarse textured pumice soils (McNaught and Dorofaeff 1965). However recent surveys of soil test results in the major dairy regions show that soil Mg levels are slowly declining, particularly on the Yellow Brown Loams (Allophanic soils) and to a lesser extent the peat soils of the Waikato and Bay of Plenty, (Roberts and Morton 1998; Ledgard and O'Connor 1998). In the past decade the average MAF quick test Mg values have declined from 25 to 21 in the Waikato and 22 to 16 in the Bay of Plenty, indicating low soil Mg levels are not solely confined to cropping soils.

Magnesium Uptake

Magnesium exists in the soil in soil solution (a readily available source) and in both the exchangeable (readily available) and non-exchangeable or mineral forms (McLaren and Cameron 1996). When the exchangeable form is depleted, usually through root uptake or leaching, the conversion of non-exchangeable to exchangeable Mg is slow. Although it is still possible for the weathering of clay minerals such as vermiculite, montmorillonite and illite to annually supply sufficient Mg for crop removal, the speed at which this occurs can lead to transient Mg deficiency (Archer 1988). This is because when plants quickly put on vegetative growth as they do through the late spring, early summer the replenishment of readily available Mg from the soil cannot immediately match the plants requirements. Plants also often find difficulty in translocating Mg quickly enough from the older to younger leaves. This is usually only a temporary phenomenum. Roots absorb Mg from the soil solution which is in direct contact with the root. The quantity of Mg in soil solution must be greater than the actual crop requirement to encourage a high enough flux rate towards the root to maintain uptake (Grimme and Huttl 1991). Mass flow is the predominant transport mechanism to the root. In sugar beet leaves take up Mg until canopy closure but the roots continue to take up Mg until harvest (Draycott and Allison 1998).

Plant uptake of Mg is influenced by many factors including the other cations, (in particular calcium [Ca] and potassium [K] and to a lesser extent sodium [Na]), soil pH, moisture status, compaction and temperature.

Light sandy soils of low cation exchange capacity dominated by other cations are the most likely to show the deficiency. Magnesium deficiency was first noted on light sandy soils in Europe eg. East Anglia and the East Midlands of England and in the Eastern United States, (Jacobs 1958, Archer 1988). In New Zealand it is often on the lighter stonier soils that crops show the symptoms. Acid soils, particularly those in the tropics are well recognized as being at risk of Mg deficiency. Significant exchangeable Aluminium (Al) in the soil (5-30% of exchange sites occupied) will not only restrict root growth of wheat but depress the uptake of Mg (Castleman *et al* 1998) and in oats (Grimme 1982). The effect in sorghum was also to impair root development and influence the efficiency of uptake and utilisation of Mg which Tan *et al* (1992a) consider are independent of each other. Mulder (1956) first suggested high concentrations of ammonium (from nitrogen [N] fertilisers) and hydrogen ions at the root surface and within the cytoplasm of cells as the most likely cause of Mg deficiency in acid soil conditions.

High Mg levels in solution reduced sorghum sensitivity to Al and at high rates actually increase dry matter yield (Tan *et al* 1992). Similarly, Mg increased the tolerance of plants to wheat plants to high concentrations of manganese (Mn) in shoot tissue and also increased the ability of the plant to discriminate against Mn ions in translocation of nutrients from roots to shoots (Goss and Carvalho 1992). Although this data would suggest Mg acts similarly to Ca in that it is competing for exchange sites with other cations, in practice as the soil contains much more Ca than Mg, this would not be a common occurrence. To support this, on wheat Mg was found to have less effect than Ca on ameliorating Al toxicity, but a much greater effect than K (Kinraide and Parker 1987). Some Mg by lime interactions have been found in maize in Australia on low pH sites but the extent of this has been confounded by some Australian limes containing minor amounts of magnesium (Aitken *et al* 1999). At low soil pH on acid sensitive crops such as sugar beet and potatoes there are benefits from both liming and applying Mg fertiliser (Bolton 1973; Kemmler 1982; Draycott and Allison 1998).

High soil pH will also reduce the effectiveness of Mg fertilisers which are alkaline, fertilisers such as calcined magnesite (magnesium oxide) and dolomite (Draycott and Durrant 1972a; Draycott *et al* 1975). Magnesium deficiency is not widespread in cereals on alkaline soils in Britain (Chalmers *et al* 1999), suggesting that Ca/Mg interaction is less important than for example K/Mg interactions. K/Mg ratios are widely used as an indicator of Mg deficiency in fruit trees, but in arable crops, soil available Mg is still thought to be a better indicator of Mg deficiency (Archer 1988). Excessive K fertilisation not only reduces the uptake of Mg, it appears plants also vary in their ability to maintain Mg levels in the presence of K (Jarrell and Beverly 1981). In a recent study on three Canterbury sites, soil and plant K levels were strongly negatively correlated to plant Mg (and Na and Ca) levels on a range of arable crops, cereals, brassica, legume, grass seed crops, (Craighead and Yule 2001). However the effect of an imbalance is not likely to be great unless the ratio of soil available K/Mg (on a weight basis) is well above 5:1 for cereals (Chalmers *et al* 1999). Hossner and Doll (1970) found that although K depressed Mg levels it did increase tuber yields, and suggested a ratio of 4:1 would be indicative of a potential Mg deficiency problem. In a potato trial interacting N, K and Mg, Draycott and Allison (1998) found a wide range of K/Mg ratios suggesting parts of the paddock were suffering from Mg deficiency. Also increasing N increased herbage Mg levels except in the presence of high rates of K (400kgK/ha). In carrots, Charlesworth (in Draycott and Allison 1998), also found herbage Mg related to soil K/Mg ratio. Kemmler (1982) has reported increasing dry matter responses with maize in pot trials in India to increasing Mg application on high K soils.

Nitrogen can ‘dilute’ herbage Mg levels through rapid plant growth, however it will also affect soil Mg availability (Blevins and Frye 1993). Under no till farming, while nitrate N will move Ca and Mg to lower depths there is usually more of both in the topsoil (0-5cm) than under conventional tillage, in part due to less physical mixing of soil and in part to more N being available in the ammonium form. While N is present in the ammonium form it may be antagonistic to Mg in that as a cation it competes for uptake at the root surface, however nitrate-N (chloride, sulphate and phosphate, ie anions) and the rapid mineralisation of organic-N to nitrate-N, often means nitrate-N can alleviate Mg deficiency symptoms through enhancing Mg uptake (Mulder 1956). Increasing use of N in New Zealand cropping regions to increase grain yields and protein levels also increases the risk of nitrate leaching. Calcium and Mg are leached in preference to K as the carrier cation with nitrate (Archer 1988). In addition nitrate leaching further lowers soil pH, further compounding the risk of an induced Mg deficiency. Mulder (1956) previously demonstrated this in work with ammonium sulphate on wheat and oats.

Soil conditions impact heavily on Mg uptake, uptake is likely to be poorer when N uptake is poor, certainly when cold soil conditions restrict ammonium conversion to nitrate (Archer 1988). Similarly spells of wet or dry weather put poorly rooted crops (such as those found in heavily compacted soils) under Mg stress, particularly in potato crops. In England it was considered that in over 60% of the cases of Mg deficiency observed in sugar beet in East Anglia, the symptoms were extenuated by bad soil conditions produced by compaction or poor soil structure (Cooke 1982). Root and lower stem pests and diseases may all restrict plant magnesium uptake (Chalmers *et al* 1999). In Canterbury hessian fly, fusarium, and take-all are common issues.

Crop Removal

An overview of the data on crop removal for various temperate crops (Metson 1974) shows the higher crop removals occur with root crops such as sugar beet and potatoes (18-50kgMg/ha), although the quoted removals are quite variable. For example, 30kgMg is removed in a sugar beet crop, 13kgMg in the 25t of tops and 17kgMg in 65t of roots (Draycott and Allison 1998). Bould *et al* (1983) quote 14kgMg is removed in a 50t potato tuber crop, however whole crop uptake can be higher, eg. 42kgMg in a 55t potato crop of which 27kg is in the tubers (Haerdter pers. comm.). Historically cereals have removed less, 5-13kgMg/ha, eg. 7kg in a 6t grain crop (Bould *et al* 1983) while vegetable crops typically remove 5-22kgMg/ha. Today crop removal values are likely to be higher as yields have substantially increased since much of this work was published. For example British work (Chalmers *et al* 1999) suggests an 8t/ha winter wheat crop removes almost 15kgMg in grain and straw at harvest, but the maximum uptake at the soft dough stage would have been in the order of 30-35kgMg/ha. This raises the possibility of the occurrence of a transient Mg deficiency. The soil exchangeable Mg does not seem affected by the actual crop rotation (Karlen *et al* 1994), rather continually cropped soils tend to be more prone to the deficiency through repeated crop removal. It may also follow that the highest nutrient removal crops are not the ones showing deficiency symptoms but rather the crops more commonly grown in the rotation, such as cereals, although symptoms in one sugar beet crop, one of the most sensitive crops to Mg deficiency, are no guarantee you will get a problem the next time sugar beet is grown in that paddock (Cooke 1982). Removal figures can also vary due to variations in soil type and therefore uptake (Craighead and Yule 2001), by pH effects and by K/Mg ratios as previously discussed.

Why are we now seeing symptoms in New Zealand crops?

In Mid Canterbury, the major cropping area in New Zealand it is not unreasonable to suggest soil Mg levels are low because of continuous crop removal, perhaps exacerbated by other changes in farm practice. This area has been continually cropped for many years, economics have dictated that land does not lie fallow for long so there is less emphasis on pasture as a restorative phase. More specialist crops such as brassica seed crops and potatoes are now grown, crops with potentially higher Mg demands. Increasing use of N (mainly as urea) and cultivation associated with more intensive cropping lead to more nitrification (McLaren and Cameron 1996) and combined with more irrigation potentially leads to more leaching losses of Mg. The situation has probably been exacerbated by the impact of new dairying in the region. This increases the opportunity for arable farmers to contract winter graze cows on specialist feeds (Mg losses are higher with cattle compared to sheep due to the less even deposition of dung and urine), and also provides a market for crop residues that may otherwise have been kept on the farm. Ryegrass seed, barley and wheat straw are now saleable items that in the past would have previously been burnt or mulched back into the soil. Dairying has also increased the demand for maize silage to be locally grown, a crop removing large amounts of nutrients including Mg.

It is common in most dairy regions to supplement Mg in dairy cows in the spring to avoid hypomagnaesemia (as opposed to growing grass), and indeed in Canterbury some farmers consider it economic to supplement for the whole season, especially in hot dry conditions, indicating that soil Mg levels are sufficiently low to impact on milk production. Anecdotal evidence also suggests that Mg levels are sufficiently low in the pasture phase of a mixed cropping programme to delay sheep fattening, subsequently affecting the economics of both the animal and spring cropping enterprises.

Role of Magnesium

The role of Mg in plants is primarily in photosynthesis as a constituent of chlorophyll. A healthy crop has 6-10% of leaf Mg associated bound with chlorophyll, increasing to 35% in a deficient crop (Draycott and Allison 1998). Other roles include its involvement in cell wall structure and cell turgor, protein synthesis, carbohydrate movement and formation, as a carrier of phosphorus particularly in oil seed crops (eg. canola), as a component or activator of several enzymes, CO_2 assimilation, cation-anion balance and cellular pH (Bould *et al* 1983; Reuter and Robinson 1998).

Symptoms

Magnesium is transported within the phloem and as such is fairly mobile within the plant, hence deficiency symptoms usually appear first in the older basal leaves often towards the end of the rapid vegetative period when Mg moves to the more active younger expanding leaves. The typical deficiency symptom is chlorosis between the veins of older leaves (Jacobs 1958) caused by a disruption to the chloroplasts and hence chlorophyll production.
In dicotyledons the chlorosis is mainly patchy (eg. mottling in brassicas), particularly in the older leaves. In potatoes the older leaves become affected during senescence, initially going yellow followed by necrosis between the veins, the margin remaining green. Dwarf beans and peas show similar symptoms. Sugar beet shows more severe symptoms with interveinal chlorosis becoming more widespread across the older leaf followed by necrosis and holes and sometimes progression to the younger leaves (Archer 1988).
In monocotyledons chlorosis is in the form of stripes, a plant first looks pale when the plant blade is held up to the light – in cereals yellow/green spots are often arranged in a string like pearls or beads against a lighter background, in older leaves (eg. Archer 1988). Symptoms are more pronounced in oats than wheat or barley. The stripes become whiter and more necrotic as the condition becomes more severe, culminating in barley with yellow/orange tips to the leaves and necrosis of older leaves (Chalmers *et al* 1999). Scott and Robson (1991) found that deficiency symptoms in wheat often appear in the youngest tissue first (paleness) before moving onto the older tissue, suggesting sometimes Mg translocation is tardy. This is despite their studies showing that when Mg supply from the roots was haltered the plant first depleted the Mg in the older leaves. Grimme (1987) found in cereals, 57-64% of the Mg was in the grain of which 39-62% was translocated from the stem and leaves. By contrast, there is some evidence magnesium does not translocate well to the seed in flax (Hocking *et al* 1987).
Recently in Mid Canterbury consultants have ascribed paleness in spinach seed crops, particularly in the older leaves to Mg deficiency although plant analysis has not always been conclusive. It may be related to soil pH since spinach prefers higher levels, pH 6.5 (in water) compared to the New Zealand optimum of 5.8-6.2 for most other crops.
In maize, mild symptoms of alternate dark and light green tramlines (or yellowish white between veins) in mid to lower leaves, have been seen in silage crops in Canterbury. Crops usually grow out of these symptoms.

Critical Levels

Soil Magnesium

Experience has identified that various field crops (cereal and brassica seed crops) in Mid Canterbury start showing symptoms of Mg deficiency at soil QTMg levels of 6-10.
Numerous reviews of Mg trials on New Zealand pastoral soils (eg. Edmeades 1999) have established that dry matter responses in pasture can only be anticipated if QTMg are 5 or less (and perhaps 6-7 with clover in glasshouse trials), and mixed pasture has a concentration of 0.15%MgDM or less. Draycott and Allison (1998) cited from pots trials after five successive crops that no significant Mg was released from non exchangeable Mg suggesting that exchangeable Mg gives a good measure of likely Mg response. In Britain, ADAS consider arable soils to be marginal at 50mg/l available Mg and low at <25mg/l available Mg (approx 4-5 on our quick test scale), especially for potatoes and sugar beet, although Draycott and Durrant (1972a) have shown the greatest responses on sugar beet are when levels are <15mg/l and cereals don't really respond unless levels are also this low (Archer 1988). In Scottish experiments on potatoes and sugar beet there was a large difference between the 30mg/l where a response may be seen and the 160mg/l that ensures high herbage Mg % is obtained

(Cooke 1975). In Australian work on maize, Aitken *et al* 1999, felt they were unlikely to see a response on soils where soil concentration was >0.27cmol/kg (approx QTMg 9). In New Zealand it is current practice to aim for QTMg of >10 for arable crops and 20-30 for vegetable crops, particularly for leafy vegetables where colour for presentation is important.

Evidence from various pastoral trials (Edmeades 1999) and routine monitoring (Craighead 1999a, Strachan pers. comm.) suggests that where pastoral soil tests are low, it takes anywhere from 3-20kgMg/ha to lift a soil test one Quick Test unit. McNaught *et al* (1973) have shown that the higher the existing soil test the more Mg is required to lift the herbage status. Given that arable soil testing is measured over 0-15cm, as opposed to 0-7.5cm for a pastoral soil, then it is likely to take more fertiliser Mg to lift an arable soil test.

Herbage Magnesium

Pastoral data well documents the seasonal nature of herbage Mg concentration (eg. Craighead 2001). Typically herbage concentrations are at their lowest in late winter, early spring, when soil temperatures are still low but growth is increasing rapidly. Stan Winter (pers. comm.) has previously shown a good relationship between climate, in particular sunshine hours and higher herbage Mg content of pasture in Southland (where warm, slightly dry seasons are desirable).

In cropping soils, herbage levels don't seem to change much with maturity in cereals such as wheat and barley, (Craighead 1999b), whereas with peas, potatoes, sugar beet and canola there may be a decline with maturity (Reuter and Robinson 1998). Magnesium deficiency symptoms in NSW, Australia wheat areas are usually attributable to cold temperatures and the restricted root system (particularly in acid soils) which prevents the roots exploring a larger soil volume (Weir 1987). High rainfall on acid sandy soils seems to be the driver for symptoms in potatoes in northern coastal NSW. In Britain, potatoes and sugar beet show symptoms on sandy soils. Symptoms in sugar beet are generally most intense in summer in hot dry conditions and can lead to yield depressions whereas seedlings often grow out of symptoms (Draycott and Allison 1998). In cereals symptoms are fairly common in spring and caused by adverse soil and weather conditions. For example spring cereals develop symptoms if early season conditions are cold and dry, usually as a consequence of a delay in emergence of secondary roots (Chalmers *et al* 1999). Canola also tends to show symptoms in similar conditions.

Recent Canterbury work further demonstrates the transient nature of the deficiency symptoms often coincide in cereals with periods of rapid growth. Crops also seem predisposed when spring temperatures are cooler as evidenced in the 1999/00 season (Craighead and Martin 2001). Crops usually grow out of the symptoms prior to ear emergence.

It is difficult to identify an optimum herbage level for crops because of the influence of maturity, soil type, soil and climatic conditions and the interaction of other fertilisers (Cooke 1982). For many plants the optimum is between 0.1-0.2%Mg, more specifically the optimum for wheat is 0.15-0.16%Mg, just prior to ear emergence (Reuter and Robinson 1998). In NSW, Australia, Castleman *et al* (1998) showed values between 0.1-0.16%Mg for whole shoots, but sometimes individual leaves showed symptoms at 0.12%Mg while Carr (1986) found leaves symptomless at 0.1%Mg. In pot trials in Western Australia, Scott and Robson (1991) found that although symptoms occurred at <0.12%Mg growth was not restricted at 0.09%Mg (ie symptoms occur before damage is detected). In New Zealand it is not uncommon for mid-vegetative herbage concentrations to be as low as 0.09-0.12%, with symptoms generally showing at 0.09-0.1%Mg. Chalmers *et al* (1999) suggest 0.1% as the critical level for wheat and cereals in general. The level appears higher for maize, 0.15-0.20% (Reuter and Robinson 1998) with symptoms certainly present at 0.16% (Weir and Cresswell 1994).

Crops such as sugar beet show symptoms at 0.025-0.05%Mg (Bould *et al* 1983), but are considered low at 0.1-0.15% (leaf) and 0.05-0.15% in the roots (Draycott and Allison 1998), while canola the critical level seems <0.14% preflowering (Reuter and Robinson 1998). Potatoes need to be above 0.15%Mg at tuber bulking in the leaf or leaf petiole and 0.2-0.22% in the early to mid flowering stage (Reuter and Robinson 1998, Weir and Cresswell, 1993). As a general rule, for most vegetable crops the critical value is 0.2%Mg (Scaife and Turner 1983).

Responses to Magnesium

Cereals

The paucity of data indicates that few trials have been carried out on the response of cereals (or crops in general) to Mg. It seems that slight symptoms produce little measurable effect on yield. The Arable Research Centre (ARC) in England (FAR 1997) has shown on wheat that a Mg application at first node did not improve herbage Mg content at flag leaf. Carver (pers. comm.) has commented that some British work showed no yield response in wheat even when herbage levels fell to 0.07%Mg. ADAS work on cereals in Britain in the 1960's on low magnesium soils showed no yield response on a wheat crop that showed leaf symptoms, yet on a barley crop that did not show symptoms one treatment of 63kgMg (as calcined magnesite) gave a significant yield response (Chalmers *et al* 1999). Trials in Scotland at a similar time showed significant yield responses (4-8%) on oats but no response in barley on two sites. ADAS trials in the 1980's on two wheat and two barley sites of low Mg (20-30mg/l) gave no response to foliar or solid Mg applications.

Other crops

Sugar beet has in the past shown responses to magnesium in England on the light sandy and gravely soils and light fen (organic) soils. In the 1960's at Rothamsted, sugar beet showed responses in yield, juice purity and sugar content and at Levington research station potatoes responded to magnesium (Draycott *et al* 1975). At the same time work at Brooms Barn (sandy soils) showed yield responses of 0-10t/ha on 50 sugar beet trials (Cooke 1982), no responses were seen above 35mg/l exchangeable Mg and soil levels had to be below 20mg/l to give >5% response. Recommendations on sugar beet aim to apply 30-50kgMg/ha as maintenance or 80-100kgMg/ha in these deficient situations, the form of Mg dependent on whether it is a first or subsequent crop and the initial soil value (Draycott and Allison 1998). Small yield responses in potatoes were reported in 13 Scottish experiments in the 1970's, 0.5t or 2% to 54kgMg/ha and 3% yield responses to 20kgMg/ha in 16 German experiments (Perrenoud 1983). The German work found no effect on dry matter however Finnish work reported in the same review found a slight reduction in dry matter and starch content with increasing Mg (up to 60kgMg/ha). Further German work on potatoes showed improvements in yield and starch from using 54kgMg/ha as kieserite and in the Netherlands in yield on sandy soils from using 16 or 32kgMg (Kemmler 1982).

Kemmler (1982) has also reported that while grain maize in France gave little response to up to 100kgMg/ha alone on deficient soils also deficient in K, it responded well when up to 160kgK was also applied.

New Zealand Data

There has been no published data on Mg in the New Zealand arable sector in the past 20+ years. The only reference has been to one now defunct wheat variety having a positive correlation to baking score in one season only (Douglas 1987). Given that Mg influences protein synthesis this result cannot be discounted. However there are some sets of unpublished data and observations that may be useful.

1. Several years ago Pyne Gould Guinness (M. Kelly pers. comm.) screened a range of liquid products as once only sprays on winter wheat, applied at the late vegetative stages. Several proprietary liquid Mg products were used and compared against solid Epsom salt ($MgSO_4.7H_2O$). No product tested satisfactorily raised herbage Mg levels (one week and four weeks after application) and by the second sampling the control crop was no longer showing symptoms.
2. In 1996/97, a replicated trial in South Canterbury showed no yield response in Agria potatoes to 25kgMg/ha as kieserite on a soil with a QTMg 24 (Craighead unpublished data).
3. In 1999-2000 kieserite in late spring partly improved wheat herbage levels 3-4 weeks after application. This work was not replicated and the crop improved over time (the control area increased by 0.02%Mg and the treated area 0.035%Mg). Anecdotally kale seed has previously responded to a spring sidedressing with 20kgMg as kieserite (QTMg of 7).

In summary, the data would suggest that Mg deficiency is not a common occurrence, it is transient in nature and responses would not be expected unless soil levels are very low. The most responsive crops would appear to be sugar beet (although this is not commercially grown in New Zealand this could be indicative that brassica seed crops could be responsive) followed by potatoes and cereals.

Potatoes remain one crop where Mg deficiency is a potential problem, as many New Zealand growers still keep acid soil conditions (pH 5.2-5.6) to avoid common scab, predisposing crops to acid induced Mg deficiency. Also growers are using increasing rates of K fertiliser to grow process potatoes, recommendations for Russett Burbank potatoes exceeding 400kgK/ha, rates known above that required to maximise yield of Russett Burbank potatoes in Canterbury (Craighead unpublished data). Hossner and Doll (1970) demonstrated lower tuber yields to up to 224kgMg as Epsom salts when 465kgK was also used. Liming reduced this effect.

Product Choice

Choice of Mg product needs to be dictated by several factors including cost, timing and soil conditions. The most feasible options are kieserite ($MgSO_4.H_2O$), calcined magnesite (MgO) and dolomite (a CaMg carbonate), however Epsom salt ($MgSO_4.7H_2O$) or Liquid Mg products may also have a place.

It is hard to evaluate many trials because much of the early European and some Australian work relates to Mg deficiency as a consequence of acid soil conditions. As previously mentioned, in these situations, symptoms were alleviated by liming or the liming effect of products such as dolomite or calcined magnesite as much as the direct benefit of Mg fertiliser.

Cost

On a cost basis (approximate bulk prices ex Ravensdown Hornby works) calcined magnesite – fertiliser grade magnesium oxide (52%Mg, $430/tonne) is more cost effective than kieserite (15%Mg, $525/tonne). Dolomite sourced from Golden Bay (11%Mg, $80/tonne) may also be cost effective in the Upper South Island depending on the distance it must be freighted and whether a liming effect is also required.

Magnesium Source

Kieserite is more soluble than calcined magnesite and dolomite. Early work on sugar beet, potatoes and wheat in England (Bolton 1973) on acid sandy soils showed Epsom salts to be twice as effective as dolomite and calcined magnesite, with kieserite somewhat intermediate in effectiveness. A disadvantage of Epsom salts is its low concentration (10%Mg), and its high solubility and therefore its proneness to leaching. Kieserite has the advantage of being equally effective over a range of pH compared to calcined magnesite and dolomite which are less effective at high pH. Work by Draycott *et al* (1975) on sugar beet, carrots and cereals generally showed kieserite as the preferred form at pH>7.0. In a glasshouse study they showed kieserites effectiveness to decrease between pH 5.5 and 6.5 and change little between 6.5 and 7.5 whereas calcined magnesites effectiveness decreased with increasing pH. Draycott and Durrant (1972a) found at pH <6.5 there was no difference in the Mg content of sugar beet tops between kieserite and calcined magnesite when 100kgMg was applied. They also found kieserite overall gave a better response than a higher rate of calcined magnesite on sugar beet over a range of soil fertilities but also found that at very low soil Mg levels the advantage to kieserite was relatively greater. Draycott has also suggested for potatoes on soils where soil exchangeable Mg was above 50-100mg/l (ie for crop removal and to lift soil levels) calcined magnesite could be used.

The hardness and fineness of both products is also important as is the degree of calcining of the magnesite. Studies on calcined brucite (a harder form of MgO) in South Canterbury have shown pasture uptake to be almost on par with that of chinese calcined magnesite (Ravensdown internal report), while laboratory elution studies by Agresearch at Ruakura (Kear and Perrott 1999) indicate brucite is only marginally slower than magnesite in solubility. Draycott *et al* (1975) showed kieserite to give both spring and autumn yield responses in sugar beet, a lightly calcined product to give better autumn responses and a heavily calcined product to be non-effective as a spring application. Calcining temperatures above 800^0C or less and screening to take out the coarse fractions was more effective (Draycott and Allison 1998). While the lightly calcined product was not as effective as kieserite it did last longer. Haerdter (pers. comm.) also sited that on a sandy soil maize had better Mg uptake when using kieserite compared to fine or coarse dolomite, especially at higher pH. Kieserite also gave better soil recovery 25mths later than fine calcined magnesite (<1mm) or coarse calcined magnesite (1-3mm) or dolomite (1-5mm). In both instances the coarse fractions were especially less effective at high pH.

Draycott and Durrant (1972b) found kieserite was generally as equally effective to a sugar beet crop if applied to the seed bed or for a previous crop, three years earlier. Even though much of the Mg was lost from the plough layer (0-25cm) by the second crop, yields indicated that some was available at depth. Seed bed addition might be the best option for a first crop after soil diagnosis. Otherwise application the previous autumn could also be an option when incorporating stubble of the previous crop in the rotation.

Soil vs Foliar Application

Soil application can economically apply more Mg than sprays. Magnesium sprays can give an immediate colour change but the rates at which they are applied only supply a small amounts, typically <2.5kgMg/ha. In potatoes it has been reasonably common in England where soil Mg levels have been marginal, to add Epsom salts with blight sprays, so the crop receives several applications (Draycott and Allison 1998). If a deficiency is short lived, 1-2 sprays may be enough, especially if ground conditions preclude efficient soil uptake due to nutrient imbalances, cool temperatures or wet conditions. Archer (1988), concluded that when symptoms are induced by soil and climatic conditions, foliar sprays are unlikely to give yield responses unless the soil levels are very low and are applied early. Where Mg deficiency is induced a response to foliar applications is unlikely.

Foliar Mg sprays to winter wheat in the English ARC trials 1995-97 failed to give significant yield responses over a range of herbage Mg contents 0.1-0.13% (Chalmers *et al* 1999). Herbage Mg levels in 1997 marginally increased through the winter (0.12-0.15%) then dropped and remained stable at 0.11%Mg through the spring before peaking at 0.17%Mg in June (post flowering). Cooke (1982) found foliar sprays to give smaller increases than applying solid Mg before sowing in sugar beet.

In Germany, cereals often receive a late (post ear emergence) spray of Epsom salts to improve grain weight and quality. While late sprays may reduce translocation and delay senescence thereby extending grain fill, the effect of Mg cannot be isolated from that of sulphur in the product. In England, ADAS trials in 1990 on moderate Mg reserve soils, showed no yield or quality responses to flowering or post flowering sprays of Epsom salts although herbage levels were increased (Chalmers *et al* 1999).

In summary, as New Zealand soils in their natural state are slightly acidic (pH 5-5.5) and regularly farmed at a pH of 5.7-6.2, then at this pH range there is likely to be less difference between kieserite and calcined magnesite. However the data still suggests that kieserite would likely be the preferred product to calcined magnesite or dolomite at very low soil tests values and for spring crops where a quicker response is required.

Overall Conclusions

1. On the major cropping soils of New Zealand, responses to Mg are more likely if soil test values are low QTMg <6 (approx 0.25-0.30 me/100g or 25-30mg/l).
2. Climatic and soil conditions are likely to influence whether responses occur, particularly cool and perhaps dry conditions.
3. Crops, cereals in particular are likely to show leaf symptoms of Mg deficiency before yield depressions are measured, and these symptoms may only be transitory.
4. In New Zealand, the effectiveness of the various solid Mg fertilisers is likely to be influenced by when they are applied, and the rate at which they can be applied rather than

excessive pH. Kieserite, calcined magnesite (magnesium oxide) and dolomite are all likely to have a place.

5. Magnesium foliar sprays are likely to be of limited value in New Zealand.

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