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

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Abstract

In some of New Zealand's arable soils, magnesium (Mg) levels are declining, and symptoms of Mg deficiency have been observed in cereal and brassica seed crops in some seasons. This review defines the extent of Mg Deficiency in New Zealand's soils and examines the relevance of Mg deficiency to New Zealand's arable farming.

Additional key words: *kieserite, calcined magnesite, dolomite, cereals, soil application, foliar application, soil magnesium, herbage magnesium, magnesium uptake*

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 - Pallic soils) and their associated Recent and Gley soils, have developed under weak to moderate leaching. Most have medium or medium to high exchangeable Mg levels (1-7 me/100g) and have medium to high reserves of Mg (7-30 me/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 (0.7-3 me/100g). Most of the Yellow Grey Earths of the Canterbury Plains tend to fall at the lower end of this range (QTMg 15-30 or 0.7-1.5 me/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, (Ledgard and O'Connor, 1998; Roberts and Morton, 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 phenomenon. Roots absorb Mg from the soil solution that 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, e.g., 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 and oats but also depress the uptake of Mg (Castleman *et al.*, 1998; 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 increased dry matter yield (Tan *et al.*, 1992b). 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 these 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, Mg was found to have less effect than Ca on ameliorating Al toxicity in wheat, but a much greater effect than K (Kinraide and Parker, 1987). Some Mg x lime interactions have been found in maize in Australia on low pH sites but the extent of this has been confounded because some Australian lime soils contain 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, e.g., 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 and5 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. Draycott and Allison (1998) examined the interactions of N, K and Mg in a potato trial and found a wide range of K/Mg ratios, which suggested that 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 (400 kg K/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 (0-5 cm) 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, i.e., 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 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. This 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 commonly occur.

Crop Removal

An overview of the data on crop removal for various temperate crops (Metson, 1974) shows that the higher crop removals occur with root crops such as sugar beet and potatoes (18-50 kg Mg/ha), although the quoted removals are quite variable. For example, 30 kg Mg is removed in a sugar beet crop, 13 kg Mg in the 25 t of tops and 17 kg Mg in 65t of roots (Draycott and Allison, 1998). Bould *et al.* (1983) quote 14 kg Mg as being removed in a 50 t potato tuber crop. However whole crop uptake can be higher, e.g., 42 kg Mg in a 55t potato crop of which 27 kg is in the tubers (Haerdter pers. comm.). Historically cereals have removed less, usually 5-13 kg Mg/ha, e.g., 7 kg in a 6 t grain crop (Bould *et al.*, *19*83) while vegetable crops typically remove 5-22 kg Mg/ha. Today, crop removal values are likely to be higher because yields have substantially increased since much of this work was published. For example British work (Chalmers *et al.*, 1999) suggests an 8 t/ha winter wheat crop removes almost 15 kg Mg in grain and straw at harvest, but the maximum uptake at the soft dough stage would have been in the order of 30-35 kg Mg/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. However, symptoms in one sugar beet crop, one of the most sensitive crops to Mg deficiency, are no guarantee there will be 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), pH effects and K/Mg ratios as previously discussed.

Why are there now symptoms appearing 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, potatoes and crops with potentially higher Mg demands are now grown. 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.

The 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 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 (e.g., 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).

Deficiency 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 (e.g., 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 progresssion 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 older cereal leaves yellow/green spots are often arranged in a string like pearls or beads against a lighter background (e.g., 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 halted the plant first depleted the Mg in the older leaves. Grimme (1987) found that in cereals, 57-64% of the Mg was in the grain of which 39-62% had been translocated from the stem and leaves. In 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 outgrow these symptoms.

Critical levels for soil magnesium

Experience has shown that 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 (e.g., 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 50 mg/l available Mg and low at <25 mg/l available Mg (approx 4-5 on our quick test scale), especially for potatoes and sugar beet. However Draycott and Durrant (1972a) have shown the greatest responses on sugar beet are when levels are <15 mg/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 30 mg/l where a response may be seen and the 160 mg/l that ensures high herbage Mg % is obtained (Cooke, 1982). In Australian work on maize, Aitken *et al.* (1999), felt they were unlikely to see a response on soils where soil concentration was >0.27 cmol/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 3-20 kg Mg/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 0-15 cm, as opposed to 0-7.5 cm for a pastoral soil, then it is likely to take more fertiliser Mg to lift an arable soil test.

Critical levels for herbage magnesium

Pastore data well document the seasonal nature of herbage Mg concentration (Craighead unpublished). Typically herbage concentrations are at their lowest in late winter - early spring, when soil temperatures are still low but growth is increasing rapidly. 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 Mg levels do not 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 wheat in NSW, Australia, are usually attributable to cold temperatures and the restricted root system (particularly in acid soils) that prevent 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 are 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 that the transient nature of the deficiency symptoms in cereals often coincides 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 no symptoms 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 (i.e., 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) suggested that 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 showed symptoms at 0.025-0.05% Mg (Bould *et al.*, *19*83), but levels were considered low at 0.1-0.15% (leaf) and 0.05-0.15% in the roots (Draycott and Allison, 1998), while for canola the critical level seemed to be <0.14% pre-flowering (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 was 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 the flag leaf stage. 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 1960s 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 63 kg Mg (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 1980s on two wheat and two barley sites of low Mg (20-30 mg/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 1960s 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.*, *19*75). At the same time work at Brooms Barn (sandy soils) showed yield responses of 0-10 t/ha on 50 sugar beet trials (Cooke, 1982), no responses were seen above 35 mg/l exchangeable Mg, and soil levels had to be below 20 mg/l to give >5% response. Recommendations for sugar beet aim to apply 30-50 kg Mg/ha as maintenance or 80-100 kg Mg/ha in these deficient situations, the form of Mg being 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 54 kg Mg/ha and 3% yield responses to 20 kg Mg/ha in 16 German experiments (Perrenoud, 1983). While the German work found no effect on dry matter, Finnish work reported in the same review showed a slight reduction in dry matter and starch content with increasing Mg (up to 60 kg Mg/ha). Further German work on potatoes showed improvements in yield and starch from using 54 kg Mg/ha as kieserite and in the Netherlands in yield on sandy soils from using 16 or 32 kg Mg (Kemmler, 1982).

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

New Zealand data

There have been no published data on Mg in the New Zealand arable sector in over 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 ($MgSO_4 \cdot 7H_2O$). 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 potatoes cv. Agria to 25 kg Mg/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 side dressing with 20 kg Mg 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 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 potatoes cv. Russett Burbank exceeding 400 kg K/ha in Canterbury (Craighead unpublished data). Hossner and Doll (1970) demonstrated lower tuber yields to up to 224 kg Mg as Epsom salts when 465 kg K 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 ($MgSO_4 \cdot H_2O$), calcined magnesite (MgO) and dolomite (a CaMg carbonate). However Epsom salt ($MgSO_4 \cdot 7H_2O$) 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 acidic soil conditions. As previously mentioned in these situations, symptoms were alleviated by liming or by the liming effect of products such as dolomite or calcined magnesite as much as by the direct benefit of the Mg.

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 values 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 that kieserite's effectiveness decreased between pH 5.5 and 6.5 and changed 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 100 kg Mg 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 *et al.* 1975) has also suggested for potatoes on soils where soil exchangeable Mg was above 50-100 mg/l (i.e., 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 that kieserite gave both spring and autumn yield responses in sugar beet, a lightly calcined product gave better autumn responses and a heavily calcined product was non-effective as a spring application. Calcining temperatures above 800 ºC and screening to take out the coarse fractions were more effective (Draycott and Allison, 1998). While the lightly calcined product was not as effective as kieserite it did last longer. Haerdter (pers. comm.) has also found 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 25 moths later than fine calcined magnesite (<1mm) or coarse calcined magnesite (1-3 mm) or dolomite (1-5 mm). In both instances the coarse fractions were particularly less effective at high pH.

Draycott and Durrant (1972b) found kieserite was generally as equally effective for a sugar beet crop if applied to the seedbed or three years earlier to a previous crop. Even though much of the Mg was lost from the plough layer (0-25 cm) by the second crop, yields indicated that some was available at depth. Seedbed 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.

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 suggest 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.

Soil vs foliar application

Soil application can apply Mg more economically than sprays. Magnesium sprays can give an immediate colour change but the rates at which they are applied only supply small amounts, typically <2.5 kg Mg/ha. In potatoes in England where soil Mg levels have been marginal, it has been reasonably common 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 1995-97 ARC trials failed to give significant yield responses over a range (0.1-0.13%) of herbage Mg contents (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 gave 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).

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 25-30 mg/l).
2. Climatic and soil conditions, particularly cool and perhaps dry conditions, are likely to influence whether responses occur.
3. Cereals crops 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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