The impact of fertiliser magnesium and potassium on the seasonal herbage magnesium concentration of some South Island dairy pastures

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Abstract

Herbage magnesium (Mg) concentrations were monitored for various Mg fertiliser regimes on dairy pasture at three West Coast dairy sites, for 2-4 years and one site at Methven, for one year. Treatments included three annual Mg rates compared against untreated pasture. Plots were duplicated and sampled prior to each grazing. On all sites, herbage Mg levels cycled through the year irrespective of Mg usage or rate of application and were generally at their lowest in the spring and highest in summer. On all sites mean herbage Mg levels lifted with increasing rate of fertiliser Mg. On one site continuous Mg application for four years lifted herbage levels permanently above 0.2 % in the last year. At a fifth site in North Canterbury where different rates of potassium (K) were used for three years, K fertiliser caused minimum depression in herbage Mg levels, except in the most responsive and driest second season when 120 kgK was used. Mean Mg concentration declined at all K rates as the effects of an initial Mg application of 20 kg Mg/ha wore off.

Additional Key Words: Mg, K, herbage nutrients.

Introduction

Pasture responses to magnesium (Mg) have been rare in New Zealand as most soils have reasonable levels of exchangeable magnesium (Metson and Brooks, 1975). There have been no dry matter responses on soils in the field with QTMg >5, or in glasshouse trials with QTMg > 6-7 (Edmeades, 1999). These soil levels usually coincide with herbage Mg levels of 0.15 % or greater. Where responses have been obtained they have been on soils such as coarse textured Pumice soils and on highly leached podzols which are marginally deficient (0.3-1.0me./100g or QTMg 4-15), (McNaught and Dorofaeff, 1965; Chittenden *et al.*, 1967).

Recent surveys indicate that soil Mg levels have declined in the major dairy regions, in particular on the Yellow Brown Loams (or 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, 1998a). In the past decade the average QTMg values have declined from 25 to 21 in the Waikato and 22 to 16 in the Bay of Plenty. This is attributed to significant losses of Mg through leaching and milk production. A mass balance for Mg based on data from the No.2 dairy farm at Ruakura indicates that 22kgMg/ha is annually being lost from a high producing dairy farm (Roberts and Morton, 1998a), although losses on a sedimentary soil in Southland were half those at Ruakura (Ledgard and O'Connor, 1998) indicating that losses vary with different soil types.

Maintaining soil QTMg values above 5 does not necessarily address the issue of animal health. A lactating dairy cow has a minimum requirement in spring herbage of 0.16 % Mg, assuming dry matter intake is sufficient to meet energy requirements (Grace, 1983). Wilson and Grace (1978) had previously demonstrated that 0.12 % Mg in spring herbage was adequate to maintain normal performance and maintain blood plasma levels indicating there are other factors which also predispose lactating cows to animal health conditions such as hypomagnesaemia. Of these, the intake of K is considered to have the greatest impact on absorption of Mg within the animal (Grace, 1983) as well as depressing Mg uptake (McNaught *et al.*, 1968a; Roberts, 1994). This effect is greater with grasses as compared to clover (McNaught *et al.*, 1968a; McNaught *et al.*, 1973b) as grasses tend to have lower herbage Mg concentrations (Kay and Hill, 1998).

Excessive calcium will also reduce plant uptake of Mg and increase leaching, although liming has enhanced Mg uptake in crops in acid soil conditions (Kemmler, 1982). Nitrogen and its form is also important, as ammonium-N also competes for plant uptake with Mg, particularly in cold and anaerobic conditions which prevent nitrification

(Mulder, 1956). However nitrate-N will enhance Mg uptake, but increase leaching, as Mg is the preferred carrier ion when nitrate is leached (Archer, 1988). Climatic and soil conditions (soil moisture, temperature, daily radiation and sunshine hours) also influence plant uptake (McNaught *et al.,* 1968b; Roberts, 1994; Winter, pers. comm.).

McNaught *et al* (1973) have shown that herbage magnesium levels vary seasonally and are usually at their lowest at the end of winter. As this time coincides with the period of greatest risk from hypomagnesaemia in dairy cows, an aim should be to lift levels at this time of year. While herbage Mg levels of 0.2-0.22 % do not necessarily prevent hypomagnesaemia (Grace, 1983) they should reduce the severity and longevity of the condition. The consensus from numerous trials is that it requires a QTMg level of 25-30 to achieve 0.22 %Mg or better in the herbage (Roberts and Morton, 1998b).

McNaught *et al* (1973a) using various Mg fertilisers demonstrated it is not difficult to lift soil Mg levels in a Yellow Brown Loam. However they showed it takes increasing amounts of Mg to lift the herbage Mg level as the initial soil level increases. It required 23 kg Mg to lift the herbage level from 0.14 to 0.17 %, 60 kg Mg to lift it from 0.2 to 0.23 % and 150kgMg to lift it from 0.26 to 0.29 %. While annual maintenance requirements for a high producing dairy farm are approximately 20-25 kg Mg/ha, O'Connor *et al* (1987) found that in order to lift soil and herbage levels quickly, high rates (eg. 100 kg Mg/ha) were more effective than a lower Mg rate, and maintained soil, herbage and animal plasma Mg levels for longer.

In Mid Canterbury and on the West Coast soil QTMg of <12 are common. While the Recent and Yellow Grey Earth (or Pallic) soils of the eastern South Island, where many new dairy conversions have taken place, have good reserves and exchangeable Mg (Metson and Brooks, 1975), the West Coast dairy soils, mainly Yellow Brown Earths (Brown or terrace soils) and Recent soils, like their neighbouring Podzols are developed under high leaching and/or weathering and may have low exchangeable and reserve Mg values. In both areas most dairy farmers regularly supplement Mg in the spring.

The objective of this paper was to look at the seasonal variations in herbage Mg levels in dairy pasture at four Canterbury and West Coast dairy sites under different rates of Mg fertiliser. Data were also taken from a fifth trial in North Canterbury where the impact of fertiliser K on herbage Mg levels was examined.

Materials and Methods

West Coast sites

In 1996 monitor plots were laid down on three West Coast dairy farms. The sites were at Westport (Norm Trebilcock), Reefton (Gym Partnership), and at Kowhitirangi (Burden Partnership). The Westport and Kowhitirangi sites were on Hokitika Recent soils and the Reefton site an Ahaura Yellow Brown Earth (terrace soil). These are typical of the main dairy soils of the West Coast. The Westport and Reefton trials ran for two seasons (1996/97-1997/98) and were on flat sites. The Kowhitirangi site continued for four seasons (until 1999/00) and was established on two year old hump and hollow pasture. On all sites, treatments included 0, 40, 80 and 120 kg/ha of Mg applied annually in the autumn. For year four at Kowhitirangi, the fertiliser treatments reverted to 40 kg Mg annually. Plots were 4 m x 2.5 m ($10m^2$) and were duplicated. Prior to grazing, a herbage sample was taken from each plot for analysis. Annual soil tests were also taken each autumn. Plots received the same fertiliser and management programme as the paddock. No fertiliser Mg was used apart from that applied by the treatments. Initial QTMg soil test values (0-7.5 cm) were 12, 12 and 4 respectively.

Methven site

The trial at this site ran for one year, 1999/00 near Methven (Tony Nixon) and was on a Gorge Yellow Brown Earth (or Brown) soil. Treatments were the same as for the West Coast sites, and the plots were treated similarly. The initial QTMg was 9.

On all four sites Mg was applied as magnesium oxide (calcined magnesite, 52 % Mg) imported from China by Ravensdown Fertiliser Co-op. Ltd.

North Canterbury site

This trial ran for three seasons, 1997/98 until 1999/00 at Pahau Pastures, Culverden and was on a Darnley Yellow Grey Earth (or Pallic) soil under border dyke irrigation. The trial was fully replicated (four replicates) and compared 0, 40, 80 and 120 kg K/ha applied as split dressings (Aug/Sept, Nov and Jan/Feb). Dressings were split 20 kg, 20 kg, 0 kg (at the 40 kg K rate), 30 kg, 30 kg and 20 kg (at the 80 kg K rate) and 40 kg, 40 kg, 40 kg (at the 120 kg K rate). Plots consisted of a full border 200m x 10m in size and were grazed and managed according to normal farm practice. Magnesium (20 kg/ha as kieserite, magnesium sulphate, 15 % Mg) was applied as an initial dressing in spring 1997 in addition to 2.5 t/ha of lime. Pasture samples were taken prior to grazing and analysed for the cations Ca, Mg, K and Na. This paper only concentrates on the K/Mg interaction. Initial QTMg levels across the site averaged almost 30.

Herbage was sampled by plucking randomly at grazing height across each plot, sufficient to give 300-500 gms fresh weight. Soil samples were taken to 7.5 cm, on the West Coast and Methven sites, 8 cores/plot. On the Culverden trial, more cores were taken randomly across the border. At this site no soil or herbage samples were taken within a metre of the base of the border check or crutch area, or within 5 m of the end of each border. Herbage was washed and soil and herbage dried and ground at Ravensdown Hornby Works or Seadown Store, and sent to Analytical Research Laboratories (ARL) at Napier (first four sites) and Celentis lab, Ruakura (Culverden site) for analysis.

Results

Herbage results for the control and the 80 kg Mg/ha treatment on the three West Coast sites are given in Figures 1a. Westport, Figure 1b. Reefton and Figure 1c. Kowhitirangi for the 1996/97 and 1997/98 seasons. The 40 kg and 120 kg rates are not shown for ease of reading.

Herbage Mg % cycled throughout the year at all three sites (Fig. 1). Levels generally declined through the winter and were at or near their lowest in the spring (spring 96 Reefton, spring 97 Westport, Kowhitirangi). Herbage Mg levels rose quickly in the summer but the time this occurred varied slightly between sites and seasons. Herbage Mg levels continued to increase in year 2 at Reefton.

Herbage Mg levels lifted with the addition of all rates of Mg (Table 1). Although at individual grazings herbage Mg levels fluctuated slightly between treatments, mean herbage concentration increased with increasing rate of Mg.

Soil Mg levels lifted on all three sites with increasing rates of Mg applied (Table 2), especially on the Reefton site where QTMg were 20-33 units above the untreated plots after two applications. This compared to 5.5-9.5 at Westport and 2-6.5 at Kowhitirangi for the same period

Herbage Mg data are given for each MgO treatment at the Methven site in 1999/00 (Fig. 2), 1999/00.

Table 1. Herbage magnesium levels averaged over first two years of trial (or one year at Methven – Nixon's).

	Westport	Reefton	Kowhitirangi	Methven
Control	0.200	0.175	0.178	0.205
40 kg Mg	0.211	0.194	0.197	0.203
80 kg Mg	0.241	0.222	0.210	0.211
120 kg Mg	0.246	0.226	0.214	0.233
$LSD_{5\%}$	0.054	0.019	0.017	0.014
Significance of linear trend (in the four rates 0, 40, 80, 120 kgMg)				
	10 % sig.	**	**	**

** = $p < 0.01$

Table 2. Autumn soil QTMg levels for three West Coast sites after two years of application and four years (Kowhitirangi).

	Westport 1998	Reefton 11998	Kowhitirangi 1998	Kowhitirangi 00
Control	9.0	13.5	5.0	6.5
40 kg Mg	14.5	34.0	7.0	13.5
80 kg Mg	16.5	45.5	8.0	14.5
120 kg Mg	18.5	46.5	11.5	17.0
$LSD_{5\%}$	12.5	21.2	5.1	4.3
Significance of linear trend (in the four rates 0, 40, 80, 120 kgMg)				
	10 % sig.	* .	**	**

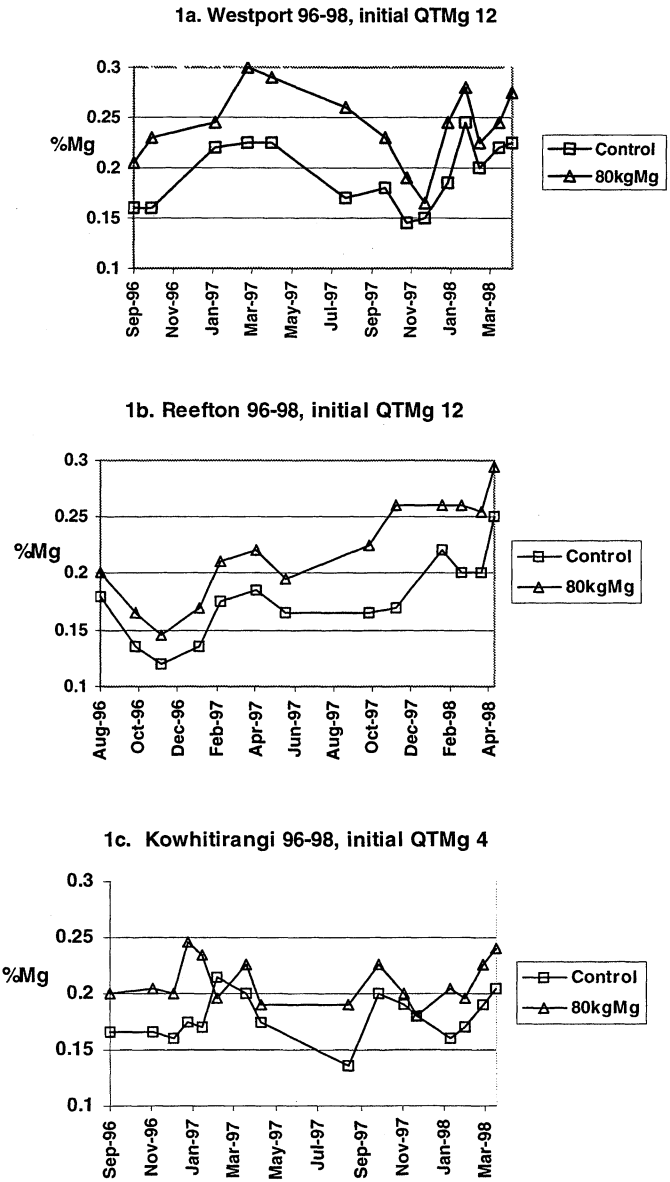

Figure 1. Herbage Mg concentration at three West Coast sites, a. Wesport, b. Reefton, c. Kowhitirangi where nil or 80 kgMg as magnesium oxide applied annually in autumn 96 and 97.

Table 3. Herbage magnesium levels averaged over each year at Kowhitirangi (Burden's). NB: Year 4 received 40 kgMg on all of treatments 2-4).

	Year 1	Year 2	Year 3	Year 4
Control	0.178	0.179	0.184	0.204
40kg Mg	0.198	0.197	0.214	0.234
80kg Mg	0.212	0.208	0.234	0.237
120kg Mg	0.217	0.211	0.238	0.248
$LSD_{5\%}$	0.036	0.009	0.028	0.009
Significance of linear trend (in the four rates 0, 40, 80, 120kgMg)	*	**	**	**

** = $p < 0.01$, * = $p < 0.05$

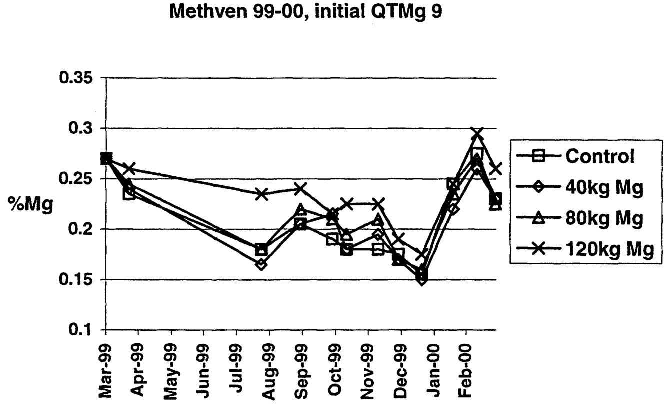

Figure 2. Herbage Mg concentration at Methven 1999/00 at different rates of autumn applied Mg as magnesium oxide.

At Methven, the annual cycling seen on the West Coast sites was repeated but is more clearly represented due to the more intensive sampling (this was a higher producing site). There was a slight decline in herbage Mg levels through the winter with the lowest values seen in the spring and early summer. Treatment differences showed up quickly, especially at the highest rate which kept herbage Mg levels above 0.2-0.22 % for most of the year. There was a significant improvement in herbage Mg concentration with increasing rates of Mg applied, especially at the highest Mg rate (Table 1).

At the Kowhitirangi site the cyclic nature of herbage Mg was demonstrated over a longer period (Fig. 3.). Continuous application of Mg gradually lifted the mean herbage concentration (Table 3) and this effect became more pronounced with time and with increasing rate of Mg applied. Magnesium fertiliser reduced the degree of decline in winter herbage Mg levels. By the last season generally all Mg treatments kept herbage Mg values above 0.2 %. After 4 years of Mg application soil Mg values had lifted 7-11.5 units above their control plots or 9.5-14 units above the initial site value (Table 2).

Herbage Mg data for the Culverden site are given in Fig. 4 on a grazing basis, and mean (annual) data in Table 4. Herbage Mg levels cycled as on the other sites, irrespective of the K treatment. Herbage values declined over time as a single application of kieserite was depleted. Over time the period in spring at which herbage Mg remained below 0.20 % also increased. Immediately after K application in year 2, there was a drop in herbage Mg levels and this was significant at the highest K rate.

Soil Mg levels drifted slightly from almost QTMg 30 in spring 1997 to almost QTMg 25 in spring 2000.

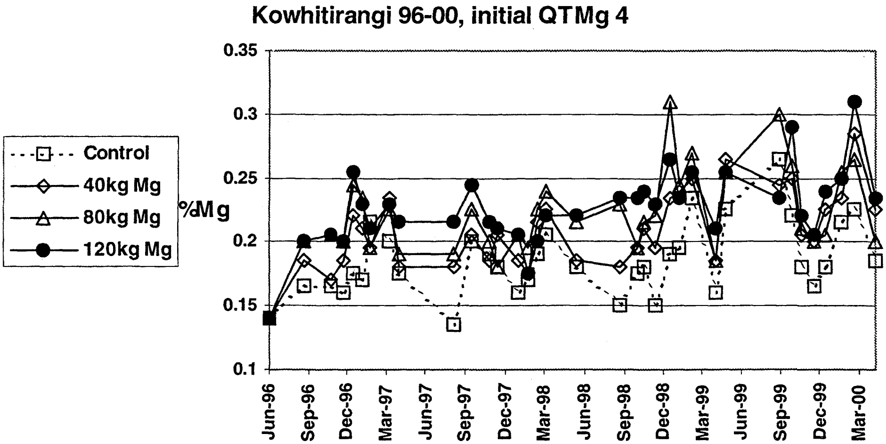

Figure 3. Herbage Mg concentration at Kowhitirangi 1996-00 at different rates of autumn applied as magnesium oxide in 96, 97 and 98 and a standard Mg rate of 40 kg in 1999.

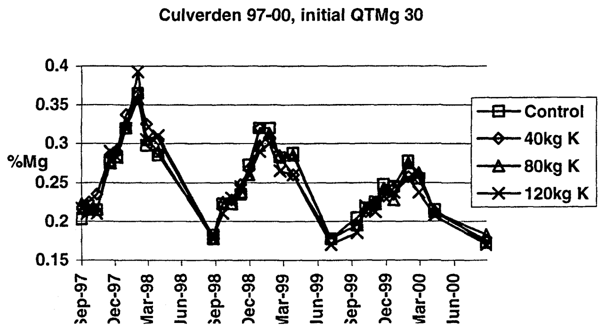

Figure 4. Herbage Mg concentration at Culverden 1997-00 at different K application rates in response to an initial spring application of 20 kg Mg as kieserite

Table 4. Herbagemagnesium levels averaged over each year, potassium trial, Culverden.

	Year 1	Year 2	Year 3
Control	0.265	0.260	0.229
40kgK	0.276	0.257	0.223
80kgK	0.267	0.256	0.226
120kgK	0.272	0.248	0.217
$LSD_{5\%}$	0.011	0.008	0.013
Significance of linear trend (in the four rates 0, 40, 80, 120kgK/ha/yr)			
	ns	**	ns

ns not significant, ** = $p < 0.01$

Discussion

Cycling

The cycling of herbage Mg concentrations was similar between the sites irrespective of the season, whether they were a highly leached Recent soil, a summer dry or moisture adequate Yellow Grey Earth or (at least in year 1), a highly leached Yellow Brown Earth. These trends are similar to those observed by others (McNaught *et al.,* 1968a; 1968b; 1973; O'Connor, 1987; Winter, pers. comm.) on a range of Yellow Brown Loams and Yellow Grey to Yellow Brown Intergrade soils, indicating the cycling effect is independent of soil type.

Climatic conditions and farm management (eg. Nitrogen (N) usage) must play some part in that while the cyclic trend is the same, the exact curve is not repeated each year. This was also observed on Taranaki pasture (Roberts, 1994). The lowest values are generally in late winter, early spring and this is shortly after the coolest months for soil temperature (June/July) and usually the lowest sunshine hours. Magnesium levels rise rapidly in summer and again this corresponds to increasing sunshine hours and soil temperature. The slight hiccups in Mg concentration sometimes experienced in December/January probably coincide with dry soil conditions. This was certainly the case at Methven where it was dry and all herbage cation concentrations were depressed at this time. All nutrient levels quickly recovered once it rained. Variances in moisture also likely contribute at other times, on the West Coast it only takes two weeks without rain to go into partial moisture deficit. Similarly high rainfall events can occur at any time, especially in September/October. There was much less variation at the Culverden site as the site was irrigated.

Nitrogen and K must also affect the results, these farmers regularly use N, particularly to encourage early spring growth which will dilute Mg levels or compete as ammonium-N for Mg uptake. Late October/early November usually coincides with the main application of K on these dairy farms and this impact is further discussed in a following section.

The Reefton site behaved differently from the other sites in the second year and management decisions are most likely the reason for this. The property changed sharemilkers between the two seasons (and following the completion of the work) and not only was a lower stocking rate run in the second year, but N inputs were severely reduced. Also as part of the share agreement a specific pasture cover was required at the end of the second season and so some cows were prematurely dried off further reducing grazing pressure. All these factors would contribute to greater regrowth allowing time for plants to accumulate Mg.

Addition of magnesium

The results show Mg fertiliser can lift mean herbage levels as demonstrated previously by McNaught *et al.,* (1973) and O'Connor (1987) on Yellow Brown Loams. Although the sites with the lower soil test levels don't necessarily have the lowest herbage Mg levels, in looking at Table 1, there is a slightly better response on the two sites with higher initial soil test values. It is the highest rate that has the most pronounced effect and the full data as displayed for the Methven and Kowhitirangi sites shows a clearer improvement initially to an autumn application and when herbage Mg levels are naturally depressed, ie the subsequent winter. This is because magnesium oxide is sparingly soluble in water compared to kieserite (<0.01g/l vs >400g/l, Haerdter pers. comm.) and so takes time to release. Higher rates will help offset this. This was demonstrated in three cropping trials at Methven on Yellow Grey Earths (Craighead and Martin, 2001). These data support O'Connor's reasoning for using high initial rates of Mg as a one off application (O'Connor *et al.,* 1987). However this needs qualifying. At Culverden the Mg status in year 1 showed that at a QTMg >25, a maintenance application of 20kgMg kept herbage Mg levels above 0.2-0.22 % for most of the year. Conversely at Kowhitirangi (where initially QTMg was 4), it took two initial applications of 80 or 120kgMg/ha followed by annual 40kg, for herbage Mg levels to stay for a sufficient period above 0.2-0.22 %Mg in year 4. Hence a single large development application may hold for sites where QTMg is intermediate, 12-25, (O'Connor's Ruakura site was 17), and further additions may be required if levels are below this.

Using the Kowhitirangi data, as a general rule, there continues to be a difference in mean herbage Mg levels between the Mg rates with time, despite reverting from 'development' rates to 40kgMg on all Mg treatments for year 4. By this time each treatment had different soil test values. Although McNaught *et al* (1973) showed it should take much more Mg to lift herbage Mg from a higher initial Mg level, and the narrowing of the difference in mean herbage between 40 and 80kg may well support this in year 4, the greater residual effect of the 120kgMg treatment has maintained its superiority in year 4. However it must be borne in mind that interpretation of treatment effects over time will be clouded by nutrient transfer between plots, as the plots were open to grazing. This influence is supported by a general improvement in the soil (which lifted to 6.5) and herbage levels of the control plots.

The 40kgMg application rate should not be seen as a development rate as it is at most only double a maintenance Mg rate (O'Connor *et al.,* 1987). This would account for the erratic response of this rate in year 1, especially on the Methven site.

Soil test results

Magnesium fertiliser improved soil test results on the three West Coast sites, but the response rate varied according to the site. At Reefton it required only 4-7kgMg for each unit increase in QTMg above the control, the greatest efficiency being at the lowest rate. Even this rate (2 x 40kgMg) lifted QTMg to over 30. This would explain why herbage Mg levels were high in year 2 on this site. At Westport it required between 14-25kgMg and at Kowhitirangi (23-38kgMg after 4 yrs). Generally the best efficiency was at the lowest rate although at Kowhitirangi it also varied between the second and fourth years. This perhaps highlights the variability associated with soil test measurements in small areas open to grazing (ie due to nutrient transfer) and this may contribute to the poorer efficiencies than those previously observed (see below). The Kowhitirangi site being a recent hump and hollow had previously had significant mixing of topsoil and subsoil prior to laying down the trial. And this may have impacted on the Mg reserves available in the resulting topsoil. Soil type may explain the site differences, the Westport and Kowhitirangi sites are Recent soils, and Reefton a Yellow Brown Earth. Methven was also on a Yellow Brown Earth and although this trial did not run for sufficient time to accurately see the effect of Mg on soil levels, regular monitoring of the farm itself showed Mg (as dolomite) lifted soil test results over 2 years, it taking approx 5-6kgMg for each unit (Strachan, pers. comm.). On Yellow Brown Loams, McNaught's data showed it takes approx 8kgMg to lift one QTMg unit (McNaught *et al.,* 1973) and from O'Connor's work at Ruakura, (O'Connor *et al.,* 1987), 11-13kgMg per QTMg unit, supporting the view that development rates will vary with soil type.

Influence of K

The Culverden results show variability in the impact of multiple K applications on herbage Mg levels. The initial maintenance dressing of Mg shows that when soil Mg levels are good, that good herbage Mg levels can be maintained despite K addition. Although mean herbage Mg levels are maintained above 0.2 % it is still of concern that herbage levels can temporarily drop below 0.2 % in late winter, indicating that other corrective measures such as Mg dusting are still required. Of greater concern is the period over which this occurs appears to increase with time as the soil and herbage Mg levels decline. In the second season K fertiliser at a high rate did significantly drop mean Mg herbage levels, although the actual Mg levels were still good. This was a relatively drier year and irrigation could not optimise dry matter production. Dry matter responses to potassium were also good in this year compared to the minimal responses displayed in years 1 and 3 (Craighead, 2000), so dilution of herbage Mg through extra growth may have had some influence. McNaught *et al* (1968a) also noticed K interacted with Mg earlier when higher K rates were used. The effect of the high rates of K was not as great as those demonstrated in early Waikato and Northland trials (Roberts, 1994) where the first application of K (30-35kgK/ha) caused a greater relative reduction in herbage Mg levels than rates of 125kgK/ha or greater. However on these trials fertiliser K lifted herbage K levels dramatically and/or to high levels of 3.8-4.4 %K whereas at the Culverden site, herbage K levels generally stayed 2.5-3.5 % throughout the year, irrespective of K treatment. The Culverden site was also not very responsive to K compared to the Waikato site. McNaught *et al* (1973b) have previously shown that K effects on Mg are greater where K deficiency needs to be corrected.

These data present a strong case for maintaining soil Mg values near 30 to maintain high herbage Mg levels, where extra K is used to boost seasonal growth. That level may well be closer to 25 as suggested by Roberts and Morton (1998b) if lower K rates or no K is used. Although the data suggested it was sometimes worthwhile to use K (Craighead 2001), the most likely economic rate would have been between 40-80kgK, rather than 120kgK. On this soil in order to impact minimally on herbage Mg levels, but give dry matter responses, a spring application of K could be avoided and 40kgK applied in late Oct to be topped up with a further 20-25kg in Jan only if the season was relatively dry.

The data from Reefton also suggest that QTMg levels above 30 will maintain herbage levels above 0.2-0.22 %. The 40kgMg treatment was not as effective as the 80 or 120kg treatment in doing this. The data from the Westport and Kowhitirangi sites suggest QTMg levels of at least 20-25 are required to keep herbage Mg levels above 0.2-0.22 %. All three sites typically receive 60kgK/ha as maintenance fertiliser and this is not considered a high rate of K.

Conclusions

Herbage Mg values cycle and are usually at their lowest in early spring and/or early summer

Fertiliser Mg lifts herbage Mg levels but does not prevent cycling.

Herbage Mg levels increase with increasing rate of Mg applied. Initially, lower application rates of Mg (40kg) give more inconsistent responses than higher rates (80 or 120kgMg/ha).

Continual Mg usage will eventually lift herbage Mg levels above 0.2-0.22 %

Soil responses to Mg differ on each site according to initial soil test and soil type.

Potassium can influence herbage Mg levels at high rates (120kgK/ha) in some (dry) seasons.

Results suggest in order to keep herbage Mg levels above 0.22 %, soil Mg levels need to be near 30 if reasonable amounts of K is used and a minimum of 20 but more likely >25, where low amounts of K are used, but this may depend on soil type and will likely vary with seasonal conditions.

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