Does the timing and rate of magnesium fertilisers affect yield and quality of winter wheat?

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Abstract

Magnesium (Mg) is a key nutrient required by wheat for photosynthesis, protein synthesis and carbohydrate metabolism. Magnesium was applied to an irrigated autumn-sown wheat crop at establishment as serpentine superphosphate and kieserite, and in spring as kieserite only at 25, 50 and 75 kg Mg/ha. An autumn/spring even split of serpentine superphosphate/kieserite at 25 and 50 kg Mg/ha was also applied. No effect of Mg fertiliser treatments on grain yield or grain quality measurements was detected. Soil sampling at the beginning of the experiment measured soil Mg levels of 7-11 QT Mg. Herbage Mg concentration was influenced by application of Mg fertilisers, however this was only sustained beyond stem extension by rates of kieserite greater than 50 kg Mg/ha in spring, or 25 kg Mg/ha if Mg had also been applied in autumn. This suggests that low Mg soil test levels or historical Mg deficiency in wheat should be combated with regular applications of maintenance fertiliser such as serpentine superphosphate, with a low Mg concentration in herbage in spring able to be corrected with an application of a soluble product such as kieserite during the growing season. When soil Mg levels are maintained sufficient for other crops and pasture grown in rotation with wheat, Mg is unlikely to limit yield or quality of wheat.

Additional keywords: *Triticum aestivum*, Canterbury, arable, serpentine super, kieserite, fertility

Introduction

Wheat (*Triticum aestivum*) yields in New Zealand have been increasing steadily since the 1990s (Millner and Roskruge, 2013). Canterbury is the largest wheat growing area, with 82% of the wheat area, planted in New Zealand (Statistics New Zealand, 2016). Wheat grown in Canterbury is part of a typical arable crop rotation of cereals, grass, clover and vegetable seeds, process vegetables and silage crops (Ministry for Primary Industries, 2012).

Magnesium (Mg) is found at the centre of the chlorophyll molecule and, therefore, is considered an essential macronutrient for photosynthesis (McLaren and Cameron, 1996; Wilkinson *et al.*, 1990). It also activates many enzyme reactions and has a crucial role in protein synthesis, and lipid and carbohydrate metabolism. In wheat, Mg deficiency will limit photosynthesis, yield and protein content. Uptake by plants occurs in the form of Mg^{2+} from soil solution. Magnesium is less available to plants at low soil pH, and uptake can also be limited by high soil levels of potassium (K), calcium or ammonium.

Magnesium is present in the soil in clay minerals (very slowly available to plants), in an exchangeable form (readily available) and in soil solution (readily available) (McLaren and Cameron, 1996). Weathering of secondary clay minerals may provide sufficient Mg to support crop or pasture growth in some soils. Average losses are 5-17 kg Mg/ha/year via leaching, which is dependent on rainfall and soil properties. The nitrification process in soils enhances leaching of Mg due to the release of H^+ ions displacing Mg^{2+} from exchange sites, with leaching of nitrate requiring a cation to accompany it to maintain charge neutrality. Thus, leaching of Mg is likely greater in cultivated soils, especially in intensive cropping.

The soil Quick test (QT) for Mg involves an ammonium acetate extraction, then determination of Mg by atomic absorption spectrophotometry (McLaren and Cameron, 1996). A QT Mg soil test of >10 has traditionally been considered sufficient for most arable crops (Nicholls *et al.*, 2009), with 20-30 being targeted for vegetable cropping (Reid & Morton, 2019). However, test values of soils considered to be deficient in in the United Kingdom are approximately equivalent to a QT Mg of 4-5 (Craighead and Martin, 2001).

The most relevant research to Mg fertilisation of wheat in New Zealand was by Craighead and Martin (2001), who conducted experiments at three sites near Methven. The reasons for these experiments were to investigate whether current Mg fertilisation practice was limiting wheat yields; citing the greater yielding crops being achieved by farmers than historically. Improvements in yields over time have been possible due to improved cultivars and agronomic management. With higher yields there is greater offtake of Mg, which as accompanied anecdotal evidence of greater incidence of Mg deficiency. Specialist seed and process crop production and greater crop rotation intensity are also factors that may have contributed to greater offtake of Mg. Low soil Mg levels on arable farms in Canterbury, particularly around the Methven region, were attributed to continuous crop removal and lack of emphasis on maintaining soil test levels. Craighead and Martin (2001) showed that even at relatively low QT Mg of 3-4, Mg fertilisation had no effect on grain yield or quality of a winter wheat crop. Since 2003, wheat yields in NZ have increased from 7.48 t/ha (Millner and Roskruge, 2013) to approximately 12 t/ha in Canterbury in 2020 (Grain Central, 2020) through a combination of cultivar improvement and agronomic management (Millner and Roskruge, 2013). Therefore, it is important to assess whether Mg requirements have changed over this period.

The aim of this research was to identify whether the application of Mg fertiliser, either as slow-release serpentine superphosphate or fast-releasing kieserite, would increase grain yield or quality in autumn-sown wheat at a low Mg soil test level in Canterbury.

Materials and Methods

Experiment details

A trial was established in a field of *Firelight* wheat, 2 km south-west of Methven, New Zealand (-43.642498, 171.615571) to determine the effect of Mg fertilisation on Mg uptake, yield and grain quality. The soil at the site was a well-drained Mayfield shallow silt loam (Typic Argillic Pallic Soil, New Zealand Soil Classification; Hewitt, 1992). The site was irrigated as required to avoid moisture deficit during the growing season using a centre pivot irrigator.

Sulphur super 15 (0-8.6-0-14.8) was broadcast at 350 kg/ha before sowing on 1 April 2019. A location within the field with low Mg availability (3-4 QT Mg units) was identified using results of grid soil sampling to 150 mm, carried out in August 2018. Soil tests (optimum ranges from Nicholls *et al.* (2009) are in brackets) taken from each replicate in March 2019 (excluding replicate three – see Discussion of Soil availability) in the area ranged from pH 6.1-6.3 (5.8-6.2), Olsen Phosphorus (P) 30-39 mg/L (>15), QT Potassium (K) 6-8 (6-10) and QT Mg 7-11; average of 9 (>10) and QT Na 5-6.

Seventy-two 11 m x 2.5 m experimental plots were established in the emerging crop on 16 April 2019 (12 treatments x six replicates). Treatments were applied to plots using a randomised block design. The autumn applied Mg treatments occurred on 16 April for the two products, serpentine super and kieserite, at 25, 50 and 75 kg Mg/ha. Serpentine super was also applied at 12.5 and 25 kg Mg/ha for the autumn/spring split application treatments. Phosphate (P) and sulphur (S) supply were balanced to all treatments using single superphosphate (0-9-0-10.5) and triple superphosphate (0-20.4-0-0).

Spring application of kieserite at 25, 50 and 75 kg Mg/ha, and a further 12.5 and 25 kg Mg/ha on the autumn/spring split application treatments, occurred on 13 September 2019, approximately two weeks after the occurrence of Zadoks growth stage (GS) 30. Sulphate-S supply was balanced to all treatments using ammonium sulphate (19.5-0-0-22) and nitrogen (N) supply using SustaiN (45.9-0-0-0). Magnesium treatments are described further in Table 1.

Irrigation, crop protection and N side-dressing were applied by the farmer, as per the surrounding field.

Table 1: Magnesium fertilisation treatments and timing.

Treatment number	Product	Magnesium application (kg Mg/ha)		
		Autumn 16 April	Spring 13 Sep	Total
1	None	0	0	0
2	Serpentine super	25	0	25
3	Serpentine super	50	0	50
4	Serpentine super	75	0	75
5	Kieserite	25	0	25
6	Kieserite	50	0	50
7	Kieserite	75	0	75
8	Kieserite	0	25	25
9	Kieserite	0	50	50
10	Kieserite	0	75	75
11	Serp. (aut)/kieserite (spr)	12.5	12.5	25
12	Serp.(aut)/kieserite (spr)	25	25	50

Measurements

Plant counts were conducted on 13 May to measure establishment. Two counts of 2 m long drill rows (15 cm spacing) per plot were taken. Whole plant samples were taken from each plot on 30 August (GS30), 8 October (GS32; 25 days after spring application) and 19 November 2019 (67 days after spring application). These were analysed by RJ Hill Laboratories Ltd, Hamilton, for Mg content (%).

An area from each plot measuring 1.65 m by 11 m was harvested with a Sampo plot combine harvester on 21 February 2020 and yield determined. An approximately 1 kg subsample was retained from each plot for grain quality measurements (protein, thousand grain weight, screenings, and test weight), which were conducted by NZGrainlab, Christchurch.

Statistical analysis

Statistical Tool for Agricultural Research (STAR) was used to perform an ANOVA and Tukeys Honest Significant Difference (HSD) test to evaluate statistical significance for plant count, herbage nutrient uptake, yield and grain quality data.

Results

Plant counts

Crop establishment was not affected by Mg application, with all treatments achieving an average of 105 plants/m^2.

Magnesium concentration in herbage

All results for yield and herbage Mg concentration are presented in Table 2.

At GS30 (30 August), autumn applied kieserite at 75 kg Mg/ha resulted in a herbage Mg concentration 0.093%, 0.020% greater than the control concentration of 0.073% Mg (P=0.0051). No other treatment was significantly different to the control.

Table 2: Herbage Mg concentration at each sampling and final grain yield for different Mg fertilisation products, rates and timings.

Trt	Timing	Product		Herbage Mg concentration (%)			Yield
			Mg (kg/ha)	GS30	GS32	GS49	T/ha
1		Control	0	0.073b	0.105b	0.120b	15.6
2	Autumn	Serp. super	25	0.083ab	0.117ab	0.142ab	15.9
3			50	0.078ab	0.122ab	0.142ab	15.7
4			75	0.083ab	0.127a	0.137ab	15.4
5		Kieserite	25	0.080ab	0.120ab	0.137ab	15.8
6			50	0.085ab	0.128a	0.142ab	15.8
7			75	0.093a	0.135a	0.142ab	15.6
8	Spring	Kieserite	25	0.080ab	0.125a	0.135ab	15.6
9			50	0.075b	0.130a	0.143a	15.8
10			75	0.073b	0.135a	0.150a	15.7
11	Autumn /spring	Serp /Kieserite	25	0.078ab	0.127a	0.133ab	15.5
12			50	0.083ab	0.128a	0.145a	15.7
		Mean		0.080	0.125	0.139	15.67
		sig		0.0051	0.0002	0.0061	NS
		CV%		10.19	8.11	7.97	1.65
		Tukey HSD		0.016	0.02	0.022	

At GS32 (8 October), the control herbage Mg concentration was 0.105%. Autumn application of serpentine super at 25 or 50 kg Mg/ha, and autumn application of kieserite at 25 kg Mg/ha were not significantly different, however autumn serpentine super at 75 kg Mg/ha, autumn kieserite at 50 and 75 kg Mg/ha, and all treatments with a spring application had elevated herbage Mg concentrations in the range of 0.125-0.135% Mg (P=0.0002)

At GS49 (19 November), herbage Mg concentration in the control was 0.120%. The only treatments that were different were spring kieserite at 50 kg Mg/ha (0.143% Mg) and 75 kg Mg/ha (0.150% Mg); and the 50 kg Mg/ha split evenly between serpentine super in autumn and kieserite in spring (0.145% Mg) (P=0.022).

Grain yield and quality

Grain yield (15.67 t/ha), screenings (0.6%), thousand grain weight (49.4 g), test weight (72.5 kg/hl) and protein (9.7%) were not affected by Mg application.

Discussion

Soil availability

The area of the field chosen for this experiment was selected based on the results of grid soil testing carried out in August 2018. The expected QT Mg level of this site was 4-6. Magnesium deficiency is typically seen in arable crops in spring and early summer, where plant requirements during rapid vegetative growth exceed the replenishment of readily available Mg from the soil, especially after winter leaching (Craighead, M. 2001). This grid sampling likely measured Mg availability at the lowest point of the year.

At the time of establishing the trial in the field of emerging wheat in March 2019, a soil test was taken from each replicate to determine exact soil fertility status of the site and determine any variability. The soil test from replicate 3 has been excluded from the ranges presented above as the Olsen P (42), QT K (11), QT Mg (17) and sulphate S (136) were very different to the results from the other replicates, which was likely caused by contamination of the sample rather than large variation of fertility confined to that replicate only. The QT Mg values for the other replicates ranged from 7-11, which was not as low as the grid sampling results, however the seasonal fluctuation of Mg availability is likely responsible for this discrepancy. These values were still considered low when using the optimum ranges presented by Nicholls *et al.*, (2009). The base saturation occupancy (as a percent of cation exchange capacity) of Mg ranged from 2.2-3.2% at this site, with deficiencies likely to occur when the base saturation is less than 5% (Mayland and Wilkinson, 1989; McLaren and Cameron, 1996).

Fertilisation treatments

Serpentine superphosphate is commonly used as a base fertiliser to provide maintenance P (6.8%) requirements for autumn cereal cropping, which also contains Mg (5%). Reverted superphosphates are less soluble than other P fertilisers and are considered more appropriate for maintenance of long-term reserves rather than capital application (McLaren and Cameron, 1996). Serpentine superphosphate was chosen for this experiment as an autumn-only application (treatments 2-4, 11-12), as this is when this fertiliser would be applied in a cropping situation, and predominantly used as a maintenance phosphate fertiliser that also contains Mg. A rate of 500-600 kg/ha serpentine super would be considered an appropriate maintenance rate for an irrigated autumn-sown wheat crop in the Canterbury region, supplying 25-30 kg/ha Mg. The rate was increased to 75 kg/ha to understand whether slow-release products could remedy deficiency at sufficient rates of Mg. Serpentine super is generally not applied in spring to autumn-sown cereals as it does not release Mg fast enough to overcome deficiency in the growing season of the crop.

Kieserite is a soluble Mg sulphate (16% Mg, 16% S) product. Due to its expense, the use is usually constrained to high-value horticultural crops, or correcting an immediate deficiency in pastoral or arable farming. Rates of kieserite are typically applied at 20-30 kg/ha to overcome a deficiency (Nicholls *et al.*, 2009). Due to the immediate solubility, Mg in kieserite is at risk of being leached if applied before winter. However, treatments 5-7 were included to understand whether it could be used to quickly increase soil levels of Mg before the period of crop demand.

The most likely treatments to occur on farm would be serpentine super at 25 kg Mg/ha (treatment 2), possibly followed by kieserite in spring at 25 kg Mg/ha (treatment 12); or superphosphate or sulphur super base fertiliser as in the case of the surround field, followed by 25 kg Mg/ha as kieserite in spring (treatment 8). Higher rates of kieserite become cost-prohibitive and deficiency symptoms would likely have been noticed in previous crops, resulting in a capital/maintenance programme incorporating serpentine super, dolomite or Mg oxide to build soil levels with slow-release products, rather than high rates of kieserite to dose the current crop beyond its requirement. Crop removal of Mg in high yielding wheat crops is suggested to be 15 kg Mg/ha, however the peak uptake may be closer to 30 kg Mg/ha (Chalmers *et al.*, 1999).

Grain yield and quality

Magnesium fertilisation had no effect on grain yield or any grain quality (thousand grain weight, protein, test weight and screenings) attributes measured in this experiment. This corroborates the findings by Craighead and Martin (2001), who did not find an effect on yield or quality of winter wheat fertilised with kieserite or Mg oxide in autumn or spring, at rates of 22.5, 45 and 90 kg Mg/ha at three different sites near Methven, with QT Mg values of 3-4. Therefore, where QT Mg values are maintained >10 to meet the requirements of other crops or pasture within the crop rotation, then it is unlikely that soil Mg status will limit wheat crop yield or quality.

Magnesium concentration in herbage

At GS30 sampling, the only autumn treatment that had increased Mg concentration above the control (0.073%) was kieserite at 75 kg Mg/ha (0.093%). No treatment met the 0.1-0.3% range specified by Nicholls *et al*. (2009) for plant dry weight. This was concordant with the results from Craighead and Martin (2001) from the trial (Grant) property, where their samples ranged from 0.082% for the control treatment, through to 0.091% when kieserite had been applied at 90 kg Mg/ha in autumn. The two other sites in their experiment achieved 0.118% and 0.099% Mg in the control treatment, up to 0.152% and 0.120% for an application of 90 kg Mg/ha as kieserite in autumn, suggesting that the trial property has a history of low Mg content in autumn-sown wheat crops, and was a suitable choice of site for this experiment.

In the current study at GS32, the control Mg concentration lifted to 0.105%, consistent with the belief that Mg availability to plants is low in early spring following winter leaching events. Autumn applied serpentine super at 75 kg Mg/ha or kieserite above 50 kg Mg/ha elevated Mg concentration when compared with the control, suggesting that the slower-release serpentine super treatment did take longer to become available when compared with the equivalent rate of kieserite at 75 kg Mg/ha, which had already had a significant effect at GS30, and 50 kg Mg/ha as kieserite was as effective at this sampling point. All spring treatments significantly increased tissue Mg concentration compared with the control, which implies that a spring application of a soluble Mg product, such as kieserite, will have an effect at rates of at least 25 kg Mg/ha, as suggested to overcome deficiency in the literature (McLaren and Cameron, 1996; Nicholls *et al.*, 2009). However, if a maintenance rate of Mg has been applied in the autumn, the rate of kieserite may be reduced to 12.5 kg Mg/ha, whilst still having a significant effect on crop Mg concentration.

By GS49 on 19 November, the control had increased to 0.120% Mg, achieving the sufficient range of 0.1-0.3% Mg specified in Nicholls *et al.* (2009). Only kieserite at 50 and 75 kg Mg/ha (0.143 and 0.150% Mg respectively), and the autumn/spring split totalling 50 kg Mg/ha (0.147% Mg) sustained a significant increase in crop Mg concentration above the control, due to the dilution effect of rapid dry matter accumulation during the stem extension and booting stages of crop development.

Craighead and Martin (2001) measured only one treatment at one site with a significant increase of 0.019% (to 0.100%) in herbage Mg concentration above the control at GS49. This was achieved by application of 90 kg Mg/ha as kieserite in autumn. The results from this earlier study at the property used for the current study had no significant effect of any treatments at this sampling.

Conclusions

In this trial where the average Mg soil test was 9 QT units at establishment was below the optimum for arable production (10 or greater QT units); Mg fertiliser rate, timing and product did not affect grain yield or quality of a winter wheat crop.

Measured low Mg concentration in herbage of the control treatment at GS30 or GS32 had increased to within the optimum range by GS49, and withholding Mg fertilisation did not result in a reduction in yield or grain quality. This suggests that whilst soil supply to the crop was constrained in early spring, soil release was able to meet crop demand this had no detrimental effect at harvest.

Based on this study and that by Craighead and Martin (2001), it is unlikely that Mg will be concern for wheat yield or quality even if Mg QT levels are low, especially if soil Mg status is maintained at a level required by other crops or pasture in the rotation. However, if Mg concentration in herbage is of concern, it can be improved using Mg fertilisers. To raise herbage Mg % at GS49 (late booting) above the control, a spring application of at least 50 kg Mg/ha was required as kieserite. If Mg had been applied in autumn at 25 kg Mg/ha, this was also achieved by an additional 25 kg Mg/ha kieserite in spring. This is the most practical strategy to apply on-farm, as the serpentine super rate applied is consistent with the maintenance phosphate requirement of an irrigated autumn-sown wheat crop. Other Mg fertilisers, such as dolomite or magnesium oxide, may also be considered for capital and maintenance applications of Mg in autumn, depending on cost-effectiveness per kg of Mg and the requirement for liming in the case of dolomite, or if the preferred delivery of P is via a soluble superphosphate product.

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