# INVESTIGATING THREE METHODS FOR IMPROVING MAGNESIUM NUTRITION OF CITRUS GROWN ON YOUNG SEDIMENTARY SOILS

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**Abstract**

Magnesium (Mg) deficiency is widespread in citrus grown in young sedimentary soils, particularly those found in Gisborne. The use of Mg sulphate fertiliser to overcome the deficiency has been unsuccessful, and foliar Mg sprays have been only partly successful, with multiple sprays causing only a small increase in leaf Mg. This paper reports on three trials aimed at improving tree Mg status. Three techniques were investigated: (1) Mg chloride fertiliser; (2) foliar sprays at higher concentrations than in previous trials; and (3) trunk injection. Fruit were analysed to determine if these treatments affected fruit quality. The fertiliser trial compared Mg chloride with Mg sulphate at 850 g Mg/tree applied for two seasons. Neither fertiliser treatment increased leaf Mg compared with the control (no Mg) treatment.

The foliar spray trial used four sprays of Mg nitrate at concentrations of 1%, 1.5% and 2% at a high water rate, or 5% Mg nitrate plus adjuvants at one-fifth water volume (to give the same Mg rate per ha as the 1% Mg high water volume treatment). The results showed that all Mg nitrate treatments increased leaf Mg and did not cause leaf burn. Leaf Mg increased as spray Mg concentration increased, with 2% Mg giving leaf Mg concentrations 0.6 g/kg higher than the control treatment. The use of 5% Mg nitrate plus adjuvants in one-fifth water volume might give a greater increase in leaf Mg than a high water volume without adjuvants and will allow five times more area to be covered on the one tank. However, this time saving will need to be weighed against the additional cost of the adjuvants.

The trunk injection trial compared Mg in four forms, as sulphate, nitrate, citrate or glycate injected at 1.5 g Mg/tree, and a high rate of Mg sulphate at 3 g Mg/tree. The results showed that only Mg citrate caused a significant (although small, 0.3 g/kg) increase in leaf Mg concentration. Increased plant Mg status did not improve fruit quality.

## Background

Magnesium (Mg) deficiency is common in citrus grown in young sedimentary soils such as those found in Gisborne, New Zealand. The Mg deficiency is believed to be caused by high ratios of K and Ca relative to Mg in these soils (Morton et al. 2008). Visible deficiency symptoms (interveinal leaf chlorosis) appear in winter as the fruit begin to mature, but the visual symptoms may disappear in spring. Magnesium concentrations of 440 leaf samples from Gisborne citrus orchards, taken between 2002 and 2005, averaged 2.1 g/kg (Morton et al. 2008), well below the recommended range of 2.6–6.0 g/kg (Sale 2001). Severe Mg deficiency can cause increased leaf abscission and twig dieback (Camp 1947), yield loss

(Dawood et al. 2001; Erner et al. 2004; Jones et al. 1971) and a decline in fruit quality (Dawood et al. 2001; Jones et al. 1971). However, it is not known whether the moderate Mg deficiency reported in Gisborne orchards is causing a decline in fruit yield or quality.

Previous fertiliser trials showed that kieserite (Mg sulphate) was ineffective in increasing leaf Mg in Gisborne citrus (Harty et al. 2002; Lupton 2005). Erner et al. (1984, 2004) also found that Mg sulphate was ineffective in raising the Mg status of Israeli citrus (orange) trees; however, large increases in foliar Mg were obtained using Mg chloride. Magnesium chloride (1.7 kg Mg/tree split over two seasons) worked into the soil in a 35 cm wide ring around the tree increased leaf Mg from 1.8 to 3.7g/kg four months after the second application.

Another strategy to increase leaf Mg is the use of foliar sprays (Harty et al. 2002, 2003; Trolove 2007). Initial trials (Trolove 2007) using pre-mixed products and label rates resulted in only small increases in leaf Mg. The Mg concentration in these products, when mixed at recommended rates (0.40–0.67% Mg nitrate equivalent), was lower than the 1% recommended by Sale (2001) for New Zealand citrus or the 1– 2% rate reported in the scientific literature (Erner et al. 1984, 2004; Jones et al. 1971). Therefore, we decided to do a further trial using Mg nitrate at 1–2%. A crystal formulation was chosen because it is much cheaper than pre-mixed liquid, and Mg nitrate was chosen because it usually gives a larger increase in leaf Mg than Mg sulphate (Embleton & Jones 1959; Trolove 2007). We also compared low water volume against the standard high water volume spray because previous trials showed that a low volume with a quantum mist sprayer gave a greater Mg uptake than a high volume sprayer with Massotti® jets (Trolove 2007). This was presumably because the quantum mist sprayer gave better coverage of the underside of the leaf (Manktelow 2005) where the stomata are located in citrus. A low volume airblast sprayer treatment was included to enable the two different sprayers to be compared, and also because most citrus growers in Gisborne have an airblast sprayer rather than a quantum mist sprayer.

Trunk injection has been successfully used to treat fungal diseases such as eutypa in grapes (Adrian Spiers, pers. comm.) and to correct micronutrient deficiencies (Fernandez-Escobar et al. 1993). This technology has promise because it avoids the need to get the nutrients in through the roots or leaves for trees grown on problem soils. From a practical perspective, injection technology could be helpful if it was quick and could supply sufficient nutrients for several years.

This paper reports trials of the three techniques mentioned above to raise leaf Mg concentration and improve fruit quality. Treatment effects on tree fruit yield were not determined because yield is generally highly variable from tree to tree and so large-scale trials over a number of years would be required to investigate the effect of increased Mg status on fruit yield. The first priority here was to develop a reliable technique for increasing leaf Mg concentration.

## Materials and methods

### *Fertiliser experiment*

The site chosen was a Satsuma mandarin orchard on a Makaraka clay loam (Table 1) at Manutuke near Gisborne, which had a history of low leaf Mg levels. There were three treatments: kieserite ($MgSO_4.H_2O$), magnesium chloride ($MgCl_2.6H_2O$), and a control. Fertilisers were applied at the rate of 850 g Mg/tree/season for two seasons (2005–06, 2006–07). The trees were approximately 1.5 m tall by 1.5 m wide, with a plant density of 3,333/ha.

**Table 1.** Soil cation concentrations prior to the trial in September 2006.

| Depth | Reserve K[1] | Soil solution[2] (mM) | | | Exchangeable[3] (meq/100 g) | | |
|---|---|---|---|---|---|---|---|
| (cm) | meq/100 g | Mg | Ca | K | Mg | Ca | K |
| 0–15 | 23.6 | 0.07 | 0.28 | 0.41 | 4.6 | 27.5 | 1.6 |
| 15–30 | 23.6 | 0.06 | 0.25 | 0.33 | 4.5 | 25.0 | 1.6 |
| 30–45 | 23.6 | 0.05 | 0.27 | 0.22 | 4.3 | 26.4 | 1.3 |
| 45–60 | 23.8 | 0.04 | 0.21 | 0.09 | 4.2 | 26.7 | 1.2 |

[1] Carey & Metherell (2003); 0.7–1.3 meq/100 g is considered normal, and 1.3–5.0 is considered high (Peter Lorentz, pers. comm.)

[2] Soil wetted up to a gravimetric water content of 60% overnight then extracted by centrifugation (Reynolds 1984).

[3] Exchangeable in 1*M* $NH_4$ acetate at pH 7.0 (Blakemore et al. 1987).

Fertilisers were broadcast on the soil surface in a 1 m wide band between 0.25 and 0.70 m from each side of the tree (i.e. the fertiliser was spread over 0.9 $m^2$, split half either side of the tree). The fertiliser was applied on 19 September 2005 and on 5 September 2006. Six trees were used for each treatment, with one tree considered a replicate.
Leaf samples (20 per tree of the youngest fully expanded mature leaves from a non-fruiting terminal) were taken on 1 March 2006 and 9 February 2007 and analysed for Mg (and also for Cl in 2006). On 12 May 2007, the number of fruit per tree was counted and 34 representative fruit were picked from each tree, 17 from each side. Fruit weight, Brix and titratable acidity (TA) were measured using standard industry techniques.

***Foliar spray experiment***
The site chosen was a block of Kwano Satsuma mandarins on Woodlands Rd near Gisborne. The trees were 2.5 m tall by 2 m wide and planted at 1481 trees/ha. Plots were 10 trees long by 1 row wide, with a guard row between each treated row. There were four replicates of each treatment. There were seven treatments, listed in Table 2. To ensure good coverage and penetration in the low volume treatments it was necessary to add a spreader, penetrant and humectant.

The first spray was applied on the 17 November 2007 at 30–40% flush and the second on the 30 November 2007 at 60% flush. The remaining two sprays were applied on the 15 and 29 December 2007 at close to full flush. Spraying was done between 6.30 and 9.30 am to maximise absorption of Mg into the leaf. Leaves in all treatments were checked 2 weeks after application for signs of leaf burn.

Leaf samples (48 leaves were taken from the six middle trees in the central row of each plot) were taken 3 weeks after the final spray (21 January 2008), and again on 4 March 2008. Trees that were not representative of the plot (i.e. they carried an unusually large fruit load or were visibly much paler) were not sampled. Leaves chosen were the youngest fully expanded leaf from the spring flush (Edwards et al. 1997). Samples were washed with distilled water then analysed for Mg. Thirty-six fruit were picked from each plot on 3 July 2008 and analysed for Brix and TA.

**Table 2**. A description of the treatments used in the experiment. LV = low water volume, QM = quantum mist and AB = airblast.

| Treatment name | Rate of Mg nitrate[1] per 100L | Water rate (L/ha) | Mg applied (kg Mg/ha per spray) | Method of application | Cost of 4 sprays per ha* in 2008 |
|---|---|---|---|---|---|
| Control | 0 | 0 | | | |
| 1% Mg nitrate | 1 kg | 1500 | 1.4 | Airblast and boom | $63 |
| 1.5% Mg nitrate | 1.5 kg | 1500 | 2.1 | Airblast and boom | $95 |
| 2% Mg nitrate | 2 kg | 1500 | 2.8 | Airblast and boom | $126 |
| Mg nitrate+ seaweed | 1 kg + Kelpak at 200 mL/100L | 1500 | 1.4 | Airblast and boom | $63+ $50=$113 |
| LV QM + Mg nitrate | 5 kg + recommended rates on adjuvants[2] | 300 | 1.4 | Quantum mist sprayer | $63+37+56+43 =$199 |
| LV AB + Mg nitrate | 5 kg + recommended rates on adjuvants[2] | 300 | 1.4 | Airblast and boom | $63+37+56+43 =$199 |

[1] Contained 9.5% Mg

[2] Liberate (a penetrant @114 mL/100 L), + Du-Wett® (a spreader @147 mL/100 L), + Humectant @300 mL/100 L

* Note: These calculations do not account for any labour costs saved using low water volumes (less time spent filling and mixing new tanks of spray)

Note: Mention of a brand name does not imply any endorsement by the authors.

***Trunk injection experiments***

The same site was used for these experiments as the fertiliser trial. In the first experiment, there were three treatments: a control, and one and two injections of $MgSO_4$. There were five replicates of each treatment.

This experiment was split into two stages. The first stage was carried out with the above treatments to determine whether there was any harmful effect of injecting a concentrated solution into the trunk. The treatments were applied on 19 September 2005, using 1 tree per replicate. After 2 weeks no difference was observed between the injected and control trees so an additional two trees per replicate were injected on 4 October 2005, making a total of three trees per replicate. On each occasion, Satsuma mandarin trees were injected with 50 mL of 30% $MgSO_4.7H_2O$ using a Stemex Stemgun via a single 8 mm diameter hole drilled centrally through ¾ of the trunk located just above the graft. The hole was sealed with a plastic plug after injection. Injection was conducted at high pressures varying from 1,700 to 3,400 kPa. Slow pumping ensured that the trunk did not split. Fifty millilitres was near the maximum amount of solution that could easily be injected. Trees from the high treatment were injected with a further 50 mL of 30% $MgSO_4.7H_2O$ on 17 January 2006. Leaf samples were taken at the standard sampling time in March (1 March 2006). At fruit harvest (12 May 2006), 15 mandarins were sampled from the outside of the canopy on the eastern side of each tree. Fruit was not collected from the 1 injection treatment, since the leaf Mg concentrations were similar to those of the control treatment. Fruit was juiced and analysed for Brix and TA.

An additional injection experiment was conducted on Satsuma mandarin trees (same orchard as above) to compare different Mg sources. It was conducted much later in the season when Mg deficiency symptoms are usually beginning to show in leaves from trees with high fruit loads. Fifty millilitres of solution, containing either 30% $MgSO_4.7H_2O$, 31.5% $Mg(NO_3)_2$ or Mg-citrate was injected into the trunk. Magnesium citrate was prepared by dissolving 20% hydrated $MgCO_3$ w/v (12.1% Mg) and 35% w/v citric acid in water. A Mg glycate treatment was applied by pouring Mg glycate powder into a hole drilled into the tree trunk on a slight angle. The rate of Mg was 1.5 g/tree, except for Mg citrate, which was 1.1 g/tree because Mg citrate is less soluble than the nitrate and sulphate salts. There was also a control treatment (not injected). Trees were injected on 5 April 2006. There were four replicates (one tree per replicate). Leaf samples were taken from each tree immediately prior to injection and again on 11 May 2006, when fruit samples were also taken. The number of fruit per tree was counted, and 34 fruit per tree (in some cases less if there were not 34 fruit on the tree) were taken to determine Brix and TA. Equal numbers of fruit were taken from each side of the tree.

## Results and discussion

### *Fertiliser experiment*

None of the Mg fertiliser treatments caused a significant increase in Mg concentration in leaves collected 6 and 18 months after the first fertiliser application (Table 3). Magnesium chloride increased fruit Brix relative to the unfertilised control. Since the plant Mg concentration was not significantly changed (as indicated by the leaf tests) it is possible that the chloride, rather than the Mg, caused the observed increase in Brix. There was no significant effect of the fertiliser on TA.

**Table 3.** Leaf Mg concentrations and internal fruit quality measurements of Satsuma mandarins following treatment with $MgSO_4$ or $MgCl_2$ at a rate of 0.85 kg Mg/tree (applied in early spring 2005 and 2006).

| Treatment | Leaf Mg[1] (g/kg) | Leaf Mg[2] (g/kg) | Brix[1] (°Bx) | TA[1] | Brix:Acid[1] |
|---|---|---|---|---|---|
| Control | 1.9[3] | 2.6[3] | 8.21 | 1.33 | 6.39 |
| $MgSO_4$ | 2.0 | 2.8 | 7.86 | 1.48 | 5.30 |
| $MgCl_2$ | 2.0 | 2.6 | 8.61 | 1.34 | 6.52 |
| Significance (*P*) | 0.33 (n.s.) | 0.24 (n.s.) | 0.004 | 0.28 (n.s.) | 0.11 (n.s.) |
| LSD(5%) | 0.3 | 0.3 | 0.37 | 0.22 | 1.27 |

[1]Measured in 2006

[2]Measured in 2007

[3]Replicate 1 from the control treatment was removed in both seasons because it was much lower than the other five replicates in both seasons.

The reasons for the lack of response to Mg fertiliser are unclear. The orchard was unirrigated and we cannot exclude the possibility that the trees may have obtained a large proportion of their nutrients from deep in the profile as the soil dried during summer. Nevertheless, these results are not unusual – Harty et al. (2002) and Lupton (2005) have also reported that large applications of Mg salts were ineffective at increasing leaf Mg in citrus grown around Gisborne.

***Foliar spray trial***

There were no symptoms of leaf burn in any of the treatments following spray application. The leaf tissue analysis showed good agreement between the January sampling and the early March sampling, indicating that the leaf Mg concentration was reasonably stable over the late summer period, which is the recommended time for leaf sampling citrus.

**Table 4.** Leaf Mg concentrations at 3 (January) and 9 (March) weeks after the final Mg spray, and fruit quality measurements at harvest (3 July 2008). LV = low water volume, QM = quantum mist and AB = airblast.

| Treatment | Leaf Mg (Jan) (g/kg) | Leaf Mg (Mar) (g/kg) | Brix (°Bx) | Acid | Brix: Acid |
|---|---|---|---|---|---|
| Control | 0.16 | 0.16 | 9.18 | 0.95 | 9.59 |
| 1% Mg nitrate | 0.19 | 0.20 | 9.43 | 0.98 | 9.61 |
| 1.5% Mg nitrate | 0.20 | 0.20 | 9.30 | 1.00 | 9.31 |
| 2% Mg nitrate | 0.22 | 0.21 | 8.95 | 0.94 | 9.61 |
| Mg nitrate +Seaweed | 0.20 | 0.20 | 8.80 | 0.97 | 9.06 |
| LV QM+Mg nitrate | 0.19 | 0.20 | 9.13 | 0.89 | 10.15 |
| LV AB+Mg nitrate | 0.23 | 0.22 | 9.35 | 0.91 | 10.36 |
| *P* | 0.01 | 0.03 | 0.48 (n.s.) | 0.36 (n.s.) | 0.49 (n.s.) |
| LSD (5%) | 0.03 | 0.03 | 0.68 | 0.11 | 0.39 |

All Mg treatments at all dates significantly increased leaf Mg concentration (except for the January sampling of the quantum mist treatment, Table 4). Increasing the rate of Mg in the spray increased leaf Mg. The January increase in leaf Mg in the 2% Mg nitrate treatment (0.6 g/kg) was approximately double that of the 1% Mg nitrate (3.5g/kg), although in March this difference was not statistically significant. Adding seaweed did not increase leaf Mg concentration.

The low water volume application with adjuvants applied by Quantum mist was not significantly different to the standard application with an airblast sprayer at high volume. The January leaf sampling showed that the low volume application with adjuvants by an airblast sprayer gave a significantly ($P$ = 0.06) greater increase in leaf Mg than the high water volume treatment that applied the same Mg rate per hectare (1% Mg nitrate). However, the March sampling showed no significant difference between these treatments. Certainly, there was no decrease in Mg uptake from reducing the water volume, meaning five times greater area can be covered without having to refill the tank. This saving in time must be weighed against the cost of the adjuvants (Table 2).

The first two replicates from the quantum mist treatment did not show increased leaf Mg concentration, whereas in the second two replicates, increases were similar to those obtained with the low volume airblast treatment. The reason for the low results from the first two replicates is unknown – good results with a quantum mist sprayer has been achieved in previous trials (Manktelow 2005; Trolove 2007).

There was no significant effect of foliar Mg sprays on fruit quality (data not shown). Other New Zealand studies have shown small changes in fruit quality due to foliar spraying with

Mg. Trolove (2007) found that Mg-deficient Valencia oranges (leaf Mg 1.9 g/kg) were more acidic (0.07 units) than those from trees sprayed with foliar Mg (leaf Mg 2.6 g/kg). Harty et al. (2003) found a small (0.4 °Bx) decrease (statistical significance not given) in Mg-deficient navel oranges (leaf Mg 1.4 g/kg) compared with Mg-sprayed trees (leaf Mg 1.8 g/kg). The few relevant scientific studies that have been published suggest that the effects of Mg deficiency on fruit quality intensify as the severity of the deficiency increases. For example, Erner et al. (2004) reported no effects of mild Mg deficiency (leaf concentration of control treatment was 2.7 g/kg; Mg-treated plots 4.2 g/kg), although there was a yield decrease in one year out of four. Moss and Higgins (1971) reported an increase in fruit acidity in the Mg deficient treatments (leaf Mg concentration 1.3–2.2 g/kg, *c.f.* 3.2–5.0 g/kg in Mg-treated treatments). In very Mg-deficient trees (leaf Mg 1.4 g/kg), Dawood et al. (2001) noticed a significant decrease in Brix and yield and an increase in acidity compared with Mg-treated plants.

***Trunk injection trial***

There was no significant difference in leaf Mg concentration among the treatments, and all values were well below the minimum recommended Mg concentration of 2.6 g/kg (Table 5).

**Table 5.** Leaf nutrient concentrations and quality measurements of fruit from mandarin trees injected with 30% $MgSO_4$ solution.

| Parameter | Control | 1 Injection | 2 Injections | *P* value | LSD(5%) |
|---|---|---|---|---|---|
| Leaf Ca (g/kg) | 42.2 | 41.1 | 42.4 | 0.86 | 5.4 |
| Leaf K (g/kg) | 15.8 | 15.0 | 14.6 | 0.10 | 1.2 |
| Leaf Mg (g/kg) | 1.8 | 1.9 | 2.0 | 0.13 | 0.2 |
| Brix (°Bx) | 7.43 | — | 8.08 | 0.04 | 0.6 |
| TA | 1.25 | — | 1.26 | 0.81 | 0.21 |
| Brix:Acid Ratio | 6.11 | — | 6.50 | 0.55 | 1.08 |
| Avg. fruit weight (g) | 128 | — | 126 | 0.92 | 30 |
| No. of fruit per tree | 115 | — | 112 | 0.90 | 43 |

Magnesium sulphate had no effect on TA or on fruit yield components. Two injections of Mg sulphate significantly increased fruit Brix by 0.65°Bx. However, stress can increase fruit Brix, e.g. girdling the tree (Yamane & Shibayama 2007), so it is not known whether the observed increase was due to the addition of Mg or to stress induced by the treatment. Certainly, it is clear that the increase in fruit Brix was not associated with any large increase in leaf Mg concentration.

The possibility that other Mg salts might be more effective than the sulphate was investigated in the second trunk injection experiment. The Mg glycate powder took the least time to apply. The Mg citrate was very viscous and needed to be pumped slowly into the tree to prevent the trunk from splitting.

Of the four forms of Mg compared, the only one that significantly increased leaf Mg concentration was Mg citrate (Table 6). Leaf Mg concentration decreased in all other treatments because Mg was transported out of the leaves and into the developing fruit. The increase in leaf Mg concentration associated with the Mg citrate treatment did not result in any significant change in internal fruit quality. The effect on leaf Mg was too small and the injection procedure too time consuming to warrant further investigation by the citrus industry.

**Table 6.** Change in leaf Mg and internal fruit quality 5 weeks after injection of various forms of Mg into the trunk of Satsuma mandarin trees. Negative values indicate a net translocation out of the leaves into the fruit.

| Parameter | Change in leaf Mg (g/kg) | Brix (°Bx) | TA | Brix:Acid |
|---|---|---|---|---|
| Control | -0.1 | 7.37 | 1.22 | 6.09 |
| Mg glycate | -0.1 | 6.81 | 1.42 | 5.06 |
| Mg citrate | 0.3 | 7.28 | 1.22 | 6.06 |
| Mg nitrate | -0.2 | 7.33 | 1.06 | 6.94 |
| Mg sulphate | -0.1 | 7.72 | 1.19 | 6.77 |
| Significance (*P*) | 0.01 | 0.13 | 0.19 | 0.03 |
| LSD | 0.2 | 0.67 | 0.31 | 1.17 |

## Conclusions

Of the three methods tested for increasing leaf Mg concentration, foliar spray was the only one that gave a significant increase in leaf Mg concentration over the control treatment of more than 0.3 g Mg/kg. There was no improvement in fruit quality that could be attributed to increased plant Mg status.

The main conclusions from the individual trials are as follows:

***Fertiliser trial***

- The application of a very large and expensive rate of Mg fertiliser (either in the chloride or sulphate form) to citrus grown on a Makaraka clay loam in Gisborne did not significantly increase leaf Mg concentrations.

***Foliar spray trial***

- Mg nitrate at 1–2% increased leaf Mg concentration and did not cause leaf burn.
- The higher the Mg concentration in the spray, the greater the increase in leaf Mg concentration.
- The use of one fifth water volume plus adjuvants may give a greater increase in leaf Mg concentration than a high water volume without adjuvants.
- Adding seaweed did not increase leaf Mg concentration.

***Injection trial***

- The only product that resulted in a significant, but small (0.3 g/kg) increase in leaf Mg was Mg citrate. However, the technique used was slow and laborious and not suitable for commercial use.

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