# Long-Term Responses of Magnesium-Deficient ‘Shamouti’ Orange Trees to Magnesium Application

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## Abstract

**Y. Erner, S. Shapchiski, M. Bazelet, B. Artzi and R. Lavon. Long-term responses of magnesium-deficient ‘Shamouti’ orange trees to magnesium application.** The effects of Mg applications on leaf Mg and yield were studied in a ‘Shamouti’ orange (*Citrus sinensis*) grove which had exhibited low leaf-Mg concentrations over six years. Soil applications of magnesium chloride were applied with a 35-cm-wide band under the tree canopy or injected into the irrigation system for two successive years, while magnesium nitrate was applied annually as a foliar spray. The band application increased the leaf Mg concentration by 0.2% and raised it to the sufficiency range for three years. One foliar spray, applied annually from the third year onwards, in addition to a soil application, maintained Mg content of the leaves within the optimal range. Average yields and the yield in year six were greater with combined soil and foliar Mg applications than in the unfertilized controls. Once leaf Mg concentrations have fallen to deficiency levels, it takes a long time for the tree to recover, therefore, growers should not let tree Mg levels fall below the optimal range.

**Key words**: *Citrus sinensis,* citrus nutrition, fertigation, mineral nutrition.

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## INTRODUCTION

Magnesium deficiency has become common citrus orchards in Israel as more growers apply potassium in an attempt to increase fruit size. The antagonism between Mg and K is well documented (Embleton *et al*., 1973b) and the standards for leaf K were raised from 0.60% to 0.75% of the dry matter about 30 year ago (water extractable method, Bar-Akiva, 1972; 1974). This new standard has increased the amount of K used and, as a result of this together with the improvement of K absorption through the use of fertigation (Dasberg *et al*., 1991; Lavon *et al*., 1990), many groves exhibit Mg deficiency. Magnesium-deficient citrus orchards need annual foliar applications of Mg, since Mg redistribution from old to young leaves is insufficient (Jones *et al*., 1971). It is recommended to apply $Mg(NO_3)_2$ annually, as a ground spray (1.6%) or as a low-volume aerial spray (Bar-Akiva *et al*., 1969), but the resulting increase in leaf Mg is only 0.02-0.07% and the method is considered unreliable (Erner *et al*., 1984). Moreover, the small increased leaf Mg content achieved by spraying was not accompanied by any visible improvement. Our previous study of the effect of soil $MgCl_2$ application (Erner *et al*., 1984) included no data on the long-term effect on yield. However, the wide distribution and intensity

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of Mg deficiency can no longer be ignored by the growers, as some dieback and loss of production has generated renewed interest in the application of Mg fertilizers.

The objetive of the present study was to examine the effects on leaf Mg concentration and yields of soil and foliar Mg applications to trees that showed Mg deficiency, over a six year period.

## MATERIALS AND METHODS

'Shamouti' orange trees (*Citrus sinensis* (L.) Osbeck) growing in the western part of the coastal citrus belt in Israel were used. The trees were 25 years old, spaced at 6 · 4 m, in a loamy sand soil. The experiment consisted of 16-tree plots, in five replicates, each plot containing four experimental trees and 12 guard trees. Trees were watered weekly by micro-sprinklers with one emitter per tree covered approximately 60% of the soil surface. Magnesium was applied to the soil as magnesium chloride ($MgCl_2 \cdot 6H_2O$; Mg content, 167 $g \cdot kg^{-1}$), or as a foliar spray of $Mg(NO_3)_2 \cdot 6H_2O$ (Mg content, 54 $g \cdot L^{-1}$).

Initially the 6-year experiment comprised three treatments + control: 1. Injection into the irrigation system (fertigation) at 14 kg of $MgCl_2 \cdot 6H_2O$ per tree; half of which (7 kg) was applied in July (after fruitlet drop) and half (7 kg) 1 year later. 2. Soil application as a 35-cm-wide band under the tree canopy, at 14 kg of $MgCl_2 \cdot 6H_2O$ per tree; the material was hoed into the soil to a depth of 5-7 cm and the amount was split as in the fertigation treatment. 3. A 1.6% aqueous $Mg(NO_3)_2 \cdot 6H_2O$ solution was applied annually in May as a foliar spray at 10 L per tree. After 2 years, the Mg treatments were divided into split plots (seven treatments, incliding control). In one half of each split plot in the $MgCl_2 \cdot 6H_2O$ treatments (soil or fertigation), no further applications were made, in order to enable evaluation of the residual effect, while the second half received an application of $Mg(NO_3)_2 \cdot 6H_2O$ as a 2% foliar spray in May, in addition to the band or fertigation treatment. In the foliar spray treatment one half of each split plot continued to receive one annual 2% $Mg(NO_3)_2 \cdot 6H_2O$ spray in May, and the other half was sprayed twice (2%), in May and June. In the sixth year, the foliar two-spray $Mg(NO_3)_2 \cdot 6H_2O$ treatment was replaced by four (2%) monthly sprayings: in May, June, July and August.

Leaf samples from fruiting terminals were taken in November, washed, dried and ground. A 50-mg sample of dried leaf powder was shaken in 10 ml water for 30 min and then filtered. An aliquot of the extract was analyzed for nitrate according to Kamm *et al*. (1965), modified for use with the autoanalyzer (Technicon, Inc., Bar-Akiva, 1972, 1974). Phosphorus was determined with amino naphthol and ammonium molybdate by use of the autoanalyzer, K was determined by flame photometry, Mg by atomic absorption, and Cl with a chloridometer.

Data were subjected to analysis of variance, and means were compared by Duncan's multiple range test ($P$ = 0.05). The Diagnosis and Recommandation Integrated System (DRIS) is an alternate approach with the old system that compare observed concentrations of the minerals to reference values. DRIS reflects nutritional balance and indicates not only the nutrient most likely to be limitting, but also the order in which other nutrients are likely to become limiting (Beverly *et al*., 1984). The Nutritional Imbalance Index (NII) was used to summarize the deviation of diagnosed tissues from DRIS norms. The NII was computed by summing DRIS indices, irrespective of sign; which has been correlated with yields (Davee *et al*., 1986) and compared with the critical concentration ranges. The larger the NII, the greater the intensity of imbalances among nutrients. NII values below 20 have been found to indicate the desired balance (I. Horesh, unpublished data).

## RESULTS AND DISCUSSION

A 6-year monitoring program showed that band application under the tree canopy increased leaf Mg and Cl concentrations significantly for at least 3 years, and that Cl dropped to the level of the control during the fourth year (Table 1). A similar trend was found in leaves for the Mg levels as found with the Cl. In the fifth year, in the band treatment the leaf levels of neither Mg nor Cl were found to be higher than those in the control, but in the band application supplemented with foliar sprays of 2% $Mg(NO_3)_2 \cdot 6H_2O$ the Mg level remained above minimum considered sufficient. These data highlight the residual effect of each treatment on the essential Mg or harmful Cl level and the necessity to combine band application and foliar spray treatments to maintain the desired Mg level.

In the fifth year leaf Mg concentrations showed significant differences between treatments (Table 2), and band application supplemented with foliar spray was found to increase yield by about 41% over the control (Table 3). However, when calculations were based on the average of the last 5 years the supplementary $Mg(NO_3)_2$ spray which was added to the soil $MgCl_2$ treatment from the third year onwards increased yield by about 23% over the control. 'Shamouti' orange, although known as a non-alternate bearing variety, fluctuates in yield by 30-40% from year to year. Since this fluctuation is bigger than the effect of Mg on yield, measurements over several years were required to get a significant yield response.

Magnesium application resulted in significantly lower leaf K content than that in the control, except for the band application that was terminated years earlier (Table 2). Chloride, P and $NO_3$ contents were not affected by the Mg treatments.

**Table 1**. Effect of Mg application on magnesium and chloride concentration in 'Shamouti' orange leaves (*Citrus sinensis*) over a six-year-period. Leaves sampled in November of each year.

***Cuadro 1.*** *Efecto de la aplicación de Mg en la concentración de magnesio y cloruro en hojas de naranja (*Citrus sinensis*) 'Shamouti' durante un periodo de seis años. Hojas muestreadas en noviembre de cada año.*

| Treatment | Year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1989 | | 1990 | | 1991 | | 1992 | | 1993 | | 1994 | |
| | Mg[1] | Cl[1] | Mg[1] | Cl[1] | Mg[1] | Cl[1] | Mg[1] | Cl[1] | Mg[1] | Cl[1] | Mg[1] | Cl[1] |
| Control | 0.13b | 0.21b | 0.22b | 0.23b | 0.27b | 0.22b | 0.27b | 0.28a | 0.28b | 0.25a | 0.28b | 0.23a |
| Soil | 0.21a | 0.83a | 0.48a | 1.12a | 0.43a | 0.61a | 0.32ab | 0.28a | 0.29b | 0.25a | 0.29b | 0.25a |
| Soil+Foliar (one spray) | 0.21a | 0.83a | 0.48a | 1.12a | 0.42a | 0.42a | 0.35a | 0.28a | 0.40a | 0.23a | 0.51a | 0.24a |

Different letters within columns indicate significant differences of means by Duncan's multiple range test, P=0.05.

**Table 2.** Effects of Mg application on 'Shamouti' orange (*Citrus sinensis*) mineral concentrations. Leaves sampled in November 1993, five years after the treatments began.

***Cuadro 2.*** *Efectos de la aplicación de Mg sobre la concentración minmeral en naranja (*Citrus sinensis*) 'Shamouti'. Hojas muestreadas en noviembre de 1993, cinco años después del inicio de los tratamientos.*

| Treatment | $NO_3$ ppm | P | K | Mg | Cl |
|---|---|---|---|---|---|
| | | % dry matter | | | |
| Control | 125a[1] | 0.082a[1] | 0.77a[1] | 0.25b[1] | 0.23a[1] |
| Soil | 137a | 0.082a | 0.62ab | 0.29b | 0.25a |
| Soil + Foliar (one spray) | 162a | 0.094a | 0.58b | 0.43a | 0.23a |
| Fertigation + Foliar (one spray) | 132a | 0.069a | 0.63b | 0.38ab | 0.24a |
| Foliar (two sprays) | 124a | 0.082a | 0.55b | 0.38ab | 0.24a |
| Optimum levels | 120-200 | >0.046 | >0.75 | >0.30 | <1.00 |

[1] Different letters within columns indicate significant differences between means according to Duncan's multiple range test ($P$ = 0.05).

The NII was found to be below 20 as a result of the application of Mg over the years, but it was not consistently correlated with yield (Table 3). Magnesium application, either as chloride or as nitrate, did not affect fruit quality (Table 4). No differences were found in acid concentration, TSS/acid ratio, or fruit weight (g) and yield in the last year; although significant differences in yield had been found in the fifth year (Table 3) and in the average over 5 years (54 ton·ha$^{-1}$ Soil + Foliar one spray and 44 ton·ha$^{-1}$ in the Control). Four sprayings of 2% $Mg(NO_3)_2$ increased leaf Mg concentration similarly to the increase triggered by the application of $MgCl_2$ plus one spray of $Mg(NO_3)_2$.

A significantly higher leaf Mg concentration than that in the control was found in 'Shamouti' orange leaves when $MgCl_2$ was applied as a band, at 14 kg per tree, divided equally between two applications. These data confirm our previous results (Erner *et al*., 1984) but the residual effect lasted only for one more year. Foliar application of $Mg(NO_3)_2$ at 1.6%, which was recommended for many years, has been discontinued by many growers because it was not considered effective. Our current data (not presented) and those from the previous work (Erner *et al*., 1984) showed that one spray of $Mg(NO_3)$ at a concentration below 2% might increase the Mg level in the leaves by not more than 0.07%, which is not sufficient to achieve a positive effect. Moreover, two sprayings per year at 2% were not always found to raise Mg to the sufficiency level, therefore the application of four sprayings per year was examined. In the present study, application of 2% $Mg(NO_3)_2$ as a foliar spray twice per year was found to increase the leaf Mg concentration by 0.13% (Table 2), and four sprayings per year at 2% increased it by 0.23% (Table 4). Once the Mg had reached a high level in the tree as a result of soil $MgCl_2$ application and annual spray of $Mg(NO_3)_2$, this combination was capable of keeping the Mg level in the leaf at a concentration significantly higher than that of the control, and equal to that achieved by four sprayings per year.

**Table 3:** Effects of Mg application on 'Shamouti' orange (*Citrus sinensis*) leaf nutritional imbalance index (NII) and yield. Leaves sampled in November each year. Treatments started 1989.

***Cuadro 3.*** *Efectos de la aplicación de Mg sobre el índice de desequilibrio nutricional (NII) en la hoja y el rendimiento en naranja (*Citrus sinensis*) 'Shamouti'. Hojas muestreadas en noviembre de cada año. Los tratamientos comenzaron en el año 1989.*

| | NII | | | | Yield, t·ha$^{-1}$ | | | |
|---|---|---|---|---|---|---|---|---|
| Treatment | 1991 | 1992 | 1993 | 1994 | 1991 | 1992 | 1993 | 1994 |
| Control | 46.2 | 59.2 | 50.1 | 35.1 | 48a[1] | 63a | 34b[1] | 49a |
| Soil | 35.4 | 46.8 | 43.6 | 32.1 | 53a | 69a | 44ab | 52a |
| Soil + Foliar (one spray) | 39.8 | 33.9 | 44.0 | 20.0 | 51a | 69a | 48a | 57a |
| Fertigation + Foliar (one spray) | 25.3 | 27.8 | 20.6 | 12.5 | 45a | 76a | 34ab | 58a |
| Foliar (two sprays) | 37.4 | 41.5 | 41.0 | 24.4 | 49a | 69a | 37ab | 49a |

[1] Different letters within columns indicate significant differences between means according to Duncan's multiple range test ($P = 0.05$).

Fertigation with $MgCl_2$ via micro-sprinklers was found to be less effective than band application in most cases, although the wetted volume was small and the roots were concentrated in this volume (under completely dry summer and autumn conditions).

Our previous work (Erner *et al*., 1984) demonstra-

**Table 4.** Effects of Mg application on 'Shamouti' orange (*Citrus sinensis*) fruit quality and leaf Mg. Concentration in 1994, six years after treatments began.

***Cuadro 4.*** *Efectos de la aplicación de Mg sobre la calidad de la fruta de naranja (Citrus sinensis) 'Shamouti' y concentración de Mg de la hoja en 1994, seis años después del inicio de los tratamientos.*

| Treatment | Mg % dry matter | Acid % | TSS/A[1] | Mean fruit weight g |
|---|---|---|---|---|
| Control | 0.28c[2] | 1.23a[2] | 9.6a[2] | 217.0a[2] |
| Soil | 0.29c | 1.24a | 9.5a | 221.0a |
| Soil + Foliar (one spray) | 0.51a | 1.23a | 9.5a | 218.0a |
| Fertigation + Foliar (one spray) | 0.41b | 1.32a | 9.0a | 225.0a |
| Foliar (two sprays) | 0.38bc | 1.27a | 9.3a | 212.0a |
| Foliar[3] (four sprays) | 0.51a | 1.25a | 9.3a | 213.0a |

[1] TSS/A, total soluble solids/acid.

[2] Different Letters within columns indicate significant differences between means according to Duncan's multiple range test (*P* = 0.05).

[3] Four sprays only in the last year of experiment; two in the earlier years.

ted that band application of 14 kg of $MgCl_2 \cdot 6H_2O$ per tree altered the Ca/Mg ratio in the soil and enhanced the Mg uptake by citrus trees. The present data show that it is possible to maintain this high Mg leaf concentration by the addition of one spray of $Mg(NO_3)_2$ per year. High levels of Cl in the leaf (1.12%, Table 1) caused neither yield reduction nor leaf abscission (Chapman *et al.,* 1969), although improper treatment such as irrigation with saline water or application to stressed trees might cause foliar damage and dieback of branches (Embleton *et al*., 1973a; Y. Erner, unpublished data). The freedom from a deleterious effect might be explained by the split application of the $MgCl_2$, which reduced the rapidity of the build-up of Cl in the trees, and by the fact that the accompanying cation was Mg and not Na, which would be present in saline water. The 7 + 7 kg of $MgCl_2$ per tree treatment placed about 0.6% more Cl in the treated leaves than in those of the control in the first year and 0.3% more in the second year (Table 1), but the Cl level dropped dramatically in the third year, because of leaching beneath the root system by rain (500 mm) and irrigation (700 mm). In the fourth year no differences were detected between treated and untreated trees.

In general, the implementation of analyses of the DRIS (Beverly *et al*., 1984) and the NII (Davee *et al*., 1986) to determine the nutritional status of the trees was found to be correlated with the standard method of critical concentration or sufficiency ranges. However, the poor correlations with yield that were found for both methods might be related to the slow response of trees to Mg application (Jones *et al*., 1971) (Table 3), although the leaves responded quite rapidly to Mg application (Table 1). The advantage of DRIS and NII analyses over the optimal sufficiency level approach may be that they are based not only on the balance of the nutrients most likely to be limiting, but also reflect the relative insufficiencies or excesses of elements. Mg sufficiency levels of 0.3% in 'Shamouti' leaves, which were always found to be insufficient by the DRIS analysis (Y. Erner, unpublished data), resulted from the high levels of $NO_3$ and K found in the leaves.

Potassium has been known to increase fruit size slightly, with a pronounced elevation of juice acidity (Du-Plessis and Koen, 1988; Embleton *et al*., 1975; Erner *et al*., 1993). However, in the present study the Mg treatments did not affect fruit internal quality or size, in spite of the significant reduction in leaf K concentration. The reduction in leaf K concentration from 0.86% (sufficient) to 0.71% (slightly below optimal - Table 2) was not great enough to affect fruit quality.

In order to increase the yield of high Mg deficiency, citrus groves Mg should be applied by band application to the soil, supplemented by one spray each year. Moreover, once leaf Mg concentrations have fallen to deficiency levels, it takes a long time to the tree to recover. Therefore, growers should not allow tree Mg levels to fall below the optimal range.

## RESUMEN

En este trabajo se estudio el efecto de aplicaciones foliares de Mg sobre la concentración de este elemento en las hojas y sobre los rendimientos, en naranjos (*Citrus sinensis*) 'Shamouti', históricamente con bajas concentraciones de magnesio foliar durante seis años. Con este propósito, aplicaciones de cloruro de magnesio al suelo se realizaron en bandas de 35 cm de ancho bajo el follaje del árbol o a través del sistema de riego por dos años consecutivos, mientras que nitrato de magnesio se aplicó anualmente como aspersión foliar. La aplicación de magnesio en banda aumentó la concentración foliar en un 0,2% y se mantuvo en un rango satisfactorio por tres años. Una aspersión foliar aplicada anualmente a partir del tercer año en adelante, además de aplicaciones en el suelo, mantuvieron el contenido de magnesio foliar dentro de un rango óptimo. La producción promedio y la producción en el sexto año fue mayor con una combinación de aplicaciones de magnesio en el suelo y foliar que en el control sin fertilizar. Una vez que las concentraciones del magnesio disminuyen a niveles deficitarios, el árbol requiere de un largo tiempo para recuperarse; por lo tanto, los productores deberían mantener los niveles magnesio dentro del rango óptimo.

**Palabras clave:** *Citrus sinensis*, fertigación, magnesio, nutrición en cítricos, nutrición mineral.

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