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Magnesium Influences on Fruit Yield and Quality of 'Valencia' Sweet Orange on Rangpur Lime

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Abstract. **Magnesium deficiency symptoms are very common on citrus orchards in the State of São Paulo, Brazil. This work was carried out, during 7 years, in order to determine the effectiveness of dolomitic limestone as Mg source to citrus, as well as, to establish patterns of Mg availability in soil, based on the results of soil testing and leaf analysis. The treatments consisted of calcitic and dolomitic limestone broadcasted at the rates of 0, 3, 6 and 9 t/ha, before planting, in a 4 x 4 factorial experiment. Four nursery trees of 'Valencia' orange on Rangpur lime were planted in each plot using a common row of guard plants. The results showed that dolomitic limestone was a good source of Mg for orange trees. Maximum yield was attained in plots in which exchangeable Mg in the soil and leaf Mg were respectively higher than 0.9 meq/100 cm³ and 0.35%. Increasing rates of dolomitic limestone increased linearly the contents of total soluble solids and acids in fruits, in the same pattern of the leaf Mg contents. Leaf analysis and soil testing were effective tools to predict Mg availability in the soil. More accurate soil testing results were obtained when samples were both taken from dripline and midrow.**

Magnesium deficiency symptoms are very common on citrus orchards in the State of São Paulo, Brazil, due to high acidity and low contents of this nutrient in the soil. Dolomitic limestone has been used as soil amendment and source of Mg for citrus plants.

Hunger signs of Mg in citrus were firstly identified by Averna-Saccá (1912) in sweet orange and mandarins on citrus orchards in Brazil. The correction of these symptoms was made by severe pruning and application of 250 g of magnesium carbonate per plant. Later in the State of Florida, USA, Camp and Fudge (1939), cited by Camp (1947) also described these symptoms mentioning that Mg malnutrition, besides yield decrease, promoted also root damage, poor fruit quality and yield alternation.

In the same paper, Camp (1947) showed that the application of magnesium sulfate increased yield of grapefruit in 67% for the average of 7 harvests. He also reported that leaf Mg in chlorotic plants was less than 0.2%, while in normal plants it was greater than 0.35%.

In young plants of 'Valencia' and 'Pineapple' orange on Rough lemon rootstock Spencer and Wander (1960) studied the effects of 4 sources and 4 rates of Mg. The results showed that although hunger signs of Mg with different intensities were visible, the treatments did not affect on trunk diameter. They observed a close correlation between leaf Mg and notes of severity of Mg deficiency (r = -0.80) and between leaf Mg exchangeable Mg in the soil (r = 0.85). Symptoms of Mg malnutrition were noted when leaf Mg and Mg in the soil were respectively less than 0.35% and 0.6 meq Mg/100 cm³ of soil.

Koo (1971) reported the results of two long-term trials testing sources and rates of Mg on grapefruit and sweet orange. Plants treated with MgO had the highest leaf Mg during the first two years of the experiment when compared with the others sources ($MgSO_4$ and $MgCO_3$), but on the average of 5 years the sources had the same performance. The rate of 150 kg/ha of MgO increased respectively 12.6% and 14.7% yield and total soluble solids in relation to the rate of 60 kg/ha of MgO. The best yield and fruit quality were attained when leaf Mg were between 0.3 and 0.4% and exchangeable Mg in the soil between 0.4 and 0.6 meq Mg/100 cm³.

Aso and Bustos (1981) working in several citrus regions of Argentina, grouped 21 lemon blocks in two categories: with Mg deficiency symptoms (leaf Mg less than 0.2%) and normals. In this study they established criteria, based on soil testing, to determine Mg availability to plants. Hunger signs of Mg were noted, on poor soil Mg when exchangeable Mg was less than 0.8 meq/100 g. In soil rich in Mg, the hunger signs were induced by high contents of K (ratio K/Mg>0.4) or Ca (ratio Ca/Mg>7).

Anderson and Albrigo (1971, 1973) carried out two nutritional citrus surveys in order to study the soil-plant relationship in dolomitic citrus groves in central Florida and to determine a soil test that would adequately predict leaf Mg status. None of the procedures tested provided soil Mg values that could be significantly related by themselves to leaf Mg. On the other hand, leaf Mg was negatively related to the ratio of soil Ca/Mg.

On acidic soils of Brazil no work has been done on this subject. Therefore this experiment was carried out in order to study the effects of Mg on yield and fruit quality, and to establish criteria, based on soil testing and leaf analysis, to determine Mg availability for sweet orange.

Materials and Methods

The experiment was carried out at Sylvio Moreira Experiment Station of Instituto Agronômico (IAC), in the State of São Paulo, Brazil. The climate of the region is classified, according to Koepen, as CWA, that is, mesothermic with dry winter in which the average temperature of the coldest month is lower than 18°C and that of the warmest month is higher than 22°C. Average annual rainfall is 1400 mm and lower than 30 mm in the driest month.

The soil used was a Dark-red clayey-textured Latosol with the following chemical properties: organic matter, 3.1%; pH ($CaCl_2$), 4.0; exchangeable cations, in meq/100 cm³, Al, 1.5; Ca, 0.4; Mg, 0.1 and K, 0.1. The CEC at pH 7.0 was 10.1 meq/100 cm³ and the soil base saturation was 6%. Therefore, it is an acid soil with high buffering capacity.

The treatments were set out in a randomized block design with two replications, in a 4 x 4 factorial experiment with four rates (0, 3, 6, and 9 t/ha) of calcitic (CaO = 47% and MgO = 6%) and dolomitic limestone (CaO = 27% and MgO = 20%), amounting to 16 combinations. The limestone treatments were broadcasted in October 1982, onto an area of 8 x 12 m, corresponding to a sampling area of four trees planted with a spacing of 6 x 4 m. The plots were separated from each other by a common row of guard plants to which only 1 kg of limestone was applied into the planting hole.

In Jannuary 1983, selected nursery trees of 'Valencia' orange on Rangpur-lime rootstock were transplated to planting holes in the field, to which 0.5 kg of ordinary superphosphate had been added. All other fertilizers were equally applied to all plots, in rates sufficient to ensure high yield.

Soil samples were taken annually in layers 0 to 20, 20 to 40, and 40 to 60 cm deep. In the first two years, samples were withdrawn only in the dripline. Subsequentely they were taken also in the midrow spacing. The soil samples were analyzed by the methods described by Raij et al. (1986).

Leaf samples (10 leaves per tree) were taken, starting in the third year, from fruit bearing twigs 6 to 8 months old. After the conventional preparation procedures, the samples were analyzed according to the methods described by Bataglia et al. (1983).

In the spring of 1988, notes for severity of Mg deficiency were attributed separately by two experts in citrus nutrition, in all sampling plants. Later, average of these notes were calculated for each plot. The notes rated from 1 (absence of symptoms) to 4 (severe symptoms).

Fruit quality evaluation was made annually, by taking at random ten fruits per sampling tree, at the time of harvest.

The experiment was carried out without irrigation, therefore, subjected to the prevalent climatic conditions of the region.

Results and Discussion

Criteria for Mg availability in the soil and its effects on yield. Sixteen levels of exchangeable Mg and bases relationships in the soil were established by combining four rates of dolomitic limestone with four rates of calcitic limestone. The results of soil testing, averaged over 4 years, were used in correlation analysis with the corresponding averaged results of leaf analysis and fruit yield to evaluate a criteria for Mg availability in the soil.

Figure 1 shows the correlation obtained between leaf Mg and soil exchangeable Mg, for samples taken from two different positions. No correlation was observed when soil samples were taken from the dripline. However, a close correlation was established when samples were collected in the midrow.

A multiple linear regression analysis were conducted, by a step-wise procedure, with the data of four years, using leaf Mg as dependent variable and selected soil characteristics (Soil-Mg, Ca/Mg and Mg/K ratios and soil base saturation) as independent variables. Soil testing results were used considering separately samples taken from dripline and midrow (Table 1).

When soil samples were taken from midrow, the main parameter of the equation was exchangeable Mg, followed by the ratio of soil Ca/Mg. The inverse occurred for samples collected in dripline. When all independent variables tested were combined, the determination coefficients (R^2) obtained were respectively

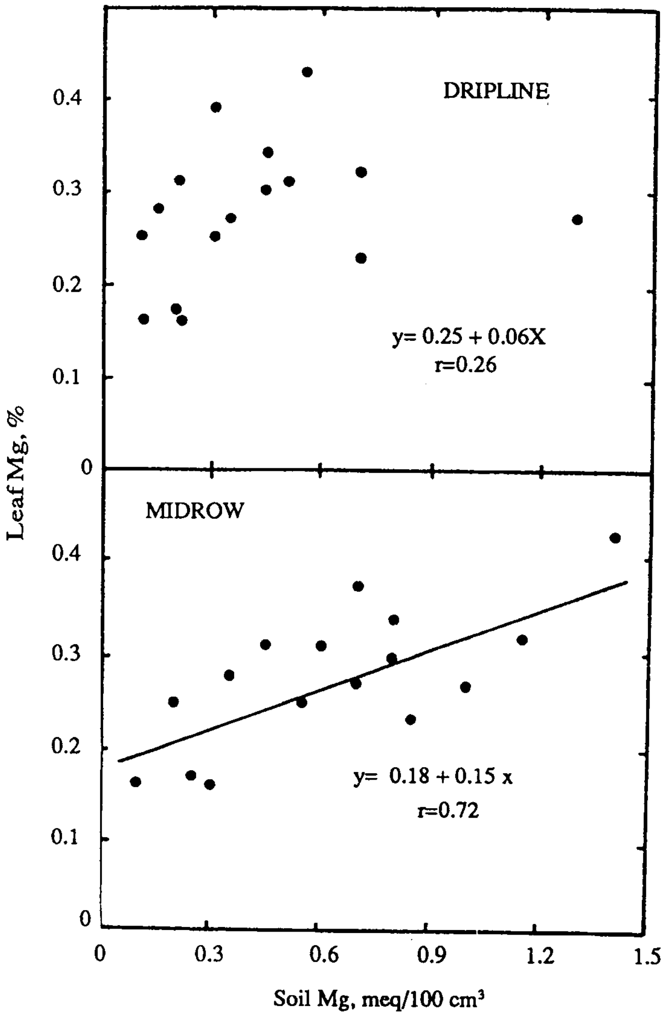

Figure 1. Correlations between leaf Mg and soil exchangeable Mg for soil samples taken from dripline and midrow.

0.53** and 0.41** for soil samples from the midrow and dripline.

It may be noteworthy that soil characteristics of samples of the midrow were more closely related to leaf Mg than those obtained in the dripline. Besides, these results might explain failures on earlier citrus surveys to establish correlations between leaf Mg and its content in the soil, as reported by Anderson and Albrigo (1971, 1973) and Caetano et al. (1984). In those studies the importance of the location of the soil sampling in citrus groves, were neglected and it was concluded that soil testing was not a good tool for predict Mg availability to citrus trees. Anderson and Albrigo (1971) conducted multiple linear regression analysis to determine soil characteristics more related to leaf Mg and found that the ratio of soil Ca/Mg was the strongest independent variable (r=0.51). This is in agreement with the results obtained in the present paper, when soil samples were taken from dripline (Table 1).

The differences observed between soil Mg results from dripline and midrow are related to fertilization mainly due to nitrogen, that promotes soil acidification and leaching losses of Mg faster than of Ca. For this reason, the Ca/Mg ratio in dripline was higher than in midrow (data not shown). Furthermore, K accumulation in dripline as a result of fertilizer application, affects the Mg uptake process.

Table 1. Multiple linear regression equations using leaf Mg as dependent variable and some selected soil characteristics as independent variables, for soil samples taken from midrow and dripline.

Leaf-Mg		Bo	Soil-Mg	Ca/Mg	Mg/K	V%	R^2
				Parameters of the equations			
				Midrow			
Mg	=	0.214	0.084**	--	--	--	0.30**
Mg	=	0.317	0.067**	-0.032**	--	--	0.47**
Mg	=	0.309	0.104**	-0.032**	-0.0037**	--	0.51**
Mg	=	0.306	0.158**	-0.001*	-0.0024**	-0.004**	0.53**
				Dripline			
Mg	=	0.403	--	-0.038**	--	--	0.31**
Mg	=	0.346	0.063**	-0.039**	--	--	0.39**
Mg	=	0.354	0.102**	-0.032**	0.0170	--	0.40**
Mg	=	0.356	0.082*	-0.035**	0.0190	0.001	0.41**

*, ** Means coefficients and equation parameters significative $p<0.05$ and $p<0.01$, respectively.
V% = Soil base saturation.

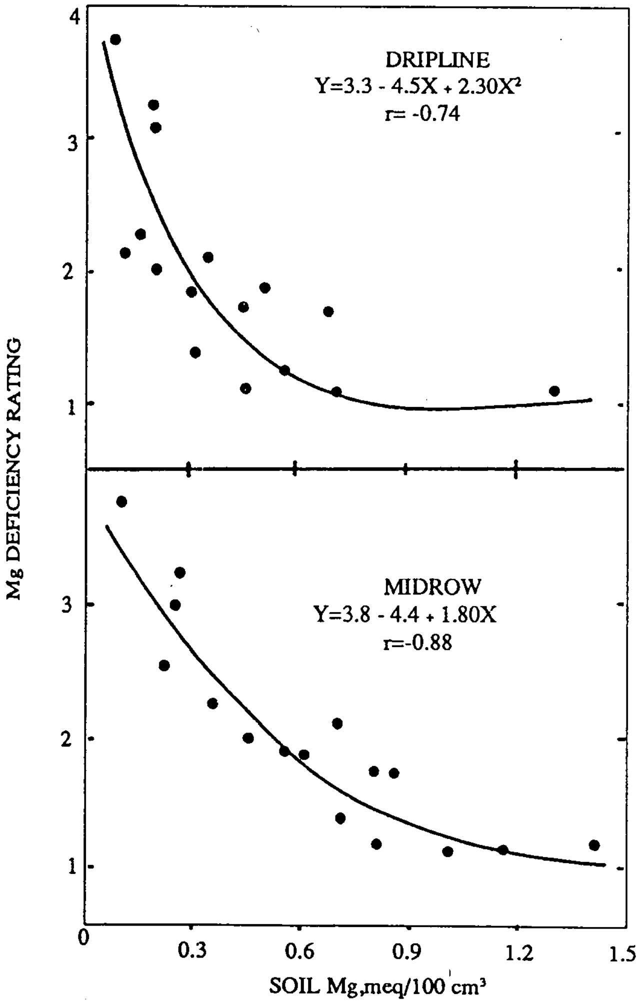

Figure 2. Relationships between notes for severity of Mg deficiency symptoms and soil Mg.

Notes for severity of Mg deficiency symptoms were attributed to the plants in 1988, rating from 1 (absence of symptoms) to 4 (severe symptoms). These notes were plotted against the corresponding soil Mg contents (Fig. 2). The correlation coefficient was greater for soil samples taken from midrow than for those

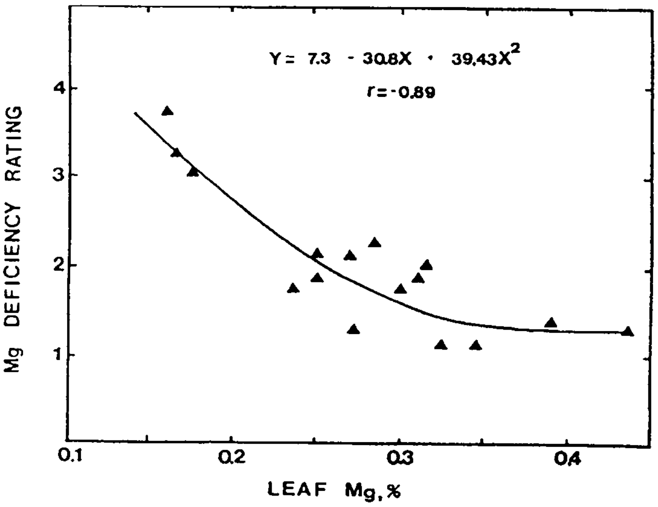

Figure 3. Relationship between notes for severity of Mg deficiency symptoms and leaf Mg.

collected in dripline. Absence of hunger signs of Mg were attained when exchangeable Mg was respectively greater than 0.6 and 1.2 meq/100 cm³, for samples taken from dripline and midrow.

The notes of severity of Mg deficiency were also plotted against the corresponding leaf Mg results as showed in Figure 3. A quadratic curve were fitted and the smallest degree of hunger signs was observed when leaf Mg was greater than 0.35%.

Interpretation of soil testing results was obtained with a calibrating curve fitted with the results of fruit yield averaged over a period of four harvests, and the corresponding means results of exchangeable Mg in the soil. In this curve the soil samples picked up in dripline and midrow were used because it was considered that together, they represent better the root environment of the citrus trees. Figure 4 shows that Mg is very important to sweet orange, and maximum yield was attained when soil exchangeable Mg was greater than 0.9 meq/100 cm³. A similar curve was traced with the results of Mg in the soil expressed as percent of CEC. The regression equation calc was $Y = 24.5 + 12.1/X$ ($r = 0.81$), which demonstr maximum yield was attained when the percent of Mg greater than 10%. This value is twice that obtair

Bustos (1981) in lemon groves in Argentina.

Fruit yield was also calibrated against leaf Mg results, in the same way as soil testing (Fig. 5). It can be noted that leaf Mg showed a worse correlation with fruit yield than exchangeable Mg in the soil (Fig. 4).

The values of leaf Mg and soil exchangeable Mg obtained in the calibration curves for maximum fruit yield, are in agreement with those observed to eliminate Mg deficiency symptoms (Figs. 2 and 3), as well as, with those reported by other authors in the literature to alleviate Mg malnutrition and to maximize fruit yield (Camp, 1947; Spencer and Wander, 1960; Koo, 1971; Aso and Bustos, 1981).

The results of Figure 6 allow a comparison between calcitic and dolomitic limestones as sources of Mg for sweet orange, 5 years after their application. The differences observed were directly related to Mg concentrations. Dolomitic limestone was shown to be a good source of Mg, and its effect was still measurable 77 months after its application. Koo (1971) pointed out that $MgCO_3$ was as effective as $MgSO_4$ and MgO, but the two later promoted faster effects in the two first years.

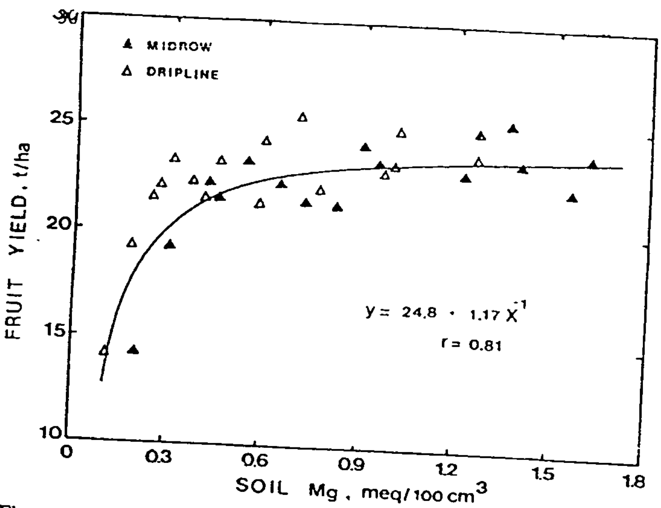

Figure 4. Response curve of sweet orange to soil exchangeable Mg, considering simultaneously samples taken from dripline and midrow.

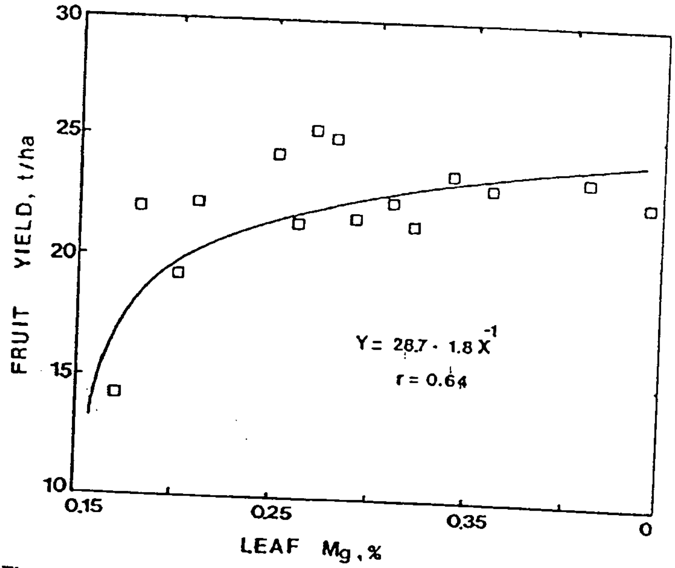

Figure 5. Correlation between fruit yield and leaf Mg.

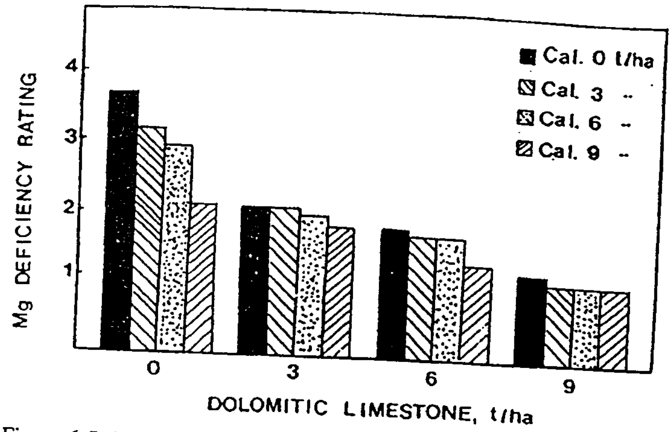

Figure 6. Influence of rates of calcitic and dolomitic limestones on the severity symptoms of Mg malnutrition.

Influence of Mg on fruit quality. Fruit size and juice characteristics were evaluated in the four first harvests of 'Valencia' orange, and the results of the group variance analysis are compiled in Table 2.

Liming did not affect fruit size, but it was noted that as the age of the plants increased the fruit height (r^2 = -0.85) and fruit diameter (r^2 = -0.89) decreased.

The percent of juice in fruit was also not affected by liming. The observed values of these fruit characteristics were normally very high. These results do not agree with those reported by Anderson (1971) who observed effects of liming on juice percent in fruits of 'Valencia' orange cultivated in a very low fertility sand soil in Florida, USA.

Table 2. Effects of rates of dolomitic and calcitic limestones on fruit size and quality. The data used in variance analysis were the treatments average of each year over a period of 4-harvests.

Limestone rates Cal. t/ha	Dol	Fruit size height	diameter mm	Juice %	TSS %	Acids %	Ratio
0	0	77.2	73.0	54.0	8.1	0.81	10.0
3	0	74.7	73.1	56.4	8.0	0.88	9.1
6	0	75.8	72.5	53.8	8.1	0.91	8.9
9	0	77.2	74.5	53.5	8.3	0.89	9.3
0	3	77.2	73.9	55.8	7.9	0.84	9.4
3	3	75.1	72.5	54.6	8.4	0.80	9.4
6	3	76.5	73.8	54.2	8.1	0.88	9.2
9	3	75.2	72.9	55.0	8.5	0.91	9.3
0	6	76.8	73.5	54.7	8.4	0.93	9.0
3	6	75.4	71.6	53.4	8.4	0.85	9.8
6	6	75.7	72.3	54.8	8.4	0.88	9.0
9	6	75.5	73.3	55.4	8.4	0.93	9.1
0	9	73.4	72.1	54.3	8.3	0.94	8.8
3	9	75.1	73.2	54.2	8.6	0.92	9.3
6	9	74.6	71.7	54.6	8.9	0.89	10.0
9	9	74.7	71.5	54.4	8.5	0.92	9.2
F Cal. NS		NS	NS	NS	NS	NS	
F. Dol. NS		NS	NS	*	*	NS	
F CalxDol.		NS	NS	NS	NS	NS	NS
CV (%)		9.9	9.8	9.8	8.3	12.2	14.7

* means significant values by F test ($p<0.05$); NS = no significant.

Total soluble solids (TSS) and acid contents in the fruit were affected only by dolomitic limestone rates (Table 1). The effect was more pronounced in the 1989 harvest, when the biggest yield was also obtained (Quaggio et al., 1992). Theses effects are related to the Mg supplying capacity of dolomitic limestone, because increasing rates of this soil amendment increased linearly TSS, in the same pattern of leaf Mg (Fig. 7). The same was observed for acid contents in the fruits (Fig. 8). For this reason, TSS/acidity ratio, remained almost constant over the treatments (Table 1).

These results are in agreement with the data published by Koo (1971), from an experiment carried out in Florida, to study the effects of rates and sources of Mg on 'Valencia' orange. Similar results were also published by Moss and Higgins (1974), in Australia from a trial conducted in nutrient solution, under greenhouse condition. They concluded that the effects of Mg on acid concentration were related to an smaller absorption of Ca by the plants, instead of less K absorption as they had initially postulated. Usually is not easy to distinguish the effects of these nutrients on citrus responses.

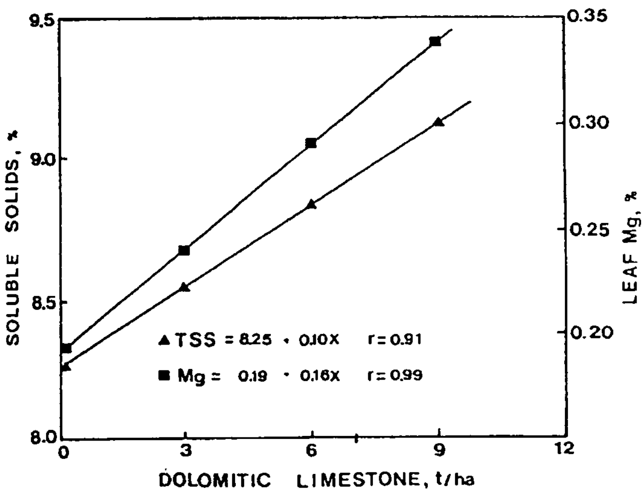

Figure 7. Effects of rates of dolomitic limestone on leaf Mg and total soluble solids in fruits in 1989.

Conclusion

The results of this experiment allowed to conclude that:

Both soil testing and leaf analysis were effective tools to predict Mg availability in soil; soil testing results became more precise when soil samples were taken both from dripline and from midrow.

Hunger signs of Mg were observed only in plots in which exchangeable Mg and leaf Mg were respectively less than 0.9 meq/100 cm^3 and 0.35%.

Dolomitic limestone was an effective source of Mg for orange tree, and its effects was long-lasting.

Increasing rates of dolomitic limestone increased linearly the contents of total soluble solids and acids in fruits. These effects were related to its high Mg supplying capacity.

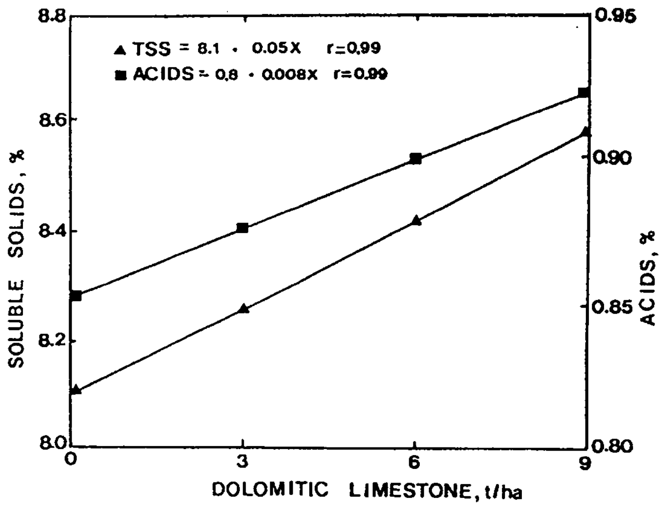

Figure 8. Effects of rates of dolomitic limestone on acid contents and total soluble sôlids. Data used were averaged over four harvests.

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