wide ranges in growth, tree condition and fruit production of young 'Valencia' trees on rough lemon rootstock. The treatment combination of medium fertilization rate and low application frequency appeared satisfactory for trees planted under soil conditions existing on interior rows of the 4-row citrus bed. Medium frequent applications and high fertilizer rate gave favorable results on exterior rows where appreciable top soil had been removed. Declining growth and yield responses to more than 4 applications per year apparently was the result of applying fertilizer during the rainy season when leaching losses are high. Young tree decline symptoms were significantly greater in low fertility plots on the interior 2 rows of the 4-row bed. Results from this experiment can be extrapolated to young citrus trees planted in groves on both optimum and marginal soil conditions in the flatwoods and marshes.

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EFFECTS OF SOIL pH AND CALCIUM ON THE GROWTH AND MINERAL UPTAKE OF YOUNG CITRUS TREES

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ABSTRACT

A soil pH—added calcium factorial experiment was started in 1964 in a 2-year-old block of 'Valencia' oranges on rough lemon rootstock located on newly cleared Lakeland fine sand. The treatments consisted of annual soil applications of sulfur, gypsum, soda ash (sodium carbonate), and calcitic limestone applied alone or in combinations to provide 4 levels of soil pH (4.0, 5.0, 6.0, and 7.0), 4 levels of added calcium (0, 100, 200, and 400 pounds calcium per acre per year), and all possible combinations for a total of 16 treatments.

Striking differences in tree growth due to treatment were observed by October, 1967. Maximum growth occurred at the highest pH level and maximum rate of added calcium. This treatment consisted of liming the soil to pH 7.0 with calcitic limestone and supplementing the limestone with gypsum to provide a total of 400 pounds added calcium per acre per year. In general, the fastest rate of growth resulted from the simultaneous increase in both soil pH and added

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calcium, in a proportion of about 100 pounds added calcium for each one unit increase in soil pH.

Chemical analyses of leaf samples revealed that some of the poorest trees in the experiment, those receiving maximum applications of soda ash, were suffering from sodium toxicity. In general, increasing levels of soil pH increased leaf calcium, magnesium, and phosphorus but decreased leaf potassium. Increasing rates of added calcium increased leaf calcium but decreased leaf magnesium, potassium, nitrogen, and phosphorus.

INTRODUCTION

Two of the important functions of limestone applied on acid soils are neutralization of soil acidity and supplying calcium, an essential element. Current liming recommendations for Florida citrus growers (10) take both factors into consideration but place greater emphasis on pH control, primarily because of the widespread occurrence of grove soils that contain excessive amounts of accumulated copper (11). Even in normal grove soils, however, optimum levels of soil pH and calcium have not been determined with precision in terms of horticultural responses. Most recent liming studies on Florida grove soils have centered on soil responses (1, 3, 4).

The pH of a soil could have both direct and indirect effects on the growth of citrus. The direct effects of hydrogen-ion concentration were emphasized in a review by Smith (13), who described nutrient solution studies with citrus seedlings in which root systems exposed to acid conditions, below pH 5, were abnormally stubby, swollen, discolored and excessively branched, much like roots produced under conditions of heavy metal toxicity. Growth was severely inhibited at pH 4 as compared to pH 6. Similar responses were reported from a pot study using citrus subsoils and corresponding virgin subsoils (9).

Studies on the effects of soil pH in many citrus-producing areas of the world were reviewed by Chapman (6), who concluded that, under most field conditions, the indirect effects or basic soil characteristics (of which pH is one indicator) are more important than the direct effects of hydrogen or hydroxide ions. He noted that high-yielding citrus groves are found on soils with pH values ranging from 4.5 to 8.5.

Calcium deficiency of field-grown citrus has been reported only rarely anywhere in the world (6). This is surprising since, 1) citrus leaves normally contain a relatively high amount of calcium and 2) in some areas, citrus is grown on highly leached, sandy soils. Apparently, citrus is a strong feeder on soil calcium. Values ranging from 2.0 to 3.0% leaf calcium have been suggested for the lower limit of calcium sufficiency (6, 10, 13). It is noteworthy that calcium deficiency in citrus has been reported in Florida (5, 14).

The objectives of this study were to separate the general effects of soil pH on growth and mineral uptake of young citrus trees from those of added calcium and to establish optimum levels of each.

EXPERIMENTAL METHODS

A 4 x 4, soil pH—added calcium factorial experiment was started in May, 1964 in a 2-year-old block of 'Valencia' oranges on rough lemon rootstock. The block was located on newly cleared Lakeland fine sand having an organic matter content of 0.9% and a cation exchange capacity of about 2 meq per 100 g. The soil contained 85 pounds calcium per acre, extractable with neutral, normal ammonium acetate, and had a pH of 5.3, determined in 1:1, soil:water suspension.

The treatments consisted on annual soil applications of elemental sulfur, gypsum (calcium sulfate), soda ash (sodium carbonate), and calcitic limestone, applied alone or in combinations to provide 4 levels of soil pH (4.0, 5.0, 6.0, and 7.0,) 4 levels of added calcium (0, 100, 200, and 400 pounds calcium per acre per year), and all possible combinations of the 2 factors for a total of 16 treatments. The soil amendment combinations and treatment numbers are listed in Table 1.

The rates of application of the 4 soil amend-

Table 1.--Soil amendment combinations used to provide the 16 factorial treatments.

	Added calcium, lbs/acre/year			
pH	0	100	200	400
4.0	1)+ Sulfur	2) Sulfur + gypsum	3) Sulfur + gypsum	4) Sulfur + gypsum
5.0	5) None++	6) Gypsum	7) Gypsum	8) Gypsum
6.0	9) Soda ash	10) Limestone	11) Limestone + gypsum	12) Limestone + gypsum
7.0	13) Soda ash	14) Soda ash + limestone	15) Limestone	16) Limestone + gypsum

+ Treatment number.

++ Sulfur was applied to all pH 5.0 plots one time only.

ments were not held constant throughout the study but were modified as deemed necessary from pH determinations in 1:1, soil:water suspensions on soil samples collected each year just prior to treatment application, which was generally in March. Some typical application rates, expressed on a yearly per-acre basis, were 350 pounds sulfur plus 1,800 pounds gypsum to provide pH 4.0 and 400 pounds calcium for Treatment 4; 800 pounds soda ash to provide pH 7.0 and no added calcium for Treatment 13; and 800 pounds limestone plus 800 pounds gypsum to provide pH 7.0 and 400 pounds calcium for Treatment 16.

In addition to the 16 factorial treatments, 3 other treatments were included. Two of these involved dolomite, a liming material that is very popular with Florida citrus growers. It was applied annually at the same rate as the calcitic limestone used in Treatments 15 and 16, about 800 pounds per acre per year. In one treatment, dolomite was applied alone; in the other, it was applied in combination with a maximum application of gypsum as used in Treatments 4 and 8. The third extra treatment consisted of a combination of soda ash and gypsum, both applied at maximum rates. All soil amendments were applied by hand over the entire area of the 4-tree plots and immediately disked in. The field design for the 19 treatments was a randomized block, replicated 4 times.

Throughout the study, the trees were fertilized with a 10-2-10-5 fertilizer at rates and frequencies recommended for young trees (10). The fertilizer mixture was made up of ammonium nitrate, concentrated superphosphate, muriate of potash, and magnesium sulfate with sand as a filler. The minor elements, copper and boron, were included in the fertilizer mixture, whereas zinc and manganese were applied annually in a dormant foliar spray. Irrigation was applied as needed using a perforated pipe system.

To determine growth responses, trunk diameter measurements were taken periodically starting with the first treatment application in May, 1964. At that time, the trees were of very uniform size throughout the block with an average trunk diameter of 2.7 cm. The treatment effects on mineral uptake were evaluated by analyzing samples of mature spring-flush leaves from nonbearing terminals. Soil samples were collected after 5 applications to study residual calcium effects.

The first application of treatments were *originally* scheduled for the spring of 1963 but because of a severe freeze in December, 1962, which froze all of the trees back to the banks without killing any of them, the application was postponed until 1964, at which time only a double rate was used. In the discussion following, the first application will be considered to be the equivalent of 2 normal annual applications. Thus, the experimental data collected in the fall of 1967, reported in the following sections, will be considered as reflecting the effects of 5 annual applications of treatments.

Results and Discussion

The 4 desired pH levels were very nearly reached after only 3 treatment applications. pH determinations on soil samples collected from the 0-6″ zone of all plots in November, 1965, 8 months after the third application, revealed average field values of pH 4.1, 5.3, 6.1, and 6.9, corresponding to the 4 treatment levels. In November, 1967, 8 months after the fifth application, the average field values were pH 4.0, 5.1, 6.2, and 7.0.

Effects of treatments on tree growth.—The growth of the young citrus trees was greatly affected by the treatments (Table 2). By October, 1967, 3½ years after the first application, the largest trees had grown almost twice as much as the smallest. Both pH and added calcium affected growth, but because of significant interacting effects, they will not be evaluated separately.

The largest growth response occurred at pH 7.0 and 400 pounds of added calcium and the second largest response at pH 7.0 and 200 pounds calcium (Treatments 16 and 15, respectively).

Table 2.--Effects of factorial treatments on increase in trunk diameter of 'Valencia' orange trees from May 1964 to November 1967.

pH	Added calcium, lbs/acre/year: 0	100	200	400
	cm	cm	cm	cm
4.0	1)+ 5.4	2) 5.9	3) 7.1	4) 5.8
5.0	5) 7.3	6) 7.1	7) 7.3	8) 7.0
6.0	9) 7.1	10) 7.6	11) 7.5	12) 7.1
7.0	13) 4.6	14) 7.2	15) 7.9	16) 8.5

F tests++: Soil pH **
Added calcium **
pH - calcium interaction **

+ Treatment number.

++ ** = Statistically significant at P = .01.

Very good responses were also found at pH 6.0 with both 100 and 200 pounds added calcium (Treatments 10 and 11). A comparison among these 4 treatments and between them and neighboring treatments indicates that the greatest rate of growth occurred with the simultaneous increase of both pH and added calcium in a proportion of at least 100 pounds added calcium for each one unit increase in soil pH. The growth trend within this region suggests that even greater tree growth might have been expected from higher pH and added calcium levels.

Extremely poor growth occurred at pH 7.0 in the absence of added calcium (Treatment 13) and at pH 4.0 with 0, 100, and 400 pounds added calcium (Treatments 1, 2, and 4).

Trunk diameter measurements were later found to be closely related to bearing surface. The correlation coefficient (degree of linear relationship) between trunk diameter and surface area of the tree canopy was r=.94 for measurements taken on these trees in 1969.

Effects of treatments on mineral composition of the leaves.—Leaf samples were analyzed for calcium, magnesium, potassium, nitrogen, phosphorus, sulfur, and sodium. The uptake of all 7 elements was affected by at least some of the treatments.

Both factors, soil pH and added calcium affected the calcium content of the leaves but again, as with tree growth, their effects interacted so that their main effects cannot be separated. The leaf calcium values for the 16 factorial treatments are listed in Table 3. From a comparison of Tables 2 and 3, it is apparent that growth responses and leaf calcium were similar. Maximum growth occurred in trees having the highest calcium content (Treatment 16), while extremely low leaf calcium levels were associated with extremely poor trees (Treatments 1, 2, and 13). In the region of fastest rate of tree growth, increasing growth was associated with an increasing calcium content of the leaves from about 2.0% to about 3.5%.

The effects of both soil pH and added calcium on the sodium content of the leaves were statistically significant. However, an examination of the individual sodium values (Table 3) indicates that the sodium response was probably not due to the 2 factors, *per se*, but to the soil amendments, specifically—soda ash. The highest leaf sodium value listed, .189% for Treatment 13, is approaching toxic levels which have been reported at .20 to .25% (12). The extremely small trees associated with this high sodium value were probably stunted as a result of both calcium deficiency and sodium toxicity. Although not investigated in this study, the root systems of these trees may have been impaired by the high level of sodium in the soil (7). The essentiality of sodium for citrus has not been established. Sodium was of interest in this study only because of the use of soda ash as a soil amendment.

Table 3.--Effects of factorial treatments on contents of calcium and sodium in leaves of 'Valencia' orange trees. Samples collected November 1967.

Leaf calcium

pH	Added calcium, lbs/acre/year 0	100	200	400
	%	%	%	%
4.0	1)+ 1.20	2) 1.68	3) 2.33	4) 2.29
5.0	5) 1.90	6) 2.09	7) 2.48	8) 2.66
6.0	9) 1.92	10) 2.93	11) 3.27	12) 3.31
7.0	13) 1.45	14) 2.41	15) 3.42	16) 3.49

F tests++: Soil pH **
Added calcium **
pH - calcium interaction **

Leaf sodium

pH	Added calcium, lbs/acre/year 0	100	200	400
	%	%	%	%
4.0	1)+ .060	2) .056	3) .071	4) .068
5.0	5) .064	6) .061	7) .067	8) .066
6.0	9) .074	10) .059	11) .069	12) .067
7.0	13) .189	14) .116	15) .072	16) .077

F tests++: Soil pH **
Added calcium **
pH - calcium interaction **

+ and ++ see footnotes of Table 2.

The 2 factors, soil pH and added calcium, acted independently on the uptake of the remaining 5 elements studied; therefore, the main effects of each can be examined. The main effects of soil pH are listed in Table 4. The 2 higher pH levels, 6.0 and 7.0, resulted in higher magnesium and phosphorus levels in the leaves but a lower content of potassium. Changes in pH did not affect the uptake of nitrogen nor, surprisingly, sulfur. The 4 treatments having a pH of 4.0 involved applications of sulfur at 350 pounds per acre per year, plus applications of gypsum at up to 1,800 pounds per acre per year. Excessive levels of leaf sulfur in citrus, above .50%, have been reported following repeated gypsum applications on similar soils (2). (0.53% sulfur was found in 1968 in leaf samples collected from Treatment 4).

Table 4.--Main effects of soil pH on mineral composition of leaves of 'Valencia' orange trees. Samples collected November 1967.

Element (%)	Soil pH 4.0	5.0	6.0	7.0
Magnesium	.43a[+]	.45a	.59b	.57b
Potassium	1.82b	1.75b	1.56a	1.55a
Nitrogen	2.56a	2.54a	2.57a	2.57a
Phosphorus	.132a	.128a	.143b	.147b
Sulfur	.24a	.25a	.27a	.25a

+ Within a given row, data followed by the same letter do not differ at P = .05.

Table 6.--Effects of factorial treatments on extractable soil calcium in 0 to 6" zone after 5 applications. Samples collected November 1967.

pH	Added calcium, lbs/acre/year 0	100	200	400
	lbs/acre-6 inches			
4.0	1)[+] 76[++]	2) 71	3) 72	4) 88
5.0	5) 79	6) 80	7) 104	8) 100
6.0	9) 79	10) 297	11) 384	12) 376
7.0	13) 98	14) 459	15) 746	16) 743

+ Treatment number.

++ Extracted with neutral, normal ammonium acetate. Data were not statistically analyzed.

Increasing rates of added calcium resulted in decreasing levels of leaf magnesium and potassium (Table 5). The 2 higher levels of added calcium resulted in somewhat reduced contents of leaf nitrogen and phosphorus. Leaf sulfur increased with increasing rates of added calcium, although this was probably another direct response to the soil amendments, in this case gypsum, rather than to either factor.

The leaf samples were not analyzed for any of the minor elements. The characteristic deficiency symptoms were either entirely absent from the leaves or, in the case of manganese, present only temporarily during the season. Special attention was given in anticipation of molybdenum deficiency; however, no symptoms of "yellow spot" were observed.

Effects of treatments on extractable soil calcium.—The source of added calcium appeared to be more important than the rate of added calcium on the amount of extractable calcium present in the soil after 5 treatment applications (Table 6). Virtually all of the calcium from gypsum, when gypsum was applied alone (Treatments 5 to 8) or in combination with elemental sulfur (Treatments 1 to 4), was lost from the surface soil within 8 months after treatment application, whereas much of the calcium from calcitic limestone remained. The highest value of soil calcium, about 750 pounds per acre, was associated with maximum tree growth.

Effects of the 3 extra treatments on tree growth and mineral composition of leaves.—The most striking response to the 3 extra treatments was that of leaf magnesium (Table 7). Dolomite was very effective in supplying magnesium to the trees. When applied alone, dolomite almost doubled the magnesium content as compared to identical rates of calcitic limestone (Treatment 15), although all trees received 5% MgO from magnesium sulfate in the mixed fertilizer.

Gypsum, when combined with dolomite, reduced leaf magnesium but substantially increased leaf calcium and appeared to increase growth, although the latter response was not significant. When combined with soda ash, gypsum had a modifying influence on the detrimental effects of soda ash on tree growth and sodium uptake (compare Treatments 19 and 13).

Table 5.--Main effects of added calcium on mineral composition of leaves of 'Valencia' orange trees. Samples collected November 1967.

Element (%)	Added calcium, lbs/acre/year 0	100	200	400
Magnesium	.63c[+]	.51b	.49b	.41a
Potassium	1.84c	1.69b	1.57a	1.57a
Nitrogen	2.63b	2.60b	2.51a	2.49a
Phosphorus	.140b	.140b	.134a	.134a
Sulfur	.20a	.22a	.26b	.33c

+ See footnote of Table 4.

Table 7.--Effects of the 3 extra treatments on the growth and leaf composition of 'Valencia' orange trees. Growth from May 1964 to November 1967. Leaf samples collected November 1967.

Treatments	Tree growth, cm	Mineral composition of the leaves, % Ca	Mg	K	N	P	S	Na
Dolomite	17)[+] 7.7	2.51	1.01	1.38	2.44	.146	.25	.063
Dolomite + gypsum	18) 8.1	3.41	.76	1.27	2.49	.146	.34	.069
Soda ash + gypsum	19) 7.2	3.18	.47	1.55	2.50	.146	.28	.087
F tests[++] :								
Factorial vs extra	**	**	**	**	**	**	*	N.S.
Among extras	N.S.	N.S.	**	N.S.	N.S.	N.S.	N.S.	N.S.

+ Treatment number.

++ **-significant at P = .01, *-significant at P = .05, N.S.- not significant at P = .05.

CONCLUSIONS

The authors are aware that the stated objective of this experiment is virtually impossible to accomplish with this or any other experimental design because of the necessity of introducing extra ions to obtain the pH and calcium levels desired. In order to perform the statistical tests, the assumption had to be made that the only variable factors affecting the measured responses were soil pH and added calcium and that the soil amendments used to obtain the different pH and calcium levels were not important. Some of the extraneous factors that were ignored by this assumption were subsoil pH, short term pH fluctuations which may have varied with different treatments, ion balance within the soil, and other factors that may have affected the development of the root system without themselves being detected through leaf analysis. Sodium, and possibly sulfur, were partially responsible for some of the observed responses.

Despite these restrictions, certain conclusions seem valid. The fastest rate of tree growth resulted from the simultaneous increase in both soil pH and added calcium in a proportion of about 100 pounds of added calcium for each one unit increase in soil pH. In acid sandy soils such as the Lakeland fine sand used in this experiment, this simultaneous increase in pH and added calcium can be expected from applications of calcitic limestone. Even when calcium did not appear to be a limiting factor, increased growth resulted from increased pH levels from pH 4 to pH 7. Extremely poor growth generally occurred at the pH 4 level.

The results described in this paper are limited to young citrus trees. It is not known at this time whether the best pH and calcium levels for the growth of young trees are also best for fruit production and fruit quality. This experiment is being continued to evaluate these other effects.

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A COMPARISON OF SOIL AND SPRAY APPLICATIONS OF FOUR MANGANESE SOURCES FOR CONTROL OF MANGANESE DEFICIENCY IN 'VALENCIA' ORANGE TREES

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ABSTRACT

A comparison of the effectiveness of soil and spray applications of 4 different manganese (Mn) sources on control of Mn deficiency in bearing 'Valencia' orange trees growing on Lakeland fine sand was made in a field experiment carried