are now under test in salt plots. Apparently, the factors responsible for salt tolerance are heritable because the progenies of several crosses have shown striking segregation for tolerance to high salt. *Eremocitrus glauca* is hardy and highly salt-tolerant but a slow, weak grower. Some of its hybrids, however, are vigorous and salt-tolerant and are being selected and tested for salt tolerance. The best of these will be used for hybridization with other species and varieties with the object of producing a cold-hardy and exceptionally salt-tolerant rootstock variety.

*Combining Cold Hardiness with Resistance to Root Rot and Other Qualities.* In a search for plants highly resistant to injury from *Phytophthora parasitica,* the chief cause of root rot or foot rot of citrus in the warm soils of the desert citrus areas, seedlings of a large number of trifoliate orange varieties and hybrids, sour orange varieties, and mandarin and tangelo varieties have been screened for resistance to *P. parasitica.* This work has been carried out during the past 3 years by John B. Carpenter, citrus pathologist at Indio. A method that results in infection of all of the seedlings was devised. Following infection most of the seedlings die and only the highly resistant ones quickly recover and resume growth. Large numbers of resistant seedlings are now under field test. Some years will be required to complete the screening of these for cold hardiness and other qualities desirable in a rootstock.

Crosses have been made between trifoliate orange varieties and the following: Suen Kat, Cleopatra, Sunki and Shekwasha mandarins, Sunshine tangelo, several shaddocks, Iran lemon and Rough lemon, and several sweet orange varieties with the object of combining the factors in the trifoliate orange that induce high quality of fruit and cold hardiness with various qualities carried by the other parent, such as the tendency to induce high yields, vigor of growth, disease resistance, or tolerance to high-lime soils.

Most of these crosses have been made so recently that few of the seedlings have fruited. Unless the seedlings of a variety are largely nucellar, it is of limited value as a rootstock even though it has otherwise excellent qualities. Until the seedlings produced by these crosses are examined for nucellar embryony and tested in other respects, no prediction of their value can be made.

The detailed method of handling the testing of seedlings produced at Orlando and Indio in the breeding of scion varieties and rootstock varieties is yet to be worked out, but present plans are to send much of this material as seed or as budwood to Weslaco for tests of salt tolerance in the field or for tests of cold hardiness in the controlled-temperature rooms and greenhouses there.

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# POT STUDIES ON THE EFFECT OF SUPERPHOSPHATES ON THE GROWTH OF CITRUS SEEDLINGS

G. K. Rasmussen and P. F. Smith

*Agricultural Research Service*

*United States Department of Agriculture*

Orlando

Phosphates ($PO_4$) applied as superphosphates at relatively high rates to experimental field plots depressed growth of feeder roots (2, 7, 8) and stunted growth of Valencia orange and grapefruit trees (5, 8, 9).

Considerable acidity is added to the soil through the use of superphosphates. On lightly buffered sands the pH may be depressed appreciably in spite of the use of dolomite for pH control (7). With only annual applications of moderate amounts of $PO_4$ this reduction in pH is apparently not serious to the tree as a whole, even though it is associated with reduced root density in the upper soil depths. With larger rates of application the effect on both pH and roots is greater. The effect of $PO_4$ on pH is usually measured several months after application when leaching, lime digestion, and soil-buffering action have largely neutralized the acidity of the solublized $PO_4$. No information concerning the possible effects when a material like superphosphate is first added to light soils has been published.

Certain tests performed in the laboratory and greenhouse during the past year focus attention on the direct acidulating effect of normal superphosphate and triple superphosphate with Lakeland fine sand. The striking effects noted are associated with excess acidity, which seemingly is the main factor leading to killing of roots in the greenhouse and field tests (5, 7), although it is impossible to rule out entirely other factors such as $PO_4$-toxicity, ion imbalance, or toxic impurities which may be carried by the applied $PO_4$ (1).

## Methods and Materials

Subsoil was taken from the 6- to 12-inch level of a 10-year-old Pineapple orange grove on Lakeland fine sand which has never received $PO_4$. This grove had received several dolomite applications and therefore the subsoil pH was high (6.1). Rock phosphate (RP), normal superphosphate (NSP), and triple superphosphate (TSP) were screened and mixed with the subsoil to give 0, 200, 500, and 2500 ppm phosphorus. These rates are equivalent to approximately 0, 900, 2200, and 11,000 lbs of $P_2O_5$ per acre. Two pH levels were maintained by mixing 4 g of screened dolomite with the 2 kg of soil in each pot in half of the treatments. Four replications with 2 Pineapple seedlings per pot were randomized on the greenhouse bench. The seedlings were watered with rainwater and given a minus-$PO_4$ nutrient solution containing N, K, Mg, Ca, and B every 3 weeks. Care was taken in watering to make certain that no leaching took place.

After 9 months the seedlings were harvested, growth measurements of shoots and roots and a spectographic analysis was made on certain root samples to see whether unusual amounts of any element could be detected.

## Results and Discussion

*Effect of $PO_4$ on growth.*—NSP and TSP decreased the soil pH sharply when first mixed into the soil. The original pH value was 6.1 and the rates of NSP and TSP reduced it to about 4.0-4.2 immediately. The seedlings in the soil with the 2500 ppm of P derived from NSP and TSP showed severe wilt the day after planting and were dead within a week.

Seedlings were then replanted in these high-P soils. These seedlings made respectable growth. Evidently in a week the initial severe toxic action was lost from the soil. The pH had also risen. By the end of the experiment, as the values in table 1 indicate, the pH had drifted upward to a fairly normal level for subsoil. The roots, however, were largely in the top 2 inches of soil in these high-P soils suggesting that the toxic factor moves down even with controlled watering.

Table 1. Effect of rock phosphate and superphosphates on soil pH and growth of Pineapple orange seedlings after 9 months.

| Treatment | | Soil[a] | Dry weight (gm/plant) | | |
|---|---|---|---|---|---|
| Source | Ppm P | pH | Root | Shoot | Total |
| Rock $PO_4$ | 0 | 6.1-6.0 | 3.5 | 2.7 | 6.2 |
| | 200 | 6.2-6.5 | 2.8 | 2.4 | 5.2 |
| | 500 | 6.2-6.4 | 2.9 | 2.6 | 5.5 |
| | 2500 | 6.2-6.3 | 3.4 | 2.9 | 6.3 |
| Super $PO_4$ | 0 | 6.1-6.2 | 3.6 | 2.6 | 6.2 |
| | 200 | 5.4-6.3 | 2.9 | 2.6 | 5.5 |
| | 500 | 4.9-5.3 | 3.1 | 3.9 | 7.0 |
| | 2500 | 4.2-5.2 | 1.5 | 2.9 | 4.4 |
| Triple Super $PO_4$ | 0 | 6.1-6.3 | 3.2 | 2.6 | 5.8 |
| | 200 | 5.6-6.0 | 3.0 | 3.2 | 6.2 |
| | 500 | 5.0-5.9 | 2.8 | 3.1 | 5.9 |
| | 2500 | 4.0-5.4 | 1.2 | 2.2 | 3.3 |
| LSD @ 19:1 | | | .48 | .43 | .83 |

a/ Indicates pH at the beginning and end of the experiment.

Table 1 also shows the effect of different sources and rate of $PO_4$ on growth of orange seedlings when no dolomite is mixed with the soil. RP at the 3 rates used had very little effect on soil pH and no significant effect on root or shoot growth. Seedling growth in the 2500 ppm P soil was as good as in the soil with no added P.

The high rates of NSP and TSP even in the presence of 4 g of dolomite decreased the soil pH initially to within 0.1 unit of the pH when no dolomite was added (table 2). The seedlings planted in soils receiving these treatments also died within 1 week. These pots were also replanted and these seedlings made somewhat better growth than when no dolomite was added except that the root growth in the high-TSP soil was not much better with dolomite than without.

Table 2. Effect of rock phosphate and superphosphates with added dolomite on growth of Pineapple orange seedlings after 9 months.

| Treatment | | Soil[a/] | Dry weight (gm/plant) | | |
|---|---|---|---|---|---|
| Source | Ppm P | pH | Root | Shoot | Total |
| Rock $PO_4$ | 0 | 6.8-7.8 | 3.7 | 2.5 | 6.2 |
| | 200 | 6.8-7.8 | 2.9 | 2.4 | 5.3 |
| | 500 | 6.8-7.8 | 3.2 | 3.0 | 6.2 |
| | 2500 | 6.6-7.7 | 3.5 | 3.0 | 6.5 |
| Super $PO_4$ | 0 | 6.8-7.8 | 3.7 | 2.5 | 6.2 |
| | 200 | 5.9-7.0 | 3.1 | 3.1 | 6.2 |
| | 500 | 5.3-6.5 | 3.9 | 4.6 | 8.5 |
| | 2500 | 4.3-5.6 | 2.7 | 3.7 | 6.4 |
| Triple Super $PO_4$ | 0 | 6.8-7.8 | 3.7 | 2.5 | 6.2 |
| | 200 | 6.2-7.5 | 3.5 | 2.8 | 6.3 |
| | 500 | 5.2-6.9 | 4.0 | 3.9 | 7.9 |
| | 2500 | 4.1-6.0 | 1.6 | 3.3 | 4.9 |
| LSD @ 19:1 | | | .53 | .45 | .89 |

a/ Indicates pH at beginning and end of experiment.

Some growth response was noted at the intermediate levels of NSP and TSP. In no case did RP have any stimulating effect on growth. NSP and TSP carry some trace-element contaminants such as molybdenum, which may have caused the slight growth response since no trace elements other than boron were added to the nutrient solutions.

No deficiency or toxicity symptoms developed in the foliage during the experiment, and preliminary spectographic analyses of roots indicate no deficiency or toxic quantities of elements are associated with the reduced root growth.

*Relation of pH.*—After harvest the soil from all treatments in table 1 were acidulated with $H_2SO_4$ to give soil pH readings of 3.7 to 4.0 and the treatments in table 2 were adjusted with either lime water or $H_2SO_4$ to give soil pH readings of approximately 6.0. The soil was then replanted.

All seedlings planted in the soils with pH readings from 3.7 to 4.0, even those in soils with no added $PO_4$, died within 6 days. The seedlings planted in the pH 6.0 soils, regardless of $PO_4$ level or source, made normal growth as judged by the control plants which received no $PO_4$. Fig. 1 shows seedlings given 4 of the treatments after 6 days. Thus, toxicity induced by lowering the pH with $H_2SO_4$, is independent of applied $PO_4$, and appears to be identical with the effect when the pH is lowered to the same range by one of the acid phosphates.

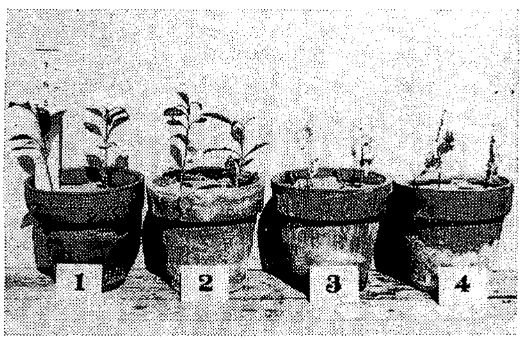


Fig. 1. Pineapple orange seedlings 6 days after planting: (1) No added P., pH 6.0; (2) 2500 ppm P, pH 6.0; (3) no added P, pH 4.0; (4) 2500 ppm P, pH 4.0.

*Loss of toxicity with time.*—Since the first seedlings planted in the high-P treatments died but when new seedlings were replanted respectable growth was made, it was decided to determine how long the toxicity lasted after mixing of TSP with soil. In a series of pots TSP was mixed with soil to give a final concentration of 2500 ppm P. In one pot the seedlings were planted immediately after mixing and in other pots 1,2,4,8,12,16,20 and 24 days after mixing. The soil was kept moist with frequent waterings and pH readings were made before each pot was planted. Through the first 4 days both seedlings died and the pH reading was near 4.0. After 8 and 12 days, the pH had risen to 4.4-4.5 and one seedling per pot died. After 16 days the pH had drifted upward to 4.6-4.8 and both seedlings lived in each pot. Thus it can be seen that it takes some time for the soil's buffering ability to reduce the acidity and at the same time better conditions for growth develop.

*Toxic factor in water phase of extract.*—In another study it was found that the toxic factor could be separated in the water-soluble extract of NSP and TSP. Fifty-five g of NSP and 25 g of TSP, equivalent to 2500 P in 2 kg soil, were washed with 300 ml of $H_2O$. The $H_2O$ extract, residue, and $H_2O$ extract plus the residue were added to the soil as 3 treatments. The water extract had a pH reading slightly less than 3.0. Seedlings planted in soil to which the $H_2O$ extract and $H_2O$ extract plus the residue were added died within 3 days. The seedlings planted in the soil to which the residue only was added made as good growth as control plants.

After mixing NSP or TSP with soil the toxicity also can be removed by leaching with water several times before planting.

*Sand trials and with another plant.*—To test the possibility that some soil factor was involved in acid-$PO_4$ toxicity and to see whether citrus was unique in its sensitivity, several treatments were tried in pots of fine quartz sand. One Pineapple orange seedling and 7 radish seeds were planted in each pot treated as shown in table 3. Frequent observations were made for the next month. The results are indicated in table 3 and illustrated in Fig. 2.

The radish response parallels the response of the citrus seedlings. In this case actual vegetative growth was either permitted or

Table 3. Effect of different mixtures or additions of triple-superphosphate to 2 kg. of quartz sand in clay pots on orange seedlings and radish germination.

| Treatments | Observations after 20 days: Orange | Radish |
|---|---|---|
| 1. none (sand only) | healthy | all growing |
| 2. 25 g. TSP[a/] | dead | 2 emerged |
| 3. 25 g. TSP + 20 g. dolomite | dead | no emergence |
| 4 25 g. TSP preneutralized with CaO | healthy | all growing |
| 5 25 g. TSP water phase[b/] | dead | no emergence |
| 6 20 g. TSP residue from 5 | healthy | all growing |
| 7. 33.5 g. $Ca_3(PO_4)_2$ powder | healthy | all growing |
| 8. 33.5 g. $Ca_3(PO_4)_2$ + $H_2SO_4$ to pH 2.9 | dead | no emergence |

a/ All except treatment 5 were dry mixed throughout sand.

b/ 300 ml $H_2O$ dissolved 5 g. of TSP out of 25 g. Clear liquid applied as surface drench.

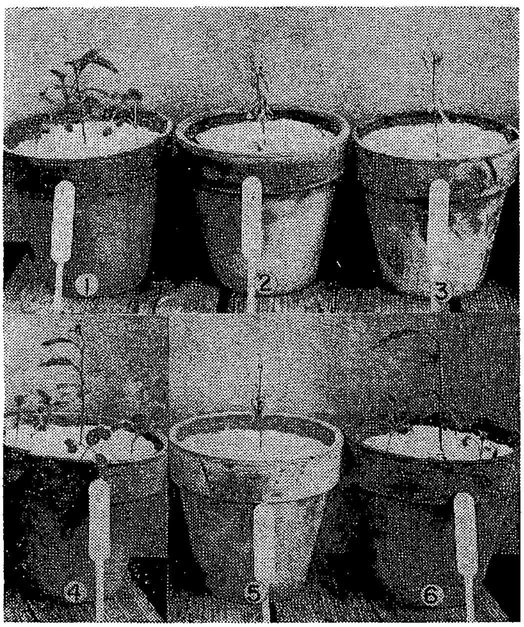


Fig. 2. Radishes and Pineapple orange seedlings planted in Crosley white sand given treatments 1-6 (table 3).

blocked, whereas little or no new growth takes place the first few weeks when citrus seedlings are transplanted. Apparently acid $PO_4$ may be toxic to plants other than citrus and soil need not be involved in the reaction.

*Neutralization of acid-$PO_4$.*—Neutralization of TSP and NSP is difficult and is not instantaneous even when it is titrated with NaOH. This undoubtedly is due to coarse, insoluble particles of the acid phosphates. About twice as much NaOH is required to neutralize TSP as NSP on an equal-weight basis. A slurry of TSP has a pH of about 2.6 and NSP a pH of 2.85. Approximately 40-percent active $CaCO_3$ by weight is required to neutralize TSP, but the reaction is slow, even in an aqueous suspension with constant stirring. Several hours were required under these conditions. When an excess of fine dolomitic limestone was mixed with TSP in water, the pH of the suspension remained below 4 for 24 hours and neutralization was not complete after 3 days with intermittent stirring. From these observations it seems highly improbable that temporary excess acidity in the field can be prevented by simultaneous application of liming materials because of spatial separation and slowness of reaction. Undoubtedly excess acidity, particularly in localized areas of the soil, will be present for some time, even when excess lime has been applied. This is most likely to be the cause of poor growth of feeder roots and lower root density in the top foot of soil when high-$PO_4$ applications have been made. Poor root growth previously has been shown to result in pot studies with subsoil and solution cultures when the pH is kept near 4.0 (3, 4).

Older Florida citrus soils show large accumulations of $PO_4$ as a result of many years' application of mixed fertilizers containing phosphatic materials (6). That severe damage from this practice has not been widely experienced is no doubt attributable to (a) the gradual additions of $PO_4$ over many years and (b) the fact that only a fraction of that applied is actually acid-$PO_4$. A large part of the excess acid is removed in the process of making ammoniated superphosphate which has been the main $PO_4$ source for mixed fertilizers. Thus, while excess use of $PO_4$ may be undesirable or actually damaging to commercial groves, the only demonstrated ill effects so far have been in experimental tests where straight acid-phosphates have been used.

SUMMARY

In a greenhouse experiment 3 sources of $PO_4$ were added to Lakeland fine sand subsoil at 4 rates with and without dolomite and Pineapple orange seedlings were grown in these pots for 9 months. In an attempt to explain the results of this test, several additional laboratory and greenhouse tests were made.

The orange seedlings in the 2500 ppm P subsoil when the P was derived from NSP or TSP died within 6 days after planting. These pots of soil were replanted with orange seedlings, which made fair growth but not as good as seedlings planted in subsoil with lower P levels. RP had no stimulatory effect upon growth of the seedlings.

The highest rates of NSP and TSP (2500 ppm) depressed the pH of the subsoil initially from 6.0 to approximately 4.0. Even in the presence of 4 g of dolomite, this sharp depression in pH resulted. RP had no influence on pH of the subsoil.

The results of the laboratory and various greenhouse tests clarify several important points. Toxicity of acid-$PO_4$ occurs only in the water phase. When acid-$PO_4$ are mixed with soil, they gradually lose their toxicity so that seedlings planted 12 days after the mixing grow normally. The toxicity can be leached from the soil as indicated by growth of seedlings planted after the leachings. Toxicity was not reduced by mixing dry dolomite or high-calcium lime with the acid-$PO_4$ even when in sufficient quantities to neutralize the acidity. Laboratory tests showed that the reaction between these is very slow even when they are stirred intermittently in an aqueous slurry. When the acidity was removed in this fashion, however, the toxicity was removed. Toxicity of acid-$PO_4$ is not limited to citrus as radish seeds failed to germinate in the presence of a high amount of TSP.

All these responses and reactions suggest that the free-acid content of acidulated phosphates is responsible for their deleterious effect on growth.

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# ADDITIONAL OBSERVATIONS ON FLORIDA CITRUS FOLLOWING THE 1957-58 FREEZES

JACK T. MCCOWN

*Assistant Citriculturist*

*Florida Agricultural Extension Service*

Gainesville

Following the freezes of the winter of 1957-58, we made an extensive survey to ascertain some of the factors which influenced the degree of freeze injury to citrus trees. A preliminary report of this survey was made during this Society's 1958 annual meeting. Now we are reporting additional observations regarding tree response in relation to horticultural practices carried on following the 1957-58 freezes.

Generally speaking, most citrus trees responded surprisingly well following the '57-58 freezes. This was perhaps due to the excellent growing conditions which occurred immediately following the freezes and continued during the growing seasons of 1958 and 1959. During both seasons, Florida citrus received more than the normal amount of rainfall, thus providing excellent growing conditions for tree recovery. The freezes of December 1957,