Rootstocks and Mineral Nutrition of Citrus

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Introduction

Mineral nutrition of plants is a topic which has been discussed since the beginning of agriculture. Aristotle wrote treatises on it, and until the 15th and 16th century the consensus was that whatever plants need to grow, it all came from the soil. Although Nicholas de Cusa and Van Helmont, after his famous experiment with a willow cutting, had ideas that the source of the materials that make up a plant was not quite as simple, it was the work of Priestly, Ingenhousz, and De Saussure, and the discovery of photosynthesis in the 18th and early 19th century that put mineral nutrition in its proper perspective as only one facet in the metabolism of plants. The grand old men of plant physiology, Sachs and Pfeffer, worked out the basis of mineral nutrition as we know it today in the second half of the last century and gave us an understanding of the constituents of plant tissues and the essentiality of some elements. In a more practical vein, their contemporaries, Boussingault, Liebig, Gilbert, and Lawes, showed the possibility of increasing crop yields by application of mineral fertilizers. Further work, mostly with solution culture, showed the essentiality of a series of elements which plants need in only very small amounts, the so-called micro-elements. A great amount of effort went into trying to find the combination of various elements for optimum plant growth and resulted in many publications of little practical value for 2 reasons. First, because much of the work was done without the statistical tools to separate real from apparent differences, and second because mineral uptake is a function of a maze of subtle cross connections of environment, development, genetics, and other various elements involved. Mineral nutrition ceased to be a glamour topic of research, although there was a brief revival when isotopes became generally available.

Mineral nutrition studies of citrus and other tree crops have almost become synonymous with leaf analysis. Following the development of instruments permitting the rapid analysis of large numbers of samples and the pioneering work of Lundegardh, a large body of knowledge has been built up empirically correlating the levels of nutrient elements in the leaves to tree performance, providing a more sensitive and less ambiguous method than deficiency or toxicity symptoms to diagnose the nutrient status of trees. The ranges given in tables of nutrient standards are usually fairly wide (2). Nevertheless, leaf levels listed as "optimum" often cannot be maintained because of local peculiarities, like irrigation water high in salt and variations in soil and climate. It is easy to overestimate the effect of mineral nutrition; miracles are often expected from fertilizer application. But the plant doesn't necessarily take up everything that's applied and as Smith (31) has shown in a nitrogen fertilization trial, the difference in yield between trees starved for N and those receiving high levels is often no more than 20%.

Rootstock Effects

Because the root system is the part of the plant which absorbs mineral elements (with the exception of nutrients applied as foliar sprays) it is only logical that rootstocks should have some influence on the composition of the scion. Substituting a genetically more or less distinct root system is bound to have an effect on the scion and many reports bear this out (see Literature Cited); however, the influence is by no means onesided. The scion also influences the size and composition of the root system (17). Basically the scion and the rootstock, because of their different genetic make-ups, remain separate entities, but one can influence the behavior of the other within certain narrow limits. The bud union is not a major factor in nutrient differences (36). Hodgson (18, 19) and Shannon and Zaphrir (28) investigated these relationships using reciprocally grafted rough lemon and trifoliate orange plants, and plants with 2 root systems of the same or both species. The scions seemed to have a greater influence on determining plant size than the rootstock. Two root systems gave no advantage in mineral uptake over one, but the rootstock species had distinct but different effects on the levels of K, Ca and Fe in the leaves. Trifoliate orange leaves were higher in K and lower in Ca than rough lemon leaves, regardless of rootstock, which seems to indicate that the scion influence was dominant in this case. When used as rootstock for rough lemon, trifoliate orange imposed the pattern of lower Ca and higher K on the scion. Rootstock and scion seemed to be equally effective in influencing the Fe concentration in the leaves, but the Fe concentrations reported are excessively high, which casts some doubt on the accuracy of the analyses. Two components determine the amount of an element in the leaf; uptake by the roots and translocation. The root only passes on materials to the scion after its own requirements are met. Analyses of plants with deficiencies, particularly micro-element deficiencies, often show that while the aboveground parts are low in some element the roots still contain adequate or even surprisingly high levels of it. The trunk, of course, is the site of translocation and the effect of inserting an interstock of sufficient length should give some indication on the relative importance of root uptake and translocation. Effects of interstocks on leaf composition of deciduous fruit trees have been reported (35, 39). Table 1 shows relative effects of rootstocks and 45-cm long interstocks on the leaf levels of 7 elements in young grapefruit trees. The trees had been grown in containers for 2 years before being planted in the field. Leaf samples were taken from 4 two-tree plots of each rootstock/interstock treatment 2 years after planting. Analysis for 12 elements showed no significant differences in P, Fe, Zn, Cu and Na with rootstock or interstock. In only a few instances was it possible to override the root influence with an interstock. Trees with *Citrus macrophylla* roots and sour orange and 'Cleopatra' mandarin interstocks had lower N levels than trees on *C. macrophylla* without an interstock. They behaved much like trees on sour orange and 'Cleopatra' roots. Trees with *Eremocitrus glauca* hybrid interstocks and *C. macrophylla* roots accumulated more chlorides than trees directly on *C. macrophylla*. Interstocks, with *C. macrophylla* as the common rootstock, affected the N concentration in the leaves. With trifoliate interstock it was higher than with sour orange, 'Cleopatra', *Evemocitrus glauca* hybrid, and satsuma interstock. *E. glauca* hybrid interstock resulted in higher K levels than 'Changsha' mandarin interstock. Mn was higher with 'Savage' citrange and 'Changsha' mandarin than with *E. glauca* hybrid interstocks. Chlorides were lower with sour orange and 'Cleopatra' interstocks than with *E. glauca* hybrid interstock and lower with sour orange than with 'Troyer' citrange. 'Cleopatra' mandarin interstock lowered B compared to 'Owari' Satsuma interstock. This is contrary to its behavior as a rootstock, where 'Cleopatra' is chloride-tolerant and B-sensitive (5). In spite of these effects of interstocks, root uptake and not translocation appears to be the dominant factor in determining leaf nutrient levels.

There are several reasons why effects of rootstocks on mineral nutrition are important. They have to be taken into account when interpreting leaf analysis data. Without a knowledge of the nutritional idiosyncrasies of a particular rootstock it is easy to misjudge the nutritional status of trees. The excessive uptake of one element can set in motion one or more nutritional imbalance reactions, such as depression of N by excessive amounts of Ca (38). Excess K depresses Mg. High levels of heavy metals can induce Fe deficiency symptoms. At least part of the mechanism of rootstock influences on fruit quality (30) is probably nutritional. If the rootstock is one of the species in the subtribal group *Citrus* there is some, but not too much, variation in leaf nutrient levels between rootstocks, but when graft-compatible citrus relatives are used greater differences can be expected. The earlier mentioned interstock data showed that the interstock causing most differences in nutrient levels was an *E. glauca* hybrid. The data in Table 2 show that *Severinia* can cause a range of unusual leaf nutrient patterns, among which accumulation of very high Mn levels is the most striking feature.

Chlorosis remains as a little understood mineral nutrition problem, although Smith *et al.* (33) have shown that levels of Fe are consistently lower in chlorotic than green leaves. But often only part of the leaves of a tree are chlorotic, or they are chlorotic only at certain times of the year. In Texas we have observed that as the trees get older they seem to be less chlorosis-prone. Nevertheless, rootstocks clearly influence the tendency of trees to show chlorosis, and this is often strikingly demonstrated in groves containing trees on more than one rootstock. In the rootstock trial described in Table 2 the samples contained both green and chlorotic leaves and the correlation Fe content-chlorosis is not very good. The high chlorosis resistance of 'Cleopatra' mandarin rootstock is noteworthy because this rootstock is often thought of as chlorosis-prone. With the advent of Fe chelates, chlorosis is no longer the serious problem it once was, but chelates are expensive and if other considerations permit, the selection of a chlorosis-resistant rootstock may be the most reasonable solution to the problem.

Salt Tolerance

One of the critical aspects of differences in mineral uptake with rootstocks is salt tolerance. Citrus is often grown in arid areas where the irrigation water contains high levels of salts. Strictly speaking "salt tolerance" refers to only sulfates and chlorides, but B tolerance is often included. Most citrus species accumulate B, and toxicity can be expected when water containing 0.5 to 1.0 ppm B is used. Sulfates and chlorides affect plant growth in 2 ways: 1) by increasing the osmotic pressure of the soil solution, an effect sometimes called "physiological drouth" and by 2) specific ion effects of the $SO4^=$ and the CL^- ions. B exerts only a specific ion effect because of its relatively low concentration in the soil. Which of the 2 effects of sulfates and chlorides is more important for citrus is a matter of contention, but at high concentrations the osmotic pressure is the dominant one. Citrus is relatively tolerant of sulfate and fairly high concentrations in irrigation water (3, 11) or culture solution (25) have little effect. As in many other aspects of citriculture, Swingle, the grand old man of citrus research, knew a great deal about B tolerance and he suggested, on the basis of seedling behavior in greenhouse experiments, that *S. buxifolia*, *E. glauca* and

Atalantia disticha be used as rootstocks in areas where B was a problem (34).

Eaton and Blair (10) took his advice and showed with reciprocally grafted trees of *S. buxifolia* and lemon in a sandculture experiment, that leaf B of 'Eureka' on *Severinia* was 283 ppm, compared to 1065 ppm on its own roots when 4 ppm B solution was applied. Leaves of *Severinia* scions grafted on 'Eureka' lemon contained 877 ppm B, while *Severinia* cuttings contained only 390 ppm B even when irrigated with 6 ppm B water. This shows clearly the ability of *Severinia* to exclude B. Roy (27), looking for rootstocks to alleviate B deficiency, found that leaves of orange trees on trifoliate orange and Cuban shaddock rootstock contained 70 and 74 ppm B while trees on sour orange contained 14 to 23 ppm. Rough lemon, sweet orange, and 'Cleopatra' mandarin rootstock also induced high B levels. Haas (14) in California obtained very similar results, with trifoliate orange, lemon shaddock, rough lemon, 'Savage' citrange, and 'Cleopatra' mandarin rootstocks accumulating high levels of B compared to several strains of sour orange. The B content of flowers, bark, and peel was also affected.

Later work by Smith *et al.* (32) in Florida, Cooper *et al.* (5) in Texas, and Embleton *et al.* (11) in California, produced similar results. A wide range of rootstocks was tested and the sweet limes were found to be B accumulators, while *C. macrophylla* was effective in keeping leaf B low.

In a series of papers in the 1950's and early 1960's, Cooper and his co-workers (3, 4, 6, 7, 9, 22) reported on the chloride uptake of a wide range of rootstocks. The results were obtained from plots watered with either saline well water or salinized river water by methods similar to those developed by the U.S. Salinity Laboratory in Riverside, California (Richards [ed.] Agri. Handbook No. 60, 1954). 'Cleopatra', some other mandarins, and 'Rangpur' lime were effective in keeping leaf chlorides low, while trifoliate orange and most trifoliate hybrids accumulated large amounts. Trees on *C. macrophylla* accumulated fairly high chloride levels but rarely showed toxicity symptoms.

In connection with chloride accumulation it was shown (23, 24) that trifoliate hybrid rootstocks known to be cold hardy in other areas, were cold tender in Texas because of their tendency to accumulate chlorides and B. In recent work (41) we investigated the effect of water application method on chloride and B uptake of young grapefruit trees grafted to 15 rootstocks, mostly 'Sunki' x trifoliate, 'Sunki' x *C. macrophylla*, and sour orange x 'Cleopatra' mandarin hybrids, together with some varieties of known salt tolerance, 'Rangpur' and 'Cleopatra'. Water containing 3000 ppm total salts (1700 ppm Cl^-) and 6 ppm B was applied separately to 3 sets of trees by flood irrigation, trickle irrigation and by subirrigation in sandculture. Trees on 5 of the 15 rootstocks took up equal amounts of chlorides with all 3 irrigation methods. On another 5 rootstocks the chloride levels were higher with flood irrigation than in sandculture with trickle irrigation intermediate. The remainder reacted in various ways.

In the B treatments only one rootstock did not respond to the method of irrigation. Nine rootstocks accumulated equal amounts of B with flood and trickle irrigation and less with subirrigation in sandculture. Four other rootstocks reacted variously, while *C. macrophylla*, known to be B-tolerant, accumulated 1134 ppm B with trickle irrigation, 718 with flood irrigation and 332 in sandculture.

The results of experiments, where water containing 3000 ppm or more total salts and 6 ppm B was applied, are difficult to interpret when recommending rootstocks for commercial use. The single most important characteristic of a rootstock is that trees on it produce large quantities of acceptable quality fruit. Often rootstocks performing well under the severe conditions of plot tests do not perform in the orchard as far as production is concerned. So the question is at what level of salt accumulation should a rootstock be eliminated. This means field tests under ordinary orchard conditions are still necessary to determine suitability.

The data in Table 4 from a recent grapefruit rootstock trial (42) show that the differences in tendency to take up chlorides and B between rootstock can be detected even when irrigated with water of acceptable quality, in this case about 1000 ppm total salts and 0.20 to 0.40 ppm B. 'Morton' citrange in this case accumulated twice as much chloride as sour orange, but the level was still in the acceptable range. Trees on 'Morton', however, yielded 30% more fruit over a 7-year period. Had these 2 rootstocks been compared in a plot test strictly on the basis of chloride uptake 'Morton' certainly would have been eliminated as unsuitable. It seems in selecting a rootstock we have to be somewhat tolerant of weaknesses and keep the overall picture in mind.

Effects of Rootstock on Individual Elements

Because of the wide range of conditions under which the tests were carried out it is impossible to put absolute values on the levels of a given element reported in the literature with a certain rootstock and classify them as "high" or "low". Most reports, however, are based on comparisons within arrays of rootstocks containing widely used rootstocks like rough lemon, sour orange, or trifoliate orange and statements on the relative amount of accumulation of elements can be made. The following is a compilation of such reports.

BORON

Rootstocks		*Reference & Scion*
High B	*Low B*	
Lemon	*S. buxifolia*	Eaton and Blair (10) Scion: *S. buxifolia* Lemon
Rough lemon 'Cleopatra' mandarin	Sour orange 'Valencia' orange	Roy (27) Scion: 'Parson Brown' orange
Trifoliate orange 'Lemon' Shaddock	Sour orange Grapefruit	Haas (14) Scion: 'Valencia' orange
'Rusk' citrange Grapefruit	Sour orange	Smith *et al.* (32) Scion: 'Valencia' orange
'Cleopatra' mandarin	Sour orange	Cooper *et al.* (5) Scion: 'Valencia' orange Grapefruit
'King' mandarin 'Sampson' tangelo	Rough lemon *S. buxifolia*	Cooper *et al.* (8) Scion: Grapefruit
'Cleopatra' mandarin	Sour orange	Cooper *et al.* (7) Scion: Grapefruit
'Cleopatra' mandarin 'Ponkan' mandarin	*C. macrophylla* *Citrus moi*	Cooper and Peynado (6) Scion: Grapefruit
Citrumelo C.P.B. 4475 'Ponkan' mandarin	*C. macrophylla* *Citrus moi*	Peynado and Young (22) Scion: Grapefruit
Grapefruit 'Yuzu'	*C. macrophylla*	Embleton *et al.* (11) Scion: Lemon
C59-24 (Rangpur x Trifoliate) 'Milam' rough lemon	*S. buxifolia* C55-24-4 ('Cleopatra' x Trifoliate)	Wutscher *et al.* (40) Scion: Grapefruit
Rough lemon	Sour orange	Sharples and Hilgeman (29) Scion: Various
'Ponkan' mandarin 'Morton' citrange	Sour orange 'Abers' sour orange	Wutscher and Shull (42) Scion: Grapefruit

CHLORIDE

Rootstocks		*Reference & Scion*
High Cl	*Low Cl$^-$*	
Sour orange	'Cleopatra' mandarin	Cooper *et al* (4) Scion: 'Valencia' orange Grapefruit
'Etrog' citron 'Rusk' citrange	'Rangpur' lime *S. buxifolia*	Cooper and Gorton (5) Scion: Grapefruit
'Thomasville' citrangequat Citrangor	'Sampson' tangelo 'Cleopatra' mandarin	Cooper and Shull (9) Scion: Grapefruit
Sour orange	'Cleopatra' mandarin	Cooper *et al.* (7) Scion: Grapefruit
'Carrizo' citrange 'Colombian' sweet lime	'Taiwanica' orange 'Cleopatra' mandarin	Cooper and Peynado (6) Scion: Grapefruit
'Troyer' citrange 'Carrizo' citrange	'Timkat' mandarin 'Cleopatra' mandarin	Cooper (3) Scion: Grapefruit
Citrus moi 'Carrizo' citrange	'Sunki' mandarin 'Timkat' mandarin	Peynado and Young (22) Scion: Grapefruit
'Troyer' citrange	'Cleopatra' mandarin Sour orange	Wutscher *et al.* (40) Scion: Grapefruit
'Carrizo' citrange 'Troyer' citrange	'Timkat' mandarin 'Bittersweet' sour orange	Wutscher and Shull (42) Scion: Grapefruit

SULFUR

Rootstocks		*Reference & Scion*
High S	*Low S*	
Rough lemon Grapefruit	'Cleopatra' mandarin Trifoliate orange	Haas (15) Scion: 'Valencia' orange
Grapefruit Sour orange	'Cleopatra' mandarin Rough lemon	Rasmussen and Smith (25) Scion: 'Valencia' orange 'Parson Brown' orange
'Cleopatra' mandarin	Sour orange	Cooper (3) Scion: Grapefruit

SODIUM

Rootstocks *High Na*	 *Low Na*	*Reference & Scion*
'Brownell' citradia 'Saunders' citrange	Sour orange Rough lemon	Cooper and Shull (9) Scion: Grapefruit
'Sampson' tangelo	'Cleopatra' mandarin 'Rangpur' lime	Jones *et al.* (20) Scion: Lemon
'Cleopatra' mandarin	Sour orange	Cooper *et al.* (7) Scion: Grapefruit
'Kara' mandarin 'Sanguinea' mandarin	Sour orange 'Gzel' sweet orange	Cooper (3) Scion: Grapefruit
Citrumelo C.P.B. 4475 'Ponkan' mandarin	Sour orange *C. macrophylla*	Peynado and Young (22) Scion: Grapefruit
'Yuzu'	Sweet orange *Citrus moi*	Embleton *et al.* (11) Scion: Lemon
Rough lemon	Sour orange	Sharples and Hilgeman (29) Scion: 'Valencia' orange
'Timkat' mandarin 'Ponkan' mandarin	'Bittersweet' sour orange 'Morton' citrange	Wutscher and Shull (42) Scion: Grapefruit

COPPER

Rootstocks *High Cu*	 *Low Cu*	*Reference & Scion*
'Rusk' citrange Sweet orange	Sour orange Rough lemon	Smith *et al.* (32) Scion: 'Valencia' orange
S. buxifolia 'Troyer' citrange	C61-251 (Shekwasha x 'Koethen') C55-24-4 ('Cleopatra' x Trifoliate)	Wutscher *et al.* (40) Scion: Grapefruit

MAGNESIUM

Rootstocks		*Reference & Scion*
High Mg	*Low Mg*	
Shaddock Trifoliate orange	Grapefruit 'Koethen' sweet orange	Haas (15) Scion: 'Valencia' orange
Rough lemon Trifoliate orange	Grapefruit	Haas (16) Scion: Grapefruit
'Rusk' citrange Rough lemon	Grapefruit Sweet orange	Smith *et al.* (32) Scion: 'Valencia' orange
Rough lemon	Grapefruit Sour orange	Wallace *et al.* (36) Scion: Various
'Cleopatra' mandarin	Sour orange	Gorton *et al.* (13) Scion: Grapefruit
'Cleopatra' mandarin	'Rangpur' sweet orange	Jones *et al.* (20) Scion: Lemon
'Taiwanica' orange 'Yuzu'	*C. macrophylla* *Citrus moi*	Embleton *et al.* (11) Scion: Lemon
'Sun Chu Sha Kat' mandarin 'Cleopatra'	*S. buxifolia* 'Changsha' mandarin	Wutscher *et al.* (40) Scion: Grapefruit
'Timkat' mandarin 'Cleopatra' mandarin	Grapefruit Citrumelo C.P.B. 4475	Wutscher and Shull (42) Scion: Grapefruit

ZINC

Rootstocks		*Reference & Scion*
High Zn	*Low Zn*	
Grapefruit Rough lemon	Sour orange Sweet orange	Smith *et al.* (32) Scion: 'Valencia' orange
C61-251 (Shekwasha x Koethen) *S. buxifolia*	C55-24-4 ('Cleopatra' x Trifoliate) 'Changsha' mandarin	Wutscher *et al.* (40) Scion: Grapefruit
'Timkat' mandarin 'Bittersweet' sour orange	'Abers' sour orange 'Carrizo' citrange	Wutscher and Shull (42) Scion: Grapefruit

CALCIUM

Rootstocks		*Reference & Scion*
High Ca	*Low Ca*	
'Siamese' shaddock Trifoliate orange	'Koethen' sweet orange Rough lemon	Haas (15) Scion: 'Valencia' orange
Sour orange Trifoliate orange	'Lemon' Shaddock Rough lemon	Haas (16) Scion: Grapefruit
Rough lemon 'Rusk' citrange	Grapefruit Sweet orange	Smith *et al.* (32) Scion: 'Valencia' orange
'Cleopatra' mandarin	Sour orange	Gorton *et al.* (13) Scion: Grapefruit
'Cleopatra' mandarin Rough lemon	'Sampson' tangelo 'Rangpur' lime	Jones *et al.* (20) Scion: 'Eureka' lemon
Rough lemon	Trifoliate orange	Shannon and Zaphrir (28) Scion: Various
Grapefruit 'Taiwanica' orange	Yuzu *C. macrophylla*	Embleton *et al.* (11) Scion: Lemon
'Troyer' citrange 'Cleopatra' mandarin	*Severinia buxifolia* C55-24-4 ('Cleopatra' x trifoliate)	Wutscher *et al.* (40) Scion: Grapefruit
Sour orange	Rough lemon	Sharples and Hilgeman (29) Scion: 'Valencia' orange

IRON

Rootstocks		*Reference & Scion*
	Low Fe	
'Rusk' citrange Rough lemon	Grapefruit Sour orange	Smith *et al.* (32) Scion: 'Valencia' orange
Rough lemon Sour orange	Trifoliate orange Grapefruit	Wallace *et al.* (37) Scion: Lemon
Rough lemon	Sour orange	Kuykendall (21) Scion: Various
Rough lemon	Trifoliate orange	Shannon and Zaphrir (28) Scion: Various
	'Rangpur' lime 'Taiwanica' orange	Embleton *et al.* (11) Scion: Lemon
C61-251 (Shekwasha x Koethen) 'Cleopatra' mandarin	C55-24-4 ('Cleopatra' x Trifoliate) C61-220 ('Cleopatra' x 'Troyer')	Wutscher *et al.* (40) Scion: Grapefruit

POTASSIUM

Rootstocks		*Reference & Scion*
High K	*Low K*	
'Koethen' sweet orange 'Sampson' tangelo	'African' sour orange Rough lemon	Haas (15) Scion: 'Valencia' orange
Grapefruit Shaddock	Sour orange Trifoliate orange	Haas (16) Scion: Grapefruit
Grapefruit Sweet orange	'Rusk' citrange Rough lemon	Smith *et al.* (32) Scion: 'Valencia' orange
Grapefruit Sweet orange	Rough lemon Sour orange	Wallace *et al.* (36) Scion: Various
Sour orange	'Cleopatra' mandarin	Gorton *et al.* (13) Scion: Grapefruit
'Rangpur' lime 'Sampson' tangelo	'Cleopatra' mandarin	Jones *et al.* (20) Scion: 'Eureka' lemon
Trifoliate orange	Rough lemon	Shannon and Zaphrir (28) Scion: Various
Severinia buxifolia 'Milam' rough lemon	'Troyer' citrange 'Sun Chu Sha Kat' mandarin	Wutscher *et al.* (40) Scion: Grapefruit
Grapefruit Citrumelo C.P.B. 4475	'Carrizo' citrange 'Troyer' citrange	Wutscher and Shull (42) Scion: Grapefruit

MANGANESE

Rootstocks		*Reference & Scion*
High Mn	*Low Mn*	
'Cleopatra' mandarin Rough lemon	Sweet orange Grapefruit	Smith *et al.* (32) Scion: 'Valencia' orange
'Yuzu' *C. macrophylla*	Sweet orange Grapefruit	Embleton *et al.* (11) Scion: Lemon
S. buxifolia	C55-24-4 ('Cleopatra' x Trifoliate) Sour orange	Wutscher *et al.* (40) Scion: Grapefruit
Rough lemon	Sour orange	Sharples and Hilgeman (29) Scion: 'Valencia' orange
'Timkat' mandarin 'Bittersweet' sour orange	'Abers' sour orange 'Carrizo' citrange	Wutscher and Shull (42) Scion: Grapefruit

NITROGEN

Rootstocks		*Reference & Scion*
High N	*Low N*	
'Koethen' sweet orange Rough lemon	'African' sour orange Trifoliate orange	Haas (15) Scion: 'Valencia' orange
'Rusk' citrange Rough lemon Sweet orange	'Cleopatra' Sour orange	Smith *et al.* (32) Scion: 'Valencia orange
Rough lemon Sweet orange	Grapefruit	Wallace *et al.* (36) Scion: various
Sour orange	Trifoliate orange	Wallace *et al.* (37) Scion: 'Eureka' lemon
Rough lemon	Sour orange	Sharples and Hilgeman (29) Scion: 'Valencia' orange
'Savage' citrange	'Troyer' citrange Sour orange	Wutscher and Shull (42) Scion: Grapefruit

PHOSPHORUS

Rootstocks		*Reference & Scion*
High P	*Low P*	
'Koethen' sweet orange Trifoliate orange	'Rubidoux' sour orange 'Lemon' Shaddock	Haas (15) Scion: 'Valencia' orange
Rough lemon Grapefruit	'Brazilian' sour orange Sour orange 'Lemon' Shaddock	Haas (16) Scion: Grapefruit
	Rough lemon	Aldrich and Haas (1) Scion: Lemon
Sweet orange 'Rusk' citrange	Sour orange 'Cleopatra' mandarin	Smith *et al.* (32) Scion: 'Valencia' orange
Rough lemon	Sour orange	Wallace *et al.* (36) Scion: various
Trifoliate orange Grapefruit	Sour orange Sweet orange	Wallace *et al.* (37) Scion: 'Eureka'
S. buxifolia	'Kunenbo'	Wutscher *et al.* (40) Scion: Grapefruit

Table 1.

Leaf levels of 7 elements of young grapefruit trees on 15 rootstocks and interstocks.

Scion	*Interstock*	*Rootstock*	*% N**	*% K*	*% Ca*	*% Mg*	*ppm Mn*	*ppm Cl^-*	*ppm B*
CES 3	-------------	Sour orange	2.06 cde**	1.07 bcd	3.66a	0.36 bc	20 de	550 c	150 bcd
Nucellar	Sour orange	Sour orange	2.10 bcde	1.05 bcd	3.36ab	0.35 cd	20 de	565 c	162abcd
Redblush	Macrophylla	Sour orange	2.01 de	1.25ab	3.80a	0.37 bc	19 e	647 c	157 bcd
Grapefruit	-------------	Cleopatra	1.96 e	0.87 cd	3.25abc	0.44ab	25 de	651 c	177ab
	Macrophylla	Cleopatra	2.07 bcde	0.81 d	3.31ab	0.46a	26 cd	588 c	194a
	-------------	Macrophylla	2.26abc	1.17abc	2.98 bc	0.26 e	37ab	706 bc	137 cd
	Sour orange	Macrophylla	2.01 de	1.25ab	2.92 bc	0.24 e	34ab	546 c	146 bcd
	Cleopatra	Macrophylla	2.00 de	1.22abc	2.82 bc	0.25 e	34ab	711 bc	127 d
	Trifoliate	Macrophylla	2.41a	1.31ab	2.89 bc	0.27 de	37ab	860abc	148 bcd
	Savage	Macrophylla	2.31ab	1.35ab	2.73 c	0.23 e	38a	850abc	152 bcd
	Troyer	Macrophylla	2.17abcde	1.27ab	2.99 bc	0.24 e	36ab	1065ab	141 cd
	E. glauca Hyb.	Macrophylla	2.15 bcde	1.52a	2.99 bc	0.27 de	32 bc	1109a	136 cd
	Changsha	Macrophylla	2.19abcde	1.08 bcd	2.92 bc	0.24 e	38a	815abc	152 bcd
	Owari Satsuma	Macrophylla	2.12 bcde	1.26ab	2.85 bc	0.25 e	35ab	917abc	172abc
	Chinotto	Macrophylla	2.24abcd	1.37ab	2.87 bc	0.26 e	34ab	748abc	157 bcd

*Means of 4 determinations based on 8 trees.

**Means within a column followed by the same letter are not significantly different at P = 0.05 according to Duncan's Multiple Range test.

Table 2.

Concentrations of P, K, Ca, Mg, Mn, Zn, and Cu in the leaves (dry weight) of 4-year-old CES 3 Redblush grapefruit trees on 16

Rootstock	*% P*	*% K*	*% Ca*	*% Mg*	*ppm Mn*	*ppmZn*	*ppmCu*
Texas sour orange	0.108 b[a/]	0.98 ef	3.30abc	0.22 c	27 b	34ab	8 b
Kunenbo	0.105 b	0.91 f	3.45abc	0.25 bc	37 b	31 b	6 bc
Cleopatra	0.117 b	1.11 def	3.64ab	0.33ab	38 b	29 bc	7 bc
C61-241, Shekwasha x Rough lemon	0.112 b	1.32 bcde	3.10 bc	0.22 c	32 b	32 b	7 bc
Changsha	0.110 b	1.32 bcde	3.00 c e	0.20 c	30 b	28 bc	7 bc
Sun Chu Sha Kat	0.109 b	0.84 f	3.08 bc	0.37a	41 b	35ab	7 bc
C61-250, Shekwasha x Koethen	0.112 b	1.56abc	2.9 c ef	0.23 c	36 b	30 b	8 b
Troyer	0.101 b	0.83 f	3.84a	0,27 bc	32 b	37ab	8 b
C61-253, Shekwasha x Chinotto	0.105 b	1.51abc	3.08 bc	0.33ab	37 b	34ab	7 bc
C59-24, Rangpur x Trifoliate	0.121 b	1.02 ef	3.63ab	0.19 c	29 b	28 bc	8 b
C61-251, Shekwasha x Koethen	0.098 b	1.44abcd	2.48 ef	0.21 c	41 b	43a	5 c
C62-252, Shekwasha x Koethen	0.105 b	1.19 cdef	2.63 ef	0.35a	46 b	43a	6 bc
Milam	0.109 b	1.60ab	3.20 bc	0.22 c	41 b	30 b	8 b
C61-220, Cleopatra x Troyer	0.108 b	1.07 def	2.51 ef	0.25 bc	30 b	26 c	6 bc
Severinia buxifolia	0.154a	1.76a	2.50 ef	0.16 d	187a	38ab	13a
C55-24-4, Cleopatra x Trifoliate	0.117 b	0.85 f	2.30 f	0.21 c	24 b	19 c	5 c

[a/] Mean followed by letter "a" is significantly different (at the 5% level) from those means not having "a"; those followed by "b" are significantly different from those not having "b", etc.

From Wutscher *et al.* (40).

Table 3. Tree volume, intensity of chlorosis, and concentration of iron, boron, and chlorine in the leaves (dry weight) of 4-year-old CES 3 Redblush grapefruit trees on 16 rootstocks growing on calcareous soil.

Rootstock	Tree survival (%) after 4 years (based on 7 reps.)	Tree volume[a/] m3	Chlorosis[b/] rating after		Fe (ppm)	B (ppm)	C1 (%)
			2 years	4 years			
Sour orange	100	4.92a[c/]	0.0 c	1.0 c	77abcd	174 bcd	0.09 cd
Kunenbo	100	4.53a	0.8abc	1.0 c	61 bcde	212abc	0.10 bcd
Cleopatra	100	4.21ab	0.5 bc	0.8 c	84ab	197 bcd	0.08 d
C61-241, Shekwasha x Rough lemon	86	2.83 bc	1.0abc	1.8 bc	65 bcde	194 bcd	0.11 bcd
Changsha	100	2.79 bc	2.0ab	1.3 c	59 cde	192 bcd	0.09 cd
Sun Chu Sha Kat	100	2.70 bc	2.0ab	2.0 bc	67 bcde	188 bcd	0.11 bcd
C61-250, Shekwasha x Koethen	100	2.70 bc	0.3 c	1.0 c	83abc	151 cde	0.11 bcd
Troyer	86	2.66 bc	0.5 bc	2.0 bc	60 cde	178 bcd	0.23a
C61-253, Shekwasha x Chinotto	71	2.55 bc	2.0ab	2.0 bc	59 cde	178 bcd	0.11 bcd
C59-24, Rangpur x Trifoliate	71	2.48 bc	0.0 c	1.8 bc	63 bcde	264a	0.10 bcd
C61-251, Shekwasha x Koethen	100	2.29 c	0.0 c	1.5 bc	94a	204abc	0.11 bcd
C61-252, Shekwasha x Koethen	100	2.20 c	0.8abc	1.3 c	77abcd	205abc	0.10 bcd
Milam	71	2.13 c	1.3abc	2.3 b	61 bcde	230ab	0.12 bc
C61-220, Cleopatra x Troyer	100	2.07 c	1.5abc	2.3 b	58 de	158 cde	0.11 bcd
Severinia buxifolia	86	1.64 c	2.3a	2.3 b	65 bcde	100 c	0.11 bcd
C55-24-4, Cleopatra x Trifoliate	100	1.42 c	1.3abc	3.5a	50 e	132 de	0.13a

[a/] Calculated by the formula $\frac{\text{width}^2 \times \text{height}}{4}$

[b/] 0 = all leaves green; 1 = trace of chlorosis; 2 = mild chlorosis; 3 = moderate chlorosis; 4 = severe chlorosis.

[c/] Mean followed by letter "a" is significantly different (at the 5% level) from those means not having "a"; those followed by "b" are significantly different from those not having "b", etc.

From Wutscher *et al.* (40).

able 4. Leaf analysis. Concentrations of 12 elements in leaves collected August 1971.

	% N	*% P*	*K*	*% Ca*	*% Mg*	*ppm Fe*	*ppm Mn*	*ppm Zn*	*ppm Cu*	*ppm Na*	*ppm C1*	*ppm B*
our orange												
bers	2.40 b*	.12 a	.93 cde	4.67 a	.33 de	68 a	33 cde	23 e	5 a	1338 ab	1299 bc	174 d
igaradier	2.46 b	.12 a	.84 cde	4.98 a	.35 d	70 a	38 bc	29 abcd	5 a	777 c	793 cd	220 c
ittersweet	2.43 b	.12 a	.97 cd	5.07 a	.33 def	62 a	35 cde	32 ab	5 a	592 c	539 d	194 d
exas sour orange	2.39 b	.12 a	1.02 bcd	4.76 a	.33 de	65 a	37 bcd	30 abcd	5 a	1049 bc	718 d	172 d
itranges												
arrizo	2.54 b	.13 a	.71 e	4.69 a	.41 bc	66 a	22 g	24 e	4 a	1118 ab	2118 a	217 c
orton	2.43 b	.11 a	.81 cde	4.25 a	.39 c	65 a	23 fg	28 bcde	5 a	698 c	1464 b	258 ab
avage	2.81 a	.14 a	.94 cde	4.62 a	.33 de	67 a	29 ef	25 de	5 a	1000 bc	1274 bc	193 d
royer	2.34 b	.12 a	.77 de	4.89 a	.39 c	70 a	23 fg	28 abcde	4 a	1011 bc	2022 a	190 d
itrumelo 4475	2.50 b	.13 a	1.23 ab	5.39 a	.32 ef	67 a	30 e		6 a	794 c	685 d	198 cd
andarins												
leopatra	2.44 b	.13 a	.81 cde	4.54 a	.43 b	59 a	42 ab	31 ab	5 a	763 c	689 d	238 b
onkan	2.38 b	.11 a	1.03 bc	4.08 a	.39 c	56 a	31 de	31 abc	5 a	1430 ab	643 d	277 a
imkat	2.47 b	.14 a	.89 cde	4.21 a	.50 a	62 a	47 a	33 a	5 a	1598 a	490 d	233 bc
edlings												
hary red grapefruit	2.41 b	14 a	1.34 a	4.69 a	.30 f	67 a	43 ab	29 abcd	5 a	1035 bc	811 cd	201 cd

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Means within a column followed by the same letter are not significantly different at P = 0.05 according to Duncan's Multiple Range Test.

rom Wutscher and Shull (42).

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