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Relationship between soil and leaf mineral nutrient concentration and yield of selected citrus species

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Abstract

Low yields of citrus in Trinidad prompted an investigation to determine whether infield yield variation in citrus was due to differences in plant nutrition induced by field variability. Selected trees of three cultivars (Valencia orange (*Citrus sinensis*), Portugal mandarin (*C. reticulata*) and Ortanique tangor (*C. sinensis* x *reticulata*) were monitored for one to two years and indicators of yield such as percent fruit set, fruit count and fruit quality measured. Leaf nutrient content of the trees and nutritive factors of the soil in the root zone were also determined. Nutrient deficiencies were found in the fields of all the three cultivars. The most common deficiencies were of calcium, zinc and magnesium. There was limited evidence of yield correlation with soil pH (P = 0.012), and leaf phosphorus content (P = 0.02), Zn (P = 0.005) and N (P = 0.001). DRIS analysis supported the notion that infield yield variability was associated with nutrients that were limiting. Percent fruit set was associated with Ca/Mg ratio (r = 0.542, P = 0.045; r = 0.607, P = 0.016) and foliar concentration of micro elements Cu (r = 0.738, P = 0.003; r = 0.667, P = 0.007) and Fe (r = 0.507, P = 0.064; r = 0.573, P = 0.026) in 1997 for one field each of Valencia orange and Portugal mandarin, respectively. The most commonly derived relationship for fruit quality was a negative relationship of leaf nitrogen concentration with fruit weight. A positive relationship between leaf concentration of manganese and peel thickness occurred in Portugal mandarin for the two years of the study.

Key words: Citrus, Valencia, Ortanique, mandarin, mineral nutrition, yield, fruit set, fruit quality

Introduction

Mean yield for oranges in Trinidad is low (Lucie-Smith, 1953; Cooper, 1956; Ali *et al*., 1973; Andrews *et al*., 2001), less than 1.5 crates per tree (41 kg per crate). It has been observed as well that there is great variation in yielding level between trees in the same field (Andrews, 1994). Increased yield can be accomplished by reduction of tree-to-tree variation and also by increasing the yield of individual trees. It is hypothesized in this study that variation in yield, percent fruit set and fruit quality are mirrored by corresponding variation in nutrient content in leaf or soil.

As in other crops, the routine method of assessing nutritional status and needs have been leaf and soil analysis in citrus (Weir, 1965; Rodriguez *et al.*, 1997). The use of sufficiency ranges and critical values have been most common for foliar analyses (Bar-Akiva *et al.*, 1968; Jorgensen, 1978; Embleton and Labanauskas, 1982; Dey and Singha, 1998). An alternative method of interpreting data from the soil and foliar analyses is the use of mineral nutrient ratios (Weir, 1969). The more recent development of this approach is the use of the Diagnosis and Recommendation Integrated System (DRIS) that allows for determination of relative deficiency or excess (Beverly *et al.*, 1984; Walworth and Sumner, 1987; Rodriguez *et al.*, 1997; Varalakshmi and Bhargava, 1998). DRIS indicates the relative limiting order among the nutrients analyzed and has been applied successfully to many annual and perennial crops (Walworth and Sumner, 1987).

A study was started in 1996 on citrus at the Todds Road estate of Caroni (1975) Limited with a view to determine the major factors influencing yield levels. This report deals with the nutrient levels in soil and leaf and their relationship with yield, fruit set and fruit quality. This information will be useful in developing a strategy for reduction of yield variation and the increase of crop yield.

Materials and methods

Tree selection: The cultivars used were Valencia orange (*Citrus sinensis*), Portugal mandarin (*C. reticulata*) and Ortanique tangor (*C. sinensis* x *reticulata*), the former two selected in two fields each on different soil types (Table 1). Five fields representing three cultivars were used and fifteen trees of similar size were selected from each field for sampling. At the time of selection, the trees represented groups of high, medium and low yielders of the 1996/1997 crop. These trees were located at the Todds Road estate in central Trinidad on Sevilla/L'Ebranche (Dystric gleysol) and Talparo clay (Eutric vertisol) soils, respectively.

Sampling: Soil sampling was done in 1997 in all plots at two depths, 0 to 23 cm and 23 to 46 cm, within the drip circle of the tree. Leaf samples were taken randomly from non-fruiting terminals and were 4 - 7 months old. Leaves from plots were collected in January - February 1997 and additionally for Portugal mandarin in one plot in December 1997 (representative of 1998).

Soil analyses: Analysis was done for pH, K and P only. Samples were extracted with ammonium acetate and read for K with a flame photometer. Phosphorus was extracted with Troug's solution and read at 660 nm using a spectrophotometer.

Foliar analysis: Foliar analysis was conducted on oven dried and ground material by digestion in sulphuric acid for N, P and K. A sample was treated with hydroquinone and ammonium

Table 1. Field characteristics of study plots at Todds Road Estate

Cultivar/Field ID	Soil type	Area (ha)	Number of trees	Year of planting	Topography
Portugal 12036	L'Ebranche clay	2.9	1082	1989	Flat
Portugal 12050	Talparo clay	2.3	954	1989	Slope
Valencia 12069	Sevilla/L'Ebranche	6.1	2325	1988	Flat
Valencia 12071	Talparo clay	4.2	1727	1988	Slope
Ortanique 12083	Sevilla/L'Ebranche	5.5	1862	1988	Flat

molybdate and P read on a spectrophotometer at 660 nm. The sample for N was treated with Nessler's reagent and read with a spectrophotometer at 408 nm. The K sample was diluted with water and read with a Flame Photometer.

Analysis of trace elements was done after dry ashing using the method of Richard (1993). Levels of Ca, Mg, Fe, Zn, and Cu were read using an Atomic Absorption Spectrophotometer. Microelement analyses were done in 1997 and 1998 on leaves from the Portugal mandarin plot at field 12050 and in 1997 only for Valencia orange, field 12069.

Yield and fruit set: Yield level was initially determined subjectively by visual inspection. All levels were associated with yield ranges and were determined by technicians skilled in visual counts and having acceptable levels of consistency (Bekele and Andrews, 1997). In 1998 and 1999, on-tree fruit, counts were used in determining yield levels in Valencia and Ortanique but not Portugal. Percent fruit set was determined by comparing flower counts of labeled branches with fruit number after three months.

Fruit quality: Fruit quality tests were conducted in order to determine mean volume, mean fruit weight, percent juice, brix, percent titratable acidity, number of seeds and peel thickness. Fruit colour was graded on a scale of 1 to 4 based on colour photographs of fruit at different maturity and colour development stages. Sugar:acid ratio was calculated from the preceding data. Fruit volume was determined by water displacement and brix determined using an Atago hand held refractometer. The percentage titratable acidity was done using method B (Wardowski *et al.*, 1991) with acidity expressed as percentage anhydrous citric acid. Juice percentage was calculated as volume over weight of fruit.

Data analysis: The relationship between nutrients and fruit quality was explored for the crop recently harvested or on-tree at the time of leaf and soil sampling. However, the yield and fruit set data were taken for the crop following sampling, as fertilizer application that influenced foliar nutrient levels was applied too late in the year to have affected either fruit set or fruit count of the crop used for fruit quality analyses.

Statistical analysis was done using Minitab Release 13.1. and DRIS analysis was accomplished with the use of the Potash and Phosphate Institute software (Version Beta 1.1) available on the Brazil (POTAFOS) site (http://www.potafos.org/). DRIS makes use of nutrient concentration ratios to interpret tissue analysis in relation to a database of analytical values of high yielding trees.

Results and discussion

Effect of soil and leaf nutrient levels on yield

Valencia: A regression equation was derived for fruit count of Valencia in field 12069 :

Fruit count (1998) = -153 + 7042 % Mg – 1451 % P + 39.9 pH ‘2’ + 6.08 Mn ppm + 168 %Ca – 85.1 Zn ppm – 26.4 P ppm ‘2’. ‘2’ refers to the 23 – 46 cm soil depth. $P < 0.01$, Adjusted R^2 = 99.5

The regression indicates that mineral nutrition was the main cause of yield variation in Valencia field 12069, however, yield variation due to tristeza infection has also been observed in that field (Andrews *et al.*, 2005). Positive yield response to correction of deficient leaf levels of Mg, Ca and Mn have been reported (Chapman, 1968; Embleton *et al.*, 1973) and support the regression formula presented for Valencia. A previous nutrition survey in citrus producing areas in Trinidad revealed widespread symptoms of magnesium, zinc and manganese deficiency (Weir, 1965).

According to sufficiency standards (Embleton *et al.*, 1973; Jorgensen, 1978) zinc, magnesium, calcium and manganese were deficient or considerably low in all three of the yield levels. When yield was considered as high, medium and low (3 levels), analysis of variance showed significant differences for leaf concentrations of zinc (Table 2). An appraisal of leaf nutrient levels of Zn at the three yield levels suggests that reducing levels of this nutrient are associated with increased yield. One possible explanation relates to the practice of applying fertilizer more liberally to high yielding trees. The applied N and K may have aggravated the existing Zn deficiency (Reuther and Smith, 1950). The leaf content of Fe showed a similar trend as Zn (Table 2) and this may have been induced by high K application which can be associated with Fe availability (Chapman, 1968).

Analysis of variance for soil and leaf nutrient concentrations showed no significant differences between yield levels in field 12071; however, soil phosphorus levels were in the range of 4 – 6 ppm and are considered low.

DRIS analysis of foliar nutritional levels for high yielding and low yielding trees in Valencia field 12069 show that in both the high and low yielding trees, zinc had the highest negative index. The second highest negative index was for manganese in high yielding trees, whereas it was magnesium in low yielding trees. The order of limiting nutrients by DRIS analysis was zinc, manganese, magnesium, iron and calcium in the high yield trees. No DRIS analyses were conducted for those fields where leaf data were limited to nitrogen, phosphorus and potassium only.

Table 2. Foliar levels of nitrogen, iron and zinc in February 1997 in relation to subsequent yield levels in Valencia orange field 12069

Yield level-1998 (fruit count)	N (%)	Zn (ppm)	Fe (ppm)
Low (<301)	2.5	10.24	133.4
Medium (301– 450)	2.7	9.47	105.2
High (>450)	2.1	3.80	59.9
Probability	0.09 NS	0.005	0.081 NS

NS – not significant (P = 0.05)

Portugal: Soil and leaf nutrient concentrations taken in January 1997 showed no significant difference when compared at the three yielding levels of the 1997/1998 crop of Portugal in field 12036. Field 12050 showed a significant difference (P=0.02) for percent leaf phosphorus only, (Table 3). Soil levels of phosphorus in field 12050 showed no significant difference at the three yield levels but the concentration is considered low. The optimum range of phosphorus in citrus leaves is 0.14 – 0.16% (Jorgensen, 1978) and 0.12 – 0.16% (Embleton *et al.*, 1973). The samples from Portugal field 12050 in 1997 showed means of 0.12, 0.14 and 0.17% (P=0.02) associated with trees giving low, medium and high yields, respectively in the 1997/1998 crop. This suggests that low yielding trees only were low or deficient in phosphorus. Analysis of variance for 1998 leaf samples for field 12050 showed no significant differences for any nutrient at the three yield levels. No regression analysis was done as data were not taken on fruit counts.

DRIS analysis of leaf nutrient data of field 12050 in 1997 indicated that the following nutrients limiting yield, in order of importance, were calcium, zinc, potassium, manganese and iron. When sufficiency ranges were considered (Embleton *et al.*, 1973; Jorgensen, 1978) calcium and zinc were deficient or low at all yielding levels. DRIS analysis of low yielding trees indicated zinc and calcium as the limiting nutrients.

In 1998, the DRIS limiting nutrients, in order of importance, were calcium, zinc, copper and manganese. Application of sufficiency range standards resulted in the same list of limiting nutrients except for manganese for which the concentration was close to critical. The order and magnitude of the DRIS negative indices was not the same for Portugal trees that were high or low yielding, suggesting that yield was lower when certain mineral nutrient limitations were more acute.

Table 3. Soil and leaf concentrations of phosphorus in Portugal trees of field 12050 (January 1997)

Yield level 1998 (fruit count)	P ppm (0 - 23 cm)	P ppm (23 - 46 cm)	P in leaves (%)
Low (<301)	8.8	8.8	0.120
Medium(301– 800)	8.3	9.5	0.140
High (>800)	8.0	10.4	0.177
Probability	NS	NS	0.020

NS – not significant (P=0.05)

Ortanique: Only soil potassium content at the 23 – 46 cm depth was significantly different for the three yield levels (Table 4) but the relationship was not linear. No adequate regression equation was derived. When data for fields 12069 and 12083 were combined because of similar soil type (Table 1) soil pH and leaf nitrogen levels became significant indicators of yield (Table 5). Yield level is inversely related to pH even though the upper limit of mean pH is 6.8 (Table 5). The high pH may have contributed to unavailability of zinc seen in Valencia field 12069 (Table 2). The high nitrogen levels (Table 5) may be reflecting phosphorus deficiency (Bar-Akiva *et al.*, 1968; Rabe and Lovatt, 1986) or calcium deficiency (Weir, 1969) which would explain the associated lower yield level.

Table 4. Mean content of soil nutrients in field 12083 in relation to the following year's yield levels (1997/1998 crop) (February 1997)

Yield level 1998 (fruit count)	K ppm (0 – 23 cm)	K ppm (23 -46 cm)	P ppm (23-46 cm)
Low (<251)	96.4	89.7	18.6
Medium (251 – 300)	146.4	117.6	18.4
High (>300)	160.0	84.0	7.5
Probability	0.072	0.038	0.525

Table 5. Effect of leaf and soil nutrient characteristics on yield level of Valencia and Ortanique grown on Sevilla/L'Ebranche clays

Yield level	pH (0 - 23 cm)	pH (23 - 46 cm)	Foliar nitrogen (%)
Low	6.6	6.8	3.1
Medium	6.5	6.7	3.2
High	6.2	6.3	2.2
Probability	0.062	0.012	0.001

Effect of soil and leaf nutrient levels on percent fruit set: The correlations in Table 6 are more revealing than ANOVA or regression analyses as it is clear that copper and iron and the calcium/magnesium ratio (indicative of calcium nutrition) were positively related to percent fruit set in Valencia and Portugal.

Within the Caroni (1975) Limited environment, leaf nutritional data of January in the years 1997 and 1998 reflect the nutritional status that can have direct effect on flowering and fruit set for the next crop, since no intervening fertilizer application occurred before August (Caroni Research Station, 1999). Only one application of fertilizer was given in those years as supplies were received late. By that time flowering would have occurred and fruit drop stabilized within eight weeks thereafter (Andrews, 1996).

The correlation analyses (Table 6) showed a positive relationship between concentration of copper, iron and calcium/magnesium ratio in the leaves and fruit set in two cultivars. Increased availability of minor element concentration has been associated with increased yield under conditions of deficiency (Chapman, 1968; Alva and Obreza, 1998) but the effect on percent fruit set has not been reported. There is generally a decrease in percent fruit set with increase in flowering (Deidda and Agabbio, 1977; Garcia-Luis *et al.*, 1988). However, Becerra and Guardiola (1984) have determined that, at the same flowering intensity, high yielding trees have higher fruit set percent than low yielding trees.

Ortanique leaf moisture content measured in February 1997 (Table 6) could not have had a direct effect on fruit set some five months later but may have been related to the tree's capacity for carbohydrate production during that period and affect fruit set indirectly.

Effect of soil and leaf nutrient levels on fruit quality

Nitrogen: The effect of nitrogen was common for Portugal and Valencia and the relationship with fruit weight was generally negative (Table 7), as seen in the derived regression equations. Significant nitrogen effect was not observed in 1997 for Portugal, field 12050, but it was present in 1998 for leaf concentration in relation to fruit weight (Table 7). The negative relationship between leaf nitrogen content and fruit size is consistent with the other reported experiences (Embleton *et al.*, 1973).

Phosphorus and potassium: Soil or leaf phosphorus appeared to be important in all three cultivars for various aspects of fruit quality, especially for peel thickness where the relationship was inconsistently positive and negative. The effect of potassium on fruit quality was weak and inconsistent.

Magnesium: Magnesium effect was limited to fruit weight and seed number in Valencia 12069 and to fruit volume and percent acidity in Portugal 12050 in 1998 (Table 7). This positive effect of magnesium content on juice acidity in the Portugal crop (Table 7) confirms to the report by Chapman (1968).

Table 6. Pearson's correlation of citrus percent fruit set with soil and leaf nutrition variables at Todds Road estate

Cultivar/ Field ID	Fruit set date	Nutrition variable	Correlation coefficient	Probability
Valencia 12069	1997	Fe	0.507	0.064
		Cu	0.738	0.003
		Ca/Mg	0.542	0.045
Portugal 12050	1997	Fe	0.573	0.026
		Cu	0.667	0.007
		Ca/Mg	0.607	0.016
Portugal 12050	1998 [1]	% K	0.580	0.030
Valencia 12071	1997 [1]	pH 0–23 cm (soil)	-0.534	0.074
		pH 23–40 cm (soil)	-0.693	0.013
		K(ppm) 23–40 cm	0.613	0.034
Ortanique 12083	1997	% Water[2]	0.844	<0.001
		K (ppm) 23-40 cm	-0.610	0.016
		P (ppm) 23-40 cm	0.529	0.043

[1]Log transformation of % set data
[2] % Water refers to leaf moisture content

The Mg/Zn relationship with seed number in Valencia 12069 (Table 7) is probably due to the more influence of magnesium than zinc as foliar magnesium deficiency symptoms are more pronounced in seedy cultivars (Chapman, 1968). The removal of foliar magnesium for seed development may be significant even though Valencia is not a seedy cultivar.

Microelements: Effects were observed for the two fields in which foliar analyses for microelements was done (Table 7). Except for the effect of manganese on peel thickness, microelement effects were not consistent by attributes for the different fields and years. The effect of manganese on peel thickness of Portugal mandarin was quite pronounced (Table 7), as the contribution to variability was 50.25% in 1997 and 17.95% in 1998. This relationship has not been previously reported although a positive correlation was found between fruit size (diameter and fresh weight) and flower content of manganese in Valencia orange (Pestana *et al.*, 2001). Some local growers believe that fruit with thick peel are favoured by buyers because of less adherence to the endocarp.

All fields showed some form of nutrient deficiency that would affect yield. There is general evidence to support the idea that yield variation is associated with variation in nutritional factors. The relationship between leaf concentration of manganese and peel thickness in Portugal mandarin suggested by preliminary data should be investigated further, including the attractiveness of peel thickness to the local market.

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Table 7. Effect of soil and leaf nutrient factors on fruit quality of Valencia orange and Portugal mandarin

Cultivar	Field ID	Year	Nutrient factor	Regression equation	Adjusted R^2 (%)	Probability
Valencia orange	12069	1997	N	Fruit weight = 181 + 61.7 %N – 455 %Mg – 5.73 P ppm '2'[a]	62.3	0.005
Valencia orange	12071	1997	N	Fruit weight = 155 + 27.6 pH – 31.7 %N	50.7	0.006
Portugal mandarin	12036	1998	N	Fruit weight = 183 – 57 %N + 796 %P	37.7	0.023
Portugal mandarin	12050	1998	N	Fruit weight = 136 – 11.9 %N + 31.2 %K – 0.143 Fe/Zn	74.7	0.001
Valencia orange	12069	1998	Mg	Fruit weight = 181 + 61.7 %N – 455 %Mg – 5.73 P ppm '2'[a]	62.3	0.005
Valencia orange	12069	1998	Mg	Number of seeds = 4.58 + 0.00665 Mg/Zn	76.3	<0.001
Portugal mandarin	12050	1998	K/Mg	Fruit volume = 102 – 2.67 K/Mg + 29.7 %K	37.5	0.024
Portugal mandarin	12050	1998	Mg	Acidity (%) = 1.03 + 0.421 %Mg – 0.00222 Mn ppm	54.2	0.004
Portugal mandarin	12050	1998	Mn	Peel thickness = 0.95 +0.00359 P ppm + 0.00192 Mn ppm – 0.0589 %N – 0.00591 K ppm	85.5	<0.001
Portugal mandarin	12050	1998	Mn	Peel thickness = 0.186 + 0.00244 Mn ppm	23.3	0.039

[a] '2' refers to the 23 – 46 cm soil depth

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