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MINERAL NUTRITION OF ORANGE AND MANDARIN CROPS IN RELATION TO SOIL TYPES IN THE DEPARTMENT OF META, COLOMBIA

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ABSTRACT

The foothills of the Llanos Orientales of Colombia are characterized by having small- and medium-scale citrus producers, who perform agronomic management practices that require adjustments to increase the productivity. The aim of this study was to diagnose the nutritional status of 'Valencia' orange (*Citrus sinensis* [L.] Osbeck) and 'Arrayana' mandarin (*Citrus reticulata* Blanco) on farms in the foothills of the Department of Meta, as a baseline for future experiments to establish nutritional requirements for these crops. Leaf samples were taken in 19 plots cultivated with orange and 18 with mandarin located in four municipalities with three soil classes (Classes II and III Inceptisols, and Class IV Oxisols). Foliar concentrations of N, P, K, Ca, Mg, Zn, B, Fe, Cu, and Mn were measured and compared with reference levels found in the literature, as well as with productivity values. Results showed that for both crops all the samples had Ca and Zn deficiencies, between 50 and 70 % of these had N, P, K, Mg, and Mn deficiencies in orange, meanwhile, in mandarin, in addition to Ca and Zn, Mg deficiencies were found in about 55 % of the samples. This indicates that in the studied area, Ca is a limiting nutrient for citrus nutrition followed by Zn and Mg. Further, the kind of soil had effects on productivity of both crops, being higher in the trees established in the Inceptisols-Class II soils.
Additional keywords: Citrus, Inceptisols, landplains, low tropics, Oxisols, yields

RESUMEN

Nutrición mineral de los cultivos de naranja y mandarina en relación al tipo de suelo en el departamento del Meta, Colombia

El piedemonte llanero de Colombia se caracteriza por tener pequeños y medianos productores de cítricos, los cuales realizan prácticas de manejo agronómico que requieren ajustes para aumentar la productividad. El objetivo de este estudio fue diagnosticar el estado nutricional de la naranja ‘Valencia’ (*Citrus sinensis* [L.] Osbeck) y la mandarina ‘Arrayana’ (*Citrus reticulata* Blanco) en relación con el tipo de suelo en fincas productoras del piedemonte del Meta, como base para futuros experimentos que permitan determinar sus requerimientos nutricionales. Se tomaron muestras foliares en 19 parcelas cultivadas con naranja y 18 con mandarina, ubicadas en cuatro municipios con tres clases de suelo (Inceptisoles clases II y III, y Oxisol clase IV). En cada muestra se midieron las concentraciones foliares de N, P, K, Ca, Mg, Zn, B, Fe, Cu y Mn, y se compararon con los niveles de referencia propuestos en la literatura como los valores de productividad. Todas las muestras de naranja y mandarina presentaron deficiencias de Ca y Zn, y entre 50-70 % de éstas presentaron deficiencias de N, P, K, Mg y Mn en naranja, mientras que, en mandarina, además de Ca y Zn, se presentaron deficiencias de Mg en aproximadamente el 55 % de las muestras. Lo anterior indica que en el área de estudio, el Ca es un nutriente limitante para la nutrición de los cítricos seguido por Zn y Mg. El tipo de suelo tuvo efecto sobre la productividad en ambos cultivos, la cual fue mayor en los árboles establecidos en los Inceptisoles clase II.
Palabras clave adicionales: Cítricos, Inceptisoles, llanos orientales, Oxisoles, rendimientos, trópico bajo

INTRODUCTION

Citrus fruits are native to the tropical and subtropical regions of Asia and the Malay Archipelago, and their commercial production is concentrated between 20° and 40° of latitude in

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both hemispheres (Roose et al., 20150). In Colombia, the production is concentrated in the low (0-500 meters altitude) and in the medium tropics (500-1,500 meters altitude) (Orduz, 2007), with a cultivated area in 2014 of 97,275 ha with a production of 1,206,856 Mg·year^{-1} (ENA-DANE, 2016). One of the main producing departments with a huge projection for citrus is Meta. This region has a unimodal rainfall regime with high rainfall, high relative humidity, high temperatures, a high number of cloudy days and acid soils, which create conditions for generation of nutritional deficiencies in citrus plantations (Smoleń, 2012). The above leads to a decrease in yields in those cases where fertilization is not carried out based on a soil management program built from the nutritional diagnosis of the crop and the soil, together with the nutritional requirements of the crop. At present, the management practices are based on the application of fertilizers and irrigation based on reference levels or crop indicators. In Colombia, many of the methodologies and reference levels were copied from soils with a chemical and mineralogical reality that is different from the existing one, and many of those methods were calibrated many years ago and in soils that are not representative of the current agricultural systems.

On the other hand, in the country, the correlation and calibration program that carried out this activity was suspended many years ago, judging by the last publication of ICA (1992). In these publication, the fourth and fifth approach to the fertilization of various crops shows that the critical levels did not change during the past 26 years. This situation conflicts with the main characteristic of a chemical analysis, where the evaluation of soil fertility is carried out empirically and it must be continuously re-evaluated. Due to the abovementioned, it is clear that the productivity in the producing regions varies significantly among regions and farms, mainly due to differences in soils and management practices among these. Moreover, the factors with the most significant weight after irrigation are the inadequate and unbalanced use of fertilizers (Srivastava et al., 2014). In this context, the aim of this research was to carry out a diagnosis of the nutritional status of the orange cultivar 'Valencia' (*Citrus sinensis* [L.] Osbeck) and the mandarin cultivar 'Arrayana' (*Citrus reticulata* Blanco) in relation to the soil types of the producing farms in the foothills of the Department of Meta, Colombia, which may serve as a baseline for future experiments that seek to establish the nutritional requirements of citrus crops.

MATERIALS AND METHODS

This study comprised the evaluation of the nutritional status of the orange cultivar 'Valencia' and the mandarin cultivar ‘Arrayana’ in producing farms located in the abovementioned areas of the Department of Meta. Purposeful sampling was carried out, considering only trees of those cultivars, which, according to the criteria of the producers, were the ones that show higher productivity and fruit quality, better health, and been more vigorous and long-lived. Plants of both crops were 10-15 years old and 2-3 m height. Nineteen leaf samples of Valencia orange and eighteen of Arrayana mandarin were taken in the same number of farms in four municipalities (Granada, Lejanias, Acacias, and Guamal) in the year 2015.

The farms are located mostly in soils of the orders Inceptisols (Class II and III) and Oxisols (Class IV). Inceptisols-Class II soils correspond to alluvial soils with slopes between 0-7 %, without erosion, good drainage and with a predominantly moderate fine texture. They have depths higher than 75 cm, medium to high fertility, without salts, and are slightly acid soils (pH 6.1-6.4) according to the classification of USDA, and with an aluminum saturation lower than 15 %. Inceptisols-Class III are modernly evolved soils, with slopes between 0 and 15 %, without or with a very slight presence of erosion, good drainage, medium predominant textural group, medium fertility, without salts, and depths higher than 50 cm. They are slightly acidic soils (pH 6.1-6.5), with aluminum saturation between 15 and 30 % and exchangeable sodium percentage lower than 15 %. Finally, Oxisols-Class IV are highly evolved soils with slopes between 0 and 25 %, with a light to moderate presence of erosion, moderate drainage and depths higher than 25 cm. The textural group is predominantly moderate fine, with low fertility, light to moderate salt content, acid (pH 4.5-5.5), with aluminum saturation lower than 60 % and exchangeable sodium lower than 50 %. Thus, the general clasification of the soils in the farms produced a total of three soil tratments as large plots.

Each leaf sample consisted of the mixture of 20 leaf subsamples taken in 20 trees per plot. The sampling was carried out following diagonal transects and randomly selecting 20 healthy trees per plot. For the collection of the leaf samples, mature and fully developed leaves of 4 to 7 months of age were taken, located in non-fruiting shoots; these leaves correspond to the third or fourth leaf of the previous shoot. Four leaves were taken per tree, one for each cardinal point, from branches located halfway up the tree.

A completely randomized experimental design was used; each soil type corresponded to one treatment and the farms to the repetitions, for a total of three treatments, each treatment including at least four repetitions depending on the availability of farms by soil types. The variables analyzed in the foliar tissue of each sample corresponded to the concentrations of N, P, K, Ca, Mg, Fe, Mn, Zn, Cu and B. Productivity per tree was computed as well.

The data obtained from the concentrations of nutrients were analyzed using the statistical software SAS version 5.1 (Cary, NC, USA). A descriptive analysis was made to establish the variability of nutrient concentrations at the level of the selected trees. Anova and Tukey test's were completed on the mentioned variables, and a principal component analysis (PCA) was performed in order to identify the correlation between nutrient concentrations in leaf tissue depending on the type of soil and its relationship with productivity.

The results of the leaf analysis were compared with the sufficiency range proposed for citrus by Molina (2000) (Table 1), and the sufficiency of concentrations was established for each leaf analysis in the different farms.

Table 1. Reference nutritional levels for oranges proposed by Molina (2000)

Nutrient	Low	Optimum	High
N (%)	< 2.3	2.4 – 2.6	> 2.6
P (%)	< 0.11	0.12 – 0.15	> 0.15
K (%)	< 0.7	0.8 – 1.1	> 1.1
Ca (%)	< 2.9	3.0 – 5.5	> 5.5
Mg (%)	< 0.25	0.26 – 0.6	> 0.6
Fe ($mg \cdot kg^{-1}$)	< 59	60 – 100	> 100
Mn ($mg \cdot kg^{-1}$)	< 24	25 – 200	> 200
Zn ($mg \cdot kg^{-1}$)	< 24	25 – 100	> 100
Cu ($mg \cdot kg^{-1}$)	< 4.9	5 – 15	> 15
B ($mg \cdot kg^{-1}$)	< 30	31 – 100	> 100

RESULTS

Nutritional characterization at the foliar level. Statistics of the concentrations of nutrients in leaves for orange (Table 2) and mandarin (Table 3) sampled in different types of soils located in the foothills of the Department of Meta show that Mg, Mn, Zn, Cu, and Fe had the highest coefficients of variation for both crops (> 25 %). The nutrients that showed the lowest coefficient of variation were B and N for orange and N and K for mandarin. Iron was the nutrient with the highest dispersion in both crops. Results for the Valencia orange show that there were significant differences ($P \leq 0.05$) for the concentrations of Ca, Mn, and Fe among the three soil types. For Arrayana mandarin, significant differences were found ($P \leq 0.05$) for the concentrations of K, Ca, Zn and B. The productivity for both cultivars also varied significantly between the types of the soil, finding higher productivity in citrus cultivated in Inceptisols class II with yields of 112.7 kg per tree in orange, and 114.9 kg per tree in mandarin; meanwhile, crops established in the Oxisols orders showed average yields of only 73.5 kg per tree in orange and 59.8 kg per tree in mandarin.

The above suggests that the agronomic behavior of citrus is influenced by the soil order.

Thus, the Inceptisols which have an incipient pedogenetic development, with differentiation of horizons due to the mineralization of organic matter, release and oxidation of iron, and structure formation that promote more fertile soils, had a better performance than Oxisols.

The differences observed are associated to the differences in soil characteristics, and also probably due to the management practices carried out by the producers, emphasizing in differences in fertilization programs, which change considerably from one farm to another (Quaggio et al., 2011; Torres et al., 2010).

Avilan et al. (1987) found that the nutritional status, size, and yield of citrus are closely related to the soil quality explored by the root system. In turn, Wutscher (1989) and Srivastava and Singh (2004) reported that many investigations highlighted citrus decline to unfavorable surface and subsoil conditions.

The principal component analysis shows that calcium and nitrogen are the nutrients that most discriminate the points of soil types (Figures 1 and 2). In the case of mandarin there is a clear positive correlation between Ca and Zn with respect to productivity; however, this is not displayed in the case of orange.

Table 2. Descriptive statistics and mean separation for foliar nutrient concentrations in Valencia orange depending on soil types of the foothills of the Department of Meta, Colombia

Soil Order and Class		N	P	K	Ca	Mg	Mn	Zn	Cu	Fe	B	Productivity
		%-					mg·kg^{-1}					kg per tree
Inceptisols Class II	Mean	2.42 a	0.11 a	1.29 a	1.40 a	0.19 a	28.2 a	9.0 a	6.0 a	125.0 a	71.0 a	112.7 a
	Minimum	2.28	0.11	1.14	1.30	0.14	23.0	8.0	4.0	97.0	68.00	73.53
	Maximum	2.59	0.12	1.40	1.55	0.26	3800	13.0	8.0	172.0	75.00	131.37
Inceptisols Class III	Mean	2.35 a	0.11 a	1.14 a	1.25 b	0.25 a	26.4 ab	7.10 a	8.50 a	94.8 ab	69.30 a	83.3 b
	Minimum	1.96	0.09	0.86	0.99	0.15	14.0	5.0	3.0	76.0	64.00	59.8
	Maximum	2.72	0.14	1.44	1.45	0.32	40.0	8.0	14.0	124.0	75.00	95.59
Oxisols Class IV	Mean	2.45 a	0.12 a	1.30 a	1.24 b	0.19 a	19.5 b	9.50 a	8.75 a	73.75 b	72.75 a	73.5 b
	Minimum	2.28	0.11	1.06	1.12	0.16	15.0	7.0	6.00	46.0	68.00	50.0
	Maximum	2.54	0.12	1.46	1.41	0.23	26.0	15.0	13.00	104.0	79.00	85.98
General CV		7.01	9.82	15.47	10.78	25.42	31.01	27.56	37.74	27.45	5.46	10.6
General mean		2.39	0.11	1.21	1.29	0.22	25.42	8.11	7.89	98.32	70.47	79.16

Means with different letters indicate a significant difference according to the Tukey's test ($P \leq 0.05$)

Table 3. Descriptive statistics and mean separation for foliar nutrient concentrations in Arrayana mandarin depending on soil types of the foothills of the Department of Meta, Colombia

Soil Order and Class		N	P	K	Ca	Mg	Mn	Zn	Cu	Fe	B	Productivity
		%					mg·kg^{-1}					Mg·ha^{-1}
Inceptisols Class II	Mean	2.63 a	0.15 a	1.38 a	1.90 a	0.29 a	36.50 a	11.25 a	7.25 a	88.00 a	80.75 a	114.9 a
	Minimum	2.52	0.12	1.20	1.84	0.24	31.00	9.00	7.00	59.00	76.00	76.72
	Maximum	2.74	0.17	1.54	2.01	0.32	42.00	14.00	8.00	114.00	87.00	135.54
Inceptisols Class III	Mean	2.44 a	0.11 a	1.15 b	1.39 b	0.27 a	28.30 a	6.40 b	6.80 a	87.10 a	67.80 ab	70.2 b
	Minimum	2.12	0.09	0.98	1.15	0.20	12.00	4.00	4.00	48.00	36.00	42.84
	Maximum	2.80	0.17	1.54	2.01	0.47	48.00	14.00	12.00	132.00	87.00	86.72
Oxisols Class IV	Mean	2.48 a	0.13 a	1.40 a	1.57 b	0.28 a	27.00 a	6.25 b	8.25 a	68.25 a	47.75 b	59.8 c
	Minimum	2.21	0.13	1.28	1.35	0.25	22.00	5.00	7.00	56.00	36.00	40.44
	Maximum	2.74	0.14	1.54	1.80	0.35	32.00	8.00	10.00	85.00	58.00	80.39
General CV		8.27	16.06	13.80	16.42	25.52	32.50	34.85	27.10	27.93	23.97	12.43
General mean		2.49	0.13	1.26	1.54	0.28	29.83	7.44	7.22	83.11	66.22	80.64

Means with different letters indicate a significant difference according to the Tukey's test ($P \leq 0.05$)

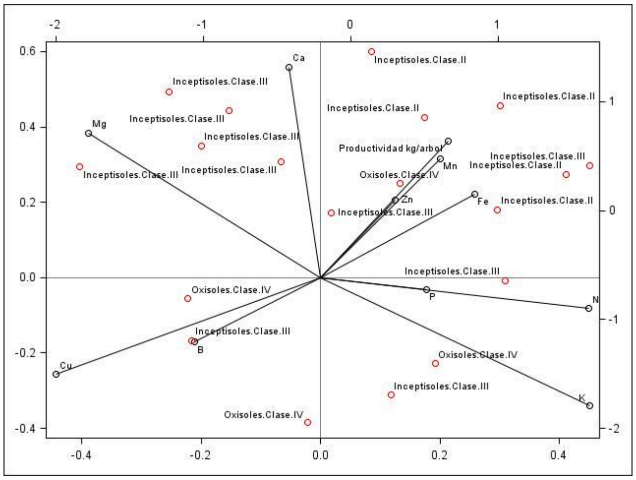

Figure 1. Principal components analysis for 14 quantitative variables evaluated in the Valencia orange cultivar

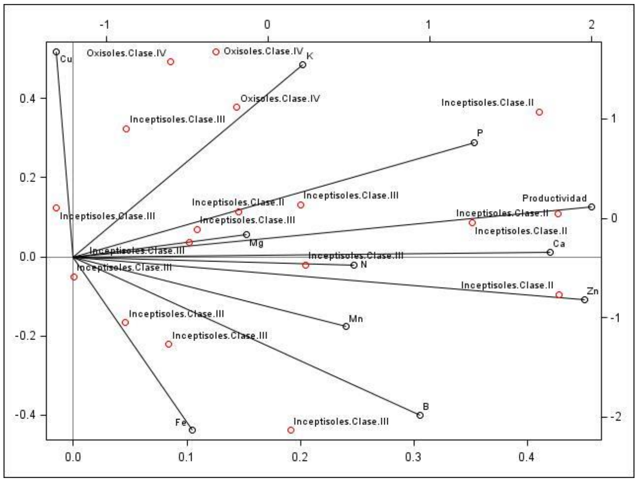

Figure 2. Principal components analysis for 14 quantitative variables evaluated in the Arrayana mandarin cultivar

Costa et al. (2014), working with Valencia orange, used spatial correlations between productivity and soil attributes, and could identify specific areas of soil management, which were closely linked to crop yield.

Aular et al. (2017) found that for citrus fruits, potassium was the element with the most considerable influence on fruit characteristics, followed by nitrogen and phosphorus, while Quaggio et al. (2002) indicated that all potassium application rates improve fruit yield and quality, and reduce fruit fall. On the other hand, as seen in our results, the mineral element requirements of citrus plants are specific and may vary depending on the type of soil and its fertility.

Comparing the concentrations of the nutrients found with the indicators proposed by Molina (2000) for both orange and mandarin, 100 % of the samples analyzed showed Ca and Zn deficiencies; further, between 50 to 70 % of these samples also showed N, P, K, Mg and Mn deficiencies in orange, meanwhile in mandarin, in addition to Ca and Zn deficiencies, Mg deficiencies were also found in about 55 % of the samples. The calcium deficiencies can be associated to the acidic condition of the studied soils.

Conversely, 100 % of the samples for both orange and mandarin showed concentrations of B at the leaf level in the optimal range (Figure 3).

Comparing the nutrient concentrations

obtained in mandarin with the results of other investigations, it can be stated that the results vary, at least partially, according to the soil type, as well as the management practices. For example, De la Yfran et al. (2017) evaluated in mandarin the incidence of foliar fertilization with K, Ca, and B on nutrition and yield, finding that the highest production (approximately 102 kg per plant) was obtained with plants that received Ca-B contributions of 0.4 %. It should be noted that in that research, the foliar concentrations of N, K, and Mg were below the concentrations reported by the trees of the present study, while, those of Ca and P were higher.

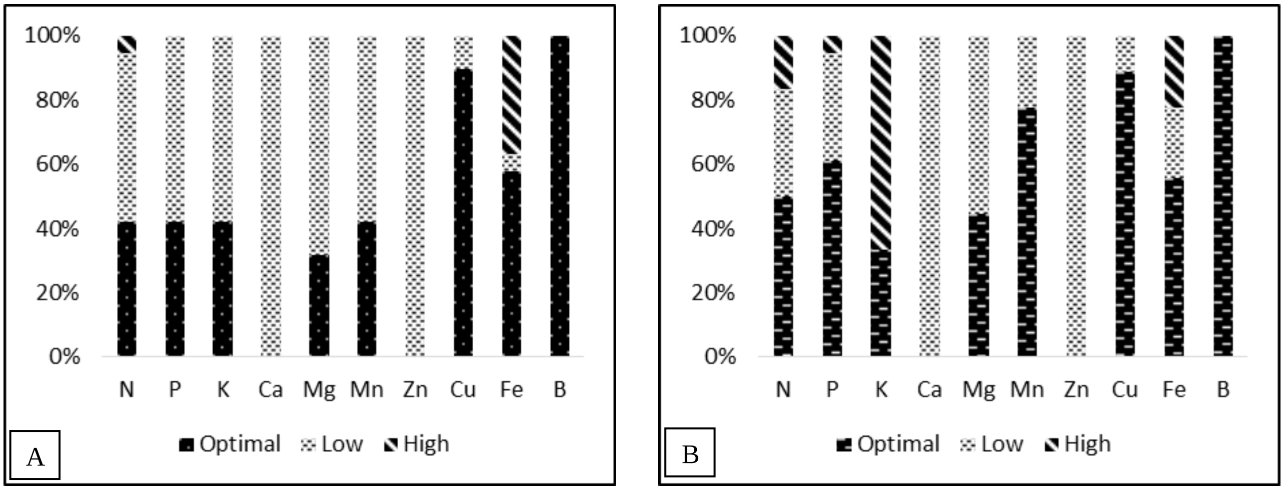

Figure 3. Optimal, low and high classification of nutrient concentrations at the leaf level according to the indicators proposed by Molina (2000). A) concentrations of nutrients in Valencia orange; B) concentrations of nutrients in Arrayan mandarin

In synthesis, for both crops, in all soils, the low concentrations of Ca, Mg, and Zn predominate, which is probably due to soil formation conditions that are very variable generating major differences in their fertility characteristics. In addition, there are variations in the management practices and scarce application of corrective measures during transplant (Orduz and Baquero, 2003).

Soils cultivated with citrus fruits in the studied area are of alluvial origin, except for Oxisols; therefore, their characteristics change between regions (Birkeland, 1999; Dengiz et al., 2006). In the case of Oxisols, only acid soils are grouped, which are characterized by having undergone an advanced evolution (high leaching of bases and low contents of weatherable minerals.

According to Rivera et al. (2013), high plain soils, similar to those of the foothills of the Department of Meta, have low chemical fertility mainly due to their high acidity, with low pH, low contents of exchangeable bases and low cation exchange capacity. In these soils, according to Baquero et al. (2018), it is necessary to apply corrective measures to neutralize exchangeable acidity and improve the availability of nutrients.

CONCLUSIONS

The soils of the foothills of the Department of Meta affect the productivity of both orange and mandarin. The productivity is higher in the trees established in the Inceptisols-Class II soils and lower in the Oxisols. For both crops, Ca is the main limiting nutrient followed by Zn and Mg.

The low levels of Ca at the plant leaf are related to low yields of the crops considering low concentrations at the edaphic level in the acidic soils of the farms where fertilization is not based on a diagnosis of the nutritional status of the crop.

This research has allowed raising basic information on the nutritional status of Valencia orange and Arrayana mandarin as an input for future research that seeks to establish nutritional requirements for these crops.

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