Micronutrient deficiencies in *Macadamia integrifolia* Maiden & Betche seedlings

Paulo Cesar L. Marrocos[a*]
Herminia E.P. Martinez[b]
Victor Hugo Alvarez[c]
Cláudio H. Bruckner[b]

[a] Centro de Pesquisa do Cacau (Cepec) (Cacao Research Center), Ceplac, CP 07, 45600-000 Itabuna, BA, Brazil

[b, c] Department of Phytotechny, and Department of Soils, Federal University of Viçosa, 36571-000 Viçosa, MG, Brazil

* *Correspondence and reprints*

Received 2 June 1999
Accepted 14 December 1999

Fruits, 2000, vol. 55, p. 127–134

RESUMEN ESPAÑOL, *p. 134*

Micronutrient deficiencies in *Macadamia integrifolia* Maiden & Betche seedlings.

Abstract — Introduction. Micronutrient deficiencies are likely to occur in macadamia nut plants grown on infertile soils of Brazil. Yet, visual symptoms and concentrations of these nutrients are not well characterized. **Materials and methods**. Micronutrient concentrations were assessed in plants of Keauhou and Ikaika cultivars of *Macadamia integrifolia*, grown with six nutritious solutions: one complete, the five others with individual omission of a specific element. **Results**. The results showed that lower leaves of macadamia seedlings grown in complete solution contained 12.9 and 18.6 mg·kg^{-1} B, 2.6 and 2.7 mg·kg^{-1} Cu, and 28.3 and 18.1 mg·kg^{-1} Zn for cultivars Keauhou and Ikaika, respectively. In the lower leaves of the plants grown in B- and Zn-free solutions, the two cultivar B and Zn concentrations were 5.7 and 6.1 mg·kg^{-1} and 20.3 and 18.0 mg·kg^{-1}, respectively. In the complete solution, lower leaves contained 221.7 and 289.3 mg·kg^{-1} Mn and 129.8 and 121.4 mg·kg^{-1} Fe, as compared to 145.5 and 91.1 mg·kg^{-1} Mn and 38.6 and 48.9 mg·kg^{-1} Fe, in the Mn- and Fe-free treatments. **Discussion**. The young macadamia plants studied did not differ in symptoms of Fe, B, Cu and Zn deficiency or in the levels related to these symptoms, although a difference between cultivars was detected for Mn levels. The elements that most limited dry matter production were, in decreasing order, Fe, Cu and Mn. © Éditions scientifiques et médicales Elsevier SAS

Brazil / *Macadamia integrifolia* / plant nutrition /mineral deficiencies / symptoms

Déficience en microéléments dans des plantules de *Macadamia integrifolia*.

Résumé — Introduction. Les macadamiers qui se développent sur les sols peu fertiles du Brésil devraient présenter des déficiences en microéléments. Pourtant, les symptômes occasionnés et les teneurs de ces éléments n'ont pas été bien étudiés. **Matériel et méthodes**. Certaines teneurs en microéléments ont été évaluées sur des plants des cultivars Keauhou et Ikaika (*Macadamia integrifolia*), développés sur six solutions nutritives différentes : l'une complète, les cinq autres caractérisées par la soustraction d'un élément donné. **Résultats**. Les plus basses feuilles des plantules développées sur solution complète contenaient, pour les cultivars Keauhou et Ikaika, respectivement, 12,9 et 18,6 mg·kg^{-1} de bore, 2,6 et 2,7 mg·kg^{-1} de cuivre, et 28,3 et 18,1 mg·kg^{-1} de zinc. Dans les feuilles les plus basses des plantules placées sur solutions sans bore et sans zinc, les concentrations ont été de 5,7 et 6,1 mg·kg^{-1} de bore, et 20,3 et 18,0 mg·kg^{-1} de zinc, pour les deux cultivars, respectivement. Les feuilles basses des plantes mises sur solution complète contenaient 221,7 et 289,3 mg·kg^{-1} de manganèse, et 129,8 et 121,4 mg·kg^{-1} de fer à comparer aux 145,5 et 91,1 mg·kg^{-1} de Mn, et 38,6 et 48,9 mg·kg^{-1} de Fe, obtenus dans les solutions dépourvues de Mn et de Fe. **Discussion**. Les plantules de macadamier étudiées n'ont pas présenté de symptômes ni de teneurs différents liés aux déficiences en Fe, B, Cu et Zn, bien qu'une différence entre cultivars ait été détectée pour le taux de Mn. Les éléments qui ont le plus limité la production de matière sèche ont été, par ordre décroissant, Fe, Cu et Mn. © Éditions scientifiques et médicales Elsevier SAS

Brésil / *Macadamia integrifolia* / nutrition des plants / carence minérale /symptôme

1. introduction

Macadamia (*Macadamia integrifolia*) is a nut tree originating from the humid forests of Australia. The plant was introduced to Hawaii about a century ago. In Brazil, commercial cultivation of macadamia only started about two decades ago; the plants are often grown on degraded soils of low fertility. Insufficient information exists in the Brazilian and international literature about the nutrition and requirements of macadamia plants, especially with respect to micronutrients.

Several studies have shown that leaf boron (B) content of macadamia plant is influenced by leaf age [1] and that the production of nuts in shell is increased in the varieties Keauhou and Ikaika when 0.02 % boron (15 L per tree) is applied to the leaves during nut development [2]. Stephenson and Cull [3] indicated that 40–75 $mg \cdot kg^{-1}$ B in leaf to be an adequate range for Australian conditions. Boron deficiency in macadamia can cause the death of terminal tissues, similar to P deficiency. However, unlike P deficiency symptoms, small leaf bunches are present on the B-affected branches. Spraying B solution on leaves of B deficient trees may stimulate new buddings in defoliated areas. In seedlings, symptoms of B deficiency are observed when B concentration in leaves drops below 15 $mg \cdot kg^{-1}$. Severe symptoms and eventual seedling death occur at 9 $mg \cdot kg^{-1}$ [4].

Symptoms of Fe and Mg deficiencies are similar and characterized by a reduction in chlorophyll production. However, unlike Mg deficiency, Fe deficiency starts from new leaves [5]. Typical symptoms of Fe chlorosis in macadamia are interveinal chlorosis of new leaves (a fine green vein network on a yellowish background) followed by whitening [4, 6–8]. This pattern coincides with Fe distribution in leaf, with the foliar lamina becoming yellowish while the vein may remain green for some time. Iron, also activates enzymes involved in chlorophyll synthesis [9]. Gilfillan and Jones [10] observed that macadamia leaves containing 20 $mg \cdot kg^{-1}$ of Fe showed slight symptoms of deficiency, and that a high correlation was obtained among leaf Fe concentration, degree of chlorosis and chlorophyll concentration.

The major symptom of Mn deficiency is interveinal chlorosis with small necrotic spots on new or mature leaves depending on the plants species [11]. Intermediate phloem mobility has been reported for Mn [12]. For macadamia, adequate Mn levels may vary from 50 to 1,500 $mg \cdot kg^{-1}$ [8]. Nagao and Hirae [4] reported that healthy leaves of macadamia can accumulate Mn levels, high enough to be considered toxic to other species.

In greenhouse studies, Nagao and Hirae [4] demonstrated that healthy macadamia seedlings had leaf Zn concentration of 31 $mg \cdot kg^{-1}$, instead of 17 $mg \cdot kg^{-1}$ in Zn-deficient plants. Severe deficiency symptoms were observed when leaf Zn concentration dropped below 14 $mg \cdot kg^{-1}$ [4].

In view of potentially wide variation in nutritional requirements among macadamia cultivars, work on mineral nutrition is of great importance to the success of macadamia cultivation in Brazil. Thus, our study objectives were to characterize the symptoms of mineral deficiencies in macadamia plants and to quantify nutrient contents in leaves associated with these symptoms.

2. materials and methods

The experiment was set up in a greenhouse at the Federal University of Viçosa using two *Macadamia integrifolia* cultivars, Keauhou (HAES 246) and Ikaika (HAES 333). Seeds obtained from the experimental station of Araponga of the Federal University of Viçosa were germinated in plastic trays containing acid washed sand. Recently germinated seedlings were subjected to adaptation in nutrient solution for approximately 30 d.

Vases containing 13 L of nutrient solution at half of the recommended concentration were used. The recommended concentrations of $H_2PO_4^-$-P, NO_3^--N, NH_4^+-N, K^+, Ca^{2+}, Mg^{2+} and SO_4^{2-}-S were 0.3, 14.0, 1.5, 4.0, 4.4, 1.0 and 1.0 $mmol \cdot L^{-1}$, respectively.

The micronutrients were supplied according to the solution of Clark [13], except for Fe, which was of 0.114 mmol·L^{-1} in the form of Fe-EDTA. The solution pH was monitored daily and kept between 5.0 and 5.5 using HCl or NaOH. After a period of adaptation, the plants were transferred to vases containing 8 L of solution developed for macadamia at its recommended strength and subjected to the following treatments: complete (N, P, K, Ca, Mg, S, B, Cu, Mo, Fe, Mn, and Zn) and with individual omission of a nutrient (-B, -Cu, -Zn, -Mn, and -Fe).

The experiment consisted of two cultivars tested with six nutrient solutions, resulting 12 treatments with three replicates arranged in a randomized complete block design. There were two seedlings per 8 L vase.

The stock solutions of macronutrients were subjected to purification for the removal of Fe, Mn, Zn and Cu. These metals were extracted with pyrrolidine ammonium dithiocarbamate using chloroform ($CHCl_3$) as solvent according to the procedure described by Fontes [14].

The stock solution of micronutrients were not subjected to any type of purification, except for the Fe solution. This stock solution was passed through a Dowex 1 x-8 anion exchange resin (50–100 mesh) saturated with Na. This form of resin would retain Zn when Zn is present in an HCl solution of 0.5 mol·L^{-1}, using the procedure cited above [14].

During the experiment, the solutions were changed periodically at intervals determined by the reduction in electric conductivity of the solutions to 30 % of the initial value. On the first change, Fe concentration was increased to 0.152 mmol·L^{-1}. The volume of the nutrient solution in the vases was kept constant by daily addition of demineralized water. An Fe concentration of 0.038 mmol·L^{-1} was added to the Fe-free solution 18 d before the end of the experiment to prevent plant death.

Symptoms of deficiency were obtained for all the studied micronutrients, except for Zn, 105 d after the application of the treatments. The plants were then collected and subdivided into upper leaves (leaves located in the upper third of the crown near the apex), lower leaves (leaves located in the two lower thirds of the crown), stalks and roots. They were washed with deionized water and dried in a forced-air oven at 70 °C until a constant weight was obtained. The plant material was then weighed, ground in a mortar to pass a 20-mesh sieve, and mineralized with a nitric-perchloric mixture (2:1). The material destined for B determination was dry-ashed at 550 °C and determined colorimetrically by the azomethine H method [15]. Iron, Mn, Zn and Cu were determined by the atomic absorption spectrophotometry, and P was measured colorimetrically by the method of phosphomolybdate reduction by ascorbic acid [16].

The data obtained were subjected to analysis of the variance and to the Dunnett test, with the level of significance set at 5 %.

3. results and discussion

In plants grown in solutions in which a nutrient was omitted, the dry matter production tends to decrease (*table I*). However, a statistically significant difference was only observed in the aerial parts of cultivar Ikaika grown in the Fe-free solution.

Macadamia seedlings grown in the Cu-free solution showed curving, deformation and marginal chlorosis in totally expanded new leaves. No description of the symptoms of Cu deficiency in macadamia was found in the literature. Only mild chlorosis was observed in new leaves of plants grown in the Zn-free solution. Leaves of B-deficient plants did not have well defined symptoms, but chlorotic spots were observed on the limb close to the borders, as well as death of the apical bud. Similar symptoms were described by Nagao and Hirae [4]. Iron-deficient plants showed interveinal chlorosis in new leaves, followed by intense yellowing, with only the central vein remaining green, and with necrotic points on the limb close to the borders and apical death.

Table I.
Dry matter production (g per plant) of the aerial part and of the root of macadamia plants, cultivars Keauhou and Ikaika, as a function of the solution used (complete or with omission of a nutrient).

Nutrient omitted	Aerial part		Root	
	Cv. Keauhou	Cv. Ikaika	Cv. Keauhou	Cv. Ikaika
Complete solution	5.00	5.45	0.86	1.16
B	3.39	4.00	0.66	0.78
Cu	3.87	3.92	0.59	0.73
Mn	3.67	4.44	0.54	0.85
Zn	4.08	4.78	0.56	0.89
Fe	3.03	2.70*	0.79	0.81
CV %	26.30		31.89	

In each ligne, no statiscally signifiant difference was observed between cultivar in a same plant part (F test at 5 % of probability).
In each column, means followed by an asterisk differed from treatment with complete solution by the Dunnett test at the 5 % of probability.

In older leaves of macadamia seedlings of cultivars Keauhou and Ikaika grown in the complete solution, Cu levels were 2.57 and 2.68 mg·kg^{-1}, respectively (*table II*) and these levels were only affected by the Fe-free treatment, which significantly increased Cu levels in leaves. In all other treatments, Cu levels were lower than 4 mg·kg^{-1}, a level considered adequate by Bittenbender and Hirae [8], and much lower than 11 mg·kg^{-1}, a level considered to be adequate by Nagao and Hirae [4]. Nevertheless, the nutritious solution contained appropriate Cu concentration, the plants did not present deficiency symptoms, which indicates that the low concentrations found in the tissues were enough for the plant growth.

In older leaves of the Keauhou and Ikaika cultivars grown in the complete solution, Zn levels were 28.25 and 18.05 mg·kg^{-1}, respectively. In the lower leaves of the two cultivars grown in the Zn-free solution, Zn levels were 20.33 and 17.98 mg·kg^{-1} (*table II*). Nagao and Hirae [4] reported Zn deficiency in leaves containing 17 mg·kg^{-1} Zn or lower.

In older leaves of the Keauhou and Ikaika cultivars grown in the complete solution, Mn levels were 211.7 and 289.3 mg·kg^{-1}, instead of 145.5 and 91.1 mg·kg^{-1}, respectively, in the Mn-free solution (*table II*). Bittenbender and Hirae [8] stated that Mn levels of 50 to 1,500 mg·kg^{-1} can be considered adequate. The range proposed by these authors as adequated is excessively wide, what was also evidenced by the results discussed above. Nagao and Hirae [4] reported that macadamia can accumulate very high Mn levels, which can be toxic to other plant species.

Copper levels were the highest in the stalk and roots (*table III*) and in the leaves (*table II*) of plants grown in iron-free solution. In general, a high Fe supply causes a reduction of Cu, Zn and Mn concentrations in plants, while high levels of these elements are observed in Fe-deficient plants [17, 18].

The boron levels observed in the lower leaves of plants grown in the complete solution (*table IV*) were low compared to the values considered adequate by others [4, 8, 19], ranging from 40 to 100 mg·kg^{-1}. However, cultivar Ikaika showed a higher B level in the leaves of plants grown in complete solution.

Boron is considered to be an element of little or no mobility in plants, with difficulty in retranslocation [20]. Long distance B transport is confined to the xylem and related to the transpiration rate [21]. In a

Table II.
Copper, Zn and Mn levels (in mg·kg^{-1}) in the leaves of macadamia plants, cultivars Keauhou and Ikaika, as a function of the solution used (complete or with omission of a nutrient).

Nutrient omitted	Cu		Zn		Mn	
	Cv. Keauhou	Cv. Ikaika	Cv. Keauhou	Cv. Ikaika	Cv. Keauhou	Cv. Ikaika
a) In the upper leaves						
Complete solution	3.58	2.23	11.27	12.13	79.6 b	180.4 a
B	4.18	2.40	13.02	11.48	143.2	162.8
Cu	3.72	2.28	12.50	11.18	120.2	177.1
Mn	3.52	2.45	9.30	10.72	34.3	37.2*
Zn	3.68	2.88	9.22	9.38	97.6	137.2
Fe	8.53*	8.35*	14.93	17.87*	237.3*	178.9
CV %	26.64		14.65		28.80	
b) In the lower leaves						
Complete solution	2.57	2.68	28.25	18.05	211.7	289.3
B	2.65	2.60	30.48	22.45	298.2	223.1
Cu	2.68	2.22	29.70	19.72	303.0	276.9
Mn	2.70	2.73	18.07	20.67	145.5	91.1*
Zn	2.92	2.95	20.33	17.98	206.3	243.6
Fe	3.88*	4.33*	17.25	20.20	279.5	242.0
CV %	20.09		30.81		23.34	

In each line, averages followed by a different letter are different for F test at 5 % of probability.
In each column, means followed by an asterisk differed from treatment with complete solution by the Dunnett test at the 5 % of probability.

Table III.
Cupper, Zn and Mn levels (in mg·kg^{-1}) in macadamia plants, cultivars Keauhou and Ikaika, as a function of the solution used (complete or with omission of a nutrient).

Nutrient omitted	Cu		Zn		Mn	
	Cv. Keauhou	Cv. Ikaika	Cv. Keauhou	Cv. Ikaika	Cv. Keauhou	Cv. Ikaika
a) In the plant stalk						
Complete solution	3.75	2.80	58.35 a	22.50 b	42.0 b	116.7 a
B	4.85	3.15	61.97 a	19.25 b	71.9	76.2
Cu	4.25	2.63	32.33	20.85	62.2	96.7
Mn	4.27	2.90	18.33*	17.25	9.3	13.3*
Zn	4.33	3.78	23.17	15.93	40.9 b	126.4 a
Fe	9.95*	9.75*	31.87	32.72	41.4	54.3*
CV %	21.72		53.78		42.04	
b) In the plant roots						
Complete solution	7.07	5.18	94.42 a	55.07 b	117.4 b	395.1 a
B	7.28	6.58	108.28 a	48.37 b	129.3 b	251.2 a*
Cu	5.97	4.67	76.98	46.37	242.7*	185.8*
Mn	12.02	5.90	48.30	53.28	24.9	38.7*
Zn	11.80	9.65	47.13	36.88	212.2 b	375.9 a
Fe	66.55 a*	51.57 b*	120.83	122.67*	278.2*	358.1
CV %	54.34		31.21		23.11	

In each line, averages followed by a different letter are different for F test at 5 % of probability.
In each column, means followed by an asterisk differed from treatment with complete solution by the Dunnett test at the 5 % of probability.

Table IV.
Bore, Fe and P levels in the upper and lower leaves of macadamia plants, cultivars Keauhou and Ikaika, as a function of the solution used (complete or with omission of a nutrient).

Nutrient omitted	B (mg·kg^{-1})		Fe (mg·kg^{-1})		P (g·kg^{-1})	
	Cv. Keauhou	Cv. Ikaika	Cv. Keauhou	Cv. Ikaika	Cv. Keauhou	Cv. Ikaika
a) In the upper leaves						
Complete solution	12.19 b	18.60 a	52.85	43.81	1.8 b	2.9 a
B	3.87*	5.86*	54.12	43.58	2.0	2.7
Cu	13.32	15.86	59.35	44.68	1.9	2.6
Mn	12.26	14.62	74.37 a	40.95 b	1.8 b	2.9 a
Zn	14.49	13.87	50.30	36.45	1.7 b	2.7 a
Fe	20.64*	21.83	21.42*	28.12	2.6	2.7
CV %	20.02		27.55		24.25	
b) In the lower leaves						
Complete solution	12.88 b	18.60 a	129.83	121.37	2.1 b	3.7 a
B	5.67*	6.11*	72.10*	77.98*	2.0	3.2
Cu	12.38	15.49	69.80*	70.80*	1.9	3.1
Mn	12.32 b	17.23 a	62.42*	73.15*	2.2	3.3
Zn	12.38 b	17.78 a	56.20*	65.67*	1.6 b	3.3 a
Fe	13.87	16.67	38.62*	48.90*	2.0	2.9
CV %	15.42		19.00		31.33	

In each line, averages followed by a different letter are different for F test at 5 % of probability.
In each column, means followed by an asterisk differed from treatment with complete solution by the Dunnett test at the 5% of probability.

study of B remobilization in tomatoes, Oertli [22] observed small new growths after the induction of deficiency and noted B movement in the stalk, but found no evidence of B translocation from leaves to new tissues. However, Hu et al. [23] isolated and characterized a mannitol-B-mannitol complex in the phloem of celery plants and detected the presence of sorbitol-B-sorbitol and frutose-B-frutose complexes in peach plants, the first proposed mechanism of the mobility of B in these species.

In the lower leaves of plants grown in the complete solution, P levels (*table IV*) were higher than those considered adequate by Bittenbender and Hirae [8], i.e. 0.8–1.1 g·kg^{-1} P. Plants cultivated in nutritious solution tend to have higher concentration of most nutrients in leaves (author's observation). Leaf P concentrations of 1.7–1.8 g·kg^{-1} or higher can lead to the development of Fe deficiency [4]. However, Fe levels in the lower leaves of Keauhou and Ikaika plants grown in complete solution were 129.83 and 121.37 mg·kg^{-1}, respectively (*table IV*).

In the roots of plants grown in Fe-free solution, Fe levels were high compared to those observed in the control treatment, probably because of the addition of Fe to the nutrient solution 18 d before harvest in order to prevent plant death. The P levels detected in the stalk and roots were higher in the cultivar Ikaika (*table V*).

4. conclusion

In B-free solution, macadamia leaves did not show well defined symptoms, but chlorotic spots on the limb close to the borders, and apical bud death were observed. Plants with Cu deficiency showed curving, deformation and marginal chlorosis in fully expanded new leaves. Plants grown in Mn-free solution showed a small difference in terms of visual symptoms, i.e. leaf narrowing and border deformation in the Keauhou cultivar and interveinal chlorosis in the upper leaves and deformation of leaf border and tip in cultivar Ikaika. Plants with Fe

Table V.
Bore, Fe and P levels in the stalk and roots of macadamia plants, cultivars Keauhou and Ikaika, as a function of the solution used (complete or with omission of a nutrient).

Nutrient omitted	B (mg·kg^{-1})		Fe (mg·kg^{-1})		P (g·kg^{-1})	
	Cv. Keauhou	Cv. Ikaika	Cv. Keauhou	Cv. Ikaika	Cv. Keauhou	Cv. Ikaika
a) In the plant stalk						
Complete solution	10.15	11.89	90.55	76.18	3.8 b	6.0 a
B	9.77	11.51	67.27	69.22	4.8	5.0
Cu	12.26	14.43	58.30	92.82	4.0	4.7
Mn	13.19	13.99	88.10	47.60	4.1 b	5.8 a
Zn	15.24	10.83	92.55	67.90	3.6 b	5.8 a
Fe	13.00	12.45	20.95*	21.70	3.6	4.0
CV %	23.69		37.84		22.46	
b) In the plant roots						
Complete solution	27.42	44.69	531.10	275.73	5.7	7.2
B	22.57	36.64	1024.50	493.80	5.3	6.1
Cu	37.31	41.83	779.45	210.78	5.3	5.9
Mn	39.63	30.84	1254.50 a	277.50 b	4.8 b	7.7 a
Zn	31.39	26.98	1287.50	1995.00*	5.5 b	7.2 a
Fe	28.72	32.45	454.70	437.27	5.7	5.6
CV %	30.97		58.72		16.48	

In each line, averages followed by a different letter are different for F test at 5 % of probability.
In each column, means followed by an asterisk differed from treatment with complete solution by the Dunnett test at the 5 % of probability.

deficiency showed interveinal chlorosis in new leaves followed by intense yellowing, with only the central nerve remaining green, and chlorotic points on the limb close to the borders and apical death.

Young macadamia plants of both cultivars Keauhou and Ikaika did not differ in symptoms of Fe, B, Cu and Zn deficiency or in the leaf concentrations of these nutrients, although a difference between cultivars was detected for leaf Mn concentrations.

Plant dry matter production was the lowest in the Fe-free treatment, followed by those in the treatments with B-, Cu- and Mn-free solutions.

note

This work is part of a doctoral thesis presented by the first author to the Federal University of Viçosa, Brazil.

references

[1] Stephenson R.A., Cull B.W. Mayer D.G., Price G., Stock J., Seasonal patterns of macadamia leaf nutrient levels in South East Queensland, Sci. Hortic. 30 (1986) 63–71.

[2] Stephenson R.A., Gallagher E.C., Effects of foliar boron sprays on yield and quality of macadamia nuts, Sci. Hortic. 32 (1987) 97–103.

[3] Stephenson R.A., Cull B.W., Standard leaf nutrition levels for bearing macadamia trees in South East Queensland, Sci. Hortic. 30 (1986) 73–82.

[4] Nagao M.A., Hirae H.H., Macadamia: cultivation and physiology, Crit. Rev. Plant Sci. 10 (1992) 441–470.

[5] Mengel K., Kirkby E.A., Iron, in: Principles of plant nutrition, International Potash Institute, Bern, Switzerland, 1987, pp. 493–511.

[6] Fox R.L., Warner R.M., Excess phosphate and micronutrient deficiency in macadamia, Hawaii Farm Sci. 20 (4) (1971) 1–4.

[7] Jones R.C., Shigeura G.T., Uehara G., Microprobe investigation of phosphorus-induced chlorosis in macadamia, Hawaii Farm Sci. 21 (2) (1972) 2–3.

[8] Bittenbender H.C., Hirae H.H., Common problems of macadamia nut in Hawaii, College of Tropical Agriculture & Human Resources, University of Hawaii, 1990, 44 p.

[9] Mortvedt J.J., Cox F.R., Schuman L.M., Welch R.M., Micronutrients in agriculture, Soil Sci. Soc. Am., Madison, USA, 2nd ed., 1991, 760 p.

[10] Gilfillan J.M., Jones W.W., Effect of iron and manganese deficiency on the chlorophyll, amino acid an organic acid status of leaves of macadamia, Proc. Am. Soc. Hortic. Sci. 93 (1968) 210–214.

[11] Taiz L., Zeiger E., Plant Physiology, The Benjamin/Cummings, Redwood City, California, USA,1991, 559 p.

[12] Mukhopadhyay M.J., Sharma A., Manganese in cell metabolism of higher plants, Bot. Rev. 57 (1991) 117–149.

[13] Clark R.B., Characterization of phosphatase of intact maize roots, J. Agric. Food Chem., 23 (1975) 458–460.

[14] Fontes R.L.F., Purificação de soluções nutritivas para indução de deficiências de zinco e cobre, em plantas, Universidade Federal de Viçosa, Viçosa, Brazil, Dissertação (Mestrado), 1986, 72 p.

[15] Wolf B., The determination of boron in soil extracts, plant materials, composts, manure, water and nutrients solutions, Soil Sci. Plant Nutr. 2 (1971) 363–374.

[16] Braga J.M., Defelipo B., Determinação espectrofotométrica de fósforo em extratos de solos e plantas, Rev. Ceres 21 (1974) 73–85.

[17] Pich A., Scholz G., Stephan U.W., Iron-dependent changes of heavy metals, nicotianamine, and citrato in different plant organs and in the xylem exudate of two tomato genotypes. Nicotianamine as possible copper translocator, Plant Soil 165 (1994) 189–196.

[18] Stephan U.W., Schmidke I., Pich A., Phloem translocation of Fe, Cu, Mn and Zn in *Ricinus* seedlings in relation to the concentrations of nicotianamine, an endogenous chelator of divalent metal ions, in different seedling parts, Plant Soil 165 (1994) 181–188.

[19] Fox R.L., Hue N.V., Boron requirements of macadamia seedlings, J. Plant Nutr. 12 (2) (1989) 207–217.

[20] Marschner H., Mineral nutrition of higher plants, Academic Press, London, UK, 1986, 672 p.

[21] Shelp B.J., Physiology and biochemistry of boron in plants, In: Gupta U.C., Boron and its role in crop production, CRC, London, UK, 1993, pp. 53–85.

[22] Oertli J.J., The mobility of boron in plants, Plant Soil 155/156 (1993) 301–304.

[23] Hu H., Penn S.G., Lebrilla C.B., Brown P.H., Isolation and characterization of soluble boron complexes in higher plants. The mechanism of phloem mobility of boron, Plant Physiol. 113 (1997) 649–655.

Deficiencia de microelementos en plántulas de *Macadamia integrifolia*.

Resumen — Introducción. Las macadamias que se desarrollan en suelos poco fértiles de Brasil deberían presentar deficiencias en microelementos. A pesar de ello, no se han estudiado bien los síntomas ocasionados y los contenidos de estos elementos. **Material y métodos**. Ciertos contenidos en microelementos fueron evaluados en plantas de cultivares Keauhou e Ikaika (*Macadamia integrifolia*), desarrolladas en seis soluciones nutritivas diferentes: una completa y las cinco restantes caracterizadas por la sustracción de un elemento dado. **Resultados**. Las hojas más bajas de las plántulas desarrolladas en solución completa contenían respectivamente, en el caso de los cultivares Keauhou e Ikaika, 12,9 y 18,6 $mg \cdot kg^{-1}$ B, 2,6 y 2,7 de Cu y 28,3 y 18,1 de Zn. En las hojas más bajas de las plántulas colocadas en soluciones sin boro y sin zinc, las concentraciones fueron de 5,7 y 6,1 B, y de 20,3 y 18,0 $mg \cdot kg^{-1}$ Zn, para ambos cultivares, respectivamente. Las Hojas bajas de plantas colocadas en solución completa contenían 221,7 y 289,3 $mg \cdot kg^{-1}$ de Mn, y 129,8 y 121,4 $mg \cdot kg^{-1}$ Fe; compárese con los 145,5 y 91,1 $mg \cdot kg^{-1}$ Mn, y 38,6 y 48,9 $mg \cdot kg^{-1}$ Fe obtenidos en las soluciones sin Mn y Fe. **Discusión**. Las plántulas de macadamia estudiadas no han presentado síntomas ni contenidos diferentes ligados a las deficiencias de Fe, B, Cu y Zn, aunque se detectó una diferencia entre los cultivares en el nivel de Mn. Los elementos que más limitaron la producción de materia seca fueron, en orden decreciente, Fe, Cu y Mn. © Éditions scientifiques et médicales Elsevier SAS

Brasil / *Macadamia integrifolia* / nutrición de las plantas / deficiencia de minerales / síntomas