Influence of Varieties and Seasons upon the Mineral Nutrient Levels of Coffee Leaves from Puerto Rico[1]

Juan A. Bonnet[2, 3]

INTRODUCTION

Knowledge of the foliar mineral nutrient content of crops adequately sampled according to variety, age, season, and soil, supplemented with soil mineral nutrient, and coupled with the influence of the climatic-edaphic factors that limit the growth of normal and healthy plants is of importance in soil and crop management.

The 13 essential nutrients for crop growth: Nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, manganese, iron, boron, zinc, copper, molybdenum, and chlorine, constitute from 5 to 10 percent of the plant dry weight.

In 1950 and 1951 Lott *et al.* (*8, 9*)[4] published data on the foliar content for 12 mineral nutrients of coffee trees from Brazil; and Espinosa (*6*) in 1961 did likewise for 5 nutrients in trees from El Salvador. The critical deficient leaf-nutrient levels in *Coffea arabica* have been reported by Cibes and Samuels (*3*) in Puerto Rico, and also by Vicente-Chandler *et al.* (*16*); by Lott *et al.* (*8, 9*) and Hagg and Malavolta in Brazil (*7*); Machado (*12*) in Colombia; Medcalf *et al.* (*14*) and Muller (*15*) in Costa Rica; and, for *Coffea robusta*, by Culot (*4, 5*) in the Congo, and by Loué (*11*) in the Ivory Coast. Lott *et al.* (*9, 10*) reported also sulfur and molybdenum deficiencies in coffee. The effect caused by the macro- and minor-nutrients in coffee and the levels considered to be deficient, adequate, and high or excessive, for growth, are demonstrated in colored plates for leaves, in the book of Malavolta *et al.* (*13*) published in 1964. Abruña and Vicente Chandler (*1*) also reported on the effect of ammonium sulfate applications on the leaf

[1] Data used were obtained from a cooperative project between the University of Puerto Rico and Michigan State University.

[2] Soil Chemist and Head of Soils Department, Agricultural Experiment Station, University of Puerto Rico, 1931 to June 1966, now retired.

[3] Thanks are extended to Professor A. L. Kenworthy, Horticulture Department, Michigan State University, for his professional advice and cooperation; to A. S. Amy and M. A. Lugo-López, Acting Head and Soil Scientist, respectively, Agronomy and Soils Department, Agricultural Experiment Station, Mayagüez Campus, University of Puerto Rico, Río Piedras, P.R., for suggesting changes in the manuscript; and to B. G. Capó, Technical Consultant, and to A. Riera, Chemist in Charge of the Central Analytical Laboratory, also of this Station, for advice on the statistical interpretation of the data, and for the preparation of the samples and the N and K analyses, respectively.

[4] Italic numbers in parentheses refer to Literature Cited, pp. 185–6.

manganese content. Vicente-Chandler *et al.* (*16*) published, in 1959, a valuable guide for intensive coffee culture; and Wellman (*17*) in 1960, made recommendations for improving the efficiency of coffee production in Puerto Rico.

This paper reports the yields and the contents of 10 essential nutrients (N, P, K, Ca, Mg, Mn, Fe, B, Zn, and Cu), and of two nonessential (Na and Al), in the leaves of high- and low-yield coffee trees from Puerto Rico sampled in 2 seasons.

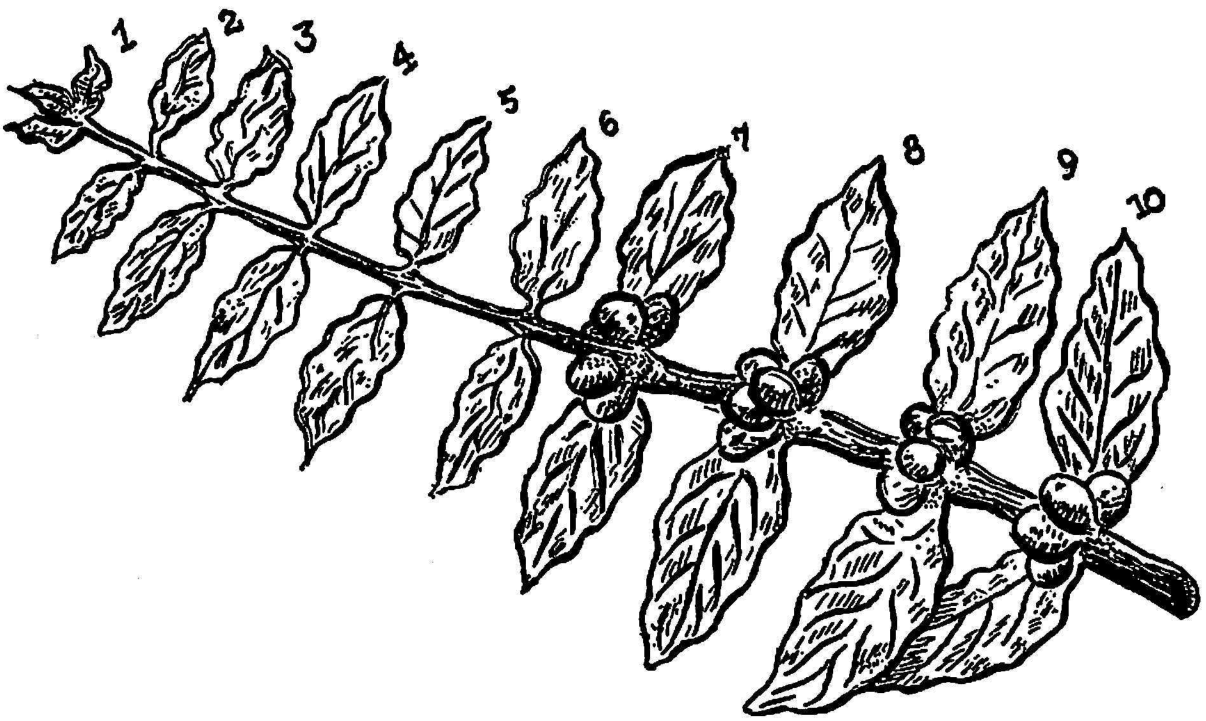

FIG. 1—A branch of the coffee tree; 1, the terminal bud; 2–6, young leaves; 7–10, mature leaves with berries. Leaves 2–5 were sampled for analysis.

EXPERIMENTAL

Twenty-six young coffee trees, about 8 years old, of three varieties and two yield groups, grown under shade in an acid upland soil, were chosen from two farms; that of the former Agricultural Experiment Coffee Substation at Castañer, and that at the present Substation farm at Limaní, both located in Adjuntas. The varieties of *Coffea arabica* selected were: Caturra, a semidwarf one originating in Brazil; and Red Bourbon from El Salvador, and Puerto Rico, commonly cultivated here. The yield data were recorded for the coffee crop harvested in the fall of 1962 from 15 high-yielding and from 11 low-yielding trees. The soil type is the acid (pH 5.0), Alonso clay, an Oxisol identified by its purple brownish color. Each tree received about 1 pound of a 10-10-8 (N-P-K) fertilizer per crop year.

The leaves were sampled in two seasons: The late summer, August 25, 1961, previous to the harvest of the 1961 crop, at the stage of fruit development and ripening; and in the late winter, March 15, 1962, when the trees were in full bloom for the 1962 crop. Young leaves were sampled from the branches of each tree below the terminal bud and above the berries (fig. 1). Leaves 2 to 5 were sampled in both seasons. Forty-nine leaf samples were collected. They were placed in closed polyethylene bags, dried in an oven at 70° C., and ground in a Wiley mill.

The following 10 essential plant nutrients were determined: N, P, K, Ca, Mg, Mn, Fe, B, Zn and Cu; and also two nonessential ones: Na and Al.

TABLE 1.—*Range and mean of the foliar composition for the high-yielding coffee trees of the 3 varieties harvested in 2 seasons*

Nutrient	Summer		Winter	
	Range	Mean	Range	Mean
	Percent	*Percent*	*Percent*	*Percent*
N	2.36–2.95	2.79	2.16–2.88	2.54
P	.11–.20	.17	.15–.28	.19
K	.61–2.54	1.67	.80–2.10	1.48
Ca	.98–1.58	1.20	1.02–1.98	1.54
Mg	.31–.94	.53	.17–.80	.42
	P.p.m.	*P.p.m.*	*P.p.m.*	*P.p.m.*
Mn	240–1190+	782	402–1193+	804
Fe	91–156	119	69–332	147
B	30–67	47	39–89	62
Cu	7–19	11	6–22	12
Zn	9–19	13	5–28	11
Al	96–190	126	62–852	235
Na	—	—	200–520	373

Nitrogen and potassium were determined in Puerto Rico; the former with the Technicon Autoanalyzer and the latter in the Beckman DU Flame Spectrophotometer equipped with a photomultiplier. The other elements were determined at Michigan State University in a Quantograph, a direct-reading spectrograph. A total of 532 determinations was made, including 49 for aluminum and 23 for sodium. The yield and mineral data derived from the coffee trees were analyzed statistically.

PRESENTATION OF THE DATA AND DISCUSSION

The composition of the leaves of the high-yielding trees sampled in the summer of 1961, and later in the winter of 1962 at the new flowering stage, is given in table 1. Likewise, the foliar values of the low-yielding trees are

TABLE 2.—*Range and mean of the foliar composition for the low-yielding coffee trees of the 3 varieties harvested in 2 seasons*

Nutrient	Summer		Winter	
	Range	Mean	Range	Mean
	Percent	*Percent*	*Percent*	*Percent*
N	2.49–3.11	2.91	2.18–2.90	2.52
P	.14–.21	.16	.16–.33	.20
K	.84–2.98	2.07	1.04–1.86	1.49
Ca	.80–1.40	1.00	.91–1.77	1.24
Mg	.20–.76	.45	.15–.59	.34
	P.p.m.	*P.p.m.*	*P.p.m.*	*P.p.m.*
Mn	362–1190+	696	825–1193+	944
Fe	37–170	114	82–458	141
B	5–51	39	40–111	64
Cu	7–23	11	1–19	9
Zn	9–36	14	7–11	10
Al	82–160	112	72–206	212
Na	—	—	220–584	377

TABLE 3.—*Analysis of variance of yield data in ounces for coffee berries per tree*

Source of variation	DF	Sum of squares	Mean square	F
Total	25	127,372		
Varieties	2	4,853	2,426	2.17 NS
Fertility	1	97,890	97,890	87.48**
Error	22	24,629	1,119	

Adjusted mean yields in ounces of berries per tree

Variety	Soil Fertility	
	High	Low
Caturra	189.67	66.37
Puerto Rico	216.76	93.46
Bourbon	194.14	70.84
Total	200.19	76.89

given in table 2. The analysis of variance of the coffee yield data is given in table 3. The respective means for each of those values for the two yield groups of trees of the three varieties, in the two seasons, are reported in table 4. The variance error obtained for each of the 12 separate statistical studies made are also reported in this table, expressed in percentages for the major nutrients and in parts per million for the minor nutrients and the 2 nonessential ones.

The differences between the mean coffee nutrient contents, between each pair of the three varieties, between the two seasons, and between the two group yields are reported in table 5. The nutrient differences for the major nutrients are again expressed in percentages and those for the others in parts per million. The blank spaces indicate that the nutrient differences were not significant. The statistical significance of the differences in each corresponding column is indicated.

TABLE 4.—*Mean values used for the statistical interpretation of the coffee-crop-composition date*[1]

Nutrient	Error variance	DF	Caturra	P.R.	Bourbon	Summer	Winter	High-yielding	Low-yielding
N	.0421	44	2.66	2.82	2.60	2.85	2.54	2.670	2.720
P	.0013	44	.16	.17	.20	.16	.19	.176	.180
K	.2328	44	1.20	1.65	2.02	1.83	1.42	1.500	1.750
Ca	.0335	44	1.56	1.17	1.10	1.10	1.45	1.410	1.140
Mg	.0167	44	.58	.49	.29	.50	.41	.500	.410
Mn	74,474.3470	44	719.93	666.24	967.14	732.63	836.25	774.160	794.160
Fe	4,441.9270	44	149.13	97.97	143.68	115.49	145.03	133.880	126.640
B	192.1032	44	56.56	63.63	42.71	44.63	63.97	56.020	52.580
Cu	16.2143	44	11.08	13.97	8.12	11.24	10.87	11.440	10.670
Zn	23.3228	44	12.59	10.79	12.63	13.17	10.84	11.840	12.170
Al	23,013.7345	44	189.06	106.07	211.45	114.96	222.76	179.840	157.880
Na	13,423.8219	19	439.62	359.02	355.22	—	—	382.530	386.710

[1] Major nutrients are expressed as percentages; others as p.p.m.

Statistical Interpretation of the Yield and Nutrient Data

The 15 high-yielding trees selected of the 3 coffee varieties yielded in 1962 from 140 to 252 ounces of berries per tree, with an adjusted mean of 200.19 ounces. On the basis of 1,000 trees per acre and considering that 18 percent of the berries' weight is marketable coffee, the adjusted mean of these high-yielding trees correspond to 22.51 cwt. of marketable coffee per acre.

The 11 low-yielding trees selected produced from 33 to 127 ounces of berries per tree, with an adjusted mean of 76.89 ounces, which corresponds to 8.65 cwt. of marketable coffee per acre.

The statistical interpretation of the mean yield data revealed that the high-yielding trees produced 2.6 times as much coffee per acre as the low-yielding ones, a highly significant difference, and no significant difference between varieties.

Highly significant or significant mean differences were obtained in 9 of the 10 essential nutrients except for zinc, between varieties; in nitrogen,

TABLE 5.—*Statistical interpretation of the leaf contents, and differences between varieties, seasons, and yields of the coffees under study*

Degrees of freedom	Nutrient[1]	Varieties						Seasons		Yields	
		Puerto Rico *vs.* Bourbon		Puerto Rico *vs.* Caturra		Bourbon *vs.* Caturra		Summer *vs.* Winter		High *vs.* Low	
		Puerto Rico	Bourbon	Puerto Rico	Caturra	Bourbon	Caturra	Summer	Winter	High	Low
44	N	.22 ± .07**		.16 ± .08*				.31 ± .06*			
44	P		.03 ± .01*			.04 ± .01**			.03 ± .01**		
44	K		.37 ± .16*	.45 ± .18*		.82 ± .17**		.41 ± .14**			
44	Ca				.39 ± .07**		.46 ± .07**		.35 ± .05**	.27 ± .05**	
44	Mg	.20 ± .04**					.29 ± .05**	.09 ± .04*		.09 ± .04*	
44	Mn		300.90 ± 91.56**			247.21 ± 97.76*					
44	Fe		45.71 ± 22.36*		51.16 ± 25.04*						
44	B	20.92 ± 4.65**					13.85 ± 4.97**		19.34 ± 3.99**		
44	Cu	5.85 ± 1.35**					2.96 ± 1.44**				
44	Zn										
44	Al		105.38 ± 50.90*						107.80 ± 43.65*		
19	Na										

[1] Major nutrients are expressed as percentages; others as p.p.m.
* Significant; ** Highly significant.
Blank spaces indicate no significant differences.

phosphorus, potassium, calcium, magnesium, and boron, between seasons; and only in calcium and magnesium, between group yields (table 5). The high-yield coffee trees displayed a highly significant mean difference of 0.27 ± .05 percent Ca and a significant one of 0.09 ± .04 percent Mg over the low-yield group. The Caturra variety gave a highly significant mean difference of 0.39 ± .07 percent Ca above that of Puerto Rico and a significant one of 0.46 ± .07 percent Ca above that of Bourbon and 0.29 ± .05 percent Mg above that of Bourbon, while the Puerto Rico variety produced a highly significant mean difference of 0.20 ± .04 percent Mg above that of Bourbon. The difference for magnesium between the Puerto Rico and Caturra varieties was not significant. A highly significant mean difference of 35 ± .05 percent Ca in the winter over that in the summer was obtained and a significant one of 0.09 ± .04 percent Mg in the summer over that of the winter.

The statistical interpretation points to the importance of sampling adequately the leaves of the coffee trees with respect to varieties and seasons, as well as to age in the corresponding soil type. The selection of the proper method of leaf-sampling is another important consideration; leaves 2 to 5, the younger ones, were selected in this work (fig. 1).

Alonso clay, the soil selected here of the Oxisol group, is well supplied with available manganese. Abruña *et al.* (*2*), reported in 1965, that this acid (pH 5.0) soil contains 10 p.p.m. of exchangeable manganese and 590 p.p.m. of easily reducible manganese. The high- and low-yielding coffee trees reported on here showed mean leaf values of 774.16 and 694.16 p.p.m. Mn, respectively (table 4), a nonsignificant difference (table 5). Ten trees gave values above 1,190 p.p.m. Mn that could not be measured by the spectograph (tables 1 and 2). These are very high values. Vicente-Chandler *et al.* (*16*) reported that about 400 p.p.m. Mn may represent toxic levels in coffee trees. Toxic symptoms were not observed in the high- and low-yielding trees reported upon here that contained about 2 times more Mn in the leaves above the above-mentioned toxic level. A highly significant adjusted mean yield of 22.51 cwt. of marketable coffee was obtained for the high-yielding trees when compared with the low-yielding ones.

Abruña *et al.* (*2*) reported that coffee trees grown under full sunlight in the same soil type had normal leaf contents of all nutrients but manganese. The affected leaves of these trees revealed 1,000 to 2,500 p.p.m. Mn compared with 100 to 250 p.p.m. for normal leaves. They describe the toxicity symptoms as follows: "In the initial stages, margins of the leaves became deep yellow, followed by yellowing of the young leaves. In the later stages, older leaves dropped off and bearing branches lost most of their berries. This was soon followed by die-back and in some cases by death of the trees". However, this condition. which became more severe following rains after a drought, was corrected in two severely affected plantings when the trees were treated with 4 tons of limestone to the acre, followed by applications of 1 ton of limestone for every ton of fertilizer applied. This treatment raised the yield of market coffee from 600 pounds per acre to over 2,000, while the manganese content of the leaves decreased to 300–400 p.p.m. (*2*).

The range of aluminum in the coffee leaves varied from 62 to 852 p.p.m. (tables 2 and 3). A mean significant difference of 105.38 ± 50.90 p.p.m. Al was found only between the Bourbon and the Puerto Rico varieties, and of 107.80 ± 43.65 between seasons (table 5). Abruña *et al.* (*2*), in 1965, reported as follows:

> High yields of full sun-grown coffee trees can be produced on soils, as Alonso clay, at pH's as low as 4.0 with exchangeable bases as low as 2 meq. per 100 g. soil and exchangeable aluminum as high as 350 p.p.m. Even at this high level of acidity the soil apparently contained sufficient calcium as a nutrient for the coffee trees and exchangeable aluminum remains below the toxic level.

The sodium content in the coffee leaves varied from 200 to 584 p.p.m. (tables 2 and 3). No significant mean difference was found between the sodium contents of the coffee varieties, seasons or group yields (table 5).

SUMMARY

Twenty-six young coffee trees grown under shade in an acid upland soil of 2 farms were selected representing 3 varieties and 2 yield-groups. The yield data were recorded for the crop harvested in the fall of 1962 from 15 high-yielding and 11 low-yielding trees. Young leaves from each tree were sampled in the late summer of 1961 and in the late winter of 1962. The following 10 essential plant nutrients were determined: N, P, K, Ca, Mg, Mn, Fe, B, Zn, and Cu; as well as 2 nonessential elements, Na and Al. The yield and leaf-composition data were analyzed statistically.

The high-yielding trees produced 2.6 times as much coffee as the low-yielding ones, a highly significant difference. There was no significant difference between the mean yields of the varieties.

"Highly significant" or "significant" mean differences were obtained in all the essential nutrients except zinc, in the coffee leaves, between varieties; in the nutrients: N, P, K, Ca, Mg, and B, between seasons; and only in Ca and Mg between yield-groups.

The acid soil, Alonso clay, is high in exchangeable manganese and in aluminum; the coffee trees used here also contained high Mn and Al in their leaves.

RESUMEN

Se seleccionaron 26 cafetos jóvenes de 3 variedades y de 2 categorías con respecto a su rendimiento, los cuales se cultivaron bajo sombra en 2 fincas

cuyos suelos eran ácidos. Los datos de la cosecha del otoño de 1962 sobre rendimiento correspondieron a 15 arbustos con un rendimiento alto y 11 con uno bajo. Se tomaron muestras de las hojas tiernas de cada arbusto en el verano del 1961 y en el invierno de 1962. Estas muestras se analizaron en cuanto a los siguientes nutrimentos esenciales: N, P, K, Ca, Mg, Mn, Fe, B, Zn y Cu, así como en cuanto a los no esenciales Na y Al. Tanto los valores del rendimiento como los de los análisis químicos de la hoja se interpretaron estadísticamente.

Los arbustos cuyos rendimientos fueron altos produjeron 2.6 veces más café en grano que aquellos con rendimientos bajos lo cual indicó una diferencia altamente significativa. No hubo diferencias significativas entre los valores medios de las variedades, al compararse los datos de los arbustos de rendimiento alto. Sin embargo, las diferencias fueron significativas entre las mismas variedades al compararse con las de rendimiento bajo.

Se observaron diferencias altamente significativas o sólo significativas entre las variedades en cuanto a los valores foliares de todos los nutrimentos, con la excepción del zinc; entre las estaciones, en cuanto a los nutrimentos N, P, K, Ca, Mg y B; y solamente en el caso del calcio y el magnesio, entre las dos categorías de rendimiento.

El suelo ácido Alonso arcilloso, es rico en manganeso y aluminio intercambiables. Los cafetos que se incluyeron en este estudio también arrojaron un alto contenido foliar de ambos elementos.

LITERATURE CITED

1. Abruña, F., and Vicente-Chandler, J., Effects of six sources of nitrogen on yields, soil acidity, and leaf composition of coffee, *J. Agr. Univ. P.R.* *47* (1): 41–6, Jan. 1963.
2. Abruña, F., Vicente-Chandler, J., Becerra, L. A., and Bosque Lugo, R., Effects of liming and fertilization of yields and foliar composition of high-yielding sun-grown coffee in Puerto Rico, *J. Agr. Univ. P.R.* *49* (4): 413–28, 1965.
3. Cibes H., and Samuels, G., Mineral-deficiency symptoms displayed by coffee trees grown under controlled conditions, Agr. Expt. Sta. Univ. P.R. Tech. Paper, 14, 1955.
4. Culot, J. P., Wambeke, A. van, and Croegaert, J., Contribution a l'étude des déficiences minérales du caféier d'Arabie au Kuvu, Inst. Natl. pour l'Etudi Agron. Congo Belge, Série Scient. 73, 1958.
5. Culot, J. P., Symptomes de déficience nutritive du caféier Robusta dans la Cuvette congolaise, *Bul. Inform. d'INEAC 8* (3): 189–99, 1959.
6. Espinosa, Flora M., Resultados preliminares del análisis foliar del cafeto en El Salvador, Inst. Salvadoreño de Invest. del Café, Santa Tecla, El Salvador, *Bol. Inform. 10,* 81 p. Jun.-Jul., 1961.
7. Haag, H. P. and Malvolta, E., Studies on the mineral nutrition of the coffee tree, *Rev. de Agr. (Piracicaba), 35* (4): 273–89, 328–37, 1960.
8. Lott, W. L., Nery, J. P., Gallo, J. R., and Medcalf, J. C., Leaf analysis technique in coffee research, IBEC Res. Inst. #9, 26 p., 1958. Rockefeller Plaza 30, New York 20, N.Y.

9. Lott, W. L., McClung, A. C., de Vita, René y Gallo, J. R., Estudio de Cafetales de San Pablo y Paraná Mediante el Análisis Foliar, IBEC Res. Inst. #26, 72 p., 1961, Rockefeller Plaza 30, New York 20, N.Y.
10. Lott, W. L. McClung, A. C., and Medcalf, J. C., Sulfur deficiency in coffee. IBEC Res. Inst. No. 22, 24 p., 1960, Rockefeller Plaza 30, New York 20, N.Y.
11. Loué, A., Studies on the inorganic nutrition of the coffee tree in the Ivory Coast, Centre de Recherches Agronomiques, Spec. Bull. 1–68, 1957.
12. Machado, A. S., Los fertilizantes para el cafeto y el diagnóstico foliar, Centro Nac. Invest. Café., Chinchiná, Colombia, *Bol. Infor.* 7 (76): 123–36, 1956.
13. Malavolta, E., Haag, H. P., Mello, F. A. F., y Brasil Sobr°, M. O. C., La Nutrición mineral de algunas cosechas tropicales, 163 p. con ilustraciones en colores indicando deficiencias de nutrimentos en café, caña de azucar, naranjo, piña, eucalipto y algodón, 1964, Inst. Int. de la Potasa, Berna 14, Suiza.
14. Medcalf, J. C., Lott, W. L., Teeter, B. P., y Quinn, L. R., Programas experimentales en el Brazil, IBEC Res, Inst. Bol. 6, 1955, Rockefeller Plaza 30, New York 20, N.Y.
15. Muller, L., Algunas deficiencias minerales comunes en el cafeto (Coffea arabica L.), Bol. Téch. Inst. Interamericano Ciencias Agric. No. 4, Turrialba, 1959.
16. Vicente-Chandler, J., Abruña, F., and Silva, S., A Guide to Intensive Coffee Culture, *U, S. Dept. Arg., Prod. Res. 31*, ARS, USDA, 1959.
17. Wellman, F. L., Recomendaciones para mejorar el cultivo del café en Puerto Rico, Bol. 153, Est. Expt. Agr. Univ. de P.R.. 113 pp.. 1960.