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Yam (*Dioscorea* spp.) response to fertilization in soils of the semiarid southern coast of Puerto Rico[1,2]

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ABSTRACT

Yam (*Dioscorea* spp.) production in Puerto Rico is located in the central mountainous zone, but there is interest in expanding production to the southern semi-arid zone, where mechanization is possible, where irrigation is available and where soil pH is neutral or alkaline. Two experiments were performed during 2000 (Experiment I) and 2001 (Experiment II) in a soil corresponding to the Pozo Blanco (Fine-loamy, mixed, superactive, isohypertermic Aridic Calciustolls) series with high exchangeable potassium and magnesium contents and with a good capacity to supply nitrogen. Yam (*D. alata* cv. Diamante and *D. rotundata* cv. Guinea Negro) response to the application of nitrogen, potassium, magnesium and micronutrients was evaluated. In Experiment I, yam (cv. Diamante) yields were severely affected by an uncharacterized tuber-root rot, and marketable production varied from 5,961 to 10,742 kg/ha. In Experiment II, the disease incidence was less than in Experiment I. The application of micronutrients increased yields by as much as 100%. There was a trend for greater marketable tuber production with the application of micronutrients and 75-12-250 kg/ha (N-P-K) for cv. Diamante (18,787 kg/ha), and for cv. Guinea Negro (10,492 kg/ha), with the application of micronutrients and 75-12-0 kg/ha (N-P-K). The results suggest that with

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good seed-quality, micronutrient foliar applications, and moderate application rates of nitrogen and potassium, adequate yam production can be achieved in these soils.

Key words: *Dioscorea* spp., fertilization, calcareous soils, micronutrients

RESUMEN

Respuesta del ñame (*Dioscorea* spp.) a la fertilización en suelos de la costa semiárida del sur de Puerto Rico

La producción de ñame (*Dioscorea* spp.) en Puerto Rico se sitúa principalmente en la zona central montañosa, pero hay interés en expandir la producción a la región semiárida del sur, donde los suelos son mecanizables, tienden a ser neutrales o calcáreos, y donde hay riego disponible. Se realizaron dos ensayos de campo durante los años 2000 y 2001 en un suelo de la serie Pozo Blanco (Fino lómico, carbonático, isohipertérmico Typic Haplustolls) con alto contenido de potasio y magnesio intercambiable y con buena capacidad de suplir nitrógeno. Se evaluó la respuesta de los cultivares Diamante (*D. alata*), y Guinea Negro (*D. rotundata*) a la aplicación de nitrógeno, potasio, magnesio, y micronutrimentos. En el 2000, el rendimiento del cultivar Diamante se afectó severamente debido a una pudrición del tubérculo y la producción mercadeable varió de 5,961 a 10,742 kg/ha. En el 2001, hubo menor incidencia de la pudrición que en el 2000. La aplicación de micronutrimentos aumentó el rendimiento más de 100% para los dos cultivares. Hubo una tendencia a una mayor producción de tubérculos mercadeables con la aplicación de micronutrimentos y 75-12-250 kg/ha (N-P-K) en el cultivar Diamante (18,787 kg/ha), y con la aplicación de micronutrimentos y 75-12-0 kg/ha (N-P-K) en el cultivar Guinea Negro (10,492 kg/ha). Los resultados sugieren que con buena calidad y manejo de semilla, aplicaciones foliares de micronutrimentos, y cantidades moderadas de nitrógeno y potasio se puede producir ñame en suelos como éstos.

INTRODUCTION

Yam (*Dioscorea* spp.) production in Puerto Rico declined steadily from 15.45 tons in 1979-1980 to 3.67 tons in 1999-2000 (Commonwealth of Puerto Rico, 2000). Disease incidence, low yields, and market price competition have contributed to the production decline. Recommended management practices for yam production have been developed from trials performed in highly weathered Ultisols of the mountainous region of Puerto Rico; however, there is an increasing trend to establish yam plantings on the southern semiarid coast, where there is little information available relating to plant response to fertilizer applications or management practices.

Gaztambide and Cibes (1975) evaluated nutritional deficiencies of yam (*Dioscorea rotundata* cv. Habanero) in sand culture, describing nutrient deficiency symptoms and plant nutrient content. Irizarry and Rivera (1985) quantified nutrient uptake and dry matter production of *D. rotundata* (cv. Habanero) in an Ultisol, and found that total plant uptake (kg/ha) was 189-25-215-35 (N-P-K-Mg). They applied 0; 1,120; and

2,240 kg/ha of 10-5-20-3 ($N-P_2O_5-K_2O-MgO$) complete fertilizer and found that significantly higher yields were obtained with the highest fertilizer level. Del Valle-González and Santiago-Córdova (1990) found no significant differences in *D. rotundata* yield (cv. Guinea negro) due to N fertilization in an Ultisol with an average yield of 46.2 t/ha. Tuber dry matter yield (*D. alata* cv. Gunung) was not significantly affected by application of fertilizer (0 to 2,667 kg/ha15-5-15-5MgO) in an Ultisol (Irizarry et al., 1995). Total plant uptake (kg/ha) was 214-19-223-9 (N-P-K-Mg).

All studies, except that by Del Valle-González and Santiago-Córdova (1990), have evaluated plant response to complete fertilizer mixtures; therefore, the fertilizer effect (if found) cannot be attributed to a particular element. In addition, from these studies soil test levels cannot be used to derive fertilizer recommendations. Environmental concerns are addressed and cost reductions can be achieved by not fertilizing when plant response probability is low (high soil test levels).

In highly weathered soils the nutrient supply is low and almost all of the crop nutrient demand must be supplied by inorganic fertilization. In contrast, soil test P, Mg, and K levels for most soils of the southern coast are in the high category, as suggested by Muñiz-Torres (1992), thus implying a low probability of plant response to inorganic P, Mg, and K application. Since plant nutrient uptake for K is greater than that for any other nutrient, we wanted to evaluate whether plant response to K occurred. In most areas of the southern coast there is available supplemental irrigation, and the soils are expected to have excellent N supplying capacity. Two experiments were conducted to evaluate yam (*Dioscorea alata* cv. Diamante, and *D. rotundata* cv. Guinea negro) response to the application of N, K, Mg, and micronutrient applications.

MATERIALS AND METHODS

Two experiments were conducted on a private farm in Guánica, Puerto Rico. The soil has been mapped as corresponding to the soil series Pozo Blanco (Fine-loamy, mixed, superactive, isohypertermic Aridic Calciustolls) (Beinroth et al., 2003). Table 1 presents chemical properties of the fields sampled at 0- to15-cm depth.

Experiment I

Soil preparation consisted of deep cultivation, followed by disking. Bed preparation was performed approximately 15 days before planting. Beds (30-cm high, 45-cm wide) were 1.5 m apart. Plot area was 18.6 m^2 and consisted of four rows 3.05 m long. A 1-m alley separated the rows

TABLE 1.—*Soil chemical properties of experimental fields to a depth of 15 cm prior to experiment initiation in 2000 and 2001.*[1]

Year	pH	Organic matter	Total N	Ca	Mg	K	Na	P	Fe	Mn	Zn	Cu
		g/kg		- - - - - - - cmol/kg - - - - - - -				- - - - - - - - - mg/kg - - - - - - - - -				
2000[2]	8.3	22.2	1.38	26.93	10.73	1.51	0.45	89.8	1.0	9.3	5.7	1.7
2001[3]	7.6	27.0	1.35	23.15	13.50	0.90	NA[4]	248.0	2.0	4.0	0.2	0.3

[1]Organic matter was determined with the dichromate oxidation method; total N was determined by using the Kjeldahl digestion; extractable bases were extracted with 1*M* NH4Oac; P was extracted with Na-HCO_3 and quantified by colorimetry.

[2]pH was analyzed in a 1:2 (soil:distilled water) mixture. Analysis for 2000 is the mean of four replicates from the field. Fe, Mn, Cu, and Zn were analyzed with the method of Lindsey and Norvell (1982). Extractable (1*M* KCL) NH_4^+-N and NO_3^--N were 14.8 and 9.25 mg/kg, respectively.

[3]pH was analyzed in a 1:2 (soil:0.01*M* $CaCl_2$) mixture. The analysis for 2001 corresponds to one composite sample. Micronutrients were extracted with a 0.1*N* HNO_3 solution.

[4]NA = not analyzed.

to avoid fertilizer interaction and tangling of vines between treatments. At planting, the top of the bed was chiseled and tuber sections of the Diamante cultivar weighing 120 g were placed at 20.3-cm intervals within the bed. Planting was on 1 June 2000 at a density of 24,219 plants per hectare. The plants were not trellised. Weeds were suppressed with a pre-emergence application of ametryn at a rate of 4.5 kg/ha. The plots were hand weeded during the experiment on three occasions. The crop received approximately 2.54 cm/wk of water either from rain or via drip irrigation.

The treatments consisted of a combination of two N levels and four K levels with four replications arranged in a randomized complete block design (Table 2). Two additional treatments tested the effects of Mg and micronutrient mixture application applied to soil. Treatment levels were established on the basis of the researchers' best professional judgment regarding nutrient amounts added and nutrient uptake values from previous studies done with other cultivars in Puerto Rico and elsewhere (Irizarry et al., 1995; IFA, 2002).

Fertilizer was applied at one and 2.5 months after planting by surface-banding the complete fertilizer mixture to each particular treatment approximately 5 cm from the plant. Phosphorus was not applied because the soil test P level (Olsen-bicarbonate) was in the high category (Table 1). In addition to the fritted trace element mixture applied to the soil, micronutrients were foliar-applied because of the observed severity of the micronutrient deficiency symptoms. Micronutrients were foliar-applied at a rate of 0.26 kg/ha per application of Fe, Mn, and Zn as Fe-DTPA (10% Fe), Mn-DTPA (13% Mn), and Zn-DTPA

TABLE 2.—*Treatment descriptions used in Experiment I.*

Treatment #	Treatment description (kg/ha)[1]
	(N-P-K)
1	75-0-0-36Mg-MN[2]
2	75-0-63-36Mg-MN
3	75-0-125-36Mg-MN
4	75-0-250-36Mg-MN
5	150-0-0-36Mg-MN
6	150-0-125-36Mg-MN
7	75-0-125-0Mg-MN
8	75-0-125-36Mg-0MN

[1]Half of the N application was urea and the other half was ammonium sulfate; K was added as KCl; Mg was added as $MgSO_4$.

[2]MN is micronutrient application. A total of 5.0, 4.0, 4.0 and 1 kg/ha of Fe, Mn, Zn, and B were added to soil, respectively. Fe, Mn, Zn, were applied as Granusol -Fe, Mn, and Zn (American Minerals, Inc., Dunedin FL), respectively; B was added as Granubor (US Borax, Rosemount, IL). Additional application of 1.3 kg/ha Fe, 0.8 kg/ha Mn, and 0.8 kg/ha Zn was foliar-applied during the experiment as Fe-DTPA, Mn-DTPA, and Zn-DTPA (Miller Chemical and Fertilizer Corp. Hanover, PA).

(14.5% Zn) (Miller Chemical and Fertilizer Corp., Hanover, PA)[6], respectively, at a water rate of approximately 470 L/ha. Foliar applications were made on 7 August 2000, 21 August 2000, and 15 September 2000. An additional 0.5 kg/ha Fe was applied on 15 September 2000 as Fe-DTPA to supplement the amount of Fe being added. A total of 1.3 kg/ha Fe, 0.78 kg/ha Mn, and 0.78 kg/ha Zn was foliar applied during the experiment.

Leaves (including petioles) were collected from the middle part of the pseudostems four months after planting to evaluate plant nutrient status. After being washed with tap water, the tissue material was dried in a forced-air oven at 65° C to a constant weight and ground through a stainless steel mill. A weighed portion (0.5 g) of material was digested with 2 ml H_2O_2 and 10 ml HNO_3 in a microwave digestion oven (CEM Corp., Mathews, NC) followed by analysis for P by colorimetry, and for K, Ca, Mg, Fe, Mn, Zn by atomic absorption spectrometry. Total N was quantified by Kjeldahl digestion (Bremner and Mulvaney, 1982).

Tubers were harvested on 19 December 2000. Surviving plants were counted, and all tubers from the two center rows counted, and separated into marketable and non-marketable categories; the fresh weight was obtained for each category. Marketable tubers were those

[6]Trade names in this publication are used only to provide specific information. Mention of a trade name does not constitute a warranty of equipment or materials by the Agricultural Experiment Station of the University of Puerto Rico, nor is this mention a statement of preference over other equipment or materials.

weighing over 320 g. Analysis of variance to evaluate treatment effects on marketable and non-marketable yields and number of tubers was performed by using SAS (SAS version, 8.01, SAS Institute, Cary, NC). Treatment means were compared by using pre-planned orthogonal contrasts. Linear, quadratic and cubic trends were examined to evaluate the effects of potassium on yields.

Experiment II

Experiment II was conducted from April to December 2001 in a field adjacent to that of the previous year. We evaluated the effects of N, K, and micronutrient application on yam production (cultivars Diamante and Guinea Negro). The soil was prepared as in Experiment I, except that plot area was 20.9 m^2 and consisted of three 4.57-m rows. Plant density was 21,531 plants/ha. A 1-m alley separated varieties within rows to avoid tangling of vines between treatments. At planting, the top of the bed was chiseled and seeds were placed at 30.6-cm intervals within the bed. Tubers of the Diamante and Guinea Negro cultivars were sectioned into pieces weighing approximately 120 g. Tuber sections were dipped for 5 min in thiabendazole at a concentration of 7.65 ml ai/L (Mignucci et al., 1984). Sections were planted 1 April 2001, and plants were trellised in rows after 30 days. Phosphoric acid at a total rate of 12 kg P/ha was applied 30 and 45 days after planting.

Weeds were suppressed with a pre-emergence application of ametryn and glyphosate at a rate of 4.5 kg ai/ha, and 1.2 kg/ai/ha, respectively, after planting but before plant emergence. For nematode control, oxamyl was applied bi-weekly at a rate of 0.50 kg ai/ha up to 90 days after planting. The plots were hand weeded five times during the experiment. The crop received approximately 2.54 cm/wk of water either from rain or via drip irrigation; tensiometers were inserted within rows to monitor and evaluate soil moisture status.

The treatments consisted of a combination of two N levels (N1 = 75 and N2 =150 kg/ha) and three K levels (K1 = 0, K2 = 125, K3 = 250 kg/ha K); these plots received micronutrient applications. An additional treatment was established to evaluate the effects of not adding micronutrients at N and K levels of 150 and 125 kg/ha, respectively. Fertilizer N and K were applied via drip irrigation at monthly intervals from May to November 2001. Nitrogen was applied as $(NH4)_2SO_4$; K was applied as KCl for the first three applications and as K_2SO_4 thereafter. Equal amounts of fertilizer N and K were applied with each fertigation. On two occasions phosphorus was applied via drip irrigation at a rate of 6 kg/ha P as phosphoric acid. Keyplex 350 (Morse Enterprises Limited, Miami, FL) was applied 28 April, 5 May, 12 May, and 22 May 2001 via drip irrigation during germination and plant establishment at a rate of 4.94 L/ha. Micronutrients (applied as Fe, Mn, and Zn sulfates) were foliar-applied bi-weekly starting 22 May 2001 and ending 29 August 2001 for a total of nine applications. The foliage was visibly wetted with the amount of solution added, which corresponded to approximately 470 L/ha. Solution concentrations were 0.1, 0.07, and 0.05% of Fe, Zn, and Mn as sulfates, respectively, for total foliar application rates of Fe, Zn, and Mn of 2.9, 3.0, and 2.4 kg/ha, respectively.

The plant greenness was evaluated by using a SPAD-502 chlorophyll meter (Minolta, Japan) 5 June and 10 July 2001 on two plants within each plot. The mean value of three fully developed leaves was obtained from each plant. In turn, these values were averaged for the two plants. Leaves were collected at approximately four months after planting to evaluate plant nutrient status. They were analyzed for total N, P, K, Ca, Mg, Fe, Mn, Zn as described in Experiment I.

Harvesting was performed 18 December 2001. Surviving plants were counted, and all tubers from the middle row within each plot were dug out. Tubers were counted, visually separated into marketable and non-marketable categories, and the fresh weight was obtained for each category as in Experiment I.

There were four replications in a randomized complete block design. The statistical arrangement was a split-strip plot with cultivars as the main plot, K levels as the subplots and N levels as the sub-subplot. Analysis of variance, to evaluate treatment effects on marketable and non-marketable yields and tubers, was performed by using SAS (SAS version, 8.01, SAS Institute, Cary, NC). Treatment means were compared by using pre-planned orthogonal contrasts after adjusting for ten plants as covariate, and by natural logarithmic transformation of yields. Reported values are the base two antilogarithmic values from least squares mean estimates.

RESULTS AND DISCUSSION

Experiment I

Experiment I was severely affected by loss of plants due to the onset of an unconfirmed causal agent which affected plants at approximately 60 days after planting. Plant death ranged from 5 to 45% in all plots. Symptoms consisted of necrotic leaf borders and black spots on the upper and lower parts of both newer and older leaves, limited root extension, partial tuber/seed decay, and plant growth reduction. Surviving plants showed symptoms throughout the experiment until harvesting. Visual symptoms were diagnosed as a root rot corresponding to the bacteria *Erwinia carotovora* (W. Almodóvar, Plant Disease

Diagnostic Laboratory, UPR-Mayagüez, personal communication). No further pathogenicity tests were performed.

The number of marketable tubers ranged from 10,047 to 14,436 tubers/ha; no significant treatment contrasts were observed. Marketable yam tuber production ranged from 5,962 (treatment #3) to 10,742 kg/ha (treatment #1). Yam response to K and Mg application at the soil test K and Mg levels of this soil could not be ascertained, probably because of the onset of disease as a limiting production factor. No negative salt nor sodium effects on plant growth were expected as chemical analyses of water used for irrigation in the experiment showed that the water was classified in the medium salinity hazard class with no sodium hazard to plants.

Experiment II

Cultivar Diamante was affected by the same visual symptoms which appeared during Experiment I, but to a lesser extent. Visual observation suggests that plant vigor was increased as a result of a more aggressive management of micronutrients. It has been suggested that other *D. alata* varieties are more susceptible to anthracnose, locally known as “Candelilla”, whereas the cultivar Diamante possesses field resistance (Mignucci et al., 1985). Anthracnose was identified and isolated from some of the black leaf spots (M. Alameda, Agronomy and Soils Department, UPR-Mayagüez, personal communication), yet the population was too low to substantiate evidence that the symptoms observed were due to the effects of anthracnose and not due to some secondary effects. Leaf spots, such as the ones observed in cv. Diamante caused by *Curvularia* sp. and *Colletotrichum* sp., have been found and identified in both *D. rotundata* and *D. alata* yams in Puerto Rico (Torres-López et al., 1986; Rodríguez-García et al., 1983).

Yam plant number of tubers (number per hectare), marketable tuber weights (kg), marketable yields (kg/ha), and total yields (kg/ha) were significantly higher in cv. Diamante than in Guinea Negro ($P < 0.05$), with values of 13,787 and 8,618; 0.927 and 0.769; 12,744 and 6,632; 15,475 and 8,229, respectively. SPAD readings were always higher in Guinea Negro and were highest for the readings taken at 97 days after planting, with values of 23.5 and 35.4, respectively.

In cv. Diamante with micronutrient additions, N addition did not influence any of the parameters measured, at the low (0 kg/ha) or high (250 kg/ha) K level (Table 3). At the medium K level (125 kg/ha), N addition reduced the number of tubers. There was no significant K effect at the high N level (150 kg/ha) for all parameters evaluated except for number of tubers, which was greatest without K application. At the low

TABLE 3.—*Effect of nitrogen, potassium, and micronutrient application on yam (*D. alata, *cv. Diamante) number of tubers, tuber weight, yields and SPAD readings taken at 91 days after planting in Experiment II.*

Treatment number, description, and contrast comparison	Marketable				
	Tubers	Tuber weight	Yield	Total yield	SPAD
	#/ha	kg	- - - - - - kg/ha	- - - - - -	
1. 75-12-0-MN[1]	14,266	0.947	13,509	15,654	23.6
2. 75-12-125-MN	17,604	0.822	14,462	16,471	24.9
3. 75-12-250-MN	17,808	1.06	18,787	20,553	21.9
4. 150-12-0-MN	16,899	0.891	15,059	17,453	24.6
5. 150-12-125-MN	9,568	1.16	11,098	14,265	27.0
6. 150-12-250-MN	13,665	0.994	13,581	16,821	23.5
7. 150-12-125	9,585	0.695	6,667	9,577	18.7
N contrast low K (1 vs. 4)	ns[2]	ns	ns	ns	ns
N contrast medium K (2 vs. 5)	0.0314	ns	ns	ns	ns
N contrast high K (3 vs. 6)	ns	ns	ns	ns	ns
K contrast low N	ns	ns	ns	ns	ns
K contrast high N	0.1075	ns	ns	ns	ns
MN contrast high N and medium K (5 vs. 7)	ns	0.0786	ns	ns	0.007

[1]N-P-K amounts in kg/ha; MN denotes micronutrient application.
[2]ns denotes non-significance at $P < 0.1$.

N level (75 kg/ha), there was a trend for number of tubers, marketable yields, weight/tuber and total yields to increase with increasing K levels. SPAD readings were affected neither by N nor K applications, with values ranging from 23.5 to 27.0 units.

Micronutrient applications significantly increased tuber weight in cv. Diamante (Table 3). Marketable and total yields were not significantly lower without micronutrient application. This finding may be due to the high coefficients of variation (CV) associated with the treatments used in the contrast. Nevertheless, there was a trend for marketable and total yields to be at least 45% lower without micronutrient applications. Plants without micronutrient applications were visibly more chlorotic than those with micronutrient application as confirmed by a significantly ($P = 0.007$) lower SPAD reading.

Leaf N, P, K, Ca, S, and Cu contents of cv. Diamante were unaffected as a result of treatments with mean values of 32.6 g/kg, 2.60 g/kg, 41.3 g/kg, 17.5 g/kg, 2.50 g/kg, and 10.27 mg/kg, respectively. There was an increase ($P = 0.09$) of Mg contents from 7.4 to 9.1 g/kg, as a result of not adding micronutrients. Leaf Fe and Mn significantly increased from 104.9 to 169.9 mg/kg ($P = 0.002$), and 32.8 to 104.6 mg/kg ($P = 0.007$), as a result of micronutrient addition, respectively. Leaf Zn concentrations of 34.7 and of 79.1 mg/kg with and without micronutrient additions, respectively, were non-significant ($P = 0.48$). The results obtained for Experiment II contrast with those of Experiment I, where no changes in leaf nutrient contents were found (data not shown). This finding is probably due to greater plant vigor and yields, and more intensive management of micronutrients in Experiment II.

In cv. Guinea Negro with micronutrient applications, the addition of N at medium K levels (125 kg/ha) significantly increased marketable and total yields from 4,339 to 8,190 kg/ha and 5,830 to 9,827 kg/ha, respectively (Table 4). Increases in yields or tuber weight as a result of N addition at the high K level (225 kg/ha) were not observed although plants were significantly greener as quantified by the SPAD reading. There was no significant K effect at high N application (150 kg/ha) for any parameters evaluated except for plant greenness, in which SPAD values were greater at the 250 kg/ha K than at 0 kg/ha K (Table 4). In treatments in which the low N level (75 kg/ha) was applied, SPAD readings and total yields were greater at the low K level (0 kg/ha) than at the medium (125 kg/ha) and high (250 kg/ha) K levels, whereas the

TABLE 4.—*Effect of nitrogen, potassium, and micronutrient application on Yam (*D. rotundata*, cv. Guinea Negro) number of tubers, tuber weight, yields and SPAD readings taken at 91 days after planting in Experiment II.*

Treatment number, description, and contrast comparison	Marketable				
	Tubers	Tuber weight	Yield	Total yield	SPAD
	#/ha	kg	------ kg/ha	------	
1. 75-12-0-MN[1]	13,805	0.760	10,492	12,309	41.9
2. 75-12-125-MN	6,174	0.703	4,339	5,830	36.9
3. 75-12-250-MN	9,443	0.753	7,133	8,568	33.5
4. 150-12-0-MN	9,138	0.949	8,672	10,211	33.1
5. 150-12-125-MN	10,014	0.818	8,190	9,827	34.3
6. 150-12-250-MN	7,545	0.811	6,123	7,917	39.3
7. 150-12-125	6,354	0.628	3,993	5,550	27.7
N contrast low K (1 vs. 4)	ns[2]	ns	ns	ns	0.002
N contrast medium K (2 vs. 5)	ns	ns	0.093	0.092	ns
N contrast high K (3 vs. 6)	ns	ns	ns	ns	0.050
K contrast low N	0.019	ns	0.074	0.064	0.017
K contrast high N	ns	ns	ns	ns	0.054
MN contrast high N and medium K (5 vs. 7)	0.092	ns	0.056	0.067	0.016

[1]N-P-K amounts in kg/ha; MN denotes micronutrient application.
[2]ns denotes non-significance at $P < 0.1$.

number of tubers and marketable yields was higher than at the medium K level (125 kg ha) only. At the same low N level, there was no significant difference between the medium and high K levels for any of the parameters evaluated.

Leaf N, P, K, Ca, and Cu contents of Guinea Negro were unaffected as a result of treatments, with mean values of 27.3 g/kg, 2.30 g/kg, 32.5 g/kg, 21.3 g/kg, and 10.76 mg/kg, respectively. As it occurred for cv. Diamante, leaf Mg content significantly increased (P = 0.03) from 7.8 to 9.9 g/kg, as a result of not adding micronutrients. Leaf Mg contents were higher than those reported by Irizarry (1985), because of the higher exchangeable Mg content of our soil. Leaf Fe, Mn, and Zn significantly increased, respectively, from 170.9 to 307.4 mg/kg (P = 0.03), 25.0 to 224.4 mg/kg (P = 0.005), and 22.1 to 160.7 mg/kg (P = 0.02), as a result of micronutrient addition. The effects of adding micronutrients were clearer in cv. Guinea Negro than in Diamante; significant decreases as a result of not adding micronutrients were observed with regard to the number of tubers, marketable and total yields, SPAD readings, and leaf Fe, Mn, and Zn contents.

An economic analysis evaluated the net income obtained as a function of the fertilizer treatments and corresponding marketable and non-marketable yields. The items included in the analyses were those recommended by the Univ. of P.R. Agric. Exp. Station (UPR-AES, 1997) with the present costs and profits of the farm where the experiment was conducted and with conditions for the southern semi-arid coast of Puerto Rico. Results reveal that the net income obtained for cv. Diamante ranged from -$3,167/ha to $4,303/ha. These estimates may not represent actual income because they are based on non-significant yield differences. For cv. Guinea Negro, net income ranged from -$4,673/ha to $2,853/ha for the 150-12-125 without micronutrient and 75-12-0 with micronutrient application, respectively. The highest net income obtained coincides with the trends observed in yields of cv. Diamante, and the highest yields obtained with cv. Guinea Negro.

Expected marketable yields for yam are approximately 17,300 kg/ha for Puerto Rico. These values will vary according to the cultivar planted, plant density, and soil and crop management. The yields for *D. rotundata* cv. Guinea Negro are lower than those from commercial fields and those reported in other studies for cv. Habanero (Irizarry and Rivera, 1985) and for Guinea Negro in an Ultisol (del Valle-González and Santiago-Córdova, 1990). Lower yields observed in our experiment may be due to poor seed quality or other management practices such as excess water, which may have reduced plant stand.

Yields for the cultivar Diamante have been reported at 40.3 t/ha in an Ultisol (Irizarry and Rivera, 1997). Yields for other *D. alata* cultivars, such as Gunung, ranged from 58.7 to 62.3 t/ha (Irizarry and

Rivera, 1993; Irizarry et al., 1995). Marketable yields in three locations for the cultivar Binugas were 45.2 t/ha in an Ultisol, 16.2 t/ha in an Oxisol, and 20.2 t/ha in a Vertisol (Lugo et al., 1993). Maximum yields of 18.8 t/ha obtained in Experiment II are in accordance with expected values for commercial plantings in Puerto Rico but lower than those published from controlled experiments. Improved yields could be obtained by controlling the unknown disease which reduced plant stand during the early stages of the growth period.

Exchangeable K levels found in these soils are considered high enough to ensure adequate K supply for plant growth. Although not statistically significant, the trend towards increased yields as a result of application of Fe, Mn and Zn, and greater yields reported in highly weathered soils, suggests that the two cultivars evaluated in this study are not micronutrient-efficient genotypes. Micronutrient-efficient plants have increased capacity to solubilize non-available nutrient forms into plant-available ones or have increased capacity to transport nutrients across the plasma membrane (Rengel, 2001). Other management strategies may improve yields by improving Fe availability and/or mobility. For example, iron chlorosis has been ameliorated as a result of K fertilization, and the combination of high NH_4^+ concentrations and nitrification inhibitors in peanuts (*Hypogea* spp.) because of the excess uptake of cations over anions leading to H^+ excretion at the rhizosphere (Barak and Chen, 1984; Kafkafi and Ganmore-Neumann, 1985). Factors which decrease high apoplastic pH such as NH_4^+ or K nutrition have resulted in re-greening of Fe-chlorotic leaves (Mengel and Geurtzen, 1986).

In Experiment I, where only the cultivar Diamante was tested, plant response to fertilizer (K, Mg, and micronutrient) application was not observed, probably because of disease incidence as a limiting factor. In Experiment II for cv. Diamante, total yields were 56% higher with micronutrient additions, but this increase was non-significant. Leaf Fe and Mn increased with micronutrient additions. For cv. Guinea Negro, highest total yields tended to result from N, P, K applications of 75, 12, 0 kg/ha, respectively, and with micronutrient additions. The application of Fe, Mn, and Zn sulfates significantly increased leaf Fe, Mn, and Zn nutrient contents, plant greenness, and yields.

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