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Factors affecting magnesium availability to plantains in highly weathered soils[1,2]

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ABSTRACT

Magnesium deficiency is a major constraint for banana and plantain (*Musa* spp.) production in highly weathered soils. A study was conducted on an Ultisol (Aquic Haplohumult) of the central mountainous region of Puerto Rico to evaluate the effect of several factors on magnesium availability to plantain. Four target levels of soil exchangeable Mg:K ratios: 0.6, 2.0, 4.0 and 8.0; two lime application treatments: no lime, limed to pH 5.5; and two fertilization programs were evaluated in a split-split plot experimental design. Results indicated a highly positive correlation between soil magnesium levels and crop performance. Significant effects were observed on days to flowering, plant height, number of leaves at flowering, leaf magnesium content, and yield. A 25% yield increase was observed at the lowest magnesium increment relative to the control. In addition, the ratio of non-bearing plants per experimental plot was reduced with increments in soil magnesium. It was calculated that in this soil a value close to 2.0 cmol(+)/kg soil would be needed to reach the 0.30% leaf tissue concentration considered critical for bananas and plantains. This value may vary for soils because of different mineralogy, and also because of the influence of factors affecting the availability of magnesium to plants (e.g., antagonistic effect of

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potassium, magnesium fixation). Our results confirm the need to base fertility recommendations on a soil test. Establishing a universally recommended dosage for all soils of the island, as has been attempted in the past, would be highly impractical because of the highly heterogeneous nature of the soils in Puerto Rico.

Key words: Magnesium nutrition, Musaceas, highly weathered soils, tropics

RESUMEN

Factores que afectan la disponibilidad de magnesio en plátanos cultivados en suelos altamente meteorizados

La deficiencia de magnesio ha sido identificada como uno de los factores más limitantes para la producción de guineos y plátanos en suelos altamente meteorizados. Se realizó un estudio en un Ultisol (Aquic Haplohumult) de la zona montañosa central de Puerto Rico para evaluar el efecto de varios factores sobre la disponibilidad de magnesio (Mg) al cultivo de plátano. En un diseño experimental de parcelas divididas se evaluaron cuatro tratamientos propuestos de proporciones de Mg:K intercambiable (0.6, 2.0, 4.0, y 8.0); dos tratamientos de encalado (sin encalar, encalado a pH 5.5); y dos programas de fertilización. Los resultados reflejan una alta correlación entre los niveles de magnesio en el suelo y el desarrollo de la cosecha. Se observó un efecto significativo en el número de días a florecer, altura de la planta, número de hojas en la florecida, contenido de magnesio en la hoja y rendimiento. Un aumento de 25% en rendimiento se observó con el incremento menor de magnesio comparado con el del control. Además, la proporción de plantas no-productoras por parcela experimental se redujo con aumentos en el magnesio del suelo. Se calculó que en este suelo se necesitarían cerca de 2.0 cmol(+)Mg/kg de suelo para alcanzar un nivel de 0.30% Mg en la hoja, el cual se considera crítico para el crecimiento óptimo de guineos y plátanos. Este valor puede variar en suelos de diferente mineralogía, debido a factores como el efecto antagónico de potasio y la fijación de magnesio. Nuestros resultados confirman la necesidad de establecer recomendaciones de fertilidad basadas en análisis de suelo. Adoptar una dosis de fertilización universal para todos los suelos de la isla, como ha sido acostumbrado en el pasado, puede resultar inefectivo debido a la naturaleza altamente heterogénea de nuestros suelos.

INTRODUCTION

Plantain and banana production (*Musa* spp.) plays an important socio-economic role in numerous regions of the tropics. The vast majority of soils on which these crops are grown to satisfy local demands are highly weathered soils of low fertility (Stover and Simmonds, 1987). Next to that of nitrogen, magnesium (Mg) deficiency is considered to have the most adverse effect on bananas, provoking notorious physiological anomalies (Caribbean Organization, 1965). Magnesium deficiency has been identified as a major constraint for banana and plantain production in highly weathered soils, causing yield reductions of up to 25% or more and increasing the incidence of physiological diseases (Simmonds, 1959; Caro-Costas et al., 1964; Hernández-Medina and Lugo-López, 1969; Samuels et al., 1975; Borges-Pérez et al., 1983; Irizarry et al., 1990).

A magnesium concentration of 0.30% in the third young leaf of seven-month-old plants is considered adequate for optimum yield and is often used as the target in most fertilizer programs (López and Espinosa, 1995). Efforts to attain such levels in highly weathered soils frequently meet with limited success. For example, in an experiment on an acid Ultisol in the humid uplands of Puerto Rico, Irizarry et al. (2000) were unable to obtain magnesium levels greater than 0.22% in banana leaf tissue with magnesium applications as high as 180 kg/ha, after having reached a value of 0.30% with similar amounts in a previous experiment (Irizarry et al., 1990).

Several factors contribute to the magnesium status of plants grown on highly weathered soils. Probably the most important factor is the inherent amount of exchangeable magnesium in the soil. Although estimates of critical exchangeable magnesium values vary with soil types, levels below 0.5 cmol(+)/kg range are generally thought to result in plant deficiencies (Hailes et al., 1997a, b). Some scientists prefer to stress the need for an adequate distribution of cations in the exchange complex, and recommend 6 to 10% Mg saturation as an index of adequate magnesium status of a soil (Bergman, 1992).

The antagonistic effect of potassium on magnesium uptake has also been identified as a cause of magnesium deficiency (Prince et al., 1946; Metson, 1974). This is particularly accentuated in plantains and bananas, because of the fertilizer potassium requirements of up to 1,500 kg/ha/yr in those crops (Stover and Simmonds, 1987). In Puerto Rico, current recommendations for banana and plantain are about 60 kg Mg/ha/yr and 700 kg K/ha/yr (Estación Experimental Agrícola, 1995), or approximately a 1:4 Mg:K ratio on an equivalent basis.

A number of studies have established critical equivalent ratios of soil exchangeable Mg:K for adequate magnesium nutrition. Current estimates vary from values as low as three to as high as 15 in some cases (López and Espinosa, 1995; Soto, 1985). This discrepancy indicates the need to consider other factors in addition to Mg:K ratio in order to establish a comprehensive magnesium management program for highly weathered soils. A key element in this scenario appears to be magnesium "fixation" induced by liming of these soils (Martínez et al., 1994, 1996; Smeck et al., 1995; Cavallaro, 1996). Preliminary evidence attributes the phenomenon to magnesium occlusion by precipitated aluminum (Al)-hydroxy species, but the kinetics and specific conditions under which it occurs are poorly understood (Myers et al., 1988). Other factors that have been proposed to explain the commonly observed magnesium deficiencies in highly weathered soils are Mg-Mn antagonism and leaching of magnesium (Ritchey and Irizarry, 1983; Cavallaro, 1996).

Although the significance of the above factors for magnesium availability is strongly evidenced by laboratory and field observations, the evidence is still fragmented. Therefore, additional field experiments are needed to establish criteria for magnesium sufficiency. Here we present results from such an experiment conducted at Corozal, Puerto Rico.

MATERIALS AND METHODS

A field experiment was established on a Corozal clay soil (clayey, mixed, isohyperthermic, Aquic Haplohumult) in the central mountainous region of Puerto Rico (200 meters above sea level). Minimum and maximum temperatures were 19 and 29.8 °C, and rainfall was 1,994 mm during the first year of the experiment. A split-split plot experimental design with four replications was established. The treatments evaluated were the following: a) main plot—four target levels of soil exchangeable Mg:K ratios: 0.6 (control), 2.0, 4.0 and 8.0; b) sub plot—two lime application treatments: no lime, and limed to pH 5.5 [using $Ca(CO)_3$]; and c) sub-sub plot—two crop fertilization programs: the currently recommended program (Estación Experimental Agrícola, 1995), and one where the Mg:K ratio in the fertilizer is similar to that in the soil exchange complex. Twelve plantain plants were planted per treatment plot, in addition to border plants, with a 2.44-m × 1.83-m spacing.

The target values of the exchangeable Mg:K ratios were achieved by broadcasting and incorporating magnesium sulfate in different amounts. One month later, soil samples were taken to verify attainment of target soil conditions. Results from these analyses (Table 1) indicated that target levels were reasonably achieved, except at the highest ratio (8.0), where the attained ratio was only about one half the target ratio.

Crop measurements included plant growth phenology (number of leaves, plant height and diameter at the flowering stage), nutrient uptake (3rd leaf) at four-month intervals, and yield. Soil measurements at the same time intervals included exchangeable calcium, potassium, magnesium and aluminum, extractable phosphorus (Olsen and Bray), and pH using standard methodology (Page et al., 1982). Relations between soil and plant parameters were assessed through regression analyses.

RESULTS AND DISCUSSION

The initial level of magnesium in the soil had a major impact on crop performance. Liming and fertilizer treatment had only a minor impact; therefore, we will concentrate our discussion on the effects of

TABLE 1.—*Magnesium status of the experimental plots one month after treatment application.*

Target Mg:K ratio[1]	Lime treatment	Actual Mg:K ratios (Avg. ± st.dev.)	Mg exch. cmol(+)/kg	Mg saturation %
0.6 (control)	Lime	0.60 ± 0.10	0.68 ± 0.24	7.15 ± 2.52
	No lime	0.56 ± 0.06	0.51 ± 0.08	5.86 ± 1.08
2.0	Lime	1.88 ± 0.49	1.42 ± 0.26	13.06 ± 3.07
	No lime	1.59 ± 0.24	1.60 ± 0.37	15.09 ± 4.75
4.0	Lime	3.30 ± 0.22	3.62 ± 0.57	32.05 ± 3.13
	No lime	3.73 ± 1.14	3.48 ± 0.55	31.60 ± 4.43
8.0	Lime	4.91 ± 1.84	4.69 ± 2.18	35.19 ± 11.90
	No lime	5.37 ± 2.14	5.18 ± 1.63	43.35 ± 14.02

[1]Experimental target ratios.

soil magnesium levels. Significant effects were observed on days to flowering, plant height, number of functional leaves at flowering, leaf magnesium content, and yield (Figures 1 to 4; Table 2). A 28% increase in yield was observed at the lowest exchangeable magnesium incre-

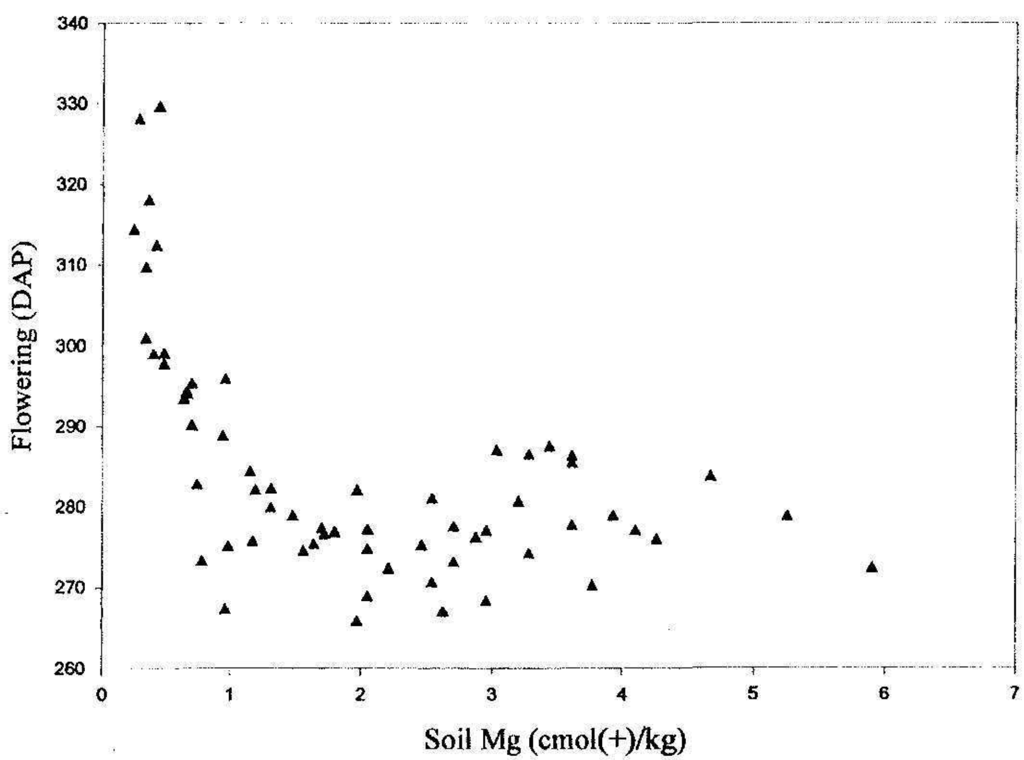

FIGURE 1. Effect of soil magnesium on number of days to flowering.

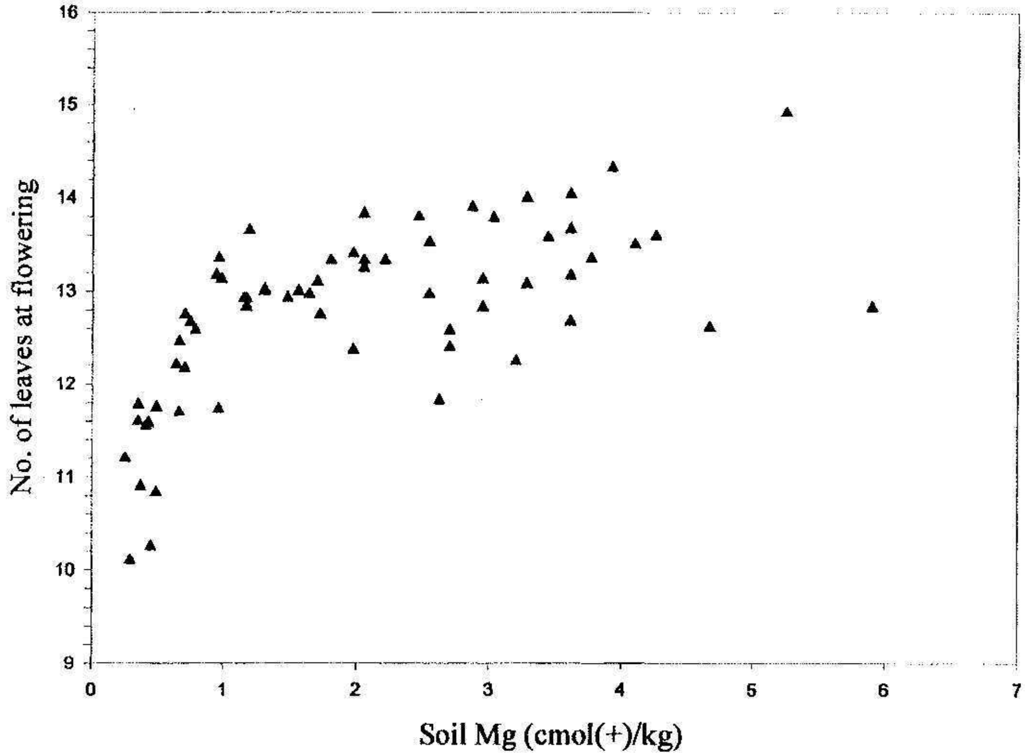

FIGURE 2. Effect of soil magnesium on the number of leaves of plantains at flowering.

ment relative to the control. This finding coincides with estimates made by others on the impact of magnesium deficiencies on crop production (Hailes et al., 1997a). Improvements in the magnesium nutritional status of the plants reduced the number of non-bearing (lodged, uprooted) plants in the experimental plots (Figure 5). A number of studies have suggested a link between the nutritional status of soils and the incidence of soil borne diseases in plantain and banana, all of which may explain these results (Borges-Pérez et al., 1983; Domínguez et al., 1997; Schadeck et al., 2000).

Magnesium addition caused a significant increase in the number of functional leaves at flowering (Table 2, Figure 2). A higher number of leaves probably contributed to the reduction of approximately 20 days in number of days required to reach the flowering stage relative to that of the control treatment. Plant height diminished as a result of magnesium additions, possibly because of the more abundant foliage under improved magnesium nutrition.

Increases in magnesium content of the leaves were accompanied by a small reduction in the amount of calcium and potassium four months after plant emergence (Table 3). However, this effect was significant only at the highest magnesium level and disappeared as the plant

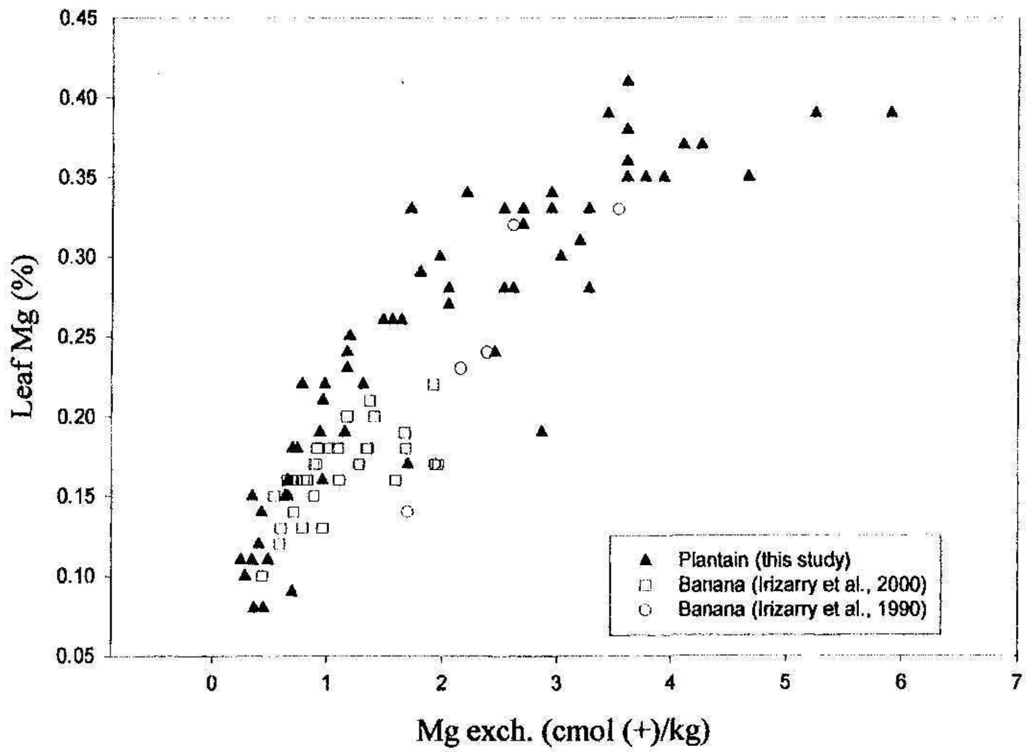

FIGURE 3. Relationship between soil magnesium and leaf magnesium content in plantains and bananas grown in an Ultisol of Puerto Rico (data from various experiments).

aged. Manganese also decreased with increasing magnesium additions and the effect was maintained throughout the growing season (Table 3). The antagonism between magnesium and manganese has been reported previously (Edward-Raja, 1997). In contrast to that of calcium, potassium and manganese, the amount of zinc increased with magnesium additions, although once again the effect was evident only at the beginning of the growing season (four months).

The amount of magnesium in the exchange complex appears to be the controlling factor for adequate magnesium nutrition in this soil. There was a strong positive correlation between soil exchangeable magnesium and leaf tissue magnesium (Figure 3). Similar to what Hailes et al. (1997b) observed in corn, we observed a linear relationship between leaf magnesium content and soil exchangeable magnesium levels below 1 cmol (+)/kg.

The need for adequate magnesium nutrition in plantain is evidenced by the relationship between the magnesium content of the leaves and yield (Figure 4). Two statistical models (continuous and discontinuous) were applied to describe the crop response to soil exchangeable magnesium (Figure 6). The Cate and Nelson approach is

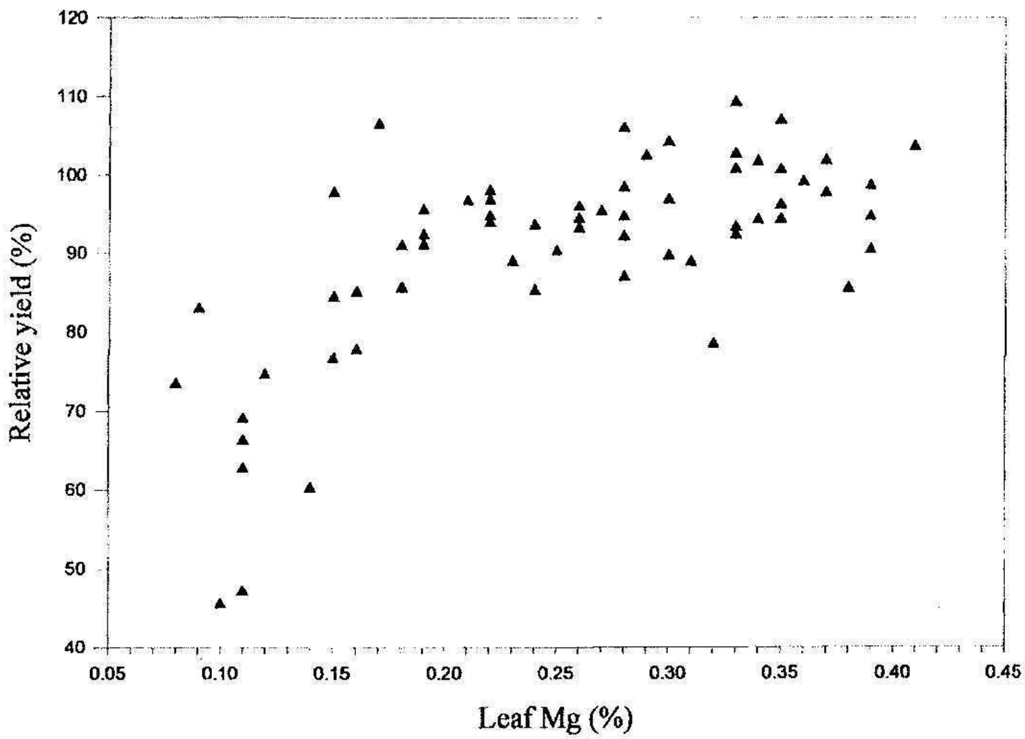

FIGURE 4. Relationship between leaf magnesium content at flowering and relative yield of plantain.

based on a discontinuous model that separates a plot of the relative yield response of a crop to a specific experimental parameter into two populations: a high and a small response (Waugh et al., 1973). The parameter value that divides the overall sample in two populations with minimum variance is considered as a critical value. Table 4 shows the critical values obtained with the Cate and Nelson model for different experimental variables. The values obtained for the magnesium leaf content (0.16%), and the soil exchangeable magnesium content [0.66

TABLE 2.—*Effect of soil exchangeable Mg:K ratios on crop performance.*

Target soil exchangeable Mg:K ratio[1]	Yield (t/ha)	Flowering (days after planting)	Number of leaves at flowering	Plant height (m)
0.6 (control)	32.70 b	303.51 a	11.61 b	3.82 a
2.0	41.89 a	279.11 b	12.98 a	3.55 b
4.0	43.52 a	273.06 b	13.14 a	3.62 b
8.0	43.14 a	280.90 b	13.41 a	3.54 b

[1]Experimental target ratios. Actual ratios varied (see Table 1).

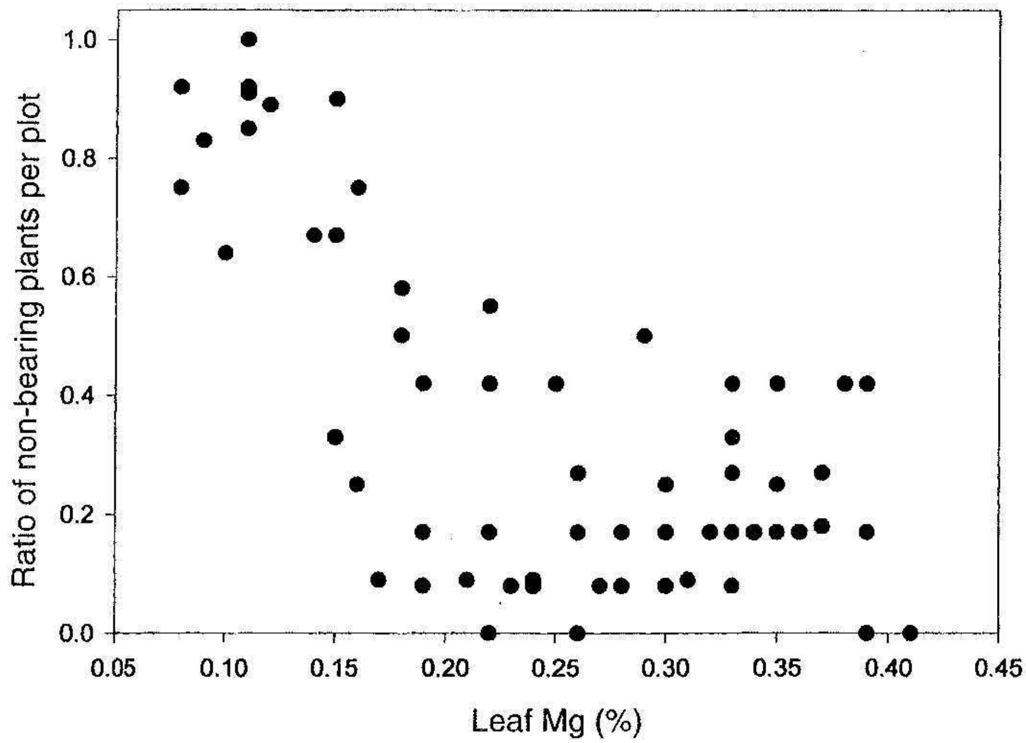

FIGURE 5. Relationship between leaf magnesium content at flowering and the proportion of non-bearing plants in the experimental plot.

cmol(+)/kg] are substantially lower than has been suggested in the literature (e.g., 0.30% leaf Mg content). A continuous model was also applied to obtain estimates of different thresholds of crop performance (Table 4). Those estimates were obtained through a best-fit routine with the aid of the computer software program Table Curve (Jandel Sci-

TABLE 3.—*Effect of magnesium on the nutritional status of plantain leaves.*

Target soil exchangeable Mg:K ratio[1]	Leaf K (%) (4 mo after plant emergence)	Leaf Ca (%) (4 mo after plant emergence)	Leaf Zn (mg/kg) (4 mo after plant emergence)	Leaf Mn (%) (4 mo after plant emergence)	Leaf Mn (%) (12 mo after plant emergence)
0.6 (control)	3.20 a	0.83 a	14.31 b	0.58 a	0.39 a
2.0	3.18 a	0.69 b	16.00 a	0.30 b	0.20 b
4.0	3.12 a	0.60 b	16.19 a	0.40 b	0.29 b
8.0	2.93 b	0.51 b	16.38 a	0.29 b	0.20 b

[1]Experimental target ratios. Actual ratios varied (see Table 1).

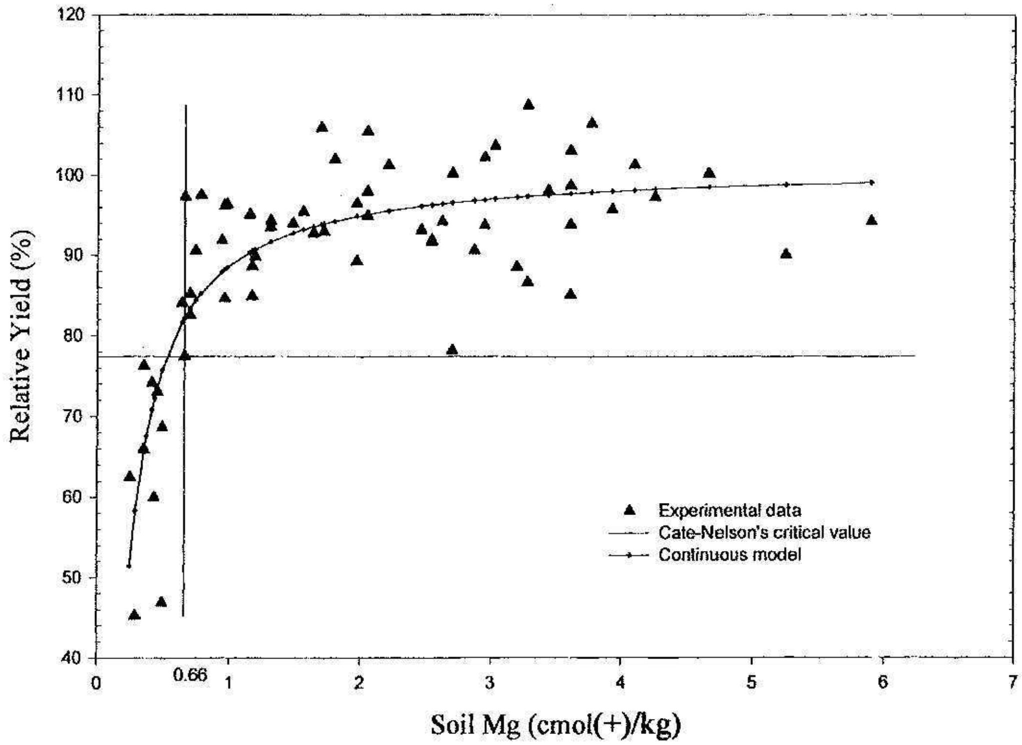

FIGURE 6. Application of a continuous and a discontinuous (Cate-Nelson) model to estimate critical levels of soil exchangeable magnesium in plantain.

entific, version 3.18).[7] For a particular equation, the program undergoes a number of iterations and calculates the values of the different fitting parameters that would result in the closest fit to the data. Thresholds for a 90% and 95% relative yield differ markedly from the critical values obtained with the discontinuous model. This difference was expected

TABLE 4.—*Critical performance variables according to a continuous and a discontinuous model.*

Prediction model	% Mg leaf	Soil exch. Mg (cmol+/kg)	Soil exch. Mg:K
Cate-Nelson Model	0.16	0.66	1.05
Continuous Model			
90% relative yield	0.21	1.11	1.77
95% relative yield	0.29	2.02	3.35

[7]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.

since the conceptual bases of the two approaches also differ. Whereas the Cate-Nelson model aims to define a single response threshold in crop performance, the continuous model can be used to estimate different response target levels (e.g., 80%, 90%, 95% relative yield). The values obtained with the continuous model fit more closely to the values recommended by others as critical for adequate response of plantain. The decision of whether to aim for maximum yield or for a particular percentage of it would in most cases be based on economic considerations.

Our results confirm the need to base fertility recommendations on a soil test. Establishing a universally recommended dosage for all soils of the island, as has been attempted in the past, would be ineffective because of the highly heterogeneous nature of the soils in Puerto Rico. The inadequacy of such an approach has been documented at the farm level, as well as experimentally. In an experiment with banana, Irizarry et al. (1990) reached 0.30% of Mg in the leaves with an application of 224 kg/ha Mg. However, in a second experiment on a similar soil, Irizarry et al. (2000) were unable to surpass the 0.22% level with a similar application (180 kg/ha Mg). A closer look at their data reveals that the initial soil exchangeable magnesium content differed greatly in the two experiments [1.7 vs. 0.4 cmol(+)/kg], despite both experimental sites being close to each other. Although similar quantities of magnesium were added to the soils, the end results were significantly different. A plot of the relation between leaf magnesium content and soil exchangeable magnesium levels reveals a strikingly similar relationship between our results and those obtained by Irizarry et al. (1990; 2000) with banana (Figure 3). Thus, it is evident that on this soil a value close to 2.0 cmol(+)/kg soil would be needed to reach the 0.30% leaf Mg considered critical for banana and plantain. This value may vary for soils of different mineralogy, and under conditions that promote the antagonistic effect of potassium and magnesium fixation in soils.

CONCLUSIONS

We corroborated that adequate magnesium nutrition is crucial for plantain and banana production, and that increases in magnesium uptake had a positive impact on crop performance. A significant increase in the number of leaves at flowering as well as a reduction in the number of days required to reach the flowering stage was observed as a result of magnesium additions. In addition, yield production increased by 30% in the magnesium treatments. A 0.30% leaf Mg content (3rd leaf, seven-month-old plants), which is considered indicative of proper plant nutrition, was achieved by increasing the amount of soil exchangeable magnesium from the natural low values of 0.5 cmol(+)/kg to approximately 2.0 cmol(+)/kg.

In the soil studied, the most relevant factor for magnesium nutrition in plantain proved to be the exchangeable magnesium content, with other factors (i.e., soil exchangeable Mg:K ratio, magnesium fixation) being less relevant. This finding stresses the importance of developing fertilizer recommendations on the basis of soil analyses and not exclusively on the basis of estimates of plant uptake.

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