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The status of phosphorus and other fertility parameters in soils of Puerto Rico[1,2]

David Sotomayor-Ramírez[3] and Gustavo A. Martínez[4]

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ABSTRACT

There is a need to quantitatively assess the soil fertility status of tropical soils. Descriptive summaries help describe the effectiveness of liming programs, nutritional limitation in soils and the relative risk of off-field nutrient transport. A database of 1,168 soil test results collected from 1989 to 1999 from nearly 400 cultivated farms in Puerto Rico was used. Samples were analyzed for pH, organic matter (Walkley-Black method), extractable phosphorus (P) (Olsen and Bray 1), and exchangeable bases (NH_4OAc method) by a commercial laboratory. Thirty-six percent of the samples had acidity problems (pH <5.5). Twenty-three percent of the samples had low organic matter content (<20 g/kg), and 16% had high category (>40 g/kg) values. Fifty-three and 56% of the samples showed a need to fertilize with magnesium (Mg) and potassium (K), respectively, because they had values below the suggested critical levels of 2.5 $cmol_c/kg$ for soil exchangeable Mg and of 0.4 $cmol_c/kg$ for K. On the basis of current soil fertility criteria, P fertilization would be required in 69% of the samples with pH less than 7.3, but only in 28% of the samples with pH greater than or equal to 7.3. Although the soils grouped with pH >7.3 had a greater proportion of samples in the "extremely high" soil test P category, the potential environmental impact may be lessened because the climatic and topographic conditions where these soils occur favor less runoff. Follow-up studies are needed to assess the spatial

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[3]Professor, Agronomy and Soils Dept., College of Agricultural Sciences, Univ. of Puerto Rico-Mayagüez Campus, P.O. Box 9030, Mayagüez, PR 00681-9030.

[4]Professor, Agronomy and Soils Dept., College of Agricultural Sciences, Agric. Experiment Station.

variability and the temporal dynamics of the nutritional status of soils of Puerto Rico.

Key words: soil test, soil fertility, nutrients

RESUMEN

El estatus de fósforo y otros parámetros de fertilidad en suelos de Puerto Rico

Existe una necesidad de realizar catastros para describir el estatus de fertilidad de suelos tropicales. Resúmenes descriptivos ayudan a evaluar la efectividad de programas de encalado, la limitación nutricional a cultivos agrícolas, y la probabilidad de riesgo de transporte de fósforo (P) fuera de los terrenos agrícolas. Se utilizó un banco de datos de 1,168 resultados de análisis de suelos de muestras recolectadas entre 1989 y 1999 en Puerto Rico en cerca de 400 fincas cultivadas. Las muestras se analizaron en un laboratorio comercial para determinar pH, materia orgánica (método Walkley-Black), P extraíble (Olsen y Bray 1), y bases intercambiables (método de NH_4Oac). El 36% de las muestras reflejaron problemas de acidez (pH <5.5). El 23% de las muestras tenían un contenido de materia orgánica (método Walkley-Black) bajo (<20 g/kg), mientras que un 16% reflejó valores >40 g/kg. El 53% y 56% de las muestras reflejaron la necesidad de fertilizar con magnesio (Mg) y potasio (K), respectivamente, ya que tenían valores por debajo del nivel crítico sugerido de 2.5 $cmol_c$/kg para Mg, y de 0.4 $cmol_c$/kg para K. A base de los criterios actuales para fertilidad de suelos, se requería la fertilización con P en 61% de las muestras de suelo con pH menor de 7.3, pero solamente en un 28% en muestras con pH mayor o igual de 7.3. Aunque los suelos con pH >7.3 tenían mayor proporción de muestras en la categoría de P extraíble "extremadamente alto", las condiciones climáticas y topográficas donde predominan estos suelos no son conducentes al transporte de P. Se necesitan estudios adicionales para evaluar la variabilidad espacial y la dinámica temporal del estatus nutricional de los suelos de Puerto Rico.

Palabras clave: análisis de suelos, fertilidad de suelos, nutrimentos

INTRODUCTION

Surface water (stream and lake) contamination by nitrogen (N) and phosphorus (P) is one of the largest environmental issues to date (USEPA, 1988; Parry, 1998) because excess nutrients in water promote accelerated eutrophication (Sharpley et al., 1994; Corell, 1998). Nutrients in runoff and eroded sediments from non-point sources such as agricultural lands are among the largest contributors to surface water contamination. The concentration of P in runoff increases as the agronomic soil test P concentration in soils increases (Sharpley and Kleinman, 2003; Schroeder et al., 2004). Since agronomic soil tests for P (STP) are routinely performed in many laboratories, they would be ideal for environmental assessment of P transport. The STP for a particular site in combination with other factors, such as runoff potential (a function of soil type, climate, vegetation, and topography) and management practices, can be used to identify critical areas or management practices conducive to excessive P movement into water bodies (Lemunyon and Gilbert, 1993; Castro et al., 2003).

The sufficiency concept for interpreting soil test results has been the accepted philosophical basis for making nutrient recommendations and for establishing nutrient management programs among university agronomists (Black, 1993; Havlin et al., 1999; Martínez et al., 2002). Categorical indices of "low, medium, and high" are respectively associated with probable, possible and unlikely crop response to applied nutrients. This concept of fertilizing the crop (Olsen et al., 1987) contrasts with the build-up maintenance concept in which there is a much more liberal fertilizer recommendation because nutrients are recommended to replace the amount likely to be removed by the crop to be grown, with the capacity of the soil to supply nutrients either discounted or misinterpreted. At present there exists no organized or published information which reports, summarizes, or describes the soil test status of agricultural lands in Puerto Rico. This information is needed for evaluating the adequacy (in terms of nutrient use) of fertilizer recommendations provided by the College of Agricultural Sciences of the University of Puerto Rico personnel and private consultants, and for identifying critical zones of deficiency or excess requiring immediate corrective action.

There have been dramatic changes in the amount and distribution of farmlands and nutrient use in Puerto Rico in the last twenty years. For example, the total land area dedicated to agricultural production has declined steadily since 1952 (Commonwealth of Puerto Rico, 1996). Also, there has been a shift in agricultural commodities as sugarcane, occupying over 130,000 ha in the 1950s, has been phased out. There have been increases in the land dedicated to horticultural crops such as vegetables, fruit trees, and plantains and bananas, all of which accounts for intensive use of fertilizers (Commonwealth of Puerto Rico, 1996). Vélez-Ramos and Muñoz (1991) performed a field fertility survey of sugarcane production areas of Puerto Rico and found that soil test P was "low" in all areas evaluated. Observation of soil test analyses from fields that were previously under sugarcane production and are now being used for production of vegetables, fruit trees, or roots and tubers contradicts this finding, as many of these fields are in the high soil test category for P (Sotomayor-Ramírez, unpublished). Soils dominated by 2:1 clays of the southern semi-arid coast may have high soil test P and K values, as solanaceous crops grown in some fields did not respond to K application and marginally responded to P applications (Sotomayor-Ramírez and Macchiavelli, 2002). Seventy-five percent of evaluated soils that were actively receiving organic dairy waste from storage lagoons were in excess of suggested agronomic critical levels for P, and 35% of the soils tested were close to established environmental soil test critical levels (Martínez et al., 2003).

The objectives of this study were to perform a descriptive summary of the soil test results (soil pH, organic matter, extractable P, exchangeable Ca, Mg, and K) in agricultural soils of Puerto Rico.

MATERIALS AND METHODS

A database of soil tests performed by a commercial soil test laboratory was utilized. The analyses were ordered by a private fertilizer company in Puerto Rico for its clients. Sampling was performed according to procedures recommended by the College of Agricultural Sciences (Muñiz-Torres, 1990a). The samples were from soils with fields under cultivation of horticultural and agronomic crops within 390 agriculturally active farms throughout Puerto Rico for the years 1989 to 1999. Some of the soil tests have results from various (two or three) fields from particular farms, for a total of 1,168 records.

Soils were sampled to a depth of 15 cm. The crop being grown or the intended crop was not included in the analysis because these activities typically change within and among years. Various analytical soil tests were performed on the soil samples collected. Organic matter was determined by the dichromate oxidation method (Nelson and Sommers, 1982). Soil pH was determined using a 1:2 soil:water ratio. Exchangeable bases (Ca, Mg, K, and Na) were extracted by using ammonium acetate (pH = 7) followed by analysis using inductively coupled plasma. Extractable P was determined by the Bray 1 (Bray and Kurtz, 1945) and Olsen P (Olsen and Sommers, 1982) methods in all soils regardless of the pH.

Descriptive variables such as mean, median, variance, and frequency distributions for the variables soil pH, organic matter, extractable P, exchangeable Ca, Mg, and K were calculated using SAS (SAS Institute, 1996). Box plots describing the 25th and 75th percentiles as well as mean and median values were computed. Correlation analysis between soil test P extracted by using the Olsen procedure and the Bray 1 procedure was performed with and without the grouping of soils according to soil pH and soil organic matter content. Soil test data are presented as the cumulative relative frequency within the soil test categorical indices suggested for Puerto Rico by Muñiz-Torres (1992). The low, medium and high soil test categories for P, Ca, Mg, and K are those in which most agronomists would predict a high, medium and low probability, respectively, of crop yield response to the application of nutrients. Categorical grouping of soil tests for P beyond the high category was performed by using that suggested by Sotomayor-Ramírez et al. (2004). The categories for pH were chosen on the basis of highly probable presence of Al toxicity in solution below 5.5 (low) and probable responses to the application of micronutrients because of low metal solubility in soil or the presence of free $CaCO_3$ (high). The categories for organic matter were chosen on the basis of the assumption that on average 5% of the organic matter is N, for which soil availability categories have been suggested (Muñiz-Torres, 1992). The soil test categories used in Puerto Rico need not correspond to those found elsewhere because of differences in response due to crops and philosophical approaches of the interpretation of soil tests.

RESULTS AND DISCUSSION

Soil productivity has misconceptually been associated with soil organic matter; thus its maintenance in soil has always been a goal for agronomists. Unfortunately, from a fertility standpoint, organic matter soil test values are difficult to interpret because of the wide diversity in intrinsic and extrinsic soil factors that influence total amounts and decomposition rates in soil, and because of the less than direct correlation between organic matter and crop production. Alternatively, attempts have been made to use soil organic matter tests as an index of soil quality (Doran and Parkin, 1994), yet this effort has also been met with skepticism because of the multiple functions and roles of soil organic matter (Greenland et al., 1992) and because certain soils can preserve organic matter better than others (Mitchell and Everest, 1995; Lal, 2002). The value in interpretation of organic matter soil tests lies primarily in monitoring relative temporal changes and, since soil organic matter is the largest soil N reserve, as a relative index of potential N availability. The interquartile range for the organic matter soil test in this study varied from 20.0 to 35.0 g/kg, with mean and median values of 29.3 and 27.0 g/kg, respectively (Figure 1). Twenty-three percent of the samples had low organic matter levels (<20 g/kg), thus suggesting that in general the crops grown in these soils are expected to respond to N fertilization. In 16% of the soils evaluated, the crops grown probably would not respond to nitrogen fertilization (organic matter values were greater than 40 g/kg). In soils where N response is not expected, it still may be useful to apply sufficient N to compensate for crop N removal and thus to avoid soil fertility changes that could lead to possible reductions in crop yields. For example, at soil organic matter mean values of 29.0 g/kg, nitrogen standing stocks are approximately 2,936 kg N/ha (15-cm depth and bulk density of 1.3 g/cm^3), about 2% of which is mineralizable annually. Annual organic matter reductions of 1 g/kg soil (0.05 g N/kg soil) will result in a loss of approximately 100 kg N/ha, thereby having a substantial effect on subsequent recommendations for soil N replenishment, especially in highly weathered soils such as Oxisols and Ultisols (Olson et al., 1987).

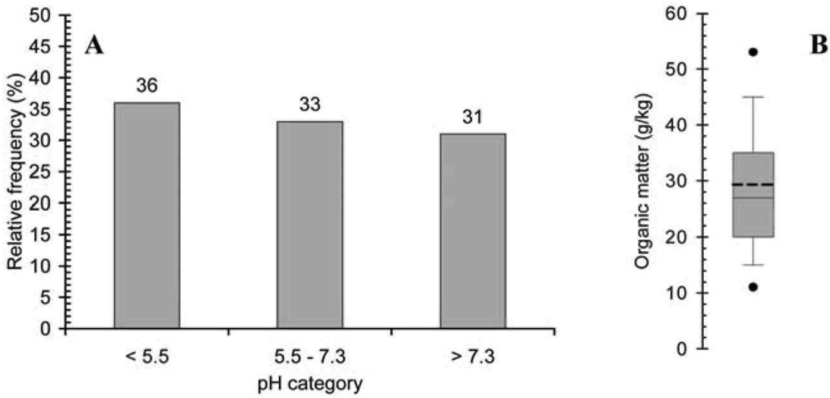

Figure 1. Soil test organic matter relative frequency distribution (A) and box plot (B) in 1,168 soil samples collected in Puerto Rico during 1989-1999. In B, the lower and upper lines of the box represent the 25th and 75th quartiles, respectively; the bottom and top whiskers represent the 10th and 90th percentiles, respectively; the bottom and top closed circles represent the 5th and 95th percentiles, respectively; the solid and dotted lines inside the box represent mean and median values, respectively.

Thirty-six percent of the samples had pH below 5.5, values at which most soils are expected to show high exchangeable and solution Al and at which liming will be required for most of the major crops grown in the tropics (Figure 2). Unfortunately, 1 M KCl extractable Al was not measured in these samples; therefore, the actual negative effects of acidity cannot be ascertained. In addition to Al toxicity, low soil pH is associated with high extractable Mn, and with limited capacity to supply P, Ca, Mg, K, and S (Sánchez and Logan, 1992). Thirty-one percent of the samples had pH values above 7.3. The probability of soils having free $CaCO_3$ is increased beyond this value, and crops grown in the soils corresponding to these samples will probably require applications of micronutrients. The areal extent of soil acidity varies according to published sources, ranging from 25 to 35% of all arable land world-wide (Sánchez and Logan, 1992; Havlin et al., 1999). Muñiz-Torres (1990b) suggested that 47% of the 174 soil series in Puerto Rico had pH values <5.5, for which liming would be required. His analysis was not based on quantitative analysis of field-collected soil samples but on field descriptions of soils detailed in soil surveys and physical and chemical properties of selected pedons of Puerto Rico which are now detailed in Mount and Lynn (2004).

Traditionally in Puerto Rico, the P content of soils has been evaluated by the Olsen test for soils with pH values >7.3, and the Bray 1 test for soils with pH values <7.3. The rationale for using particular tests is that a portion of the total soil P extracted into solution originates from

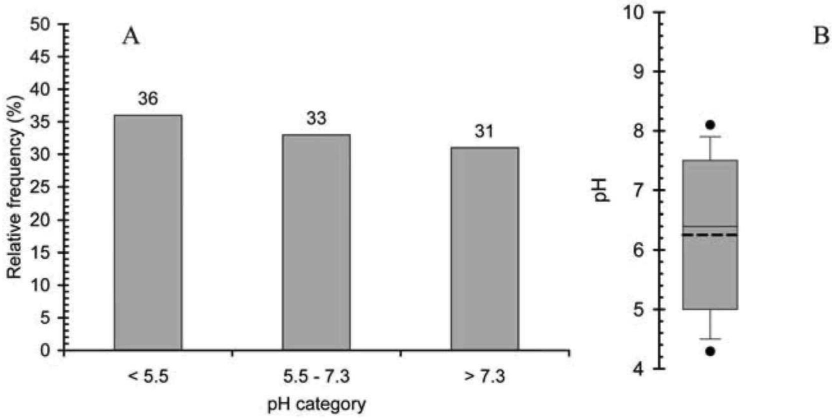

Figure 2. Soil pH relative frequency distribution (A) and box plot (B) in 1,168 soil samples collected in Puerto Rico during 1989-1999. In B, the lower and upper lines of the box represent the 25th and 75th quartiles, respectively; the bottom and top whiskers represent the 10th and 90th percentiles, respectively; the bottom and top closed circles represent the 5th and 95th percentiles, respectively; the solid and dotted lines inside the box represent mean and median values, respectively.

a total P pool that reacts with the reagents added, and is proportional to that available to the plants. The most important aspect really is that extractable P (by a soil test) need be related to crop production with the probability of maximizing crop production with increasing soil test values. Sixty-four percent of samples with pH <7.3 and 51% of samples in soils with pH >7.3 had soil test P values in the low and medium categories, thus suggesting that some fertilization is needed (Figure 3). Although the percentages are similar for both groups of soils, soils with pH <7.3 have a greater number of soils in the low category and therefore a higher probability of crop response to P fertilization. For example, soils evaluated by the Olsen method (pH >7.3) had soil test P median values of 92 mg/kg (n = 359) whereas those evaluated with the Bray 1 (pH <7.3) method had soil test P values of 10 mg/kg (n = 809). The interquartile range for soils evaluated using the Bray 1 method varied from 4 to 27 mg/kg whereas for the Olsen method it varied from 29 to 150 mg/kg. Soils of kaolinitic and oxidic mineralogy have greater P fixing capacity and lower P availability at equal P loadings than calcareous soils, which are usually dominated by 2:1 mixed layer silicates. The data demonstrate that in soils with pH <7.3 there is a need to fertilize with P on a greater number of soils.

Tropical soils in the "extremely high" category for soil test P are expected to exceed environmental critical levels of dissolved P

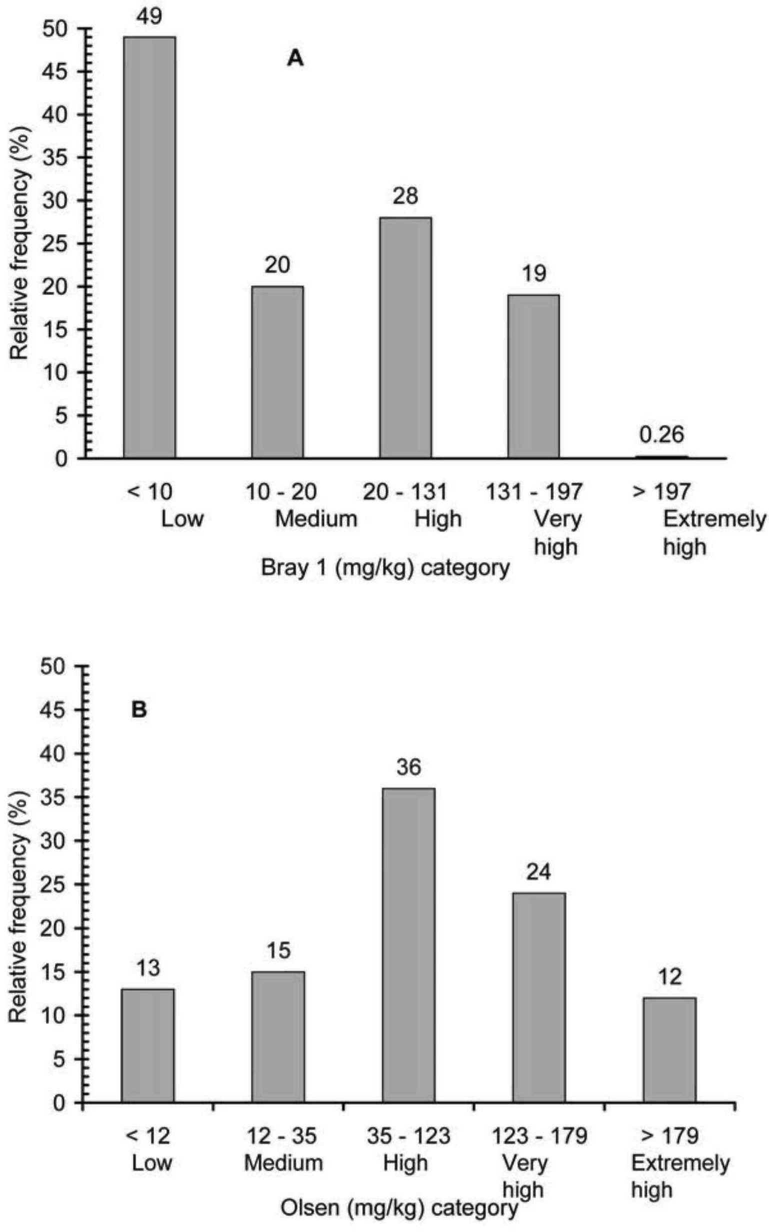

Figure 3. Soil test phosphorus relative frequency distribution in 1,168 soil samples collected in Puerto Rico during 1989-1999 with pH ≤7.3 as analyzed using the Bray 1 method (A) and >7.3 using the Olsen method (B).

(Sotomayor-Ramírez et al., 2004; Ramírez, 2005); therefore, no additional external P source (organic nor inorganic) should be added. Five percent of the soils evaluated by the Olsen method and 0.3% of the soils evaluated by the Bray 1 method tested in the "extremely high" category. Nevertheless, the off-site transport of P is dominated not only by soil test P but also by a number of site and source factors which are considered in the P index (Lemunyon and Gilbert, 1993; Sharpley, 1995; Castro et al., 2003). Acid soils are expected to be able to receive greater P loadings because of their high P fixation capacity relative to that of calcareous soils. Although the soils grouped with pH >7.3 had a greater proportion of samples in the "extremely high" soil test P category, the potential environmental impact may be lessened because the climatic and topographic conditions where these soils occur have lower runoff potential (Mount and Lynn, 2004). Soils of the southern semi-arid coast of Puerto Rico, originating from sedimentary parent material, are generally dominated by 2:1 clay layer silicates, and the pedogenic processes giving rise to these soils favor their having high pH values (Beinroth, 1971). On the basis of the results presented here, we suggest that agronomic best management practices need to be implemented for reduction of P losses in runoff in only a small group of soils within farms of Puerto Rico similar to those included in this analysis.

In a previous study, the equation Bray 1 = 0.836 (Olsen) + 5.60, explained 83% of the variation for five soils of Puerto Rico with varying soil P contents (Sotomayor-Ramírez et al., 2004). The slopes and intercepts of the lines varied somewhat when the relationship between Bray 1 and Olsen extractable P was evaluated for each of the individual soils separately, because the amount of P extracted will differ according to the soil physico-chemical properties (e.g., pH, sesquioxide content, clay type, organic matter content, and P status). In this study, a single equation for groups of soils with pH <7.3 and with pH >7.3 was not possible because of the wide variability in the data set (Figure 4). The relationship using soils with pH <7.3 was better related to previous data generated. The lower slope in the Olsen extractable P method as compared to the Bray 1 method corroborates the lower extracting P capacity of the latter in soils with pH >7.3. The data suggest that both the Olsen and Bray 1 tests could be used successfully to evaluate P availability in soils of Puerto Rico having pH <7.3.

Fifty-three and 56% of the samples had values below the suggested soil test critical levels of 2.5 $cmol_c/kg$ for Mg, and of 0.4 $cmol_c/kg$ for K (Figure 5); thus crops grown in corresponding soils suggest a need to be fertilized with Mg and K, respectively. Other criteria can be used for interpretation of soil tests. For example, the basic-cation ratio concept, which originated in the 1940s as a basis for soil test interpretation and

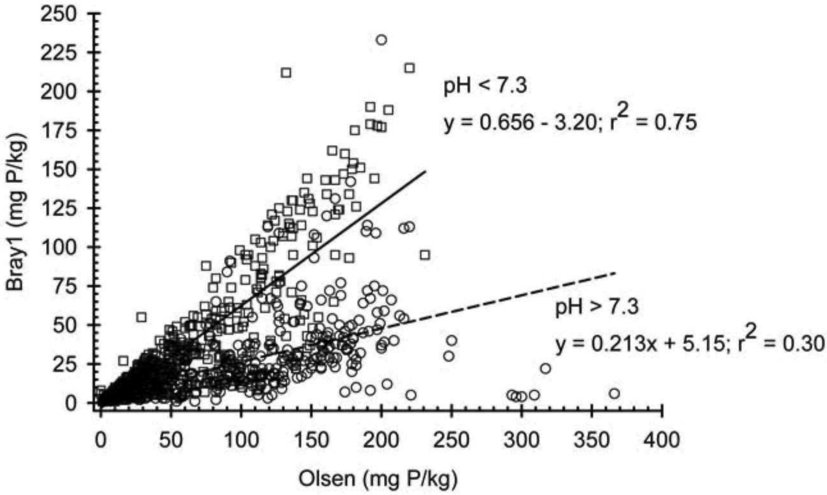

Figure 4. Regression between soil test P quantified by the Bray 1 and Olsen methods in samples collected in farms of Puerto Rico from 1989 to 1999 as grouped by pH. Solid line includes soils with pH ≤7.3; dotted line represents soils with pH >7.3.

fertilizer recommendation, was developed on the basis that the degree of colloidal exchange saturation of one cation influenced the availability of itself and other cations (Eckert, 1987). Although the original theory has since been disproven, it is still a useful tool for evaluating possible nutrient deficiencies, primarily when one of the cations is near or below the soil test critical level (Bertsch, 1995). We used the soil exchangeable (Ca+Mg)/K ratio to demonstrate that out of the 652 soil samples testing low or medium in K, the problem will be exacerbated in 60% of the cases because of ratios greater than 40. Under K-limiting conditions, excess Ca and Mg at colloidal exchange sites may result in greater K limitation because of plant uptake competition of cations. This condition will probably occur because of management, such as excess liming of acid soils, or because of the natural fertility status of soils of the southern semi-arid coast of Puerto Rico. Of the 623 soil samples testing low in Mg, 70% of the samples had Mg/K ratios < 8; which is considered as a threshold value below which there is a high probability of Mg deficiency due to excess K availability. This finding is important because Mg deficiency has been identified as a limiting factor for plantain and banana production in highly weathered soils of Puerto Rico (Martínez et al., 2002).

The information presented describes the fertility status of soils as evaluated by fertility indicator parameters from soil test results of agricultural soils at sites under presumed intensive management

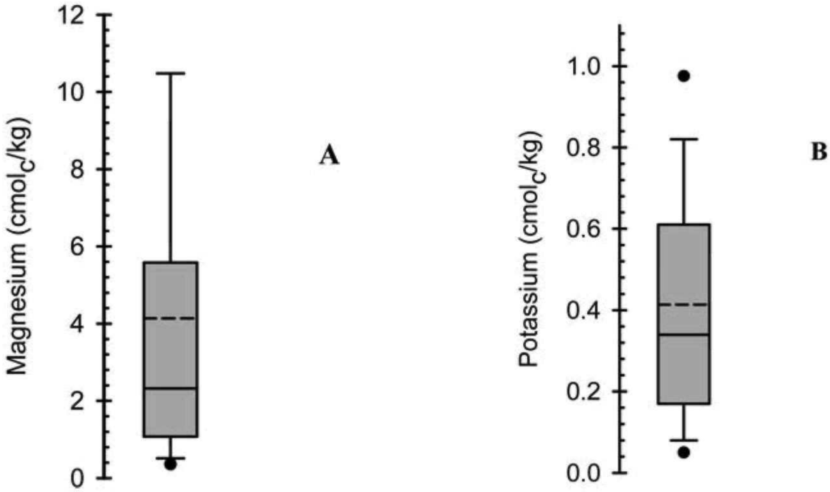

Figure 5. Soil test magnesium (A) and potassium (B) in 1,168 soil samples collected in Puerto Rico during 1989-1999. The lower and upper lines of the box represent the 25th and 75th quartiles, respectively; the bottom and top whiskers represent the 10th and 90th percentiles, respectively; the bottom and top closed circles represent the 5th and 95th percentiles, respectively; the solid and dotted lines inside the box represent mean and median values, respectively.

practices. Routine soil testing on a regular basis establishes crop needs for the current year, permits the monitoring of changes over time, and guides nutrient management for optimum crop production and environmental protection. Soil testing serves to establish direct relationships between nutrient availability and fertilizer probability response for parameters such as P, Ca, and Mg, and to assess the risk for off-site transport for P. Soil testing can also indicate whether liming programs are being adequately followed. Improved interpretations can be obtained by using information related to mineralogy, texture, crops grown and available technology. Limitations of the analysis herein presented are that some areas of Puerto Rico could be over- or underrepresented; some farms were sampled more than once over a period of ten years, and the samples were obtained from farms associated with high input agricultural activities.

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