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Chemical and physical properties of two tropical soils treated with sewage sludge compost[1]

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ABSTRACT

The effects of sewage sludge compost applications on a Mollisol and an Ultisol of Puerto Rico were evaluated. Experimental rates were control (0 compost), 37, 74, and 148 t/ha/yr, which were to be applied during a three-year period. In addition, a treatment consisting of a single application of 445 t/ha was included to assess the impact of single massive applications vs. continuous applications of compost. Results here presented pertain exclusively to the project's first year. The compost was obtained from the sewage sludge compost facility of Puerto Rico's Solid Waste Management Authority in Arecibo. The material was predominantly inorganic and exhibited a high soluble salt content, which diminished its quality. Compost additions caused significant pH increases in both soils. The effects were more noticeable on the Ultisol (Corozal clay), where pH increased from 4.55 in the control to 6.45 with the lowest compost treatment. The electrical conductivity of both soils increased considerably with compost additions, sometimes ap-

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proaching limits considered detrimental to support crop growth. The organic matter content of both soils also increased with compost additions. This increase had a positive effect on their water retention capacity. Nitrogen contributions from the compost were minimal. However, significant increases in the levels of phosphorus were observed in both soils. Compost additions caused significant increases in the levels of EDTA extractable metals (i.e., Cu, Zn, Cd, Cr, Fe). However, elements regulated by the U.S. Environmental Protection Agency (e.g., Cd, Pb, Cr) were added in amounts well below the established limits, and thus were not a reason for concern.

Key words: sewage sludge compost, tropical soils

RESUMEN

Propiedades químicas y físicas de dos suelos tropicales tratados con composta de cieno sanitario

Se realizó un estudio para evaluar el efecto de aplicaciones de composta de cieno sanitario en un Mollisol y un Ultisol de Puerto Rico. Los tratamientos evaluados fueron los siguientes: control (0 composta), 37, 74, y 148 t/ha/año, a ser aplicados durante un periodo de tres años. Se incluyó un tratamiento consistente de una sola aplicación de 445 t/ha para comparar el efecto de aplicaciones masivas vs. aplicaciones secuenciales. Los resultados aquí presentados corresponden exclusivamente a datos obtenidos durante el primer año del proyecto. La composta se obtuvo de la planta de composta de cienos sanitarios de la Autoridad de Desperdicios Sólidos de Puerto Rico en Arecibo. Dicho material resultó ser predominantemente inorgánico y alto en sales solubles, lo cual afectó la calidad del producto. Las aplicaciones de composta causaron un aumento significativo en el pH de los suelos. Los efectos fueron más marcados en el Ultisol (Corozal arcilloso) donde el pH aumentó de 4.55 en el control a 6.45 con el nivel más bajo de composta. La conductividad eléctrica de los suelos aumentó significativamente con aplicaciones de composta, acercándose en algunos casos a los límites considerados detrimentales para el crecimiento de los cultivos. Los niveles de materia orgánica en los suelos también aumentaron significativamente lo cual causó una mejoría en la capacidad de retención de agua de los suelos. La contribución de nitrógeno al suelo por la composta fue mínima. Sin embargo, se observaron aumentos significativos en los niveles de fósforo de ambos suelos. Las aplicaciones de composta causaron aumentos significativos en los niveles de metales (i.e., Cu, Zn, Cd, Cr, Fe) extraíbles por EDTA. Sin embargo, elementos regulados por la Agencia de Protección Ambiental Federal (e.g., Cd, Pb, Cr) se añadieron a niveles muy inferiores a los límites establecidos, por lo que no representaron riesgo.

INTRODUCTION

Solid waste management constitutes one of the biggest challenges Puerto Rico will face in the coming years. One of the most densely populated areas in the world (FAO, 1994), with one of the highest rates in the U.S. of area based solid waste generation (≅ 850 t/m^2), our island has plunged into a capacity crisis of alarming proportions. Alternatives for waste disposal must be implemented to cope with future populational and industrial growth.

Composting has long been recognized as one of the most cost effective and environmentally sound alternatives for solid waste recycling.

The ability to remove large amounts of refuse (municipal and industrial) from conventional disposing routes, such as landfilling and incineration, makes composting an appealing alternative for modern societies. Through composting, objectionable organic substrates such as sewage sludge are transformed into an odorless and pathogen free material with a myriad of potential applications.

In general, composts are highly organic materials that exhibit some fertilizer value. Thus, agricultural applications constitute the main means of their disposal. The benefits of composts in agricultural soils are well documented (Parr et al., 1993; Hyatt, 1995; and Garland et al., 1995). Repeated applications of compost have significantly improved the physical properties of soils. Improvements in aggregate stability, water holding capacity, infiltration rates, and bulk density are generally attributed to the increases in organic matter content associated with compost additions to soils (Stratton et al., 1995; Giusquiani et al., 1995; Lindsay and Logan, 1998). The susceptibility to erosion may also be greatly reduced as a consequence of organic matter additions (Harris-Pierce et al., 1995). Beneficial effects may also be observed in the chemical properties of the soil. Increases in the cation exchange capacity of the soil and overall nutritional status (e.g., nitrogen and phosphorus) have frequently been observed (McCoy et al., 1986; Hernando et al., 1989; Cavallaro et al., 1993; Rodella et al., 1995). In acid soils, additions of compost have been recommended to alleviate aluminum toxicity (Hue, 1992; Pocknee and Sumner, 1997). Compost may raise the level of microbial activity and suppress soil-borne pathogens (Thurston, 1991; Atkinson et al., 1996; Banerjee et al., 1997). All these effects combined generally translate into crop yield increases (Bevacqua and Mellano, 1994; Maynard, 1995).

Despite such potential, wide use of compost has been limited by negative experiences associated with the use of immature (unstable) or low quality compost. Immature compost may contain pathogens potentially harmful to plants, animals or humans; create nutritional imbalances in crops; induce reducing conditions, thus increasing odor problems and mobility of trace elements through the soil; cause localized increases in temperature affecting seed germination; and introduce hazardous compounds to the environment (Jiménez and García, 1989; He et al., 1992; Inbar et al., 1990). Low quality compost may cause nutritional imbalances in crops, salinity problems, or toxicity to the surrounding biota, while rendering no benefits as a soil amendment.

In the case of sewage sludge compost, the potential introduction of trace elements (e.g., Hg, Cd, Pb, Cr), organic pollutants, and pathogenic organisms into the human food chain has raised fears over the deleterious effects on health that could be associated with a land application program (Wang et al., 1995; McBride et al., 1997; Logan et al., 1997; Sloan et al., 1997). To ensure public safety, the U.S. Environmental Protection Agency (USEPA) implemented the 503 rule, which establishes limits on the cumulative amount of pollutants that can be added to a soil, as well as on the allowable concentration of pollutants in products derived from sludge that are intended for land application (USEPA, 1993). Despite the extensive research that went into the creation of this rule, serious concerns have risen as to its effectiveness in different ecosystems. Critics point out that such regulation is based primarily on short-term experiments with corn, soybean and lettuce as their test crops, and they warn against the possible deleterious consequences in nontraditional U.S. agricultural systems (McBride, 1995). This is particularly relevant in the case of Puerto Rico because of the year-round intense agriculture and the non-traditional crops (e.g., *Dioscorrea alata* L., *Xanthosoma* L., *Carica papaya* L., *Cajanus cajan* L.) grown on the island. In addition, studies on highly weathered soils, such as the deep reddish soils in Puerto Rico's humid uplands, are limited. Experiments must be conducted locally to generate the background information needed to establish a sound biosolid compost application program, which is the focus of this study.

MATERIALS AND METHODS

The study began in August 1996 on two research farms of the Agricultural Experiment Station of the University of Puerto Rico. An Ultisol (Corozal clay, Aquic Haplohumults), and a Mollisol (San Antón loam, Cumulic Haplustolls) were used. Five experimental treatments were evaluated by means of an experimental design consisting of four replicates of each treatment randomly allocated in separate blocks. Treatments were control (0 compost), 37, 74, and 148 t/ha. These compost rates were to be applied annually for a three-year period. In addition, a treatment consisting of a single application of 445 t/ha was included to evaluate the effect of single vs. continuous applications of compost. Results here presented pertain exclusively to the first year. The experimental plots were 8.51 m by 9.12 m with 1.52-m border rows between them.

We used sewage sludge compost produced at Arecibo's Solid Waste Management Authority compost facility. At the time the study started, the facility was undergoing a transition from the Puerto Rico Sewer and Aqueduct Authority to the Waste Management Authority of Puerto Rico. The material used during our first year was produced under the supervision of the Sewer Authority personnel although it was under the custody of the Waste Management Authority personnel when acquired.

Treatments were applied with the aid of a front load tractor. Compost rates were applied uniformly to the experimental plots and incorporated in the first 15 cm of soil. Plots were planted to cassava (*Manihot esculenta*, PI 12095) a month after treatment incorporation. Soil samples of the first 7 cm were obtained one month, five and 11 months after compost application. Analyses included pH (2:1, 0.01N $CaCl_2$:soil), water retention, electrical conductivity (3:1, D.D. H_2O:soil), KCl-available N, P (Olsen), %O.M. (Walkley-Black), EDTA extractable metals (i.e., Fe, Zn, Cu, Cd, Cr, Co), and soil exchangeable (NH_4OAc) cations (Ca, Mg, K, Na, Fe, and Al) (Page et al., 1987). In addition, estimates of dissolved organic matter (DOM) were obtained on aqueous extracts (2:1, water:soil suspensions), by quantifying sample absorbance (280 nm) on a DU-68 Beckman UV/VIS spectrophotometer[6] (Chin et al., 1994).

RESULTS AND DISCUSSION

Material Characterization

Table 1 describes the chemical and physical properties of the sewage sludge compost used in our study. The material resembled a mixture of compost with an alkaline stabilized product, rather than a typical compost. Its highly inorganic character (73% ash) could be attributed to the coagulation agents ($CaCO_3$, $FeCl_3$) used at the treatment plant. The end product had an extremely high electrical conductivity, a factor that could negatively affect crop growth at high application rates. The presence of $CaCO_3$ also turned this product into a potentially effective liming agent.

The total nutrient content (N, P, K) of this compost falls within the expected range (He et al., 1995) (Table 2). It must be stated, however, that in general composts are considered primarily ameliorative agents for the physical properties of soils (e.g., aggregate stability, water retention, soil friability). Their role as fertilizers is highly variable and will depend not only on the total elemental composition but on the availability of those nutrients. Percentages of nitrogen and phosphorus availability in composts range from values as low as 3% to as high as 40% of their total, with median values of 10 to 20% (Epstein, 1997; Epstein et al., 1978; McCoy et al., 1986; O'Keefe et al., 1986). Thus, not all composts can be considered organic fertilizers. The total trace element

[6]Trade names in this publication are used only to provide specific information. Mention of a trade name does not constitute a warranty or endorsement of equipment or materials by the Agricultural Experiment Station.

TABLE 1.—*Chemical and physical properties of the Arecibo sewage sludge compost.*[1]

Item	Result
Carbon (%)[2]	19.70
Nitrogen (%)[2]	1.45
C/N	13.59
Sulfur (%)[2]	0.11
Calcium (%)	11.04
Potassium (%)	0.10
Magnesium (%)	0.30
Zinc (%)	0.11
Sodium (%)	0.08
Iron (%)	4.69
Phosphorus (%)	0.48
Copper (%)	0.048
Manganese (%)	0.047
Arsenic (mg/kg)	3.65
Selenium (mg/kg)	1.29
Chromium (mg/kg)	66.30
Cadmium (mg/kg)	5.20
Molybdenum (mg/kg)	5.20
Lead (mg/kg)	65.10
Nickel (mg/kg)	31.20
Boron (mg/kg)	46.30
pH[3]	7.63
Ash (%)[4]	75.60
Organic Matter (%)[5]	24.40
Moisture Content (%)	21.30
Electrical Conductivity (dS/m)[6]	14.38
Total Fineness Efficiency (TFE) (%)	68.05
Bulk Density (g/ml)	0.58
Particle Density (g/ml)	2.27

[1]Compost sample obtained in October 1996 at the Arecibo plant. Total elemental analyses are reported on a dry weight basis (% w/w).

[2]Measurements made on a LECO SC-32 Elemental Analyzer.

[3]Compost pH values measured on a 3:1 (0.01N $CaCl_2$: compost) suspension.

[4]Values obtained by combustion (16 h at 440°C) on a temperature regulated muffle furnace.

[5]Difference between ash content and total.

[6]Measured on a 3:1 (w/w) water (D.D.): compost suspension.

content of this compost falls well below the EPA limits; thus making it a suitable material for land application.

In all, this compost cannot be considered a high quality product. Its elevated inorganic content and associated high soluble salt content are

TABLE 2.—*Effect of compost on soil pH and exchange fraction composition (one month after treatment applications).*

	pH[1]	Σ cations cmol(+)/kg	% Sat. Ca	% Sat. Mg	% Sat. Al	% Sat. K
San Antón soil						
Control	7.47	26.89	84.55	12.47	0	2.97
37 t/ha	7.70	35.25	88.74	8.99	0	2.27
74 t/ha	7.79	37.46	89.66	8.07	0	2.26
148 t/ha	7.74	43.57	91.35	6.47	0	2.18
444 t/ha	7.79	44.44	93.83	4.07	0	2.09
$LSD_{0.05}$	0.134	3.90	1.47	1.00		0.55
Corozal soil						
Control	4.55	11.16	59.38	10.14	21.96	8.50
37 t/ha	6.45	21.17	89.98	4.57	0	5.45
74 t/ha	7.51	31.35	93.90	2.23	0	3.86
148 t/ha	7.52	32.98	94.62	1.93	0	3.43
444 t/ha	7.59	41.24	95.34	1.64	0	3.00
$LSD_{0.05}$	0.7118	1.65	1.38	1.30	2.28	0.59

[1]Average of four replicates.

major obstacles for its use in agriculture. The material also suffered from a lack of stability, implying that there were some operational problems at the plant during the time the material was produced (Santiago-Talavera, 1997).

Effect on soil properties

pH—The impact of organic sources on soil pH is highly variable, ranging from significant increases in some cases, to acidification in others (Rodella et al., 1995; Pocknee and Sumner, 1997). Pocknee and Sumner (1997) indicated that the overall impact of organic amendments on soil pH will largely depend on the amount of basic cations present in the organic substrate, as well as on their nitrogen content. The former would promote increases in pH whereas the latter may promote acidification of soils through nitrification.

In this study, compost applications had a marked impact on soil pH, particularly on the Corozal soil (Figure 1; Table 2). Significant increases in the pH of this soil were observed even at the lowest compost rate, all of which confirms our initial conjecture in terms of the acid neutralizing capacity of this material. This neutralizing is the result of the material (i.e., $CaCO_3$) employed as coagulation agent at the waste treatment plant. Contrary to being an asset, this is an indication of im-

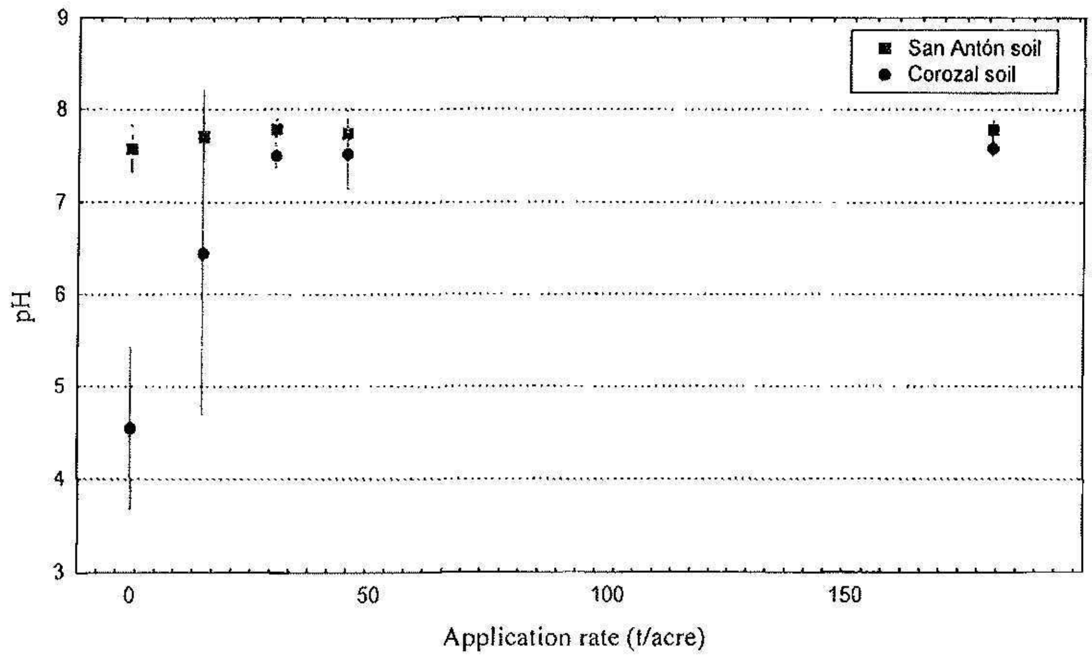


FIGURE 1. Effect of compost applications on soil pH (one month after treatment application).

proper compost quality standards, and of low quality sludge. The influence of this compost on soil pH comes primarily from its inorganic constituents, and little contribution from the organic portion would be expected. These results may not be representative of those that would be obtained with a high quality compost material.

Additions of compost caused a significant change in the composition and size of the exchange fraction of both soils (Table 2). A month after compost addition, the cation exchange capacity of the San Antón soil had increased significantly. Even when this soil is dominated by permanently charged clays (i.e., the number of exchange sites is not affected by changes in soil pH), the exchange sites contributed by the organic fraction of the compost would be expected to increase the cation exchange capacity of the solid phase. Under the slightly alkaline conditions prevailing in those treatments, most of the sites contributed by the organic source will be available for cation binding, thus making the overall contribution of the compost more significant. The composition of the exchange fraction was also altered by compost additions. Magnesium saturation decreased from 12% under the control treatment to 4% at the highest compost rate. Calcium saturation went up from 84 to 94%, whereas potassium was only slightly affected, decreasing from 3 to 2% at the highest compost rates despite an increase in terms of absolute amounts. These changes are a reflection of the chemical composition of the compost used in this study.

In the Corozal soil a similar effect was observed. As expected, the size of the exchange fraction was more drastically influenced in this soil than in the San Antón soil. Contributions of exchange sites in this soil come not only from the organic component but also from the pH dependent sites of its mineral components that are made available by the pH increases caused by compost additions. As in the San Antón soil, magnesium saturation decreased markedly (from 10.1% to 1.6%), and calcium saturation increased as a result of compost additions. Potassium in the Corozal soil also behaved similarly to that in the San Antón soil, decreasing in relative terms (% saturation) while increasing in absolute amount. The observed increase was comparable to the total amount of potassium added in the compost treatments.

Organic matter

A month after compost application, both soils experienced a significant increase in the amount of organic matter (Table 3). Except for the highest treatment, these results were as expected, considering the organic matter content of the material employed (≅ 25%). The values obtained at the highest compost load, especially in the San Antón soil, reflect a larger contribution than the amount that could be attributed

TABLE 3.—*Effect of compost applications on soil organic matter (SOM), and estimates of dissolved organic matter (DOM) content.*

	S.O.M. (%) one month after applications	S.O.M. (%) 11 months after applications	D.O.M. one month after applications[1]	D.O.M. five months after applications[1]
San Antón soil				
Control	1.17	1.49	0.077	0.197
37 t/ha	1.66	1.55	0.228	0.188
74 t/ha	1.85	2.06	0.120	0.308
148 t/ha	2.50	2.97	0.452	0.457
444 t/ha	7.54	8.06	1.069	1.244
$LSD_{0.05}$	2.99	2.09	0.37	0.134
Corozal soil				
Control	1.96	2.05	0.065	0.062
37 t/ha	2.34	2.37	0.372	0.170
74 t/ha	2.59	2.59	0.556	0.224
148 t/ha	3.03	2.59	0.667	0.297
444 t/ha	4.62	7.62	1.165	1.010
$LSD_{0.05}$	0.9953	0.8016	0.299	0.098

[1]Absorbance readings of aqueous extracts (280 nm).

to the chemical composition of the compost. This finding is probably the result of uneven incorporation of the material into the plow layer. Eleven months after compost application, levels of organic matter remained practically unaltered, thus suggesting that the benefits associated with this effect would persist throughout the growing season of an annual crop such as the one employed in this study. Estimates of dissolved organic carbon confirmed the beneficial effects of compost additions on the organic carbon pool of both soils. As with the solid phase estimates, the effects on dissolved organic carbon were still noticeable five months after compost application.

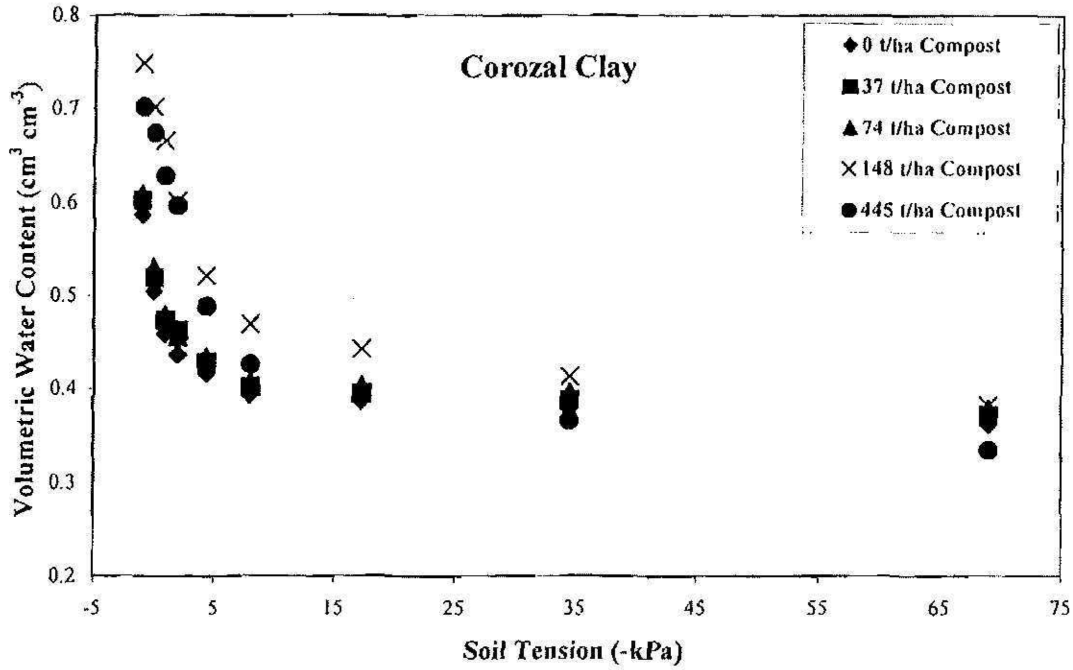
Increases in the organic matter content of the soils improved their water retention capacity, but only at the highest compost rate, 444 t/ha (Figure 2). Even though the amount needed for this effect could be reduced by almost 50% with high quality compost, a considerable application (i.e. ≅ 200 t/ha) would still be necessary in order to produce an immediate impact on the physical properties of soils. A more practical alternative for improving soil physical properties might be to aim at a long-term effect by relying on a series of sequential applications of smaller amounts. This alternative would significantly reduce the economic and logistic inconveniences associated with a massive application.

Plant nutrients

Additions of compost had practically no effect on the levels of KCl-extractable NH_4 and NO_3 of the soils. Nutrient contribution from a compost material will depend not only on its total content but also on its availability. Most composts report nitrogen mineralization rates that vary from 3 to 30% (N'Dayegamine et al., 1997; Epstein, 1997; Epstein et al., 1978). Therefore, even a material exhibiting a seemingly adequate nitrogen content may not be capable of entirely sustaining a crop's demand for this nutrient.

An effect opposite to that of nitrogen was observed with phosphorus (Figure 3). In this study, to avoid the uncertainties of correlating results obtained with different methods, all estimates of plant available phosphorus were obtained with the Olsen method, regardless of soil pH. The Olsen method has proven to be adequate when analyzing samples that cover a wide pH range (Menon et al., 1988; Muñoz et al., 1992).

Estimates of plant available phosphorus indicate that a significant portion, approximately 25% in the first two compost treatments, was readily available a month after compost addition in both soils. The higher compost loads exhibited a lower availability rate, thus suggesting that other mechanisms could be controlling phosphorus solubility at those levels. This was more evident in the highly weathered soil



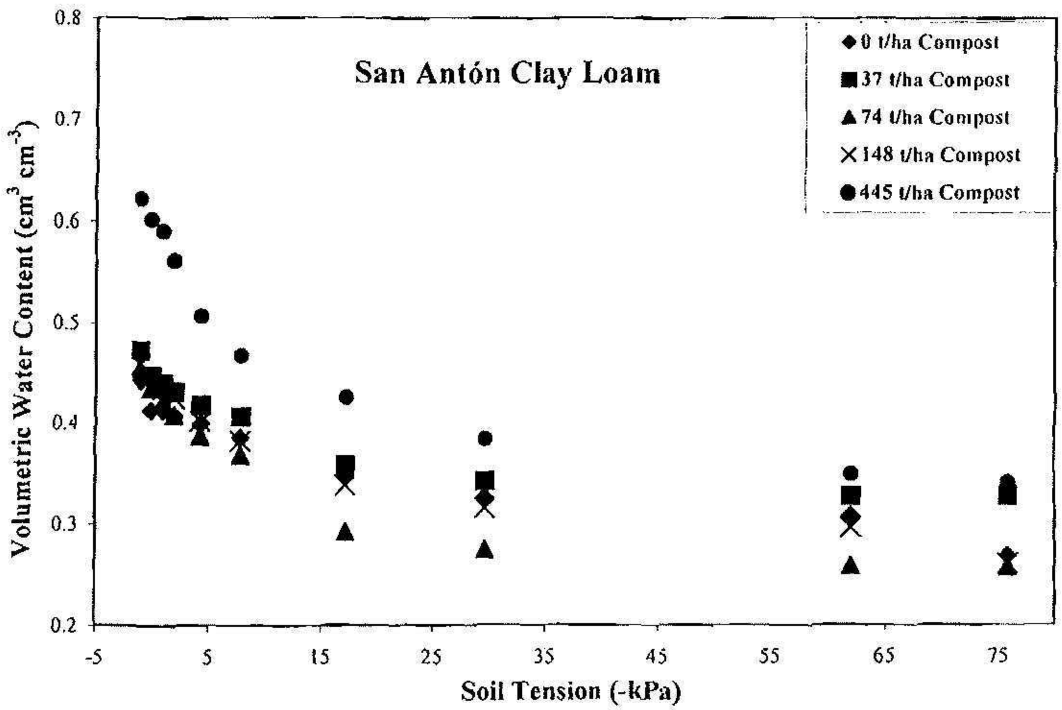


FIGURE 2. Water retention curves of compost amended soils.

(Corozal clay), a finding which is consistent with the phenomenon of phosphorus sequestration by mineral oxides. Eleven months after compost addition, the effects were still noticeable although a significant decline had occurred between the one- and five-month samples (Table 4).

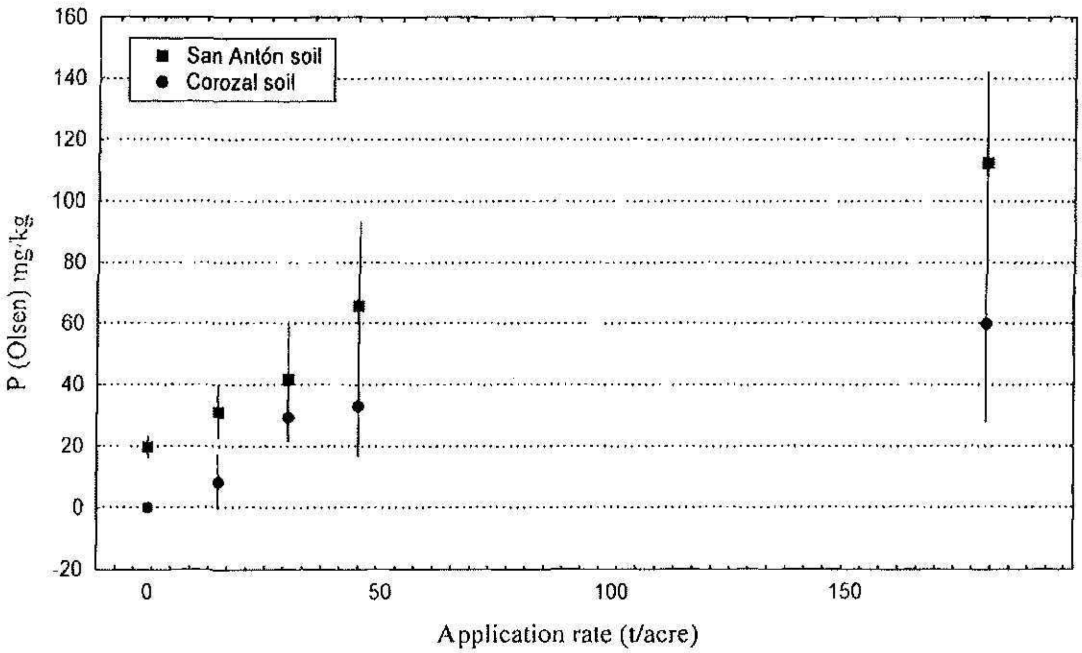


FIGURE 3. Effect of compost on soil phosphorus (Olsen) (one month after treatment application).

Whereas this decrease could be due to factors such as plant use, or formation of a more stable controlling phase, the possibility of extensive phosphorus losses through soil runoff raises concern for the potential contamination of water sources (Daniel et al., 1998; Correll, 1998). Agricultural runoff is considered the primary source of surface water contamination in the U.S. Consequently, agricultural practices have been the main target of regulatory agencies in their effort to minimize contaminant loading in those systems. Even what at first glance would appear as an environmentally friendly practice, such as compost application, could have devastating effects if inadequately implemented.

Electrical conductivity

Compost additions caused a significant increase in the electrical conductivity (EC) of both soils (Figure 4). Because of the differences in the bulk density of the samples, a fixed sample:water ratio (1:3 w/w) was used to obtain water extracts for EC measurements, instead of the traditional paste saturated extracts. Therefore, the measured EC values should be lower than those obtained from a water saturated solid paste, and a correction factor would be needed to correlate these values to the saturated paste extract values used for agronomic purposes. A rough estimate could be obtained by normalizing the measurements to unit volume, although that could underestimate the results at the highest compost rates.

TABLE 4.—*Effect of compost application on estimates of plant available phosphorus (P), Olsen, and on soil electrical conductivity (SEC).*

	P (mg/kg) one month after applications	P (mg/kg) 11 months after applications	SEC (dS/m) one month after applications[1]	SEC (dS/m) 11 months after applications[1]
San Antón soil				
Control	19.69	13.25	0.400	0.239
37 t/ha	31.27	14.10	0.575	0.242
74 t/ha	41.65	19.25	0.675	0.299
148 t/ha	65.88	31.34	1.04	0.439
444 t/ha	112.37	60.15	1.32	1.085
$LSD_{0.05}$	15.07	19.10	0.435	0.3985
Corozal soil				
Control	0	3.15	0.325	0.246
37 t/ha	8.39	9.79	0.550	0.341
74 t/ha	29.57	12.12	0.625	0.375
148 t/ha	25.73	15.61	0.675	0.408
444 t/ha	60.20	48.25	1.350	0.503
$LSD_{0.05}$	17.63	8.39	0.2128	0.1591

[1]Analyses performed on 1:3, solid:solution extracts.

Although increases in the electrical conductivity of soils are a common effect of compost applications, the values observed in this study at the highest treatments closely approach the limits considered detrimental for crop growth (once correlated to saturated paste values). Excessive soluble salt contents remained even a year after compost application, especially on the San Antón soil. The difference between the two soils could be a reflection of the irrigation systems used at the two sites (drip irrigation in the San Antón soil, natural irrigation for the Corozal soil), as well as differences in the rainfall patterns at the two sites. Nevertheless, in the Corozal soil the highest compost treatments still exhibited significant differences in their dissolved salt content a year after application, thus implying that periodic leaching by means of rainfall was not sufficient to completely rectify the problem (Table 4). It is imperative that the salinity of this product be reduced if the material is to be used for agricultural applications. For instance, a material such as this could not be recommended for use as a growing media in pots for ornamental purposes.

Trace elements

The trace element content of this material falls well below EPA requirements; therefore, it is suitable for land application. Materials such as these are often referred to as "clean sludge derived products,"

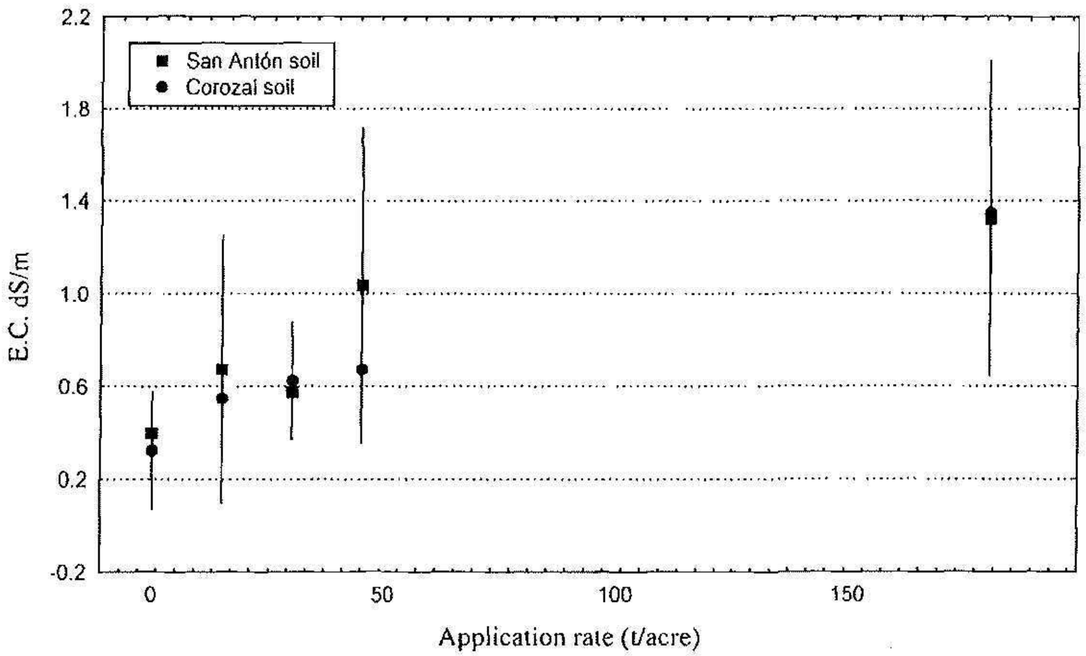
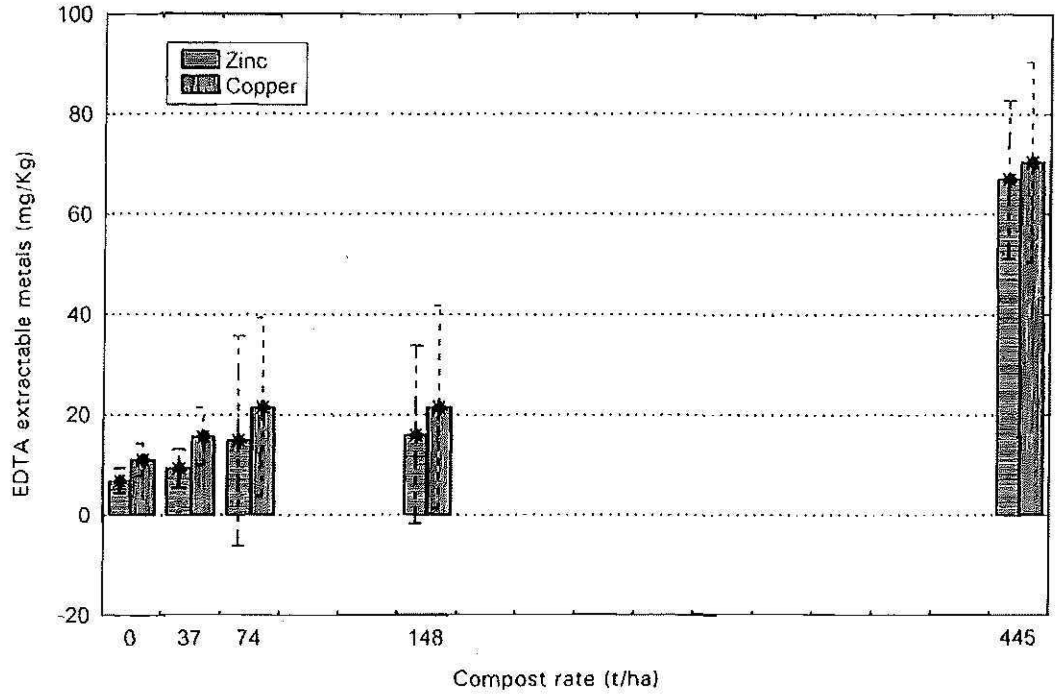


FIGURE 4. Influence of compost on soil electrical conductivity (E. C.) (one month after treatment application).

meaning that in terms of trace elements there is little risk for contamination. In fact, on the basis of its total trace element content, this material should behave more as a fertilizer than as a pollutant if properly used. However, even with this kind of material it is important to monitor the fate of trace elements in the environment. That is particularly relevant in soils and crops such as we have in Puerto Rico, about which very little is known in terms of contaminant behavior.

For years, scientists have attempted to establish estimates of plant nutrient availability as a means of assessing risks associated with application of biosolids to agricultural lands. In most cases a particular chemical compound (or a series of compounds of different reactive power) is made to react with the solid matrix in an attempt to extract that fraction of a particular element that is available for plant uptake. Even though the limitations of said approach are widely recognized, it is still a useful tool to evaluate the impact of different management practices. In this study, the EDTA soil extractable fraction is used to represent the plant available fraction. Compost additions resulted in significant increases of most EDTA extractable metals in both soils (Figures 5a and 5b). In the case of zinc, between 40 and 60% of the total added in both soils was available for extraction regardless of the compost load (Table 5). A year after treatment application, the levels of zinc decreased in the mid-level treatments, reflecting the effects of nutrient losses through leaching, runoff and/or plant uptake. Between 70 to 80%

a)



b)

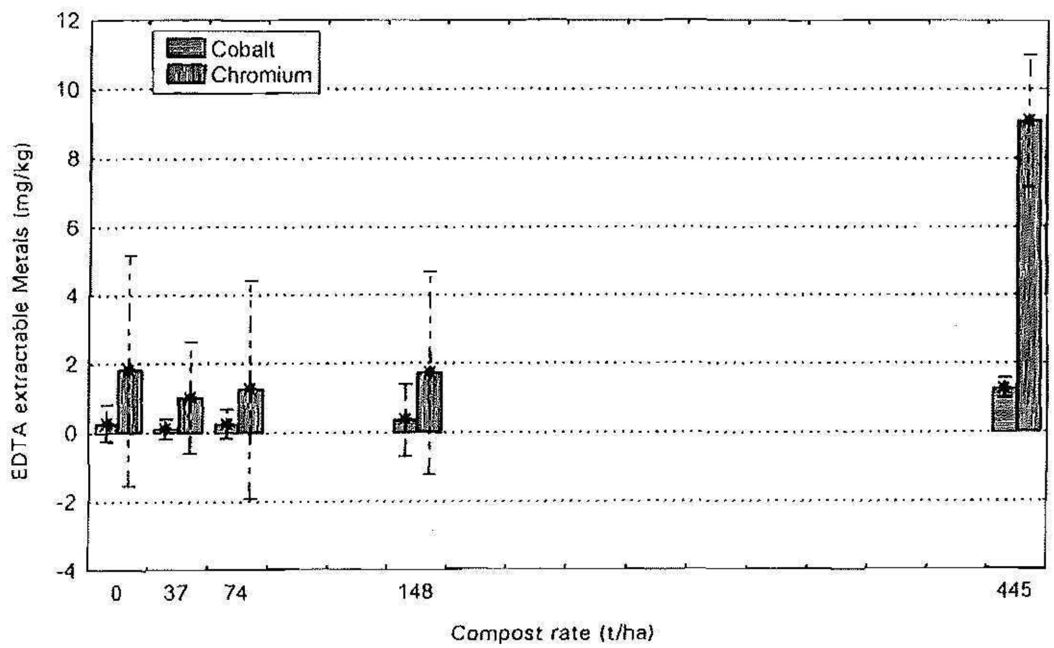


FIGURE 5. Levels of EDTA extractable metals in an Ultisol (Corozal clay) 11 months after compost application: a) copper and zinc, b) cobalt and chromium.

TABLE 5.—*Effect of compost on EDTA extractable zinc, copper, and iron.*

	Zn (mg/kg)[1]	Zn (mg/kg)[2]	Cu (mg/kg)[1]	Cu (mg/kg)[2]	Fe (mg/kg)[1]	Fe (mg/kg)[2]
San Antón soil						
Control	4.00	4.77	13.32	23.50	179.50	159.25
37 t/ha	13.50	5.93	19.10	25.25	246.50	174.00
74 t/ha	25.53	16.50	23.85	32.25	404.37	284.25
148 t/ha	46.60	32.25	30.68	42.75	409.73	426.75
444 t/ha	75.00	77.25	48.30	78.50	240.00	818.00
$LSD_{0.05}$	19.36	19.78	7.500	16.87	68.50	184.98
Corozal soil						
Control	4.00	6.75	4.95	11.00	2,035	2,368
37 t/ha	10.00	9.25	11.25	15.75	1,579	1,676
74 t/ha	26.50	14.75	20.38	21.50	2,396	1,884
148 t/ha	29.00	16.00	21.25	21.50	1,979	1,926
444 t/ha	60.50	67.00	33.88	70.50	1,808	2,072
$LSD_{0.05}$	11.56	11.91	7.51	12.85	NS	NS

[1]Samples obtained one month after compost applications.
[2]Samples obtained 11 months after applications.

of the copper added through compost was available for plant use, except at the highest treatment, where that percentage was reduced to ≅ 50% (Table 5). This trend continued throughout the first year for most treatments. However, a significant increase in copper availability was observed at the highest rate a year after treatment application. Close to 80% of the copper added became available, thus denoting a significant change in the mechanism that controlled the solubility of this metal in soil. This apparent increase in metal availability close to a year after biosolid applications has been observed by others, and has been attributed to the decomposition of metal organic complexes (Sloan et al., 1997). Copper is known to occur principally in metal-organic complexes, and thus it is expected to be influence by the transformations in the soil organic pool. Although we cannot rule out this possibility in our study, the nature of the material employed requires that aspects such as mineral phase transformations also be considered.

The amount of EDTA extractable cobalt, chromium, and cadmium also increased as a result of compost additions. However, the levels of these elements in the compost were so low that the effects became relevant only at the highest treatment (data not shown).

A completely different behavior was observed in the case of iron. Despite being one of the metals added in greatest amounts after calcium, only a small portion (≅ 5 to 20%) became available in the San Antón soil during the first six months (Table 5). With the highest compost treatment, iron values remained similar to those of the control until harvest, when a significant increase was noted, thus denoting behavior similar to that observed with copper. In the case of the Corozal soil, additions of compost did not increase the levels of extractable iron. These results suggest the possible formation of a solid phase at the highest metal loadings that could limit the solubility of this element. The results attest to the importance of studies on metal fate and bioavailability in our soils and the need to consider these aspects when establishing limits for nutrient and pollutant loadings in natural ecosystems.

CONCLUSIONS

Compost production in Puerto Rico is expected to increase dramatically over the next few years. Agricultural applications will play a determinant role on the fate of this endeavor. Results from this study indicate that the quality of the material locally produced must be improved in order for it to become a valuable product from an agricultural standpoint. Production efforts should concentrate not only on generating a product that meets EPA standards for pathogens and vectors. It is imperative that special attention be given to factors such as organic matter and soluble salt content, as well as nutrient content and availability of the material.

The compost used in this study was uncharacteristically inorganic in character. Consequently, its effects on soil properties may not be representative of those to be obtained with a quality compost. The high soluble salt content of this compost makes it unfit for most agricultural applications; thus, potential users should be extremely cautious. Despite this negative aspect some positive effects were observed. The organic matter content of the soils increased from compost additions. As a result, the water retention capacity of both soils improved. From a nutritional standpoint the material proved to be an adequate source of phosphorus, but not of nitrogen. Trace element content in the compost was well below EPA requirements; therefore, the introduction of contaminants (i.e., Cd, Pb, As, Se) into the human food chain did not represent a reason for concern under the circumstances here evaluated.

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