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Combined organic amendment effects on eggplant yield, soil fertility characteristics and humic acid quality[1,2]

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ABSTRACT

Soil fertility and organic matter have been hindered due to unsustainable agricultural practices. There is a need to develop and better understand the effect of combined organic amendments that have the potential to increase soil fertility and agricultural system sustainability. Compost incorporations, the use of coordinated fallows and other biological amendments are alternatives to better the soil and increase crop yield. Information is scarce about the effect of combined organic amendments over soil chemical properties and their impact on vegetable production. The objective of the present study was to assess the effect of a combination of organic amendments we termed soil treatment management cycles (STMC) on soil chemical properties and eggplant yield in a San Antón soil. The STMC amendments consisted of incorporating organic matter from coffee pulp compost, planting and incorporation of a mixture of four green manure species, adding a mycorrhizae culture to the soil as well as compost tea. The different STMC were: control, no STMC (CL0); one STMC (CL1); two consecutive STMC (CL2); and three consecutive STMC (CL3). Results

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showed that CL1 was enough to significantly increase organic matter, P, K and S content in the soil compared with the non-amended soil. The concentration of Ca was significantly increased by three (CL3), and that of Mg by three (CL3) and two (CL2) STMC, compared to the other treatments. All treatments significantly changed soil pH, buffering it toward neutrality with increasing cycles when compared with pH 7.9 of no STMC control soils. Treatments CL1, CL2 and CL3 increased humic acid content 2.8, 3.8 and 5.9 times, respectively, when compared with CL0. Humic acids, extracted from unamended soils exhibited more condensation and more aromaticity when compared with those of amended soils. Nevertheless, the humic acids of amended soils showed high levels of polymerization. The enhancement in soil properties promoted by STMC resulted in an increase in eggplant fruit yield and biomass production.

Key words: organic matter, mycorrhizae culture, green manure, compost tea, coffee pulp, vegetable production

RESUMEN

Efectos de las enmiendas orgánicas combinadas sobre el rendimiento de berenjena, las características de fertilidad del suelo y la calidad de los ácidos húmicos

La fertilidad de suelos agrícolas así como los niveles de materia orgánica se han visto afectados por prácticas agrícolas no sustentables. Hay una necesidad de desarrollar y entender los efectos de las enmiendas orgánicas y sus combinaciones y el potencial que tienen en aumentar la fertilidad de los suelos y de los sistemas agrícolas sustentables. El uso de composta, coordinación de barbechos y el uso de otras enmiendas biológicas son alternativas para mejorar el suelo y aumentar la producción del cultivo. Poca información está disponible de los efectos de prácticas combinadas de enmiendas orgánicas y sus efectos en las propiedades químicas y su impacto en la producción de hortalizas. El objetivo de este estudio fue enmendar un suelo de la serie San Antón con una combinación de enmiendas orgánicas y observar su impacto en las propiedades químicas del suelo, así como en la producción de berenjenas. Al conjunto de estas prácticas le dimos el nombre de manejo de ciclos de tratamiento de suelo (en inglés, soil treatment management cycles o STMC). Los STMC consistieron en añadir al suelo materia orgánica de composta de pulpa de café, sembrar e incorporar una mezcla de cuatro leguminosas de abono verde, uso de micorriza, así como té de composta. Los tratamientos fueron: el control, no STMC; un STMC (CL1); dos STMC consecutivos (CL2); y tres STMC consecutivos (CL3). Un solo CL1 fue suficiente para aumentar el contenido de materia orgánica, P, K y S en el suelo cuando se compara con el CL0. La concentración de Ca aumentó con CL3 y la de Mg con CL2 y CL3, comparados con los otros tratamientos. Todos los tratamientos cambiaron el pH, reduciéndolo hacia la neutralidad con aumento en STMC cuando se compara con el pH de 7.9 de suelos control. Los tratamientos CL1, CL2 y CL3 aumentaron el contenido de ácidos húmicos en 2.8, 3.8 y 5.9 veces lo encontrado en suelos sin enmendar CL0. Los ácidos húmicos extraídos de suelos sin enmendar exhibieron mayor condensación y aromaticidad cuando se comparan con suelos enmendados, sin embargo, los ácidos húmicos de suelos enmendados demostraron niveles más altos de polimerización. Las mejoras en las propiedades del suelo promovidas por STMC resultaron en un aumento en producción de berenjenas así como en producción de biomasa.

Palabras clave: micorriza, abono verde, té de composta, pulpa de café, producción de hortalizas

INTRODUCTION

Soil organic matter status has been identified as the most important indicator of soil quality because of its impacts on physical, chemical and biological soil properties (Reeves, 1997; Carter et al., 1999; Lal, 2004). The effects of organic amendments on soil properties are determined by their application rate and amendment quality. The humic fraction of soil organic matter plays a major role in the long-term fertility of soils influencing the slow release of nutrients, pH buffering activity, cation exchange capacity, metal ions and organic molecules interactions and other soil physical properties (Stevenson, 1994, Senesi et al., 1996). The increase in soil humic acid (HA) content is considered to enhance the long-term fertility of the agroecosystem because of the durability of this fraction (Senesi et al., 1996).

Composting has been pointed out as an effective method to process organic materials to produce stable organic matter (Rivero et al., 2004; Bernal et al., 1998). The enhancement of native soil HA properties through the addition of composted organic residues has been demonstrated to be of considerable potential in the reclamation of degraded soils (García-Gil et al., 2004). The effect of the organic amendment on soil HA is determined by the nature of the organic amendment and its degree of maturation (Senesi et al., 1996).

There is a growing list of practices being adopted in sustainable agriculture systems that include compost additions, enhanced fallows, compost tea and other organic and biological amendments that intend to improve soil fertility status and sustainability. Agricultural sustainability aims to enhance soil fertility in the long term by the efficient use of local resources, increasing agroecosystem resilience and stability and reducing dependence on external inputs (Schiere et al., 2002). The use of compost has been reported to have a positive effect on soil organic matter status (Aggelides and Londra, 2000; Ferreras et al., 2006), availability of N, P, K, Ca, Mg (Chukwuka and Omotayo, 2008; Bustamante et al., 2011; Babalola et al., 2012) and soil pH (Clark et al., 1998). The quality of the composted organic residues and the composting method predominantly determine final compost quality and its effect on soil properties. Compost has shown to improve crop productivity and farmers' income in undeveloped countries where soil degradation has led to food shortage (Ouédraogo et al., 2001). The implementation of leguminous fallows has been proposed to increase soil organic matter and available N in agricultural soils. Leguminous cover crops have been shown to enhance soil organic matter quality by increasing its nitrogen content when compared with non-coordinated fallows (Koutika et al., 2001; Nezomba et al., 2012). *Crotalaria* spp., *Mucuna* spp., *Canavalia* spp. and *Vigna* spp. are tropical legumes that have been proposed as options for improving fallows in Puerto Rico because of their high biomass production, nitrogen fixation and adaptability (Carlo, 2009). Legume fallows have been demonstrated to enhance N supply and increase yields of subsequent crops (Fischler et al., 1999; Wortmann et al., 2000) by enhancing soil chemical, physical (Fischler et al., 1999) and biological properties (Tejada et al., 2008). Amendments based on a liquid extraction of compost have been tested on different crops. The main difference between them is the quality of the compost from where it originates, the preparation time and the oxygenation of the mixture. Compost tea additions have been reported to reduce disease severity and promote plant development (Sidiqqui et al., 2008; Sidiqqui et al., 2009; Pane et al., 2012; Pant et al., 2012). Further different mechanisms of action of compost tea include the enhancement of nutrient efficiency serving as a nutrient and HA source, by suppression of plant pathogens, by the promotion of beneficial biota and by inducing plant inherent resistance (Siddiqui et al., 2008; Siddiqui et al., 2009). Soil microbial communities have multiple functions directly related to soil fertility including the cycling and availability of soil nutrients (Oberson et al., 2006; Zhao et al., 2009), pathogen suppression, and pest control (Drinkwater et al., 1995; Altieri and Nicholls, 2003). Specifically, mycorrhizae are a primary soil biological functional group associated with the improvement of soil physical properties, nutrient uptake and biological quality adding considerable sustainability elements to crop production (Cardoso and Kuyper, 2006). It is necessary to understand the impact of the combination of different sustainable practices on soil properties and crop production since most of the studies have concentrated on the effect of individual practices. However, agricultural sustainability will require the use of many soil building tools.

This study had what we termed soil treatment management cycles (STMC) consisting of coffee pulp compost tilled into the soil, seeded cover crop legumes, and mycorrhizae, which was also added to the soil as well as compost tea once the grown legumes were used as green manure. These organic amendments are of common use under ecological production systems in Puerto Rico. The objective of this study was to evaluate the effects of the combined organic amendments on soil chemical fertility parameters and eggplant yield. The study did not intend to measure the individual effects of each practice, but to mimic the overall effect on the soil of a sustainable agricultural system. The changes in soil HA quality were measured as an index of long-term soil fertility. Measurable effects of the adoption of a sustainable approach to agricultural production could become visible in the long term (Funes-Monzote et al., 2009). The consecutive application of the STMC was done to mimic in a short time frame what could be achieved regarding soil properties with long-term management of the proposed organic amendments and to study its combined effect as an emerging sustainable agricultural system.

MATERIALS AND METHODS

Experimental design and treatment establishment

The experiment was conducted at the University of Puerto Rico Agricultural Experiment Station in Juana Díaz, Puerto Rico (18°01’45.65” N, 66°31’34.17” W). The soil at this location is a San Antón soil series (Fine-loamy, mixed, superactive, isohyperthermic Cumulic Haplustolls). The experimental plot had a fallow history of more than three years. The field experiment consisted of four treatments arranged in a complete randomized block design with four replications per treatment, for a total of 16 experimental units. Each experimental unit was a 2.4 x 3.0 m plot. The plots were drip irrigated twice a week with deep well water. Weeds around the plots were mechanically controlled with a tractor mower.

Each STMC lasted 60 days and included the following three practices: 1) incorporation of 5% OM from coffee pulp compost; 2) planting, growth and incorporation of a cover crop mixture of four legume species *Crotalaria juncea* (Sunn hemp), *Canavalia ensiformis* (jack bean), *Vigna unguiculata* (cowpea) and *Mucuna pruriens* (velvet bean); and 3) the addition of mycorrhizae (MycoApply® Soluble Endo)[7] and compost tea. The control CL0 did not receive any STMC. Each STMC was either not performed (CL0), or performed one time (CL1), or twice consecutively (CL2) or three times consecutively (CL3). The STMC were scheduled starting with CL3, followed by another cycle with CL2 and CL3 at the same time, and final STMC cycles with CL1, CL2 and CL3 at the same time. The CL0 treatment never received any STMC, but the soil was tilled when the other treatments were tilled. After all

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

treatments were established eggplants were grown and yield quantified in each of the experimental plots.

The purpose of the treatments was to mimic the overall effect on the soil of a sustainable agricultural system, not to measure the individual effects of each practice. The coffee pulp compost was made with a passively aerated static pile method (Rynk, 1992). The chemical properties of the coffee pulp compost are shown in Table 1. At the beginning of each STMC, exempting the control, an equivalent of 5% of OM as coffee pulp compost was till-incorporated into the top 15 cm of soil of each plot. Right after till-incorporating the compost, four legume seeds were broadcast over the experimental plots at rates of 42, 14, 13 and 13 kg/ha for *Canavalia ensiformis*, *Crotalaria juncea*, *Mucuna pruriens* and *Vigna unguiculata,* respectively. Three weeks after the legumes were planted, each plot was inoculated with a 2,400 ml/L aqueous suspension of commercially available mycorrhizae (MycoApply® Soluble Endo), which contained four endomycorrhizal species (21,450 propagules per kilogram each). At the end of each STMC, at 60-day intervals, the different legume species were cut at the soil line, chopped, weighed and till-incorporated into the top 15-cm soil depth. On the same date, control plots (receiving none of the above management practices) were tilled as well. Once the different legumes were incorporated into the soil, 7.5 L of compost tea was applied to each

TABLE 1.—*Chemical properties of coffee pulp compost and well water used.*

Coffee pulp compost	
Organic matter (%)	60
pH	7.13
Total organic N (% N)	1.61
Available nutrients	
NH_4-N (mg/kg)	77
NO_3 (mg/kg)	14,699
P (mg/kg)	309
K (mg/kg)	4,781
Ca (mg/kg)	4,020
Mg (mg/kg)	562
Na (mg/kg)	ND
Well Water	
pH	7.2
*NO_3 (ml/L)	44
**K (ml/L)	3
**Ca (ml/L)	148
**Mg (ml/L)	13

*Well water nitrate was analyzed by colorimetry after reducing all the NO_3 to NO_2.

**K, Ca and Mg were determined with an inductively couple plasma (ICP) following EPA-200.7 method (USEPA, 1996).

plot with a watering can. The compost tea was prepared by mixing 11.5 kg of mature wood chip compost obtained from a local distributor and 120 mL of unsulfured molasses in 80 L of water, which was aerated continuously with an aquarium pump for 24 h. Each new STMC was started seven days after the latest compost tea addition. The STMC corresponding to the CL3, CL2 and CL1 treatments were established at 60-day intervals, so that all treatments were concluded at the same time (Table 2).

Soil sampling and analysis

Soil samples were collected after all treatments were completed. Composite soil samples consisting of four subsamples were collected at each experimental unit from the 0- to 15-cm layer avoiding the edge of the plot. Soil samples were air-dried, passed through a 6-mm sieve and stored until analysis. Samples for inorganic N were stored at -20° C until analyzed.

Organic matter and humic acids

Organic matter was determined by the Walkley and Black method described in Nelson and Sommers (1982). A factor of 1.725 was used for conversion of percent organic carbon to percent organic matter. For extraction and purification of HA, the soil was first treated with 0.1 M HCL to separate the fulvic acid. Then the soil was further extracted with 0.1 M NaOH to obtain the HA. Humic acids were precipitated with HCl 6 N solution until a pH of 1 was reached. The precipitated HA were separated by centrifugation and redissolved in a 0.1 N KOH solution. Dissolved HA were again reprecipitated with 6 N HCl, centrifuged and redissolved with a solution of 0.1N HCl + 0.3 N Hydrofluoric acid to remove silicates. The HA were purified with a cation exchange

Table 2.—*Representation of treatment application every 60 days starting with CL3, then CL2 and CL3 at 120 days from eggplant planting, followed by CL1, CL2 and CL3 60 days before eggplant plantings.*

	Treatments[1]			
Days to plant	CL0	CL1	CL2	CL3
180				STMC
120			STMC	STMC
60		STMC	STMC	STMC
0	Soil sampled and eggplants planted			

[1]STMC is soil treatment management cycles. CL0 represents the control where no STMC were applied, CL1 the application of one STMC, CL2 the application of two STMC and CL3 the application of three STMC before eggplant planting.

resin (Dowex 50WX8-100). The HA was finally lyophilized. For quantification, lyophilized HA were weighed in an analytical balance.

Characterization of humic acids

E_4/E_6 *ratio* - The ratio between the absorbance at 465 and 665 nm were determined by dissolving 2 mg of HA in 25 mL of 0.025 M $NaHCO_3$ (Lguirati et al., 2005). The absorbance at 465 and 665 was obtained with a Beckman DU 520 UV/Vis spectrophotometer. This ratio is used as a parameter to estimate the degree of HA humification; these values provide a measurement of aromaticity and recalcitrance.

Fourier Transformed Infrared - Humic acids infrared analysis was done on a KBr pellet using an Infrared Transformed Infrared Spectrophotometer (FTIR) Perkin Elmer Paragon 1000 from 4000 to 400/cm (Lguirati et al., 2005). The pellet was prepared from 100 mg KBr and 1.5 mg HA.

Elemental Analysis - For elemental analysis, one composite sample of humic acids was used per treatment. Carbon, Hydrogen and Nitrogen elemental analysis was performed on 0.4 to 1 mg using a 2400 Perkin-Elmer CHN Analyzer. Oxygen was determined by pyrolysis with an oxygen accessory kit fitted to the Perkin-Elmer 2400 Elemental Analyzer that converts oxygen to carbon monoxide. Carbon monoxide was measured as a function of thermal conductivity.

Soil pH was determined by using a glass electrode immersed in the supernatant of 1:2 soil:water mixture after a 2-h shaking period. Phosphorous was determined using the Olsen extraction method (Olsen et al., 1954). Exchangeable bases were determined by atomic absorption spectrometry after a soil extraction with NH_4OAc solution with pH 7.0 (Bower et al., 1952). Nitrate and ammonium were determined by colorimetry with a QuickChem 8500 auto-analyzer after an extraction with 2 *N* KCL.

Eggplant plantings

After all STMC had been performed, eggplant seedlings of the traditional Rosita cultivar were transplanted to each plot to evaluate yield and biomass production. A total of four rows of eggplant were planted on each plot leaving 80 cm between rows and 60 cm between plants. The plots were drip irrigated twice a week with deep well water. Well water analysis is shown in Table 1. Weeds were hand removed within plots. Pests, principally white flies, were controlled by weekly applications of a sesame seed oil-based commercial insecticide. Eggplants were harvested weekly for seven weeks beginning 10 weeks after transplanted. Data were collected from the two central plant rows (10 plants). Eggplants were harvested and weighed when the fruit color became opaque. After the last fruit picking, all the plants from the two central rows were cut at ground level and dried at 70° C to determine dry weight.

Statistical analysis

Analysis of variance (ANOVA) and Fisher's least significant difference (LSD) at a significance level of 0.05 throughout the study were used for comparison of means using Infostat Statistical Software (Di-Rienzo et al., 2011). Correlation analysis was performed using Pearson Coefficient Analysis on Infostat.

RESULTS AND DISCUSSION

Effect on chemical parameters

N and Organic Matter

Soil nitrogen results include the N of green manures as soil samples were collected right after green manures were plowed. The soil treatment management cycles resulted in higher concentrations of organic matter (OM) and inorganic N species (Table 3). Soil organic matter is considered a major parameter of soil health and is directly related to physical and biological properties (Pérez-Piqueres et al., 2006) and is responsible for the release of plant-available nutrients. The measured soil organic matter (SOM) was 1.01% in CL0, 2.50% in CL1, 4.11% in CL2 and 4.97% in CL3 (Table 3). The amount of compost applied every STMC was equivalent to 5% of OM in the top 15 cm layer of soil. This amounted to approximately 5, 10 and 15% of soil organic matter added initially as compost to the CL1, CL2 and CL3 treatments, respectively. Additionally, the biomass production of the intercropped green manures incorporated at each STMC ranged from 5,560 to 6,402 kg/ha. Comparing these expected values with the final OM values in Table 3 indicates that between 50 and 67 percent of the added OM mineralized during the experimental period. This finding is consistent with other results (Rivero et al., 2004; Bernal et al., 1998), which show that even though composting produces a high proportion of fairly stable OM, a considerable portion of this OM becomes labile during the first two months after incorporation into the soil. In the present study, the HA fraction of SOM in amended soils ranged from 23.6 to 30.1%. This represents a considerable portion of SOM contributing to its stabilization because of the strong resistance to decomposition of HA attributed to their complex chemical structure (Stevenson, 1994).

Treatment CL0 and CL1 had similar inorganic nitrogen species, NO_3-N and NH_4-N, and CL3 had the highest value at the end of the treat-

TABLE 3.—*Available soil nutrients, pH, organic matter and humic acid content as affected by the implementation of soil treatment management cycles (CL0, CL1, CL2, CL3) of combined practices.*

	pH	Bulk density (g/cm^3)	OM (%)	Humic Acids (g/kg)	N-NO$_3$ (mg/kg)	NH$_4$-N (mg/kg)	P (mg/kg)	SO$_4$ (mg/kg)	K (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)	Na (cmol/kg)
CL0	7.9 a[1]	1.59 a	1.0 d	2.5 d	19.9 c	6.6 c	23.8 d	6.0 c	0.73 d	21.21 bc	3.67 c	0.60 b
CL1	7.6 b	1.34 b	2.5 c	7.1 c	28.07 c	10.1 bc	38.0 c	29.3 b	1.95 c	20.68 c	4.60 b	0.69 a
CL2	7.2 c	1.22 c	4.1 b	9.7 b	88.18 b	15.0 ab	45.3 b	45.3 a	3.04 b	22.17 b	4.84 a	0.73 a
CL3	7.0 d	1.08 d	5.0 a	15.0 a	138.6 a	17.5 a	54.5 a	50.0 a	3.74 a	23.76 a	5.18 a	0.73 a

[1] Means within a column followed by the same letter are not significantly different at $p \leq 0.05$ using Fisher's least significant difference (LSD)

ments (Table 3). The reported increase in inorganic soil nitrogen could be explained by the high nitrate content of the compost (Table 1). In addition to on-farm composting, fresh residues rich in N were incorporated at each STMC and contributed to the increase in SOM and the release of inorganic N. The total increase of inorganic nitrogen (NO_3-N and NH_4-N) was 13.5, 125.6 and 189.7 kg N/ha for CL1, CL2 and CL3, respectively, when compared to CL0. The high nitrate content of CL3 (Table 3) could have an adverse environmental impact by ground water pollution. Other studies in Puerto Rico have also seen OM as a source of nutrient contaminants (Martínez-Rodríguez et al., 2010). The total biomass production of the green manures at each STMC ranged from 5,560 to 6,402 kg/ha.

Characterization of humic acids

Treatments CL1, CL2 and CL3 increased the HA content 2.8, 3.8 and 5.9 times, respectively, when compared to CL0 (Table 3). This effect could be attributed to the compost, which based on its maturity and amount incorporated at each STMC had the strongest effect in HA quality and quantity. The STMC produced an increase in H, N, O and O/C ratio in the HA of amended soils. Soil HA showed lower C, C/H and C/N ratios with increasing STMC (Table 4) and this has been attributed to the incorporation of proteinaceous matter and lower levels of humification when compared with native soil HA (Lguirati et al., 2005). There is a trend between increasing E_4/E_6 ratio and increasing cycles of compost and legume incorporation. Since E_4/E_6 ratio is related to HA molecular weight and degree of humification (Lguirati et al., 2005), increasing E_4/E_6 ratio with increasing cycles (Table 4) suggests lower levels of humification and condensation in compost HA compared to that of native soil HA. Despite this, according to C/H ratio (Table 4), HA of amended soil show considerable levels of humification; C/H ratios above 0.90 have been associated with high levels of condensation, polymerization and aromaticity (García et al., 1989; García-Gill et al., 2004; Lguirati et al., 2005). According to Kakezawa et al. (1992), the

TABLE 4.—*Elemental composition, atomic ratios and E_4/E_6 ratio of soil humic acids after addition of soil treatment management cycles (CL0, CL1, CL2, CL3) of combined practices.*

	C (%)	H (%)	N (%)	O (%)	C/H	O/C	C/N	E4/E6
CL0	53.20	3.42	3.38	34.69	1.31	0.49	18.37	4.47
CL1	50.93	4.41	4.57	34.26	0.97	0.50	13.00	4.98
CL2	50.05	4.69	4.9	35.15	0.90	0.53	11.92	5.42
CL3	49.33	4.57	5.06	35.85	0.91	0.55	11.37	5.87

higher C/H and lower O/C ratio in HA from non-amended soils could be attributed to greater degradation of lignin fractions due to the higher residence time of soil HA.

There are contrasting features between FTIR spectra of amended and unamended soil HA to further explain the effect of STMC. The identified bands on FTIR spectra of HA were (Table 5): a broad band at about 3,400 cm^{-1} commonly attributed to OH stretch, a peak at 2,925 cm^{-1} (aliphatic C-H stretching), a band at 1,740 cm^{-1} (C=O stretching of COOH and ketones), a band at 1,640 cm^{-1} (aromatic C=C), a band in the 1,590 to 1,517 cm^{-1} region (C=N stretching), a peak at 1,460 cm^{-1} (aliphatic C-H), a band at 1,280 to 1,200 cm^{-1} range (C-O stretching of aryl ethers, C-O and OH of COOH) and a peak in the 1,080-1,030 range (C-O of polysaccharide-like substances). The spectra in Figure 1 have shown a clear shift toward larger frequencies of the carbonyl group, which is in accord with a lower aromatic content with the increase of STMC cycles that was suggested by the E4/E6 ratio.

The spectra obtained (Figure 1) from HA of amended soils (CL1, CL2 and CL3) show a band at 2,925 cm^{-1} that is weaker in CL0 samples. The lower intensity of 2,925 cm^{-1} band in CL0 samples could be attributed to long-term aliphatic structural biodegradation of native soil HA (Ait Baddi et al., 2004). This is a characteristic of the C-H aliphatic absorption band and is evidence of the more aliphatic character of HA from amended soils. Also, the amended soil HA spectra showed an increase in absorbance in the 1,080 to 1,030 cm^{-1} range that is attributed to the presence of carbohydrate-like substances. Treatments CL1, CL2 and CL3 presented a small peak at 1460 cm^{-1} corresponding to C-H of methyl groups that are absent in CL0 spectra. The presence of fewer methyl groups in unamended soil HA is due to decarbonation during long-term humification process. Gigliotti et al. (1999) reported similar results in which an annual application of urban waste composts produced a modification in soil HA with an increase of aliphatic

TABLE 5.—*Assignment of infrared bands of soil humic acids according to Stevenson (1994).*

Wavelength (cm^{-1})	Assignment
3400-3300	O-H stretching, N-H stretching
2940-2900	Aliphatic C-H stretching
1725-1720	C=O stretching of COOH and ketone
1620-1600	C=O stretching in quinones and/or ketonic acids and amides.
1590-1517	COO^- symmetric stretching, N-H deformation and C=N stretching
1460-1450	Aliphatic C-H
1280-1200	C-O stretching and OH deformation of COOH, C-O stretching or aryl groups
1080-1030	C-O of polysaccharides or polysaccharide-like substance

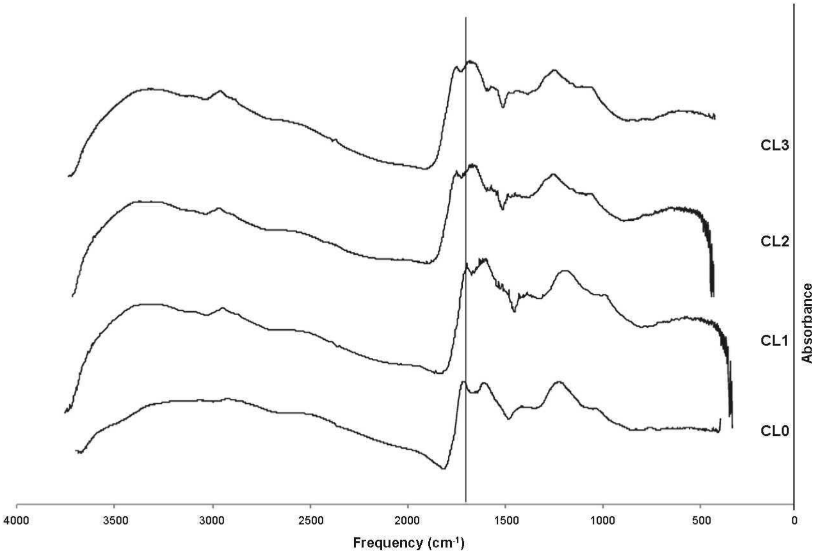

FIGURE 1. Infrared spectra of soil humic acids from the soil treatment management cycles CL0, CL1, CL2 and CL3.

groups and polysaccharide content. Unamended samples exhibit a more prominent and sharper band in the 1,280 to 1,200 cm^{-1} range that has been commonly assigned to a C-O stretch of aryl ethers and it is evidence of more aromaticity of CL0 samples. Unamended soil samples presented distinguishable and similar intensity bands at 1,640 cm^{-1} and 1,740 cm^{-1} but CL1, CL2 and CL3, samples exhibited a less prominent peak at 1,740 cm^{-1} associated with the decarboxylation of organic matter during humification (Ouatmane et al., 2000) and by ester break down producing the release of alkyl material (Ait Baddi et al., 2004). A distinguishable feature of CL1, CL2 and CL3 samples is a band at the 1,590 to 1,517 cm^{-1} region, corresponding to amide structures that becomes more evident with increasing STMC and is absent in CL0 samples. This data corroborates the observed increase in the elemental content of N (Table 4) in treatment samples and agrees with the high nitrogen content of compost and leguminous green manures incorporated in CL1, CL2 and CL3 treatments. Ouatmane et al. (2000) reported similar results with HA extracted from two different composts prepared from materials rich in N compounds. These results concur with studies by García et al. (1989) and Lguirati et al. (2005) in which HA extracted from composts exhibited higher N content than unamended soil HA. The organic treatments significantly increased soil HA content with a direct impact on long-term soil fertility as previously reported (García-Gil et al., 2004). These authors showed the impact of compost on soil HA in terms of molecular size and elemental compositions after the application. However, HA extracted from amended soils do not show the same degree of condensation and aromaticity as unamended soil HA. The organic treatments significantly increase soil HA content with each STMC (Table 3), which could have a direct impact over long-term soil fertility.

Effect on soil pH

All amended treatments resulted in a decrease in soil pH as the number of STMC increased (CL0>CL1>CL2>CL3). The STMC were able to decrease soil pH from 7.9 in CL0 to 7.0 in CL3 treatment (Table 3). At a pH of 7.9 in the untreated soil, a reduction in micronutrient availability is expected (Havlin et al., 2005; Sotomayor-Ramírez and Martínez, 2006), representing a constraint to crop growth and productivity. This phenomenon has been reported in tropical root crops on the semiarid southern coast of Puerto Rico (Sotomayor et al., 2003). The pH buffering capacity of organic amendments effectively adjusting soil pH toward neutrality has been reported after compost (Aggelides and Londra, 2000), animal manure and cover crop incorporation (Clark et al., 1998). The present work demonstrates the pH buffering capacity of organic amendments from alkaline conditions toward neutrality. Three consecutive STMC (CL3) were able to decrease pH almost an entire unit. The decrease in soil pH as a result of the organic amendments has been attributed to the action of acid functional groups present in HA (Jouraiphy et al., 2005). García-Gil et al. (2004) reported short and long-term improvement of buffering capacity of HA extracted from soils amended with municipal solid waste compost. The buffering effect of HA after compost additions has been recorded as much as nine years after the addition of organic amendments (García-Gil et al., 2004). The HA buffering capacity arises from the acidic functional groups like carboxyl and phenol in the HA (García-Gil et al., 2004). The significant increase in soil HA reported in the present study (Table 3) and the pH decrease in the soil supports the pH buffering role of HA.

Phosphorus and sulfate

Treatments CL1, CL2, and CL3 were able to increase Olsen extractable P by 60%, 91% and 129%, respectively, when compared with CL0. Although this soil series is considered highly fertile and this region is categorized by the United States Natural Resources Conservation Service (NRCS) as prime farmland, the P fertility levels of CL0 were in the medium phosphorus concentration category of soil fertility

(Muñiz-Torres, 1992). This result suggests that crops grown in these soils under natural conditions will show a response to P fertilization. One STMC (CL1) increased soil P availability to 38 mg/kg, which is above the 30-mg/kg target level for required conventional fertilization. However, other authors propose higher Olsen P concentration levels (>40 mg/kg) when growing vegetables (Kelling et al., 1998). According to our results, two cycles (CL2) were needed to reach this level. These results are in accordance with other studies that have reported an enhancement in soil P availability after additions of mature composts from different sources (Wong et al., 1999; Soumaré et al., 2003; Weber et al., 2007; Courtney and Mullen, 2008; Bustamante et al., 2011). Numerous studies have concluded that soil available P is directly related to the amount of organic residues applied to the soil (Wong et al., 1999; Warman et al., 2009; Courtney and Mullen, 2008). In addition to the immediately available P, 53 to 86% of total P has been reported to act as a low release source after compost incorporation to the soil (Frossard et al., 2002). A portion of the observed increase in P concentration could be explained by using the reduction of soil alkalinity achieved by the pH buffering activity of the STMC. Plant available P shows maximum solubility in the 6.5 pH (Havlin et al., 1999). It is expected that at pH 7.9 of CL0, P precipitates with Ca reducing its availability (Hopkins and Ellsworth, 2005). The implementation of the STMC reduced pH, with treatment CL3 achieving pH 7. Despite the significant increase in P as a result of organic amendment addition, the levels of soil P were kept within the moderate category (31 to 70 mg/kg) of pollution potential for the Caribbean area developed by Martínez et al. (2002). It can be suggested that the continuous monitoring of P in compost-amended soil should be performed, especially when using compost from animal manures. Sulfate concentrations responded directly to organic treatment. At the end, treatments CL1, CL2 and CL3 significantly increased SO_4 content when compared to CL0. Treatments CL3 and CL2 presented the highest values.

Effect on soil cations

The established treatments CL1, CL2 and CL3 increased exchangeable potassium 2.7, 4.2 and 5.2 times, respectively, when compared with CL0 (Table 3). Treatments CL1 and CL2 did not increase Ca content over CL0. Three consecutive STMC significantly increased Ca content when compared with the other treatments. Treatment CL2 and CL3 resulted in the highest Mg concentration with about a 30% increase when compared with CL0. Similar results have been reported by numerous authors where the application of different types of compost increases K, Ca and Mg concentration in the soil (Wong et al., 1999; Soumaré et al., 2003; Weber et al., 2007; Courtney and Mullen, 2008; Bustamante et al., 2011). The increase in nutrient content was expected since the coffee pulp compost applied is considered a source of nutrients characterized by high levels of potassium (Chong and Dumas, 2012). A portion of the observed increase in the concentration of available cations could be attributed to the implementation of green manures as previously reported. The increase in soil nutrients, in addition to N, has been achieved after the implementation of fallows consisting of tropical legumes (Koutica et al., 2001).

The use of organic amendments changed cation concentration (Table 3), increased the effective cation exchange capacity (ECEC) at every level of the STMC and affected the cation distribution (Table 6). The addition of STMC reduced the saturation of Ca from 81.0% in CL0 to 71.1% in CL3. Treatments CL1, CL2 and CL3 were able to increase K saturation by 2.5, 3.6 and 4.1 times, respectively, when compared with the control. There were minor changes in Mg and Na saturation, respectively (Table 6). Although the STMC increased Na concentration (Table 3), the saturation of Na did not significantly increase and did not present a fertility constraint for plant development. These results concur with that of Walker and Bernal (2008) in which the incorporation of different types of organic amendments favored the saturation of Ca, Mg and K over Na.

Effect on crop yield and biomass

Unamended plots (CL0) did not produce fruits until the last two weeks of picking (Figure 2). The implementation of one STMC cycle (CL1) significantly increased eggplant production (Table 7). Treatments CL2 and CL3 produced the highest total eggplant yield, which represented a 64 and 97% yield increase over CL1, respectively. Yields of CL2 and CL3 (Table 7) treatments surpass expected crop yields for the same eggplant variety under conventional production recommen-

TABLE 6.—*Effective cation exchange capacity and percent base saturation as affected by the implementation of soil treatment management cycles (CL0, CL1, CL2, CL3) of combined practices.*

	ECEC (cmol/kg)	Ca saturation (%)	Mg saturation (%)	K saturation (%)	Na saturation (%)
CL0	26.2 d[1]	81.0 a	14.0 b	2.8 c	2.3 a
CL1	27.9 c	74.1 b	16.5 a	7.0 b	2.5 a
CL2	30.8 b	72.0 abc	15.7 ab	9.9 a	2.4 a
CL3	33.4 a	71.1 c	15.5 ab	11.2 a	2.2 a

[1] Means within a column followed by the same letter are not significantly different at $p \leq 0.05$ using Fisher's least significant difference (LSD).

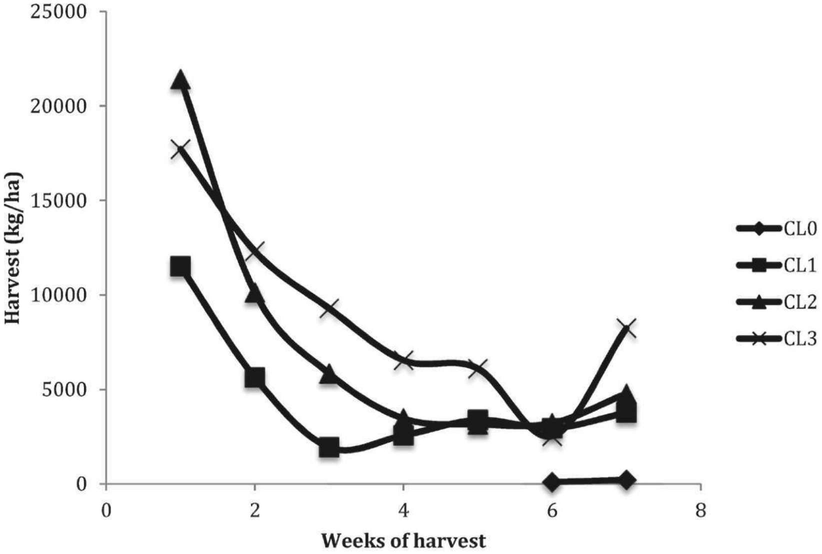

FIGURE 2. Effect of the implementation of soil treatment management cycles (CL0, CL1, CL2, CL3) of combined practices on weekly harvest.

dations (UPR-AES, 2006). Altieri and Esposito (2010) have seen the potential of organic amendments in promoting crop productivity comparable to expected yields under conventional production systems. The positive effect of the individual application of compost, legume fallows and compost tea on crop yield has been previously reported. In this study, the combination of practices within each STMC resulted in a positive effect on eggplant productivity. The increase in yield could be attributed to the enhanced nutrient availability of essential nutrients previously discussed. These results concur with that of Warman et al.

TABLE 7.—*Effect the implementation of soil treatment management cycles (CL0, CL1, CL2, CL3) of combined practices on eggplant yield, fruits per plant and dry weight.*

	Total eggplant yield (kg/ha)	Fruits per plant	Dry weight (g/plant)
CL0	311.1 c[1]	0.1 c	14.7 c
CL1	31,765.2 b	3.8 b	124.9 b
CL2	52,031.3 a	6.0 a	238.3 a
CL3	62,761.3 a	7.4 a	273.6 a

[1] Means within a column followed by the same letter are not significantly different at $p \leq 0.05$ using Fisher's least significant difference (LSD).

(2009) who reported that different rates of municipal waste compost provide equal or higher nutrient levels than NPK fertilizer applications designed to meet crop demand. Although the nutrient concentration of well water was considerably high, particularly in nitrate, this nitrate did not seem to increase growth as demonstrated by CL0 plants. Our results are in accordance with other authors who have reported an increase in crop yield because of a nutrient increase induced by organic amendments (Ouédraogo et al., 2001; Soumaré et al., 2003; Courtney and Mullen, 2008). Also, the positive interaction of growth promoting agents, present in highly stabilized organic matter, with crop productivity has been suggested. Their identity is still unclear but they have been related to humic substances (Keeling et al., 2003). Although the San Antón soil is recognized as supporting high crop yields, there were limiting conditions in unamended soils (CL0) that were constraining crop productivity. In addition to the chemical parameters assessed, eggplant yield increase could also be attributed to the enhancement of the soil's physical and biological properties as reported in Pagán-Roig et al. (2016).

Cycles of combined sustainable practices, STMC, not only had a positive effect on fruit yield but also on eggplant biomass. All treatments significantly increased plant biomass compared to CL0 (Table 7). Treatments CL2 and CL3 were not significantly different, but both reported the highest production of plant biomass. The enhancement of dry matter production due to the application of organic amendments has been reported on crop plants (Ouédraogo et al., 2001; Wong et al., 1999; Guerrero et al., 2001) and on spontaneous vegetation (Guerrero et al., 2001; Tejada et al., 2009). The latter have relevant implications in the reclamation of highly degraded land since the promotion of vegetation cover in highly degraded areas is key to conserving soil against erosion and preserving soil from further degradation (Guerrero et al., 2001; Tejada et al., 2009).

CONCLUSION

Our results demonstrate the positive effects of the combination of STMC on soil fertility and humic acid properties. The objective of consecutive applications of STMC and the high rates of compost additions were done trying to simulate in a short time frame what could be achieved under a long-term regime of typical organic amendments. This was reflected by the reported changes of HA characteristics. From the present study we can conclude that the implementation of STMC of coffee pulp compost application, planting and incorporation of green manures, mycorrhizae addition and compost tea are potential alternatives to improving soils for vegetable production. The application of STMC produced an enhancement in the overall soil chemical fertility parameters. The pH was positively affected by a shift toward neutrality, where most nutrient availability is expected. Organic matter content and quality were increased in amended soils having a positive impact on the long-term soil fertility status expressed in terms of soil HA. Humic acids were significantly increased in amended plots. Soil HA extracted from unamended plots showed a higher level of condensation and aromaticity compared to organic samples, although the latter showed a relatively high degree of stabilization and humification. When considering soil nutrients, the consecutive application of the STMC produced a general buildup, which underlines the importance of measuring soil nutrients and understanding the use of sustainable practices, because these can also be a source of environmental pollution. These changes in soil fertility carried out by the implementation of STMC were reflected in an increase in eggplant biomass production and yields comparable to that expected under conventional vegetable production systems. There is a need to study real agroecosystems to better understand the on-farm dynamics of well-established sustainable production systems.

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