Topical Application of Manufactured Aggregates to *Cordyline fruticosa* and *Phaselous vulgaris*

Sangchul Hwang and Isomar Latorre

Department of Civil Engineering, University of Puerto Rico, Mayaguez, PR 00681

KEYWORDS: manufactured coal ash aggregates, outdoor experiment, plant growth

INTRODUCTION

A number of studies have been conducted to evaluate the effects of coal combustion byproducts (CCPs) application on growth of plants and crop production [1]. Reported benefits of CCPs (mainly, fly ash (FA)) application include (1) increase in water holding capacity that could decrease irrigation frequency and subsequently increase water savings [2,3], (2) reduction of soil acidity-related constraints [4], and (3) provision of essential micronutrients for plant growth and development [1]. Negative aspects of agricultural CCP application include (1) excessive trace element loadings that may increase food chain metals [5], (2) high soluble salt loadings that may reduce initial plant growth [6], and (3) toxic substance leaching into the groundwater [7]. It should be noted, however, that the effects of CCPs on plant growth and crop production largely depend on the physiochemical properties of CCPs and soils.

Manufactured coal ash aggregates (MAs) are a 2:1 (w/w) solidified composite of FA and bottom ash (BA) that are mixed in water and then air-dried. They gain strength with time due to cementitious reactions. The current study was conducted to assess the feasibility of beneficial MAs utilizations as a plant growth supporter. Outdoor experiments assessed the growth of *Cordyline fruticosa* (lucky plant) and *Phaselous vulgaris* (common bean) with topical application of MAs.

MATERIALS AND METHODS

Soil Sampling

An organic-rich soil from a local area (Santa Isabel, Puerto Rico) was used as topsoil for the experiments. Soil characteristics are shown in Table 1. After being transported to the laboratory, the soil was dried at 105 °C for 24 h, and then sieved to collect soil particles smaller than 2.0 mm.

Manufactured Aggregates

MAs were collected from a local coal-burning power plant (AES Puerto Rico) located in Guayama, Puerto Rico. The plant combusts coals in a circulating fluidized bed. Selective non-catalytic reaction, circulating dry scrubber with limestone, and electrostatic precipitator are used for reductions of nitrogen oxides, sulfur dioxide, and particulate matter, respectively, in flue gas emission. The main MAs chemical components were 51% (w/w) mixture (silica, alumina, and ferric oxides), 30% (w/w) lime, and 15% (w/w) sulfur trioxide (Figure 1). According to the American Society for Testing and Materials (ASTM) (ASTM Standard C 618), FA can be classified in two main types: Class C and Class F. Although the ASTM classification of FA is not applicable to MAs that are a solidified composite of FA and BA, MAs can be regarded as a Class C-type CCP based on the chemical properties. However, the sulfur trioxide concentration of 14% in MAs exceeds the maximum concentration of 5% for a Class C- or F-type FA. Prior to use, they were crushed mechanically and sieved to collect the particles sizes ranging from 2.36 to 9.53 mm.

Table 1. Characteristics of top soil used (± standard deviation, n=3).

Characteristics	**Unit**	**Value**
pH	Unitless	6.5 ± 0.1
Soil organic matter	%	5.69 ± 0.17
Total nitrogen	mg/g as N	0.20 ± 0.01
Total phosphorus	mg/g as P	0.04 ± 0.01
Total heterotrophic bacteria	CFU/100 mL	6×10^6
Soil dehydrogenase activity	µg TPF/100 mL	1428 ± 403
Soil texture classification	Loamy sand (Sand 75.1 ± 2.0%; Silt 13.3 ± 0.2%; Clay 11.6 ± 2.1%)	

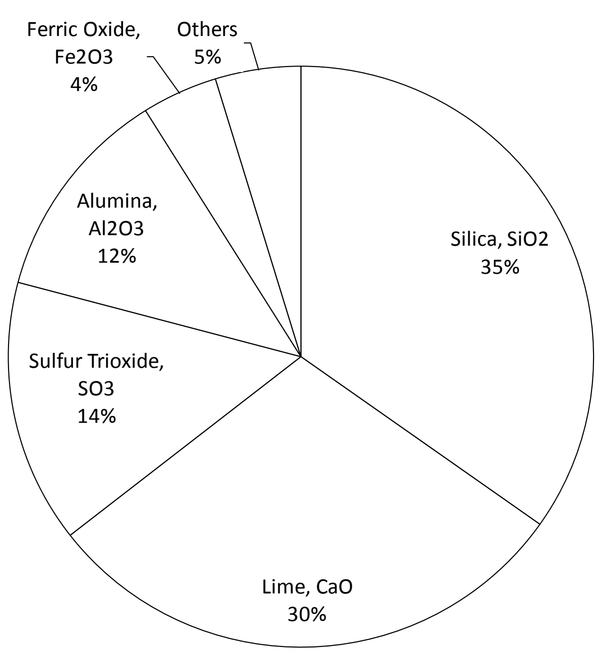

Figure 1. Metal oxide composition of the MAs (%, wt).

Topical Application of MAs to P. vularis

An outdoor experiment evaluated the influence of MAs put on the surface of topsoil on the growth of *P. vulgaris* (Figure 2). For this, two 33- × 20- × 20-cm pots were used. Each pot had three perforated 2.5- × 20- × 2.5-cm troughs where the MAs and gravel were placed for the treatment and control pots, respectively. Gravel (835 grams) or MAs (430 grams) were evenly placed on the three troughs in the control or treatment pots respectively. This corresponded to an MA application of 65 tons/hectare. Six inches of the topsoil was placed at a bulk density of 1.53 ± 0.02 g/cm^3 (n = 2). Eight *P. vulgaris* seeds were sown in the top soil at 3.8-cm depth. Subject to natural weather conditions (e.g. precipitation, wind, evapotranspiration, sunlight), *P. vulgaris* survival, physiology, and growth dynamics were assessed for 52 d. Natural weather environments were monitored via a weather station located in the experiment area.

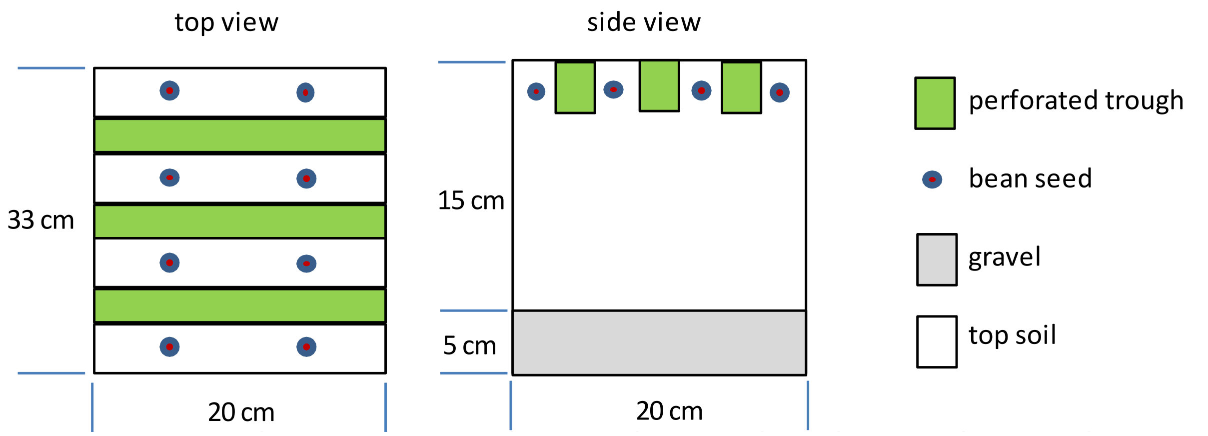

Figure 2. Schematic diagram of the pots with *P. vulgaris* seeds with topical MA application.

Topical Application of MAs to C. fruticosa

Four pots were packed with a commercial pot soil and planted with *C. fruticosa*. Each pot had three plants. Two pots were the controls without MAs and another two pots were the treatments with topical MA application. 15.3 kg of soil was put in each pot to the height of 25 cm. the treatment pots received 350-gram MAs that was evenly divided to six perforated bowls. This corresponded to a topical MA application of 30 tons/ha. Later, the each treatment pot received additional 800-gram MAs which was evenly applied on the surface. This equals an MA application of 95 tons/hectare. *C. fruticosa* physiology and growth dynamics were assessed for 183 d under natural weather environments.

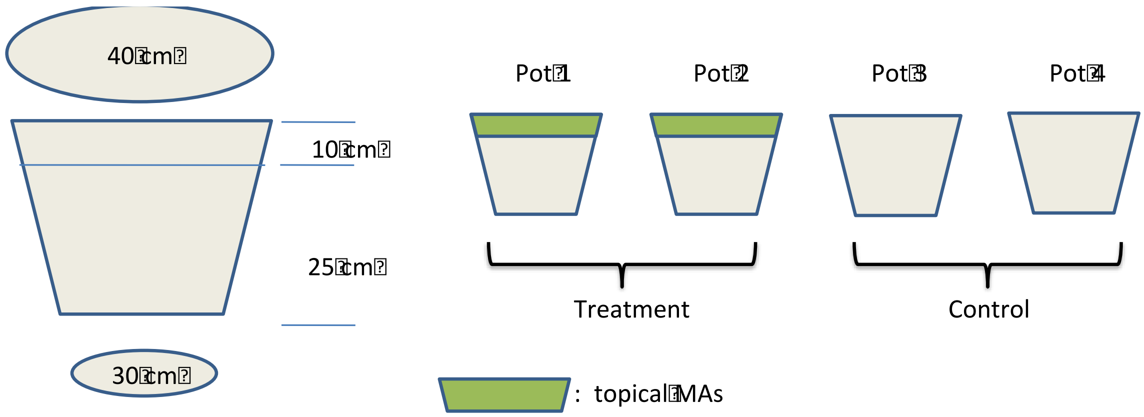

Figure 3. Schematic diagram of the pots with *C. fruticosa* with topical MA application.

Analysis
Soil pH (in 0.1% (w/v) $CaCl_2$ solution) was measured with an Orion pH meter and soil organic matter was quantified by the Loss-on-Ignition [8]. Total nitrogen and phosphorus concentrations in soils were analyzed by HACH methods following the Digesdahl digestion process. Soil texture classification was done with a hydrometer analysis [9].

The shoot height of *P. vulgaris* and *C. fruticosa* were measured. Plant health was monitored by measuring leaf chlorophyll intensity with a chlorophyll meter (SPAD-502, Konica Minolta).

RESULTS AND DISCUSSION

P. vularis Growth with Topical MA Application
P. vulgaris grown in the outdoor pots with MAs were taller and had more leaves than in the control pot (Figure 4). As shown in Table 2, *P. vulgaris* were subjected to typical autumn weather in the subtropics. As designed, the rainwater leached through the troughs of the MAs or gravel and infiltrated to the topsoil in the pot. Similar to the indoor experiments, the enhanced *P. vulgaris* growth in the MAs-containing outdoor pot was likely attributed to the micronutrients leached from the MAs.

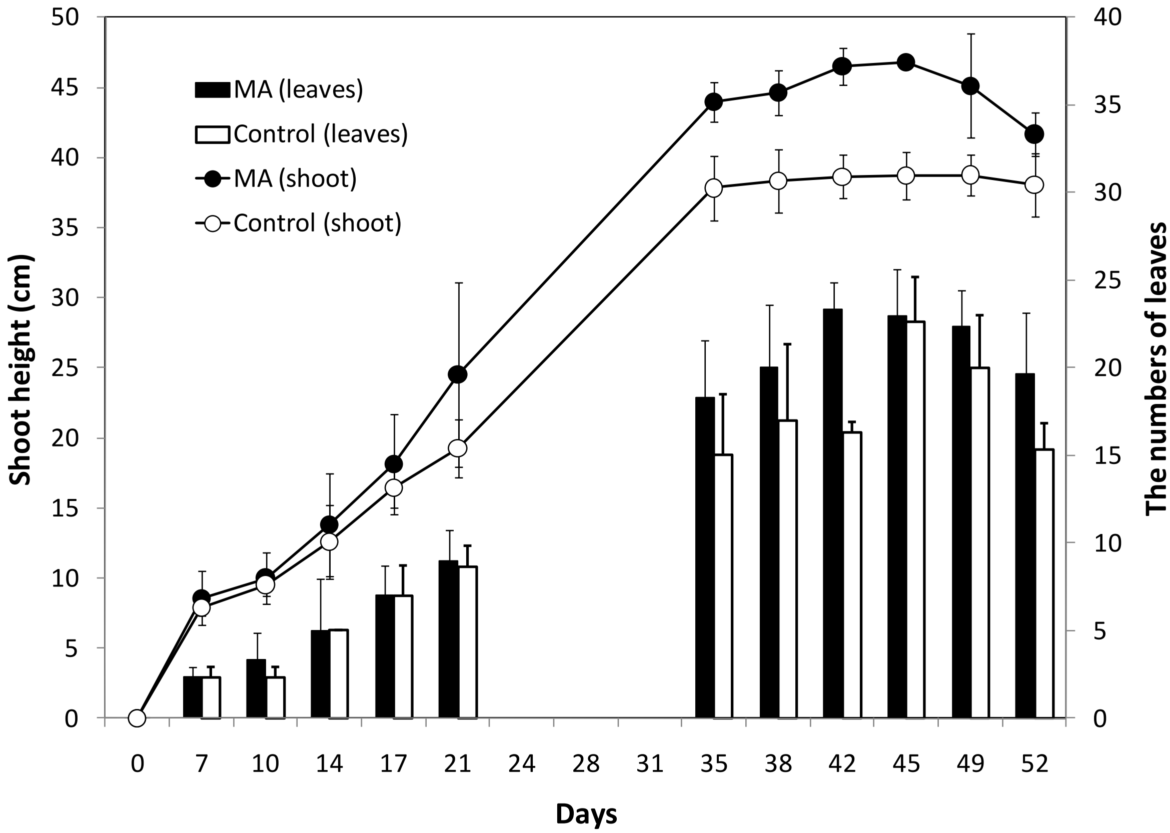

Figure 4. *P. vulgaris* shoot heights and leaf number when grown outdoors with MAs on the surface of the top soil (average ± standard deviation, n=8).

Table 2. Key weather information during the outdoor experiment with *P. vulgaris* (Sep 17 ~ Nov 5, 2009).

	Temperature	**Humidity**	**Wind speed**	**Rain intensity**	**Solar radiation**	**UV Index**	**Evapo-transpiration**
(unit)	**(°C)**	**(%)**	**(km/h)**	**(mm/hr)**	**(W/m^2)**	**-**	**(mm)**
High	33.5	97	8	195.1	1133	16	0.69
Average	25.3	87	1.1	0.74	173	2.6	0.03
Low	19.9	49	0	0	0	0	0

Chlorophyll intensity was monitored on every leaf suitable for measurement using the chlorophyll meter. *P. vulgaris* grown in the MAs-containing pot had higher chlorophyll concentrations (Figure 5). Chlorophyll is one of the major chloroplast components for photosynthesis, which allows plants to obtain energy from light. Therefore, relative chlorophyll content has a positive relationship with photosynthetic rate and, hence, plant health. For example, the effect of heavy metal accumulation on the leaf chlorophyll concentration in *Typha latifolia* (cattails) was studied [10] and an inhibitory effect of heavy metal accumulation was found correlated with a decrease in chlorophyll concentration.

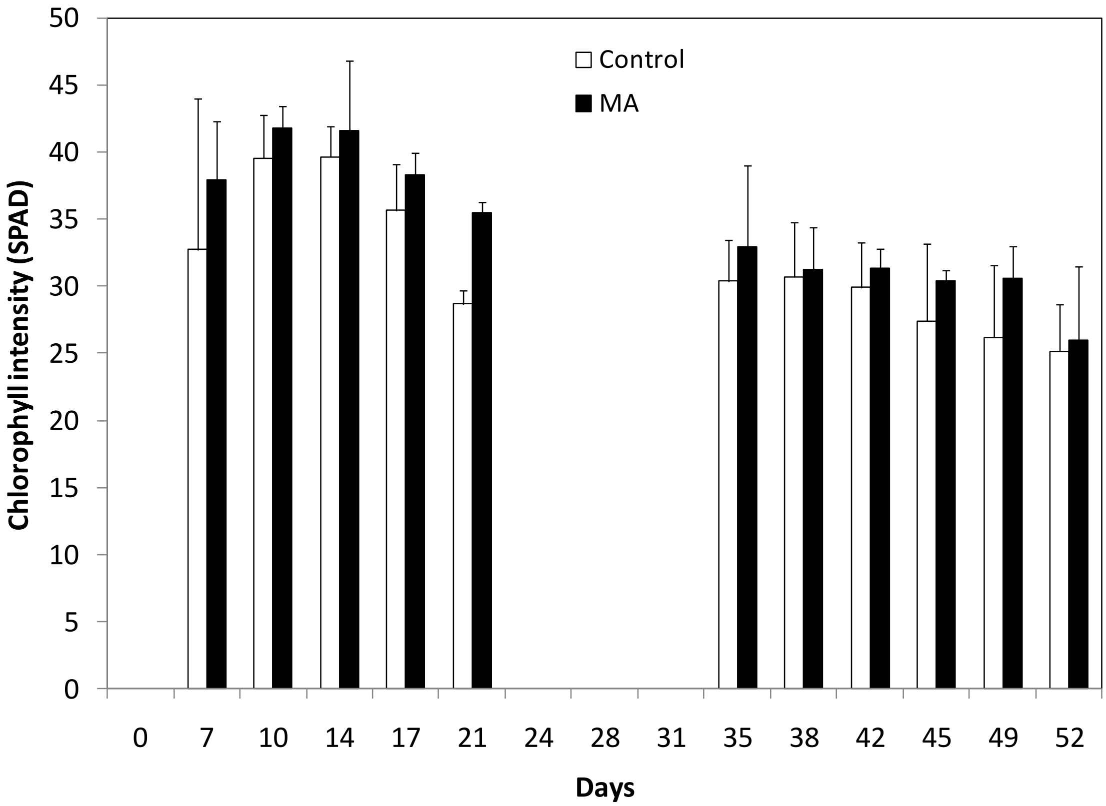

Figure 5. Chlorophyll intensities (SPAD) of *P. vulgaris* grown outdoors with topical MA application (average ± standard deviation, n=8). The same leaf of each plant was used for the measurement.

C. fruticosa Growth with Topical MA application

As shown in Figure 6, *C. fruticosa* grew better, resulting in taller heights. At the beginning of the experiment, the plants in the treatment pots were shorter than those in the control pots. However, they were taller at the end of the experiment due to faster growth rates with topical MA applications. The intensity of leaf Chlorophyll was found greater for *C. fruticosa* in the treatment pots throughout the experiment for 183 days (Figure 7). Weather conditions during the experimental period (May 27-Nov 26, 2010) were similar to those shown in Table 2.

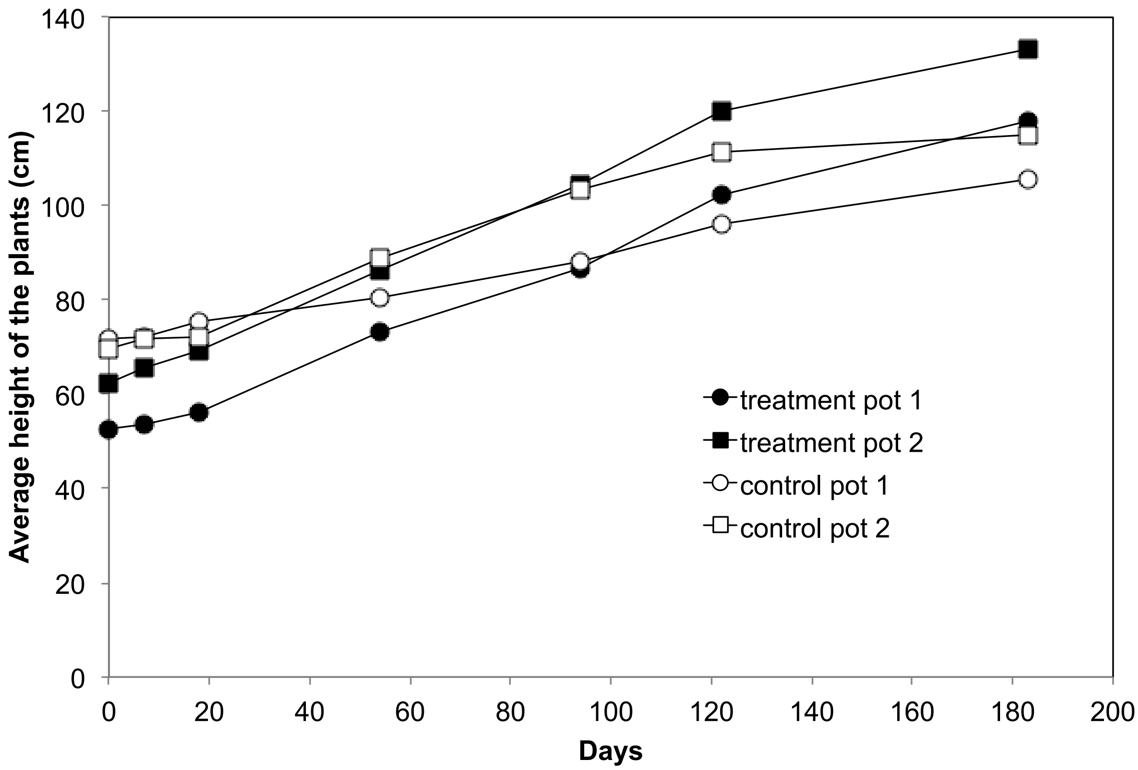

Figure 6. The height of *C. fruticosa* on average (n=3).

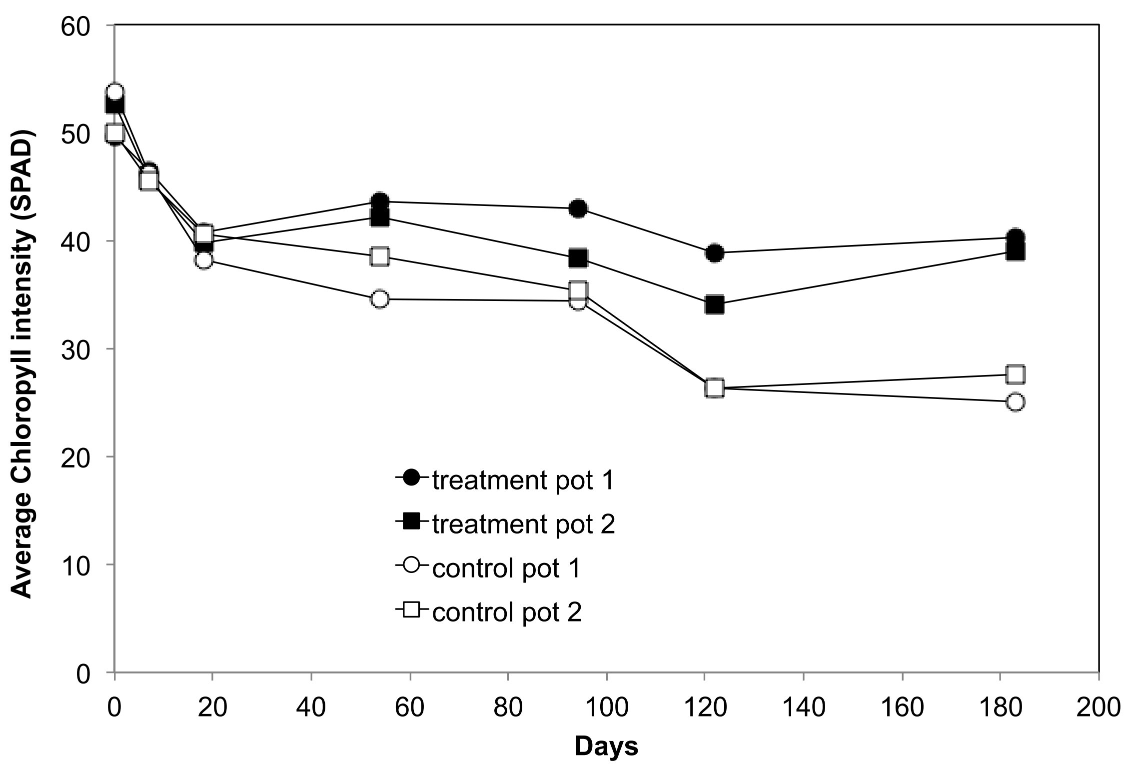

Figure 7. Chlorophyll intensity of *C. fruticosa* leaf, on average (n=3).

CONCLUSIONS

Outdoor growth experiments showed that *P. vulgaris* grew better with topical application of MAs at an application rate of 65 tons/ha, having taller shoots, more leaves, and higher leaf chlorophyll intensity. *C. fruticosa* also grew better at a topical MAs application of 95 tons/ha resulting in taller shoots and healthier leaf conditions.

ACKNOWLEDGMENTS

The authors would like to express sincere appreciation to the AES Puerto Rico and US Geological Survey Water Resources Research Grant State Program for their financial support for the project.

REFERENCES

[1] Jala, S., Goyal, D., 2006. Fly ash as a soil ameliorant for improving crop production-a review. Bioresource Technology 97, 1136-1147.
[2] Belyaeva, O.N., Haynes, R.J., 2009. Chemical, microbial and physical properties of manufactured soils produced by co-composting municipal green waste with coal fly ash. Bioresource Technology 100, 5203-5209.
[3] Pandey, V.C., Abhilash, P.C., Upadhyay, R.N., Tewari, D.D., 2009. Application of fly ash on the growth performance and translocation of toxic heavy metals within *Cajanus cajan* L.: Implication for safe utilization of fly ash for agricultural production. Journal of Hazardous Materials 166, 255-259.
[4] Pandey V.C., Singh, N., 2010. Impact of fly ash incorporation in soil systems. Agriculture, Ecosystems and Environment 136, 16–27.
[5] Peralta-Videa, J.R., Lopez, M.L., Narayan, M., Saupe, G., Gardea-Torresdey, J., 2009. The biochemistry of environmental heavy metal uptake by plants: Implications for the food chain. The International Journal of Biochemistry & Cell Biology 41, 1665–1677.
[6] Palumbo, A.V., McCarthy, J.F., Amonette, J.E., Fisher, L.S., Wullschleger, S.D., Daniels, W.L., 2004. Prospects for enhancing carbon sequestration and reclamation of degraded lands with fossil-fuel combustion by-products. Advances in Environmental Research 8, 425–438.
[7] Singh, G., Paul, B.C., 2001. Assessment of groundwater quality impacts due to use of coal combustion byproducts to control subsidence from underground mines. Environment International 26, 567-571.
[8] SSSA. Methods of Soil Analysis: Part 3. Chemical Methods (ed.: D.L. Sparks). Soil Science Society of Amrica, Inc., Madison, WI.
[9] USDA. Natural Resources Conservation Services (http://soils.usda.gov/technical/classification, accessed Mar 2010).
[10] Manios, T., Stentiford, E.I., Millner, P.A., 2003. The effect of heavy metals accumulation on the chlorophyll concentration of *Typha latifolia* plants, growing in a substrate containing sewage sludge compost and watered with metaliferus water. Ecological Engineering 20, 65-74.