Sludge and Compost Amendments in Tropical Soils: Impact on Coriander (*Coriandrum sativum*) Nutrient Content

Ml. López-Moreno, Le. Lugo Avilés, Fr. Román, J. Lugo Rosas, Ja. Hernández-Viezcas, Jr. Peralta-Videa, Jl. Gardea-Torresdey

***Abstract*—**Degradation of agricultural soils has increased rapidly during the last 20 years due to the indiscriminate use of pesticides and other anthropogenic activities. Currently, there is an urgent need of soil restoration to increase agricultural production. Utilization of sewage sludge or municipal solid waste is an important way to recycle nutrient elements and improve soil quality. With these amendments, nutrient availability in the aqueous phase might be increased and production of healthier crops can be accomplished. This research project aimed to achieve sustainable management of tropical agricultural soils, specifically in Puerto Rico, through the amendment of water treatment plant sludge's. This practice avoids landfill disposal of sewage sludge and at the same time results cost-effective practice for recycling solid waste residues. *Coriander sativum* was cultivated in a compost-soil-sludge mixture at different proportions. Results showed that Coriander grown in a mixture of 25% compost+50% Voladora soi+25% sludge had the best growth and development. High chlorophyll content (33.01 ± 0.8) was observed in Coriander plants cultivated in 25% compost+62.5% Coloso soil+ 12.5% sludge compared to plants grown with no sludge (32.59 ± 0.7). ICP-OES analysis showed variations in mineral element contents (macro and micronutrients) in coriander plant grown I soil amended with sludge and compost.

***Keywords*—**Compost, *Coriandrum sativum*, nutrients, waste sludge.

I. Introduction

Puerto Rico (PR), with only 100 miles long by 35 miles wide is a commonwealth of the United States and it is located in the northeastern Caribbean region. Arable land is about 1.8 million acres in the island but 70% consists of steep slopes at the mountains and alluvial floodplains along the coasts. From the remaining 30%, only 15% is highly productive while the rest depends on weather conditions such as moisture and warm, and physical and chemical characteristics like low nutrient content, acidic pH, and salinity, among others [1]. According to soil taxonomy classification, PR has nine types of soils. Voladora belongs to Ultisols soil order and has low pH value, low nutrient content, and its cation exchange capacity is from low to moderate. Voladora soil can be found in regions where rainfall is high. Coloso soil belongs to Inceptisols. This soil order lacks from clay horizons, has high compaction and moderated low pH. Inceptisols are the most widespread soils of PR [2]. Intensive use of agricultural soils to manage food demand, fertilization practices and contamination from anthropogenic activities are some of the causes of soil erosion and unproductiveness. Use of compost and sludge from waste water plants might be an option to supply and to increase nutrient availability to several crops. Recycling of wastes is a feasible alternative to decrease solid waste disposal in PR landfills and a cost-effective method to restore soils. At this time, a sewage sludge recycling plan is necessary in PR, because of the ban on disposal at sea [3]. Compost is a biodegradable material which specific characteristics of porosity, aeration, drainage and water holding capacity among others. Compost can vary in composition and it is a potential nutrient supplier and plant growth stimulator. There are several reports describing the use of composts to increase plant growth and productivity and to alleviate soil infertility. Reference [4] cultivated *Petroselinum crispum* in a mixture of compost from a Florida wastewater treatment plant and a sandy soil (Florida USA). They reported an increase in nutrient concentration in parsley's tissues after winter and spring growing seasons when compost was mixed with soil. Reference [5] described the positive effect of sewage sludge on *Hordeum maritimum.* Plants grown in saline conditions and soil amended with compost did not show to be affected in their growth, chlorophyll content, total protein content, and mineral uptake.

Puerto Rico is facing the problem of solid waste management due to population growth. According to [6] there is a lack of landfills in Puerto Rico that complies with the environmental safety requirements. There is a need to look for alternative and cost effective waste management strategies to reduce solid waste disposal in landfills. Compost produced in waste water treatment plants might be a feasible alternative to reduce waste disposal and to enhance nutrient availability in soils. The aim of this research project was to study the feasibility to grow Coriander plants in a compost-soil-sludge mixture at different proportions to increase the nutrient content in coriander leaves. Coriander was chosen because is a fresh culinary herb which has been consumed and employed

ML. Lopez-Moreno, LE. Lugo Aviles, and FR Roman are with Chemistry Department, University of Puerto Rico at Mayagüez, Mayagüez 00681, Puerto Rico (phone: 787-832-4040; fax: 787-265-3849; e-mail: martha.lopez@upr.edu).

J. Lugo Rosas is with Puerto Rico Aqueduct Sewer Authority, Mayaguez, PR, 00680. (e-mail: Joel.LUGO@acueductospr.com).

JA. Hernandez-Viezcas, JR. Peralta-Videa, JL. Gardea-Torresdey are with Chemistry Department and Environmental Science and Engineering PhD Program, The University of Texas at El Paso, 500 West University Ave., El Paso TX 79968, United States. (e-mail: jahernandez19@utep.edu, jperalta@utep.edu, jgardea@utep.edu).

as seasoning source and staple food in a daily basis by Caribbean islanders. Nutrient concentrations (particularly micronutrients) were quantified in roots, stems and leaves of Coriander plants.

II. Materials and Methods

A. pH and Electrical Conductivity in Compost-Soil-Sludge Mixtures

pH measurements were taken in Voladora and Coloso soils, sludge, and compost-soil-sludge mixtures. 50 g of dry mixtures were transferred to 250.0 mL Erlenmeyer flasks and mixed with 50.0 mL of DI water. Soil solutions were shaken for 30 minutes and left standing for 30 minutes. pH was measured with an ORION pH/ISE meter (Model 710A Boston, Massachusetts, USA). For conductivity measurements, 40.0 g of dry soil-mixtures were transferred to a 250.0 mL Erlenmeyer and mixed with 80.0 mL of deionized water. Soil solutions were shaken for 1 h and left standing for 30 min. Suspensions were filtered and electric conductivity (EC) was measured with a HACH CO 150 Conductivity Meter (Loveland, Colorado, USA).

B. Compost-Soil-Sludge Mixtures

Compost-soil-sludge mixtures were prepared mixing compost at a 25% per volume, soils (Coloso and Voladora both PR soils) and sludge (from river wastewater treatment plant) at different percentages to complete a total of 100% by volume. Eleven treatments (three replicates per treatment) were set for pH and -conductivity (from A1 to A11) and only 8 treatments for germination and mineral uptake (from A4 to A11). Treatments were: Voladora soil (treatment A1); Coloso soil (treatment A2); Sludge (treatment A3); 25% compost + 75% Voladora soil (treatment A4); 25% compost + 62.5% Voladora soil + 12.5% sludge (treatment A5); 25% compost + 50% Voladora soil + 25% sludge (treatment A6); 25% compost + 37.5% Voladora soil + 37.5% sludge (treatment A7); 25% compost + 75% Coloso soil (treatment A8); 25% compost + 62.5% Coloso soil + 12.5% sludge (treatment A9); 25% compost + 50% Coloso soil + 25% sludge (treatment A10); 25% compost + 37.5% Coloso soil + 37.5% sludge (treatment A11).

C. Coriander Germination

Coriander seeds were planted in triplicate (15 seeds per pot) in 6.5" x 6.0" pots in a complete random design. Pots were set in a greenhouse and every day the plants were sprayed with fresh water. Plants were grown for 23 days and harvested for further analyses. (For germination experiment, only treatments with 25 % compost were set).

D. Total Chlorophyll Content

Chlorophyll content was determined in coriander leaves using a portable chlorophyll meter SPAD-502 (Minolta, Ltd., Osaka, Japan). Values were recorded after 23 days of plant growth and thirty measurements were made in leaves from plants grown in compost-soil-sludge mixtures.

E. ICP-OES Mineral Quantification in Coriander Tissues

Plant tissues were digested on a CEM microwave oven (CEM Corporation Mathews, NC; USA) with 3 mL of plasma pure HNO_3 (SCP Science, NY) and diluted to 25 mL with Millipore water according to USEPA 3051 method. Concentrations in plant tissues were determined by ICP-OES (Perkin-Elmer Optima 4300 DV, Shelton CT). Certified standard reference materials (NIST-SRF1570A and 1547) of metals and metalloids (Metuchen, NJ) and a certified standard from all elements were used for QC/QA purposes. Results are expressed in mg/g DW of dry weight (DW).

C. Statistical Analysis

Data from all experiments was reported as mean ± Standard Error (SE). A one-way ANOVA using General Linear Model followed by Tukey's Honestly Significant Difference (HSD) test based on a probability of $p \leq 0.05$ was performed using INFOSTAT statistical package (Argentina).

III. Results and Discussion

A. pH and Conductivity in Compost-Soil-Sludge Mixture

Table I shows pH and conductivity for compost-soil-sludge mixtures. As seen in Table I, the pH increase in all mixtures including compost and sludge. Highest pH was found in treatment A11 (6.82 ± 0.07). Availability of nutrients in soils is driven by soil pH and most vegetable crops have an optimum growth at pH range of 5.50 to 7.00. Incorporation of compost and/or sludge helps to increase pH for the best development of plants [7]. EC increased in all treatments compared to Coloso and Voladora soils (Table I). EC provides information about salinity and cation exchange capacity (CEC) in soils [8]. Compost elaborated from sewage sludge from Puerto Rico Aqueduct Sewer Authority (PRASA) has high EC (6133.30 ± 28.50). When compost is added to certain types of soils in high proportion may affect soil-water balance, crop yields, plant nutrient availability, and microorganisms' activity in soils [9]. EC values < 1000 μS/cm are considered non-saline and do not impact most crops and soil microbial processes. EC values greater than 1000 μS/m are considered saline and may impact important microbial processes [8]. In some cases, sludge application increased production of CO_2 which benefits soil microbial respiration [10].

TABLE I
pH and Conductivity of Compost-soil-sludge Mixtures

Treatments	pH	Conductivity (μs/cm)
A1	4.55 ± 0.10	65.20 ± 0.70
A2	5.93 ± 0.08	117.10 ± 1.30
A3	7.75 ± 0.10	154.00 ± 0.10
A4	5.15 ± 0.09	1126.20 ± 3.60
A5	4.84 ± 0.10	1303.40 ± 24.54
A6	5.57 ± 0.02	925.80 ± 5.86
A7	5.64 ± 0.20	1531.40 ± 9.56
A8	6.38 ± 0.10	761.70 ± 1.80
A9	6.60 ± 0.03	699.30 ± 2.00
A10	6.69 ± 0.03	588.30 ± 2.90
A11	6.82 ± 0.07	1310.30 ± 8.70

B. Coriander Germination Percentage

Fig. 1 shows coriander germination percentage in compost-soil-sludge mixture. All treatments were amended with 25% compost in order to compare the effect of adding sludge in compost-soil mixtures (treatments A4 to A11). Germination percent in Voladora soils was 44±15 % in treatment A4 and increased to 74±6% in treatment A6. In Coloso soil, germination percentage in treatment A8 was lower (77±18%) compared to germination in treatment A10 (89±6%). When compost is applied as single soil modifier, germination of some seeds may decrease due to the high mineral content [11]. Reference [12] reported that germination percentage *in Brassica napus* cv. Tassilo decreased when sludge amounts were added to soil. Reference [13] also reported that application of three types of sludge to three types of soils (black, red, and fluvo-aquic soils) did not influence seeds germination of Rape, Maize, and Wheat. Germination also depends on the type of soil, the amount of sludge added, and plant seeds.

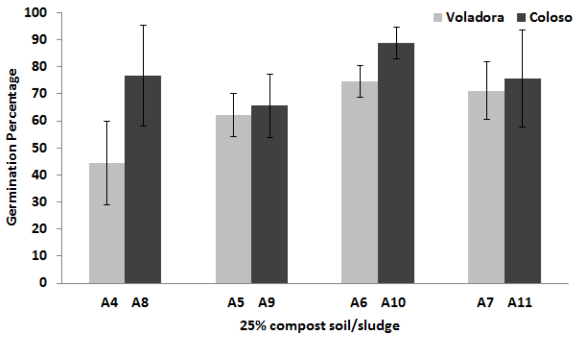

Fig. 1 Germination percentage of coriander seeds in ▢ Voladora and ■ Coloso soils amended with 25 % compost and sludge at different percentages. Data are average of 30 replicates. Error bars indicate ± S.E.

C. Coriander Root and Stem Growth

Root and stem length of coriander plants grown in different treatments are represented in Figs. 2 (a) and (b). As seen in this figure, an increase in root length was noticed in both Voladora and Coloso soils amended whit different proportions of sludge. There was not a significant difference in Coriander stem length in treatments A6 and A10 compared to treatments A4 and A8 (no sludge). However, a decrease in stem length was observed in treatments A5, A9, A7 and A11. Amendment with compost and sludge also increased biomass of Coriander plants (data not shown). Sludge addition to soil may have influence on the water retention by plant roots. Increasing the amount of soil pores, water holding capacity of the soil-mixture can increase. Reference [14] stated that the regime of soil moisture is modified when sludge is applied to soils due to additional pores which are able to hold more water, pore surface roughness (which increases water retention) and reduction of the microcraking of soil pores. Soils that hold water support more plant growth and are less susceptible to nutrients losses [15]-[17]. Reference [18] reported an increase of stem height of ryegrass (*Lolium perenne* L.) after the application of sewage sludge to mudflats in China. In other study, an increment in shoot length, leaf area, and number of nodules of *Vigna radiata* L. when sewage sludge was added to soil was reported [19]. Reference [20] grew three tree species in soils amended with sewage sludge (*Quercus acutissima, Liriodendron tulipifera,* and *Betula schmidtii*) and a significant increase in height was noticed. Reference [21] evaluated the effect of treated wastewater and sewage sludge on the growth of *Cynara cardunculus* L. Plants growth increased in both treatments compared to control plants. Germination, growth and development depend upon compost and sludge physical and chemical characteristics as well as plant species.

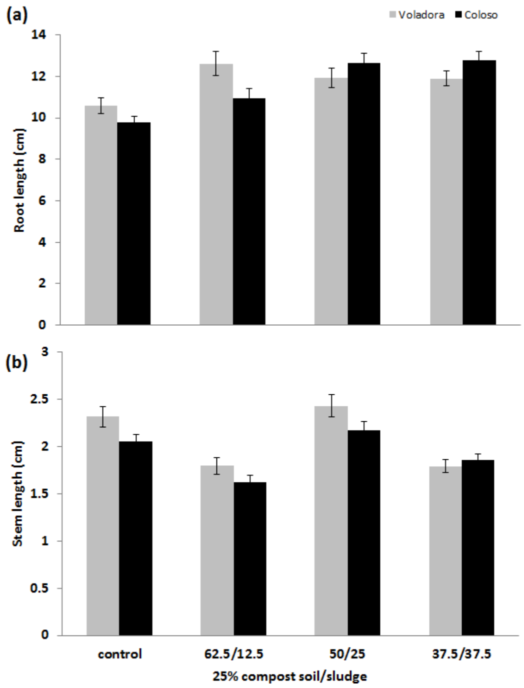

Fig. 2 (a) Root and (b) stem length of coriander plants grown in ▢ Voladora and ■ Coloso soils amended with 25 % compost and sludge at different percentages. Error bars indicate ± S.E.

D. Total Chlorophyll Content

Chlorophyll content in Coriander leaves was not significant affected by sludge's addition to Voladora soil (Fig. 3) in all treatments compared with treatment A4 (no sludge). In plants grown in Coloso soil, chlorophyll content slightly decreased in treatments A10 and A11 respect to treatment A8, indicating no sludge effect. Some researchers have found that chlorophyll content increases when sludge or compost are added to soils due to the increase in the photosynthesis rate [12] and [20]. Reference [22] reported that chlorophyll content in wheat and jews mallow plants was enhanced with the addition of 0-75 % of sludge to desert soil. In this study, plants did not show any toxicity symptoms.

D. ICP-OES Mineral Quantification in Coriander Tissues

Mineral quantification in Coriander tissues (roots, stems and leaves) is essential to monitor nutrient translocation to the leaves. The main objective of this project was to increase the nutrient uptake with the addition of compost and sludge to soil.

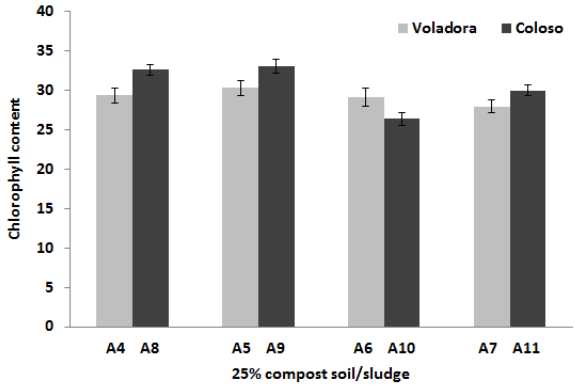

Fig. 3 Chlorophyll content in Coriander leaves of plants grown in in ☐ Voladora and ■ Coloso soils amended with 25 % compost and sludge at different percentages. Error bars indicate ± S.E.

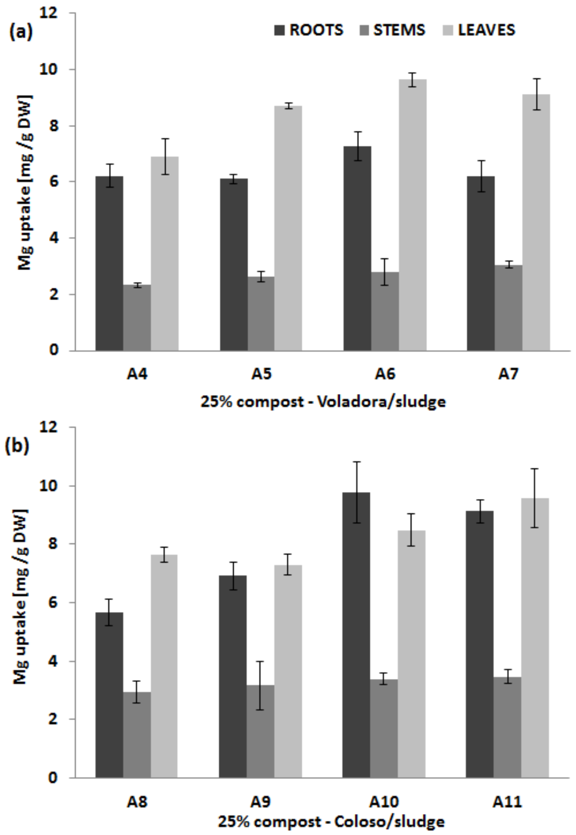

Fig. 4 Mg concentration in Coriander ■ roots, ■ stems, and ☐ leaves grown in (a) Compost-Voladora and (b) Compost-Coloso soils and different sludge proportions. Error bars indicate ± S.E.

Fig. 4 represents Mg concentration in Coriander tissues. Mg concentration in roots grown in Voladora soil (Fig. 4 (a) and treatment A6 was higher than root concentrations in all Voladora soil treatments (7.30 ± 0.5 mg/g DW). Mg concentrations in stems did not show a significant difference between treatments. However, in leaves, Mg uptake was higher in treatment A6 (9.63± 0.2 mg/g DW). According to USDA National Nutrition Data base [23], coriander leaves have Mg content around 6.94 mg/g DW. In this case, addition of compost and sludge increase Mg uptake in leaves by about 39%. In Coriander is desirable that minerals translocate to the stems and leaves which are the most common edible tissues. Fig. 4 (b) displays Mg concentrations in tissues of plants grown in Coloso soil. Treatments A10 and A11 had the highest Mg concentration in roots (9.77 ± 1.0 and 9.14 ± 0.4 mg/g DW respectively). Maximum Mg translocation to the leaves was in treatment A11 (9.60 ± 1.0 mg/g DW). These results are in agreement with previous reports that have shown Mg and Ca levels tissues and fruits are higher after addition of sludge to different types of soils [8]. Mg plays an important role in several mechanisms related to human energy metabolism, proteins and nucleic acid synthesis, as well as regulation of the electrical potential in cell membranes. According to FAO/WHO [24], recommended dietary intake for Mg is 150-500 mg/day. Coriander leaves grown in both soils amended with compost and sludge have Mg concentration values in a range of 7.0 to 9.5 mg/g DW. Coriander leaves might be a source of Mg for dietary intake.

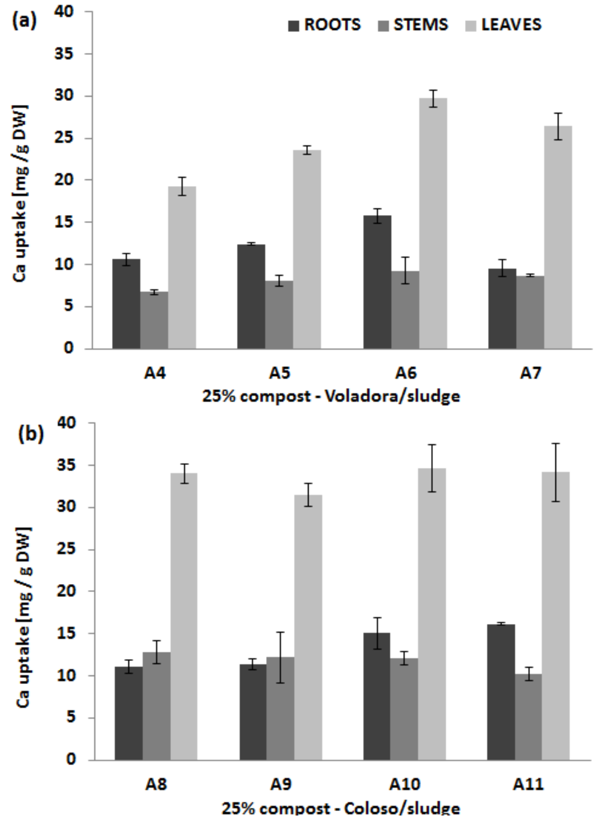

Fig. 5 Ca concentration in Coriander ■roots, ■ stems, and ☐ leaves grown in (a) Compost-Voladora and (b) Compost-Coloso soils and different sludge proportions. Error bars indicate ± S.E.

International Journal of Biological, Life and Agricultural Sciences
ISSN: 2415-6612
Vol:9, No:4, 2015

Ca uptake by Coriander roots in Voladora soil was higher in treatment A6 (Fig. 5 (a) with a concentration of 15.76 ± 0.8 mg/g DW. There was no significant difference in Ca uptake by stems in all treatments compared to treatment A4 (no sludge); however, there was more Ca translocation to the leaves in treatment A6 (29.70± 0.9 mg/g DW) than in all treatments. In Coloso soil (Fig. 5 (b)), roots from treatments A10 and A11 accumulated slightly more Ca than roots from treatments A8 and A9. Ca concentration in stems remained practically same in all treatments. Nevertheless, it is noticeable that in Coloso soil, Ca was translocated from the roots to the leaves and sludge did not produce any effect on Ca mobility. Ca translocation depends on soil, sludge, and compost type. Reference [25] reported that *Abelmoschus esculentus* L. (okra) cultivated in compost organic fertilizer showed lower Ca concentration in shoots (0.93 mg/kg) than in roots (1.30 mg/kg). According to FAO/WHO [24] Ca is an essential mineral for humans since this mineral provides skeleton rigidity and it participates in many metabolic reactions inside human body. Ca daily intake doses are debatable due to the diverse needs around the world. Recommended Ca intake for adults in North Americans and western Europeans has been established to a range between 1000- 1300 mg/day [24]. Coriander leaves cultivated in these compost-soil-systems could be a potential source of Ca.

Micronutrients' availability in soil-sludge varies with the type of amendment applied and some of them are also influenced by soil OM content [26]. Highest Cu concentration in Coriander roots was 0.23 ± 0.01 mg/g DW in treatment A6 in Voladora soil (Fig. 6 (a)) and it was 0.22 ± 0.03 mg/g DW in treatment A11 in Coloso soil (Fig. 6 (b)). Cu plays an important role in plant photosynthesis and respiration, formation of cell walls, carbon and nitrogen metabolism, among others [27]. Incorporation of sludge to compost-soil mixture increased root Cu uptake in both soils in all treatments compared to treatments A4 and A8 (no sludge). Cu content in leaves was higher in treatment A6 in Voladora soil (0.045 ± 0.002 mg/g DW) and in treatment A8 in Coloso soil (0.051 ± 0.004 mg/g DW). Addition of sludge to Coloso soil did not increase Cu translocation to leaves; however, Cu concentration did not decrease significantly in treatments A10 and A11. Reference [28] found that Cu levels increased in perennial ryegrass using sludge as soil amendment. Reference [16] also found that Cu levels in *C. ladanifer*, *A. serpyllifolium* and *Z. mays* were increased with long-term sewage sludge application. Cu in soils is linked to OM, occurs in the chemical form of Fe-Mn oxides, and its availability depends from the seasonal period by decomposition of organic matter [29].

Fig. 7 represents Mn uptake by Coriander tissues. Fig. 7 (a) reveals that addition of sludge to compost-Voladora mixture increased translocation of Mn to Coriander leaves in all treatments by about 50% compared to A4 treatment (no sludge). Highest Mn content in roots was found in treatment A6 (4.25 ± 0.3 mg/g DW). In Coloso soil (Fig. 7 (b)), Mn concentration was increased as % of sludge also was increased in the compost-soil mixture in roots and Coriander leaves.

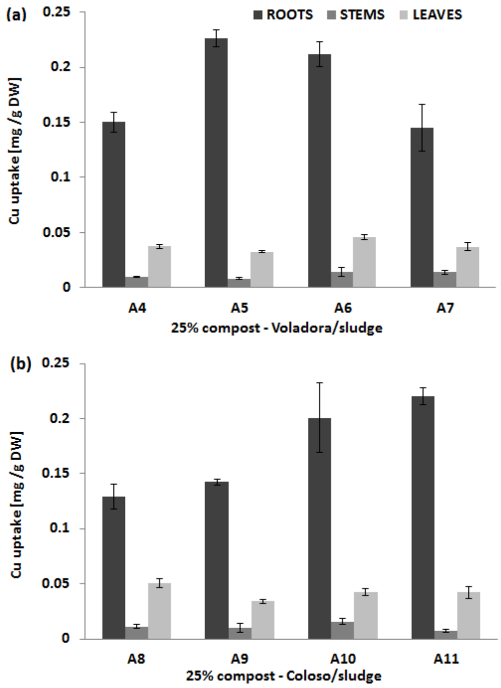

Fig. 6 Cu concentration in Coriander roots, stems, and leaves grown in (a) Compost-Voladora and (b) Compost-Coloso soils and different sludge proportions. Error bars indicate ± S.E.

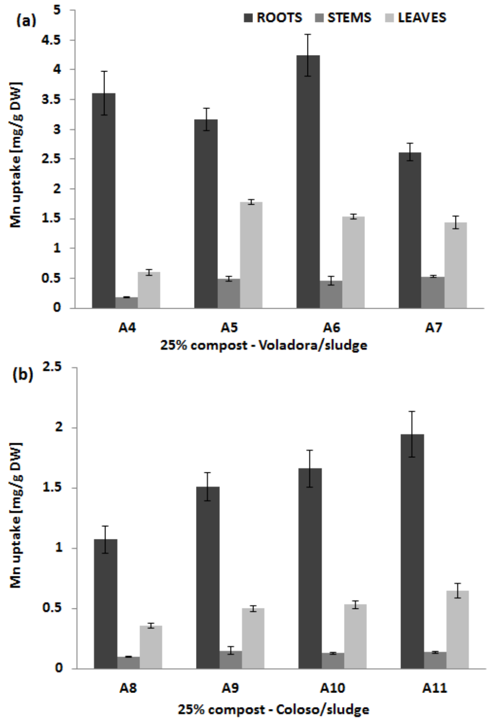

Fig. 7 Mn concentration in Coriander roots, stems, and leaves grown in (a) Compost-Voladora and (b) Compost-Coloso soils at different proportions. Error bars indicate ± S.E.

Reference [18] reported that Mn concentrations in shoots of *Lolium perenne* L. at reproductive stage increased by 50 % when 150 and 300 t ha^{-1} of sewage sludge were added to mudflats. Mn participates in metabolism of lipids, proteins, carbohydrates and is a cofactor for several enzymes involved in hydrolysis, phosphorylation, and decarboxylation, among others [30]. Mn dietary intake for adults has been established to 2–5 mg/day [23].

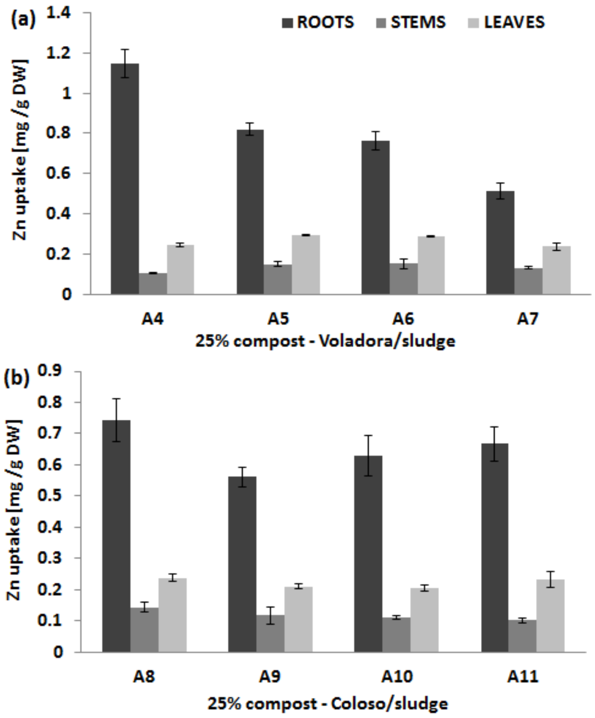

Fig. 8 Zn concentration in Coriander ■ roots, ■ stems, and □ leaves grown in (a) Compost-Voladora and (b) Compost-Coloso soils and different sludge proportions. Error bars indicate ± S.E.

In Voladora soil (Fig. 8 (a)), Zn concentration in Coriander roots decreased as sludge incorporation to compost-soil mixture increased. In Coloso soil (Fig. 8 (b)) Zn uptake decreased in roots treated with 12.5% sludge (0.56 ± 0.03 mg/g DW). However, in both soils, translocation of Zn to stems and leaves was not affected by the sludge incorporation. Zn was found in Coriander leaves a range between 0.20 -0.30 mg/g DW. Several researchers have found that Zn tends to have an antagonistic effect on the Cu uptake by plant roots. Contrary, Cu has a synergistic effect on Zn uptake [31] and [28]. Zinc and other metals like Cu, Mn and Fe are essential for human nutrition. Zn participates in several synthesis and degradation processes in cell metabolism and plays a crucial role in more than 300 enzymes and in the immune system [24]. Reference [32] stated that Zn deficiency in soils has been noticed in recent years producing a decrease in the plant uptake and translocation of Zn to fruits or seeds. Availability of Zn and other micronutrients in soil soluble fraction is related to their salt solubility, speciation, and ability to form complexes with organic acids.

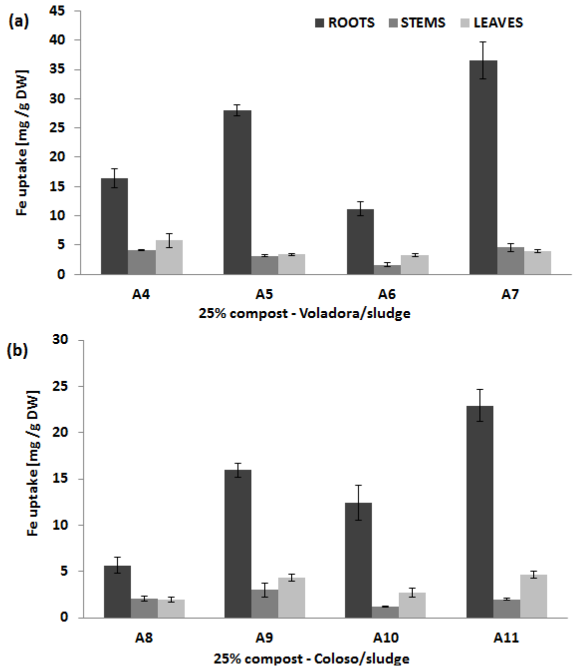

Fig. 9 Fe concentration in Coriander ■ roots, ■ stems, and □ leaves grown in (a) Compost-Voladora and (b) Compost-Coloso soils and different sludge proportions. Error bars indicate ± S.E.

Fe uptake in Coriander roots is shown in Figs. 9 (a) and (b). It can be noticed that Fe concentration in both soils increased when 12.5% of sludge was added to the compost-soil mixture, decreased with the addition of 25%, and increased again when 37.5% was added. Fe can retained in the roots as insoluble compounds including oxides, hydroxides or phosphates, or perhaps Fe reacts with proteins, organic acids, and cellular exudates in the media [33]. Fe distribution in stems and leaves follow the same behavior than roots. According to [23], Fe concentration in Coriander leaves is 0.42 mg/g, while Fe content in both soils and in all treatments is between 2-4 mg/g. Reference [34] reported an increase in Fe concentration in *Triticum vulgare* and *Corchorus olitorius* plants grown in desert soils modified with sewage sludge. This could be a feasible alternative for crop cultivation in desert lands with low OM content.

Analysis for some heavy metals (Cd, Cr, Pb, Se, and As) was done in compost and sludge samples. Values were under DL of the instrument.

IV. Conclusion

Recycling sludge from a river water treatment plant and compost from sewage wastewater plant might be a good alternative to increase crop yield and mineral nutrition. This study suggests that combination of compost-soil-sludge increase mineral nutrition in Coriander plants. Total amount of compost and sludge as well as number of applications need to be monitored in crop cultivation and soil environment. This could be a feasible and cost-effective alternative to restore soils as well as to generate economical profits. Further investigation will be needed to see the impact of biosolids application.

ACKNOWLEDGMENT

The authors acknowledge Center for Education and Training in Agricultural and Related Sciences (CETARS) Program through USDA (award number 2011-38422-30835) and Puerto Rico Aqueduct Sewer Authority (PRASA) project number 2006-00095, for their financial support.

This material is based upon work supported by the National Science Foundation and the Environmental Protection Agency under Cooperative Agreement Number DBI-0830117. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or the Environmental Protection Agency. This work has not been subjected to EPA review and no official endorsement should be inferred. This work was also supported by Grant 2G12MD007592 from the National Institutes on Minority Health and Health Disparities (NIMHD), a component of the National Institutes of Health (NIH). Authors also acknowledge the USDA grant number 2011-38422-30835 and the NSF Grant # CHE-0840525 J. L. Gardea-Torresdey thanks the Dudley family for the Endowed Research Professorship, the Academy of Applied Science/US Army Research Office, Research and Engineering Apprenticeship program (REAP) at UTEP, grant # W11NF-10-2-0076, sub-grant 13-7, and STARs programs of the University of Texas System.

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