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EFFECTS OF SEWAGE SLUDGE AND SEWAGE SLUDGE COMPOST AMENDMENT ON SOIL PROPERTIES AND *Zea mays* L. PLANTS (HEAVY METALS, QUALITY AND PRODUCTIVITY)

Rocío VACA[1], Jorge LUGO[1], Ricardo MARTÍNEZ[1], María V. ESTELLER[2] and Hilda ZAVALETA[3]

[1] Laboratorio de Edafología y Ambiente, Facultad de Ciencias, Universidad Autónoma del Estado de México, Instituto Literario No. 100, 50000 Toluca, México. rociovpaulin@gmail.com
[2] Centro Interamericano de Recursos del Agua, Facultad de Ingeniería, Universidad Autónoma el Estado de México, Cerro Coatepec S/N 50130 Toluca, México.
[3] Colegio de Postgraduados, Instituto de Recursos Naturales. km 36.5 Carr. México-Texcoco, Montecillo 56230, México.

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Keywords: biosolids, heavy metals, soil, corn quality

ABSTRACT

The use of organic wastes in agriculture can improve the soil's productive capacity, and physical and chemical characteristics. This study evaluated the effects of sewage sludge, sewage sludge compost and inorganic fertilizer applications on nickel, copper and zinc contents in soil and corn grains (*Zea may*s L); maize productivity, and grain nutritional quality. Sewage sludge and sewage sludge compost at 18 Mg ha^{-1} and a mineral fertilizer (N-P-K) with a formulation of 150-75-30 were applied. Significant differences were observed in organic matter, phosphorus and zinc content between sewage sludge-soil and compost-soil, and inorganic fertilizer-soil ($P \leq 0.05$). Copper concentration was significantly high in compost-soil ($P \leq 0.05$). Productivity in compost-soil and sewage sludge-soil mixtures was higher than in inorganic fertilizer-soil. Grain quality, measured by relative percentage of starch, total nitrogen, protein, acid detergent fiber and neutral detergent fiber were adequate for human consumption. Application of sewage sludge or compost did not increase heavy metal concentrations in grain with respect to inorganic fertilizer-soil.

Palabras clave: biosólidos, metales pesados, suelo, calidad de maíz

RESUMEN

El uso de residuos orgánicos en la agricultura puede mejorar la capacidad productiva del suelo así como sus características físicas y químicas. En el presente estudio se evaluó el efecto de la adición de lodo residual, composta de lodo residual y fertilizante inorgánico en el contenido de níquel, cobre y zinc del suelo y grano de maíz (*Zea mays* L), así como en la productividad de maíz y calidad nutrimental del grano. Se aplicó una dosis de 18 Mg ha^{-1} de lodo residual o composta de lodo residual mientras que el fertilizante inorgánico aplicado fue fórmula 150-75-30 (N-P-K). Se observaron diferencias significativas en el contenido de materia orgánica, fósforo y zinc entre suelo-lodo residual, suelo-composta y suelo-fertilizante ($P \leq 0.05$). La adición de composta incrementó significativamente la concentración de cobre en el suelo ($P \leq 0.05$). La productividad de maíz obtenida en el suelo-composta y suelo-lodo residual fue más alta respecto al suelo-fertilizante. La calidad del grano, medida como porcentaje relativo de almidón, nitrógeno total, proteína y fibra detergente ácida y neutra, fue buena para el consumo humano. La aplicación de lodo residual o composta al suelo no incrementó la concentración de metales pesados en el grano de maíz.

INTRODUCTION

The application of organic waste or compost on soils used for crop production is of great importance due to the nutritional input and low cost (Mantovi *et al.* 2005). Organic waste, such as sewage sludge and sewage sludge compost, can improve the availability of nutrients thanks to the low molecular weight aliphatic compounds that interact strongly with the soil minerals (Hue and Ranjith 1994); moreover, it increases the soil's cation exchange capacity (CEC) (McBride *et al.* 1997, Shuman 1998). The factors that affect the bio-availability of elements in soil are waste source, pH, organic matter content and chemistry of the elements (Mantovi *et al.* 2005).

Sewage sludge from the treatment of municipal wastewater is characterized by high content of organic matter, N, P, K, Ca and Mg, as well as the presence of some potentially toxic elements such as heavy metals, which, in high doses, can cause toxicity in the food chain (Chang *et al.* 1981, Sadovnikova *et al.* 1993, Porta *et al.* 1999).

The composting process transforms organic matter into a drier, uniform and biologically stable product that could act as a good source of plant nutrients (Sullivan *et al.* 2002). Sewage sludge is often composted prior to application to the soil in order to reduce metal availability, since during this process there is a mineralization of organic compounds, which control the availability of heavy metals and cations to plants. Also, pathogens are eliminated during composting, and so this process produces an adequate agricultural product (Bernal *et al*. 1998, Casado-Vela *et al.* 2007).

Sewage sludge and sewage sludge compost were found to increase the availability of nutrients; however, despite their notable benefits to soil fertility, they were associated with negative effects on corn, water and soil ecological quality (Korboulewsky *et al.* 2002).

Heavy metals such as Zn and Cu are essential nutrients for plants and are present in sewage sludge and sewage sludge compost. Research has shown the effects of the application of sewage sludge on Cu and Zn levels in maize. Sewage sludge promoted an increase in total Zn concentration without becoming excessive for human consumption (Reddy *et al.* 1989, Cajuste *et al.* 2000, Warman and Termeer 2005a). Chang *et al.* (1992) found that total Cu concentration in corn does not exceed the limit of 25 mg kg^{-1}, but that this limit could be exceeded when Cu concentrations greater than 1500 kg ha^{-1} are applied to topsoil. Total Zn concentration in maize tissue may exceed the limit of 300 mg kg^{-1} when high amounts of Zn are applied to the soil (Lutrick *et al.* 1982). Chang *et al.* (1992) recommended Zn to be applied at concentrations of 3500 kg ha^{-1} to prevent adverse effects on plant growth. However, while there are a few studies about the effects of agricultural land application of sewage sludge compost on Cu and Zn concentrations in plants, only a small number of studies focus on corn as the source of study (Cajuste *et al.* 2000, Warman and Termeer 2005a).

The use of sewage sludge in the production of maize and grass as forage has also been documented (Warman and Termeer 2005b, Mantovi *et al.* 2005). These studies have evaluated the productivity, concentration and uptake of N, P and K by plants, as well as heavy metal concentrations in plant tissues and soil, but not the corn quality.

The disposal of municipal sewage sludge is an environmental problem that cities face today, and the use of these wastes as fertilizers is an issue of debate. In view of the above, the present study was carried out to assess the effect of different sewage sludge or sewage sludge compost concentrations on quality characteristics and yield of maize (*Zea mays* L.). Ni, Cu and Zn accumulation in soil and corn grain was also quantified to determine the relationship between heavy metal accumulation and type of organic amendment.

MATERIALS AND METHODS

Study area

The experiment was conducted in an agricultural farm in a rural area of Toluca (México), located at

19º 23´ 57´´ N latitude, 99º 42´ 47´´ W longitude and 2600 m above sea level, between March and November of 2006. This period of the year is characterized by mean monthly maximum and minimum temperatures of around 15 and 11.3 ºC respectively. Total rainfall is 765.3 mm (García 1988).

The soil is characterized as clay loam Haplic Phaeozem (CETENAL 1976, FAO/ISRIC/ISSS 1998); it is used for dryland farming (*Zea mais* L. or *Vicia faba* L.) and is rarely irrigated. The geology is alluvial (INEGI 1999).

Experimental design

Nine land plots of 8 x 6 m each were defined and distributed in a latin square. Three plots were used as controls and treated with N-P-K inorganic fertilizer with a 150-75-30 formulation (IF-S), another three were treated with 18 Mg dried sludge ha^{-1} of sewage sludge (Sw-S), and the remaining three plots were treated with an equal field rate of compost (SwC-S).

Sewage sludge and compost

Sewage sludge (Sw) was collected from a municipal wastewater treatment company called ECOSYS in Toluca, Mexico. For compost, Sw was mixed with fragments of corn stalks as a source of carbon and with shredded tire chips as a bulking agent. The composting was carried out as 55 ºC, to kill pathogens and decompose phytotoxic substances, for 35 days in cone-shapped, 1.5-m diameter static piles with a C/N 30-40 ratio according to Garrido *et al*. (2005).

Sewage sludge and sewage sludge compost (SwC) samplings were performed according to EPA methodology (1988), taking an individual sample of Sw or SwC of approximately 3 kg during seven days of wastewater plant operation. These were placed in polythene bags, air dried in the shade and mixed to form a compound sample. Later, they were quartered, finely ground, passed through a 2-mm stainless steel sieve and stored in a refrigerator (4 ºC).

Soil sampling

Soil samples were collected from the Ap horizon (0-20 cm). Sampling was conduced prior to soil amendment and at the end of the corn growth cycle. All samples were air-dried and ground in an agate mortar, homogenized and sieved to <2 mm, prior to being stored in plastic bags at room temperature until analysis.

Chemical analysis

All tests were performed at a constant dry weight. The chemical and physical determinations of soil before amendment (S), Sw, SwC, IF-S and soil mixtures (Sw-S and SwC-S), were cation exchange capacity (CEC) and cation exchange (K, Ca, Mg, Na) by the amonium acetate method (AS-12 method, NOM-021-SEMARNAT-2000), pH in water suspension using a 1:2.5 soil:solution ratio (w:w) after 30-min equilibrium time (McLean, 1982), organic matter content (OM) by the Walkley and Black (1947) method, total N by the Kjeldahl digestion-distillation procedure (Bremner 1996) and, phosphorous (P) by the Olsen method (Bremner 1996). Total heavy metal concentration was analyzed in samples sieved through a 0.149-mm mesh and digested with aqua regia (conc. HNO_3 -conc. HCl) 4:1 v/v on a hot plate and available heavy metals were determined using 0.005 M DTPA extraction (Lindsay and Norvell, 1978); the solutions were analyzed for Ni, Cu and Zn by flame atomic absorption spectrophotometry (AAS), Perkin Elmer model 3110 (Perkin Elmer, Norwalk, CT, U.S.A.).

Plant analysis

Plant sampling was conducted according to Eckblad (1991), obtaining a sample of 8 plants per experimental plot, with a total of 24 plants per treatment. The plants were taken from the middle groove (4 and 5) of each plot. Corn grain samples of each plot were harvested to determinate the chemical quality.

The chemical quality parameters of corn grains were total nitrogen by micro Kjeldahl method (AOAC 1995), starch by enzymatic methods, acid detergent fiber (ADF) and neutral detergent fiber (NDF) by the Van Soest method (1966), and protein by AOAC (1995) method. Crop productivity was determined according to Muchow (1994); total plant height (m) was measured from the ground to the spike; stem length (m) from the ground up to the youngest leaf with exposed ligule; number of leaves per plant; leaf area; number of nodes in the main stem; number of ears; and total productivity of maize grain.

Heavy metals were determined using Van Loon's method (Van Loon *et al.* 1973). Quantification was performed by flame atomic absorption spectrophotometry (AAS), Perkin Elmer model 3110 (Perkin Elmer, Norwalk, CT, USA).

Data analysis

Statistical analysis was performed using Statgraphics Plus ver. 5.0 software. An analysis of variance (ANOVA) for the latin square design and Tukey's test (Montgomery 1984), at 95 % confidence level, were performed to detect significant differences in soil and plant characteristics between IF-S, Sw-S and SwC-S.

TABLE I. HEAVY METAL CONCENTRATIONS IN SOIL, SEWAGE SLUDGE, AND SEWAGE SLUDGE COMPOST

Metal	Maximum permitted (mg kg^{-1})			Concentration measured (mg kg^{-1})		
	Soil[a]	Sewage sludge[b]		S	Sw	CSw
		Good	Excellent			
Zn	110 – 400	7500	2800	32.71 ± 1.23	808.60 ± 2.02	760.75 ± 1.68
Cu	60 – 125	4300	1500	8.03 ± 0.65	243.44 ± 2.33	239.64 ± 1.89
Ni	20 – 100	420	420	nd	31.47 ± 0.35	31.23 ± 0.56

[a]Kabata-Pendias and Pendias (1992). [b]NOM-004-SEMARNAT-2002. S, soil before amendment; Sw, sewage sludge; SwC, sewage sludge compost; nd, below detection limit. Data are mean ± SE (n = 9).

RESULTS AND DISCUSSION

According to the maximum permissible amounts of Zn, Cu and Ni in sewage sludge and biosolids for their final disposal, as reported by Mexican Standards (NOM-004-SEMARNAT-2002), the Sw and SwC employed in this experiment were classified as excellent amendments for agricultural use (**Table I**). The selected chemical properties of S, Sw, SwC, IF-S, and soil mixtures are given in **table II**. The pH, CEC and exchangeable ions, did not change significantly among IF-S, Sw-S, and SwC-S (P > 0.05). The pH from IF-S and soil mixtures was slightly acidic, promoting a high availability of nutrients.

The sewage sludge compost contained less OM than Sw; this could be due to microbial decomposition of carbon and its subsequent release as CO_2 (Baziramakenga and Simard 1998), therefore, during the process of composting, OM mass and bulk usually decrease due to the volatilization of organic carbon to carbon dioxide (Peña *et al.* 1992). The carbon remaining after the bio-oxidative phase of composting is relatively resistant to microbial degradation (Bernal *et al.* 1998). The agricultural land application of Sw or SwC increased the content of OM in soil (P ≤ 0.05); at the end of the corn growth cycle, OM increased 2.54 and 2.51-fold in Sw-S and SwC-S with respect to IF-S, respectively (**Table II**).

Total N in soil increased 2 and 1.6-fold in Sw-S and SwC-S with respect to IF-S, respectively; similar results were found by Singh and Agrawal (2007). N mineralization of the organic fraction could increase with the subsequent application of organic amendments; and so organic N will gradually become inorganic N, which is used by plants (Rodriguez *et al.* 2003, Warman and Termeer 2005b). P concentration in Sw-S and SwC-S was significantly higher (P ≤ 0.05) than in IF-S (**Table II**). The absorption of P added to the soil through the application of Sw or SwC was promoted by the presence of Ca^{2+} in the soil, since this element is characterized by having a high P fixing capacity. It has been reported that P added to soil by compost or other fertilizers could form complexes with Ca^{2+} ions (Korboulewsky *et al.* 2002, Esteller *et al.* 2009) making them less available to plants. Higher quantities of proteinic materials

TABLE II. SELECTED CHEMICAL PROPERTIES OF SOIL BEFORE AMENDMENT, SEWAGE SLUDGE, SEWAGE SLUDGE COMPOST, FERTILIZED SOIL AND SOIL MIXTURES AT 180 DAYS AFTER AMENDMENT (CORN HARVEST)

	S	Sw	SwC	IF-S	Sw-S	SwC-S
pH	6.4 ± 0.11	6.4 ± 0.10	7.0 ± 0.23	6.1[a] ± 0.28	6.2[a] ± 0.10	6.2[a] ± 0.10
OM (%)	3.11 ± 0.30	61.60 ± 2.30	59.66 ± 3.56	2.81[a] ± 0.29	7.14[b] ± 0.31	7.08[b] ± 0.46
N (%)	0.11 ± 0.06	6.83 ± 1.38	4.95 ± 1.89	0.17[a] ± 0.03	0.33[b] ± 0.03	0.28[b] ± 0.03
P (%)	93.60 ± 4.98	519.20 ± 13.00	494.54 ± 6.36	91.60[a] ± 2.08	129.00[b] ± 1.00	136.00[b] ± 3.40
CEC (cmol kg^{-1})	18.0 ± 3.4	39.0 ± 2.2	41.0 ± 3.8	18.1[a] ± 0.9	20.7[a] ± 4.1	20.0[a] ± 1.6
Ca^{2+} (cmol kg^{-1})	5.68 ± 0.33	10.67 ± 0.78	8.53 ± 0.69	6.76[a] ± 0.51	6.62[a] ± 0.06	6.60[a] ± 0.68
Mg^{2+} (cmol kg^{-1})	3.32 ± 0.09	6.25 ± 1.23	4.49 ± 0.44	4.10[a] ± 0.46	5.29[a] ± 0.54	4.42[a] ± 0.52
K^+ (cmol kg^{-1})	0.21 ± 0.01	3.29 ± 0.80	2.78 ± 0.69	0.24[a] ± 0.05	0.23[a] ± 0.00	0.23[a] ± 0.00
Na^+ (cmol kg^{-1})	0.17 ± 0.01	2.0 ± 0.05	1.1 ± 0.08	0.15[a] ± 0.02	0.20[a] ± 0.02	0.20[a] ± 0.02

S, soil before amendment; Sw, sewage sludge; SwC, sewage sludge compost; IF-S, inorganic fertilizer-soil; Sw-S, sewage sludge-soil; SwC-S, sewage sludge compost- soil. Data are mean ± SE (n = 9). Different letter in the same row show significance differences (P ≤ 0.05).

TABLE III. TOTAL AND AVAILABLE METALS OF FERTILIZED SOIL AND SOIL MIXTURES AT 180 DAYS AFTER AMENDMENT (CORN HARVEST)

	Total Zn (mg kg^{-1})	Total Cu (mg kg^{-1})	Total Ni (mg kg^{-1})	Available Zn (mg kg^{-1})	Available Cu (mg kg^{-1})	Available Ni (mg kg^{-1})
IF-S	$35.15^{a} \pm 0.63$	$10.06^{a} \pm 0.07$	$9.48^{a} \pm 2.63$	$5.23^{a} \pm 0.07$	$4.39^{a} \pm 0.04$	$0.39^{b} \pm 0.05$
Sw-S	$41.65^{b} \pm 0.45$	$11.05^{a} \pm 0.58$	$10.93^{a} \pm 2.04$	$7.06^{b} \pm 0.50$	$4.30^{a} \pm 0.22$	$0.67^{ab} \pm 0.18$
SwC-S	$45.04^{b} \pm 4.38$	$13.03^{b} \pm 1.37$	$11.29^{a} \pm 2.68$	$9.55^{b} \pm 1.72$	$4.80^{b} \pm 0.52$	$0.98^{a} \pm 0.27$

IF-S, inorganic fertilizer-soil; Sw-S, sewage sludge-soil; SwC-S, sewage sludge compost-soil. Data are mean ± SE (n = 9). Different letter in the same column show significance differences ($P \leq 0.05$).

and polyphosphate compounds from detergents in Sw (Singh and Agrawal 2007) increased N and P contents in SwC and, therefore, in the soil mixtures.

Heavy metals in soil

In this study, total and available concentrations of Zn, Cu and Ni in IF-S and soil mixtures are reported (**Table III**). Zn was the most abundant metal, followed by Ni and Cu.

IF-S had the lowest total and available concentration of Zn ($P \leq 0.05$) (**Table III**). Total Zn concentration increased in plots amended with compost and sewage sludge due to the contribution of Zn by waste. Special attention is given to Zn if the soil is amended several times with these biosolids, because the Sw and SwC applied to the soil presented high concentrations of this element, which may be available to the plants. However, organic matter helps decrease this effect, because stable complexes are formed, which reduce the availability of this metal (Cripps *et al.* 1992). Total Zn was negatively correlated with pH ($r = -0,645$, $P \leq 0.05$); at low pH values most of the Zn is present in cationic form (soluble), whereas humate complexes are formed at increased values (Shuman 1999). Zn is an element that reacts with i) organic compounds from sewage sludge, which control its speciation, mobility and bioavailability; ii) organic acids from waste, including substances with O-functional groups, and iii) other molecules that form metal complexes; as a result of the properties of organic polyelectrolytes, these complexes reduce the activity of Zn (Martinez and McBride 1999).

Data on metal bioavailability gives more indication of toxicity than the total content analysis, and they could help predict the potential risk of metal uptake by plants and mobility in the system (Bell *et al.* 1991). The lowest percentage of Zn availability was observed in IF-S (14.88 %), followed by Sw-S (16.95 %) and finally SwC-S (21.20 %); similar results were reported by Ciba *et al.* (1997).

Total Cu concentrations were similar in IF-S and Sw-S, while SwC-S had significantly higher values ($P \leq 0.05$). The percentage of availability was as follows: SwC-S (36.84 %) < Sw-S (38.91 %) < IF-S (43.64 %). This element has less mobility in soil amended with sewage sludge or compost because it forms stable links with organic matter, thus decreasing availability (Zhu and Alva 1993).

Although Zn and Cu concentrations increased with the addition of waste, final metal concentrations in SwC-S and Sw-S remained below the maximum allowable metal concentrations in soil according to Kabata-Pendias and Pendias (1992) (**Table I**).

There were no significant differences between IF-S and soil mixtures with respect to total Ni concentration ($P > 0.05$) (**Table III**). Available Ni was low in all treatments. Similar results were reported by Thompson *et al.* (2001) and Bedell *et al.* (2006).

Productivity and corn grain nutritional quality

Maize plants cultivated in soil mixtures were significantly higher than IF-S ($P \leq 0.05$) (**Table IV**).

TABLE IV. PRODUCTIVITY AND MORPHOLOGICAL PARAMETERS OF MAIZE CULTIVATED (180 DAYS AFTER SOWING) ON FERTILIZED SOIL AND SOIL MIXTURES

	Height (m)	Stem diameter (cm)	Number of Leaves	Foliar area (cm^{-2})	Number of nodes	Number of corn cob	Productivity t ha^{-1}
IF-S	$2.29^{a} \pm 0.15$	$8.07^{a} \pm 1.06$	$8.95^{a} \pm 0.75$	$391.91^{a} \pm 81.66$	$8.62^{a} \pm 0.64$	$1.00^{a} \pm 0.00$	4.09^{a}
Sw-S	$2.40^{b} \pm 0.24$	$7.94^{a} \pm 1.40$	$9.12^{a} \pm 0.85$	$396.83^{a} \pm 64.20$	$9.04^{a} \pm 0.69$	$1.34^{a} \pm 0.20$	5.22^{ab}
SwC-S	$2.47^{b} \pm 0.15$	$7.90^{a} \pm 0.92$	$9.20^{a} \pm 2.30$	$439.51^{b} \pm 82.07$	$8.95^{a} \pm 0.64$	$1.16^{a} \pm 0.38$	5.77^{b}

IF-S, inorganic fertilizer-soil; Sw-S, sewage sludge-soil; SwC-S, sewage sludge compost-soil. Data are mean ± SE (n = 9). Different letter in the same column indicate significance differences ($P \leq 0.05$).

Wastes are rich in N and organic matter, providing more nutrients to plants and promoting plant growth. Stem diameter did not show significant differences among treatments (P > 0.05). The soil analysis results indicated similar concentrations of Mg^{+} in all treatments (**Table II**), which could be related to the uniformity in stem diameter; this element is linked to the production of thick stems (Llanos 1984).

Number of leaves and leaf area are very important characteristics for corn cob development and the filling of the grain. The number of leaves produced per plant did not show significant differences among treatments (P > 0.05), since this characteristic is only associated with the maize genotype. Plant growth in SwC-S showed the largest leaf area (P ≤ 0.05), while IF-S and Sw-S did not show any difference.

With regard to the number of corn cobs per plant, there were no significant differences among treatments (P > 0.05), but maize productivity (Mg ha^{-1}) in SwC-S was significantly higher than in IF-S (P ≤ 0.05) (**Table IV**). Leaves are the photosynthetic machinery in plants, so it is expected that a larger leaf area will provide more carbohydrates for grain filling (Llanos 1984, Reyes 1990). This increase in grain production may be explained by the improvement in oil properties due to the OM and plant nutrients present in sewage sludge (Melo *et al.* 2007).

Several studies have focused on phytotoxicity caused by heavy metals and elements such as P and N (Kidd *et al.* 2007, Bose and Bhattacharyya 2008), but only a few works focus on grain quality. In corn and wheat crops, heavy metals such as Cu, Cd, Ni and Zn are accumulated in different parts of the plant, such as leaves, stems and roots, but little is known about their effect on starch, NDF, ADF, protein and nitrogen. In this study, the application of sewage sludge or compost did not significantly affect these chemical parameters in the grain corn (**Table V**) and no significant differences were observed between treatments (P > 0.05). The quality values found in this work are lower than those established by Llanos (1984), Reyes (1990) and FAO (1993).

Heavy metals in corn grain

Maize plants showed normal growth in the field and did not exhibit any symptoms of heavy metal toxicity. Melo *et al.* (2007) observed that metals and other toxic products did not affect maize plant growth after the application of sewage sludge to soil.

Cu and Zn concentrations in corn grain (**Table V**) were not significantly different among IF-S, Sw-S and SwC-S (P > 0.05). When pH in soil increases or is between 5 and 7, Zn and Cu are less available and less absorbed by plants.

In corn grain, Ni was below detection limits. The trace content of this heavy metal in the grain was not associated with pH or metal concentration in the soil, but rather attributed to the low metal availability and high organic matter content in the soil (Mantovi *et al.* 2005). Melo *et al.* (2007) conducted a study on maize uptake of Ni and found that the addition of sewage sludge to the soil increases the content of this metal in the shoots, but not in the grain. This shows that Ni translocation from the leaves and stem to the grain is not significant.

The concentrations of Zn and Ni in the corn grain were lower than those reported for the same species (Mantovi *et al.* 2005). By contrast, the concentrations of Cu in the corn grain were higher than those reported by Mantovi *et al.* (2005). Corn growth in IF-S also showed high concentrations of Cu, a fact attributed to the solubilization of a metal-organic complex by reducing pH to 6.1, which increased and promoted Cu transfer to plant tissue. It is known that heavy metal concentration in plants depends on concentrations of waste, OM, soil pH and translocation, which depends on plant species (Kim *et al.* 2003, Bose and Bhattacharyya 2008).

Zn concentration in wheat grain should be < 34 mg kg^{-1} for it to be fit for human consumption (Andersson and Petersson 1981); however, Zn concentrations in maize cultivated in IF-S, Sw-S and SwC-S were greater than those suggested for wheat (**Table V**). With applications of sewage sludge and compost, Zn concentration in the grain did not

TABLE V. CHEMICAL QUALITY AND METAL CONTENT IN MAIZE GRAIN CULTIVATED (180 DAYS AFTER SOWING) ON FERTILIZED SOIL AND SOIL MIXTURES

	Starch (%)	N (%)	Protein (%)	ADF (%)	NDF (%)	Zn (mg kg^{-1})	Cu (mg kg^{-1})
IF-S	71.34^a ± 0.68	1.83^a ± 0.14	11.45^a ± 0.91	8.08^a ± 2.35	23.65^a ± 2.95	40.88^a ± 3.17	26.20^a ± 1.17
Sw-S	70.65^a ± 2.93	1.76^a ± 0.11	11.06^a ± 0.70	11.04^a ± 6.34	24.77^a ± 12.11	40.47^a ± 2.40	25.33^a ± 4.81
SwC-S	66.99^a ± 0.78	1.71^a ± 0.17	10.70^a ± 1.08	7.03^a ± 0.59	21.62^a ± 1.19	42.43^a ± 4.80	27.60^a ± 1.19

IF-S, inorganic fertilizer-soil; Sw-S, sewage sludge-soil; SwC-S, sewage sludge compost-soil. Data are mean ± SE (n = 9). Different letter in the same column indicate significance differences (P ≤ 0.05).

increase significantly and was similar to IF-S. The results of this study were similar to those observed by Bose and Bhattacharyya (2008). Cu availability was higher than Zn; plants take Zn rather than Cu because antagonism occurs between these elements (Kabata-Pendias and Pendias 1992).

The concentrations of total and available Cu were low in Sw-S and SwC-S, in contrast, concentrations of this element in corn grain were quite high, mainly due to Cu concentration increasing continuously with the successive plant growth stages and to the roots ability to retain Cu under conditions of both Cu deficiency and excess (Bose and Bhattacharyya 2008). Cu concentration in grain increased due to the field rate application of sewage sludge and compost to the soil, indicating that Cu was available to the plants even though the soils were neither acidic nor calcareous (Alloway 1995).

CONCLUSIONS

The results of the present study indicate that the addition of sewage sludge or sewage sludge compost does not imply environmental risks, offering a solution to the problem of final disposal of organic waste in this region.

Soil amended with sewage sludge and sewage sludge compost increased organic matter (2.5-fold), phosphorus ($\geq$ 1.4-fold) and nitrogen content ($\geq$ 1.6-fold), as compared to the inorganically fertilized soil (N-P-K).

The addition of these organic wastes to the soil did not cause toxicity nor did it affect the number of leaves and corn cobs per plant; nevertheless, it did increase grain production. The percentages of starch, ether extract, protein, phosphorus, and nitrogen, were within the range established by FAO (1993). Neutral detergent fiber in the corn grain increased with the addition of sewage sludge, without affecting the quality parameters.

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