Dynamic Soil, Dynamic Plant ©2008 Global Science Books

Sewage Sludge Compost Evaluation in Oats, Pepper and Eggplant Cultivation

Antonis A. Zorpas

[1] National Technical University of Athens, Department of Chemical Engineer, Laboratory of Environmental Science 9, Heroon Polytechniou St., Zographou 157 00, Greece
[2] ENVITECH Ltd., Institute of Environmental Technology & Sustainable Development, P.O. Box 34073, 5309, Paralimni, Cyprus

Correspondence: **antoniszorpas@yahoo.com, envitech@cytanet.com.cy, www.envitech.org**

ABSTRACT

Environmental problems associated with sewage sludge disposal have prompted legislative actions over the past years. Composting of sewage sludge can enhance its quality and suitability for agricultural use. The presence of heavy metals in raw material is one of the most serious problems limiting its use as a final product in agriculture. The application of natural zeolite, has the ability to take up heavy metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn) in significant levels ($p<0.05$) as indicated by the final results: 25% (w/w) of zeolite in sludge takes up 100% of Cd, 20% of Co, 36% of Cu, 12% of Cr, 10% of Mn, 40% of Fe and Zn, 32% of Pb and 53% of Ni. The compost was added in pots which contained soil at 25, 50, 75 and 100 (w/w). Oats, pepper and eggplant seed were cultivated in order to observe the absorbance of metals that remain in the compost through the roots, the looms and the leaves. The crop uptake of heavy metals through the roots increased with the amount of compost used in the pot. The application of compost in pepper, oats and eggplant cultivation increased while zeolite could retain the heavy metals and did not let them pass from the roots to the final product. Also, the phytotoxicity and the humics of the final product are presented as a function of evaluation. The substrate was characterized as non-phytotoxic after 80 days of maturity, and the (Germination Index) GI was 78, 75 and 72 for oats, eggplant and pepper seeds, respectively. Total humics was low due the low concentrations of lignin and cellulose in the initial sample.

Keywords: germination index, removal of metals, sewage sludge, zeolites

INTRODUCTION

Land application of compost materials (like municipal solid waste, sludge) usually results in a positive effect on the growth and yield of a wide variety of crops and the restoration of ecologic and economic functions of land. Agricultural uses of compost have given a promise for a variety of field crops (e.g., maize, sorghum, forage grasses) and vegetables for human consumption (e.g., lettuce, cabbage, beans, potatoes, cucumbers). Responses by plant systems have ranged from none to over a twofold increase in yield. Specific responses are crop and site dependent. In most cases, yields were higher when composts were applied with fertilizer management programs. In some cases, elevated trace metal uptake was noted with lead and boron of greatest concern. Where long-term monitoring has been possible, benefits persist and actually accrue when sound soil/crop management practices are followed. Levels of toxic elements in plants for human consumption are either not well known or thresholds were not reached, as little mention was made in the literature.

Sewage sludge, also referred as biosolids, is a byproduct of sewage treatment processes (Singh and Agrawal 2008). Land application of sewage sludge is one of the important disposal alternatives. Characteristics of sewage sludge depend on the quality of sewage and type of treatment processes followed. Being rich in organic and inorganic plant nutrients, sewage sludge may substitute fertilizer, but availability of potential toxic metals often restricts its uses. Sludge amendment to the soil modifies its physicochemical and biological properties. Sewage sludge is a wastewater industrial sub-product with high organic matter and nutritional contents traditionally used as an agricultural soil fertilizer and to promote biomass production (Zorpas 1999). Sludge resulting from wastewater treatment constitutes a valuable source of essential nutrients for agricultural cultivation (Mendoza *et al.* 2006). In addition, organic matter from sludges improves some physical and chemical properties of soil, leading to better plant growth. Along with this, sludge application to soils is considered a useful method for their final disposition (Han *et al*. 2001; Mendoza *et al*. 2006).

However, sludge may contain high amounts of potentially toxic trace elements, which may exceed soil natural concentration by two or more order of magnitude (Oliver *et al.* 2005; Mendoza *et al*. 2006).

Land application of sewage sludge (biosolids) has been a worldwide agricultural practice for many years (Warman and Termeer 2005). Land application of sewage sludge has been extensively used as an effective dispersive method throughout Canada, the United States and Europe for more than 40 years. Many studies have demonstrated the positive effect of land application of sewage sludge or sludge compost on corn and forage yields and soils (Warman 1986; Tiffany *et al.* 2000). It effectively disposes of a 'waste' product while recycling valuable nutrients into the soil-plant ecosystem; however, too often the dispersal has created environmental problems that force government agencies to restrict the amount and type of sewage sludge which can be land applied.

A number of vegetation sludge treatment methods have been recently employed, and these can be divided into physico-chemical, biological methods and physical methods. The use of sewage sludge in agriculture is not new, since it is an inexpensive source of organic matter and its use contributes to solving a serious environmental problem (Morenom *et al*. 1996). However, there are certain risks involved in its use, some of which, such as those derived from the instability of the organic matter or from the mineralizable organic nitrogen content, are only of transitory nature. Such

Received: 17 June, 2008. Accepted: 6 September, 2008.

Original Research Paper

problems are easily eliminated by composting, a process which stabilizes the organic matter content.

One of the most serious problems for the application of sewage sludge in agriculture is the presence of the heavy metals. Some of these are extremely toxic and when added to the soil along with the organic amendment, negatively affect plant development and even enter the food chain. Composting of sewage sludge with natural zeolite (clinoptilolite) can enhance its quality and suitability for agricultural use. Zeolites have been world-wide for the last decades, either for their cation exchange or molecular sieving properties. Natural zeolites nowadays are mostly used in catalysis, in air enrichment, as filers in paper and rubber industry, in soil benefication, as animal feed supplements, and in water and wastewater treatment for the ammonia and heavy metal removal.

At present the zeolite group includes more than 40 naturally occurring species, and is the largest group of minerals among the silicates. Before 1960s, zeolite minerals were thought to be mainly distributed in hydrothermal veins and geodes in basalts, andesites and other volcanic rocks (Tsitsishvili *et al.* 1992). Zeolite in such settings forms large, well-shaped crystals and druses. Due to the usual small size of veins and because of poly-minerality, these deposits have no practical importance, but samples of vein origin have been used to establish the properties of the mineral and the possibility of their utilization in industry (Tsitsishvili *et al.* 1992). According to the bibliography (Tsitsishvili *et al.* 1992), in the 1980s more than 300000 t of natural zeolites were used in world market (150000 t in Europe and 90000 in Japan) and the most common zeolites were: clinoptilolite, mordenite, phillipsite and chapazite. Zeolite minerals are known to distribute rather unevenly in Nature. Clinoptilolite, mordenite, phillipsite, chapazite, stilbite, analcime and laumontine are very common whereas offretite, paulingite, barrerite and mazzite, for example, are much rarer, and sometimes limited to single occurrences (Tsitsishvili *et al.* 1992). According to Zorpas (1999) and Tsitsishvili (1992) zeolites can be used as structurally materials, in paper industry, to improve soil properties, in the animal feeds industry, in wastewater treatment plants, for the cleaning and improve the properties of the drinking water, for metal removal, etc.

In the greater region of Athens, with almost 4,500,000 citizens, the main wastewater treatment plant operating is on the rock-island of Psittalia. At Psittalia, approximately 850,000 $m^3 day^{-1}$ of mainly municipal wastewater along with industrial wastes are subjected to primary treatment, producing approximately 350 tones day^{-1} of dewatered anaerobically stabilized primary sewage sludge (DASPSS).

Landfilling is the main disposal route for sewage sludge in Athens, generating potential environmental hazards, including the production of odour and methane gas, as well as the contamination of groundwater by the leachate produced (Zorpas *et al.* 1998).

The aim of this work is to remove the heavy metals from sewage sludge compost before the application of compost in pepper, oats and eggplants cultivation (in pots) as well as to observe the behavior of the heavy metals through the absorbance of the roots. Also, the phytotoxicity (through the Germination Index, GI) and the humics of the final product are presented as a function of evaluation.

MATERIALS AND METHODS

Materials used, composting experiment, methods of chemical analysis

The dewatered anaerobically stabilized primary sewage sludge (DASPSS) samples were collected for a period of six month (April–September: 200-250 kg every 2 days) from the Psittalia wastewater treatment plant. Then the DASPSS samples were dried, homogenized and stored. Natural zeolite, clinoptilolite (Cli), used as a bulking agent, was collected from Evros, (Region in North Greece). The Cli was added to DASPSS at a rate of 0 to 30% at 5% increment, creating seven composting treatments (designated as treatment S0 to S7) (**Table 1**). The basic properties of Cli and DASPSS are given in **Table 2**.

The composting process was carried out in the Laboratory using an In-Vessel reactor of 1 m^3 active volume (Finstein *et al.* 1992; Zorpas 1999). The thermophilic phase in the reactor lasted 15 days. The temperature in the center of the reactor was about 60-65°C and the moisture percentage between 40-50%. The samples were aerated using an aerated air force, (oxygen concentration range between 5-8%). A temperature indicator controller controlled the operation of the fan in order to maintain the temperature at about 60°C, according to the following principle: minimum air flow (2.3 m^3/m^3 active volume) was provided at low temperature

Table 1 Treatments used in the composting experiment.

S0	0% clinoptilolite	+	100% DASPSS
S1	5% clinoptilolite	+	95% DASPSS
S2	10% clinoptilolite	+	90% DASPSS
S3	15% clinoptilolite	+	85% DASPSS
S4	20% clinoptilolite	+	80% DASPSS
S5	25% clinoptilolite	+	75% DASPSS
S6	30% clinoptilolite	+	70% DASPSS

Table 2 Selected physicochemical properties of sewage sludge, clinoptilolite and soil.

	DASPSS	SD	Clinoptilolite	SD	Soil	SD
Moisture, %	70.10	2.50	7.15	0.50	9.5	0.7
pH (solid : water = 1:10)	7.05	0.05	7.85	0.05	7.58	0.05
EC mS/cm (solid : water = 1:10)	1.001	0.002	0.155	0.002	0.959	0.002
Organic matter, % dry weight	45.10	1.25			32.2	1.5
Ash, % dry weight	24.50	1.50	80.65	1.50	25.34	1.5
TOC, % dry weight	26.10	0.50			17.6	1.25
TKN, % dry weight	1.75	0.25	0.032	0.002	1.1	0.05
C/N	14.91	0.25			16.65	0.05
NH_4-N	957	35	140	15	0.757	0.02
Total humics, % dry weight	2.45	0.05			3.52	0.05
Humification Index	0.04	0.001				
Cd, mg/kg	2	0.1	---		---	---
Cr, mg/kg	552	20	---		4	0.5
Cu, mg/kg	258	25	---		---	---
Fe, mg/kg	5098	250	1964		10012	105
Mn, mg/kg	150	15	10		176	15
Ni, mg/kg	41	2	---		---	---
Pb, mg/kg	326	21	111		6	0.2
Zn, mg/kg	1739	30	5		120	5
Na, mg/kg	724	23	1786		128	25
K, mg/kg	723	22	5493		1222	150

SD: Standard Deviation, ---: not detected.

(<30°C) and maximum air flow (28 m^3/m^3 active volume was provided at high temperature (>60°C). The minimum air flow corresponds to the minimum oxygen demand for the micro-organisms and the maximum to the necessary air for cooling. After the thermophilic period, in which the organic material was biodegraded, the compost was piled to an enclosed package where it remained for about 4 months to mature. The Cli in final compost was removed using sieve (2.5-2.7 mm diameter).

For all the raw materials and final compost (after Cli removed) obtained from the seven treatments, the following parameters were measured: pH value, conductivity, Total Organic Carbon (TOC), Organic Matter (OM), Total Phosphorous (PO_4-P), Total Kjeldahl Nitrogen (TKN) and ammonia content, C/N ratio, and total heavy metals content (Cd, Cr, Cu, Fe, Mn, Ni, Zn, and Pb), (Adamas 1990; Zorpas *et al.* 1998; Zorpas 1999). For the metal concentrations, the sludge samples were digested (1 g sample with 10 ml c. HNO_3 + 2 ml c. H_2SO_4), vacuum filtered and the filtrates were used for the metal determination by atomic absorption spectroscopy using a Perkin-Elmer 2380 spectrophotometer (Zorpas *et al.* 1998). Humic substances were extracted according to the following scheme (Schnitzer 1982): 2.5 g of sample were shaken for 24 h in ambient temperature using 100 ml of NaOH 0.5 N. Suspensions were filtered through Whatman No 1 filter paper. Then the filtrate was dried at 80°C and the dry weight was obtained. Lignin and cellulose were determined by a digestion technique with 72% sulphuric acid (Zorpas *et al.* 1998; Zorpas 1999).

Seed germination index

Compost samples from S5 treatment were collected periodically during composting and maturing and were used in seed germination and root length test. Briefly, water extracts were obtained by mixing 10 g of compost samples with 20 ml of de-ionized and distilled water (DDW) for 2 h. The test solution was obtained by centrifuging the slurry at 5000 rpm for 30 min, and then filtered through Whatman No 1 filter paper. A 10 ml of test solution was pipetted into a sterilized plastic Petri dish. Also, one blank with only DDW was carried out. Twenty seeds of each group were placed in each Petri dish and incubated at 22°C in the dark for 7 days. The GI was calculated according to the following formula (Tiquia and Tam 1998):

$$GI = \frac{(\%G)(\%L)}{100} \quad (1)$$

where % G = Growth index,

$$\%L(Root\ \ Length) = \frac{(Root\ \ Length\ \ of\ Treatment)}{(Root\ \ Length\ \ of\ Control)} * 100 \quad (2)$$

In our study, if the 0 < GI < 26 the substrate is characterized as very phytotoxic, 27 < GI < 66 the substrate is characterized as phytotoxic, 67 < GI < 100 the substrate is characterized as non-phytotoxic and if the GI > 101 then the substrate is characterized as phyto nutrient.

Metal uptake by plant

In order to observe the behavior of heavy metals in cultivation, oats, pepper and eggplant seeds have been used. The seeds of oats, pepper and eggplant were transpired in pure water as described above (Seed Germination Index) and were transplanted as one plant per pot. Pots were maintained around filed capacity by daily watering with distilled water. The compost from either S0 (0% Cli) or S5 (25%Cli) was mixed with soil (**Table 2**) at a rate of 25, 50, 75 and 100% (w/w) and used in the pot experiment and growth on natural conditions for about 30 days. The plant samples were separated (by hand) into leave, loom and root and the analysis was carried out as described above.

Statistical analysis

Statistical analysis was performed using Microsoft Excel (2003).

RESULTS AND DISCUSSION

Effect of zeolite on metal concentration in compost

Table 3 presents the metal content in DASPSS, and in the final products. When comparing the metal content of the first sample (So), sewage sludge compost and DASPSS sample, it can be observed that the concentration of chromium, nickel, manganese, lead and zinc appeared to increase while that of copper and iron to decrease. Composting can concentrate or dilute heavy metals present in sewage sludge (Wagner *et al.* 1990). This change in metal concentration depends on the metal loss through leaching and on the overall concentration of metals due to organic matter destruction. Natural zeolite has the ability to exchange sodium and potassium. It is also seen that increasing the amount of zeolite the concentration of all heavy metals in the compost samples decreased and the concentration of sodium and potassium increased. It is observed that the zeolite can take up a significant ($p<0.05$) amount of heavy metals. 25% (w/w) of zeolite takes up 100% of Cd, 20% of Co, 36% of Cu, 12% of Cr, 10% of Mn, 40% of Fe and Zn, 32% of Pb and 53% of Ni.

Seed germination index

Seed germination GI) was studied under S5 sample, compared with a control. During the composting process (until the 15th day) the G.I was less than 20 due to the fact that compost was immature. The appearance of the phytotoxicity in the first step of the composting process related to the decomposition of the organic matter. The immature composts seem to have high phytotoxicity due to the fact that phytotoxic compounds are produced by microorganisms and also because at the first step of composting the pH is

Table 3 Metals content in raw material and in cured compost.

Metal[1]	Cured compost [2]							
	DASPSS	So	S1	S2	S3	S4	S5	S6
Cd	0.002 ± 0.0005	0.002 ± 0.0001	nd [3]	nd	nd	nd	nd	nd
Cr	0.552 ± 0.025	0.578 ± 0.023	0.552 ± 0.023	0.550 ± 0.023	0.542 ± 0.020	0.501 ± 0.024	0.488 ± 0.025	0.478 ± 0.025
Co	0.599 ± 0.032	0.557 ± 0.032	0.550 ± 0.030	0.525 ± 0.031	0.501 ± 0.033	0.488 ± 0.031	0.475 ± 0.032	0.461 ± 0.029
Cu	0.258 ± 0.005	0.205 ± 0.005	0.265 ± 0.006	0.184 ± 0.006	0.181 ± 0.004	0.172 ± 0.004	0.163 ± 0.006	0.140 ± 0.007
Fe	5.098 ± 0.310	4.118 ± 0.225	3.963 ± 0.170	3.838 ± 0.125	3.217 ± 0.125	3.191 ± 0.150	2.999 ± 0.150	2.673 ± 0.100
Ni	0.041 ± 0.003	0.045 ± 0.003	0.040 ± 0.002	0.038 ± 0.001	0.038 ± 0.001	0.034 ± 0.001	0.019 ± 0.002	0.018 ± 0.001
Mn	0.150 ± 0.003	0.168 ± 0.005	0.150 ± 0.003	0.149 ± 0.003	0.139 ± 0.002	0.136 ± 0.003	0.136 ± 0.002	0.114 ± 0.001
Pb	0.326 ± 0.004	0.335 ± 0.004	0.199 ± 0.004	0.187 ± 0.003	0.178 ± 0.002	0.177 ± 0.003	0.157 ± 0.004	0.145 ± 0.005
Zn	1.739 ± 0.028	1.801 ± 0.030	1.400 ± 0.045	1.216 ± 0.037	1.117 ± 0.040	1.083 ± 0.035	1.027 ± 0.025	0.938 ± 0.027
K	0.723 ± 0.020	0.772 ± 0.012	0.772 ± 0.018	0.902 ± 0.013	0.965 ± 0.015	1.121 ± 0.025	1.215 ± 0.033	1.235 ± 0.045
Mg	1.132 ± 0.010	0.796 ± 0.012	0.786 ± 0.014	0738 ± 0.017	0.695 ± 0.009	0.620 ± 0.009	0.589 ± 0.010	0.538 ± 0.009
Na	0.724 ± 0.006	0.732 ± 0.006	0.783 ± 0.007	0.796 ± 0.007	0.865 ± 0.009	0.901 ± 0.012	1.011 ± 0.011	1.121 ± 0.010
Ca	13.827 ± 1.055	14.001 ± 1.185	13.159 ± 1.150	12.414 ± 1.005	11.825 ± 1.015	11.613 ± 1.005	10.320 ± 0.958	10.002 ± 0.950

[1] mg/g dry sludge; zeolite has been removed from the final products by sieving of 2.5-2.7 mm diameter.
[2] Mean value of 20 samples ± standard deviation.
[3] not detected.

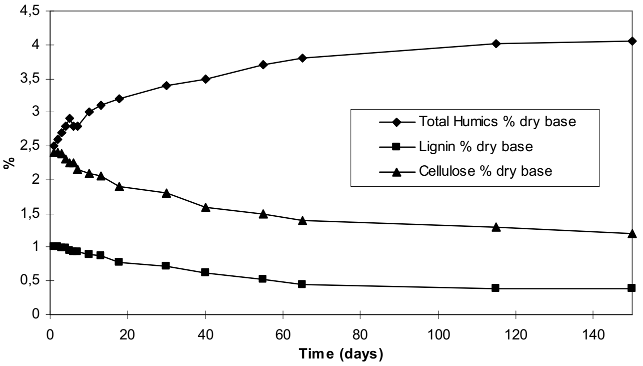

Fig. 1 Humics formation and the variations of lignin and cellulose in S5 compost sample.

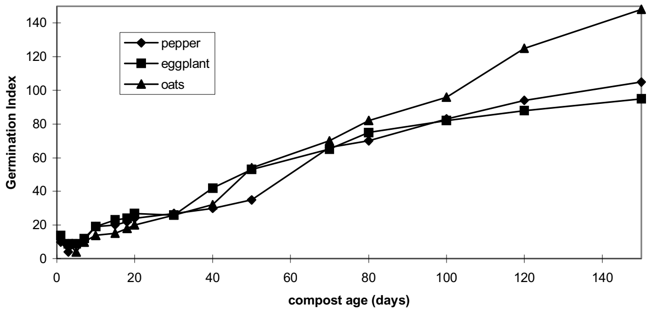

Fig. 2 Germination Index for oats, pepper and eggplant seeds for the S5 Sample.

initially low, due to the acid formation (pH <5.5) and ammonias (pH >8.5) (Zorpas 1999; Zorpas *et al.* 2000). From the 20–75 d (which we have the formation of humics, **Fig. 1**) the GI were up to 70 almost for all the cultivations. The Growth Index (%G) at the same time was 75, 70 and 70% for oats, pepper and eggplant cultivation, respectively while at the same time the %L (root length) was 89, 150 and 135%, respectively for oats, pepper and eggplant cultivation. From **Fig. 2** it is obvious that it is unable to use the substrate for cultivation before the 80th day of maturity. The substrate is characterized as non-phytotoxic after 80 days of maturity in which the GI is 78, 75 and 72 for oats, eggplant and pepper seeds, respectively. Total Humics are presented to low (which is 27.43 mg/g, or 2.45%, in the initial sample) due the low concentrations of lignin and cellulose in the initial sample, which are 0.211 mg/g (1.01%) and 10.32 mg/g (2.40 %), respectively. After 150 d of composting and maturity time oat's GI = 147, that of pepper = 108 and that of eggplant = 96.

In order to observe the behavior of heavy metals in cultivation, oats, pepper and eggplant seeds have been used. The compost was added in the pot with soil (**Table 3** presents the soils physicochemical characteristics) at 25, 50, 75 and 100% (w/w).

Tables 4, **5**, and **6** present the metal concentration in roots, looms and leaves in oats, pepper and eggplant cultivation, respectively. The results indicated that when sludge compost applied to the soil the absorbance of heavy metal thought the roots is greater than when we applied the composted material with zeolite (S5 sample) in all ratios and for all the cultivations. This is because zeolite retains the metals in their structural cable.

With respect to the species the accumulation of the metals are present in the following series:

Cr: eggplant roots > pepper roots > oats roots; oats looms > pepper looms > eggplant looms; oats leaves > pepper leaves = eggplant leaves.

Cu: pepper roots > eggplant roots > oats roots; pepper looms > eggplant looms > oats looms; pepper leaves > eggplant leaves > oats leaves.

Fe: pepper roots = eggplant roots > oats roots; oats looms > pepper looms = eggplant looms; oats leaves > eggplant leaves > pepper leaves.

Mn: pepper roots > eggplant roots > oats roots; oats looms > pepper looms = eggplant looms; oats leaves > pepper leaves = eggplant leaves.

Ni: oats roots > pepper roots > eggplant roots; oats

Table 4 Metal concentration (mg/g) in roots, looms and leaves in oats cultivation.

Control	Compost	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Roots									
100%		---	---	0.002 ± 0.0005	2.050 ± 0.245	0.075 ± 0.005	---	---	0.105
0%	100%So	---	0.113 ± 0.012	0.014 ± 0.002	2.348 ± 0.245	0.053 ± 0.005	0.035 ± 0.003	0.125 ± 0.009	0.460± 0.024
0%	100%S5	---	0.085 ± 0.009	0.012 ± 0.002	1.761 ± 0.135	0.045 ± 0.005	0.025 ± 0.003	0.093 ± 0.009	0.345 ± 0.019
25%	75% So	---	0.052 ± 0.008	0.012 ± 0.002	1.984 ± 0.150	0.033 ± 0.005	0.025 ± 0.003	0.080 ± 0.008	0.355 ± 0.019
25%	75% S5	---	0.039 ± 0.008	0.008 ± 0.002	1.435 ± 0.172	0.035 ± 0.005	0.019 ± 0.003	0.060 ± 0.008	0.259 ± 0.012
50%	50% So	---	0.042 ± 0.009	0.007 ± 0.001	1.542 ± 0.127	0.020 ± 0.004	0.017 ± 0.002	0.025 ± 0.004	0.299 ± 0.013
50%	50% S5	---	0.017 ± 0.003	0.004 ± 0.001	1.257 ± 0.179	0.020 ± 0.004	0.015 ± 0.002	0.029 ± 0.004	0.285 ± 0.013
75%	25% So	---	0.024 ± 0.004	0.006 ± 0.001	1.062 ± 0.192	0.010 ± 0.002	0.009 ± 0.001	0.022 ± 0.004	0.254 ± 0.012
75%	25% S5	---	0.009 ± 0.001	0.003 ± 0.001	0.987 ± 0.109	0.015 ± 0.003	0.009 ± 0.001	0.015 ± 0.003	0.300 ± 0.010
Looms									
100%		---	---	0.001 ± 0.0002	0.950 ± 0.092	0.015 ± 0.003	---	---	0.015 ± 0.002
0%	100% So	---	0.035 ± 0.006	0.004 ± 0.0003	0.748 ± 0.076	0.018 ± 0.003	0.011 ± 0.003	0.045 ± 0.005	0.160 ± 0.009
0%	100% S5	---	0.032 ± 0.006	0.003 ± 0.0002	0.610 ± 0.063	0.015 ± 0.003	0.005 ± 0.001	0.033 ± 0.005	0.125 ± 0.009
25%	75% So	---	0.021 ± 0.005	0.004 ± 0.0002	0.984 ± 0.096	0.011 ± 0.003	0.011 ± 0.003	0.020 ± 0.003	0.165 ± 0.009
25%	75% S5	---	0.013 ± 0.003	0.002 ± 0.0002	0.535 ± 0.054	0.012 ± 0.002	0.007 ± 0.001	0.018 ± 0.003	0.090 ± 0.008
50%	50% So	---	0.020 ± 0.002	0.002 ± 0.0002	0.542 ± 0.055	0.007 ± 0.001	0.006 ± 0.001	0.008 ± 0.001	0.104 ± 0.009
50%	50% S5	---	0.006 ± 0.001	0.001 ± 0.0002	0.457 ± 0.046	0.007 ± 0.001	0.005 ± 0.001	0.009 ± 0.001	0.085 ± 0.007
75%	25% So	---	0.007 ± 0.001	0.002 ± 0.0002	0.362 ± 0.041	0.003 ± 0.001	0.003 ± 0.001	0.007 ± 0.001	0.088 ± 0.007
75%	25% S5	---	0.003 ± 0.001	---	0.345 ± 0.037	0.005 ± 0.001	0.003 ± 0.001	0.005 ± 0.001	0.105 ± 0.009
Leaves									
100%		---	---	0.001 ± 0.0002	0.050 ± 0.007	0.005 ± 0.001	---	---	0.005 ± 0.0005
0%	100% So	---	0.003 ± 0.0005	0.002 ± 0.0002	0.548 ± 0.052	0.005 ± 0.001	0.001 ± 0.0002	0.005 ± 0.0005	0.006 ± 0.0005
0%	100% S5	---	0.002 ± 0.0002	0.001 ± 0.0002	0.352 ± 0.045	0.003 ± 0.0005	0.001 ± 0.0002	0.003 ± 0.0005	0.005 ± 0.0005
25%	75% So	---	0.002 ± 0.0002	0.001 ± 0.0002	0.484 ± 0.044	0.003 ± 0.0005	0.001 ± 0.0002	0.001 ± 0.0002	0.005 ± 0.0005
25%	75% So	---	0.001 ± 0.0002	0.001 ± 0.0002	0.335 ± 0.039	0.002 ± 0.0002	0.001 ± 0.0002	0.001 ± 0.0002	0.003 ± 0.0002
50%	50% So	---	0.001 ± 0.0002	0.001 ± 0.0002	0.342 ± 0.041	0.001 ± 0.0002	0.001 ± 0.0002	0.001 ± 0.0002	0.003 ± 0.0002
50%	50% S5	---	0.001 ± 0.0002	---	0.265 ± 0.033	0.001 ± 0.0002	0.001 ± 0.0002	0.001 ± 0.0002	0.001 ± 0.0002
75%	25% So	---	0.001 ± 0.0002	---	0.162 ± 0.018	---	---	0.001 ± 0.0002	0.001 ± 0.0002
75%	25% S5	---	0.001 ± 0.0002	---	0.095 ± 0.010	---	---	---	---

Mean value of 20 samples ± standard deviation.

Table 5 Metal concentration (mg/g) in roots, looms and leaves in pepper cultivation.

Control	Compost	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Roots									
100%		---	---	0.004 ± 0.0005	0.910 ± 0.099	0.029 ± 0.005	---	---	0.030 ± 0.004
0%	100%So	0.001 ± 0.0002	0.086 ± 0.012	0.092 ± 0.009	3.442 ± 0.379	0.115 ± 0.009	0.009 ± 0.001	0.025 ± 0.004	0.108 ± 0.012
0%	100%S5	---	0.024 ± 0.003	0.025 ± 0.006	1.286 ± 0.198	0.020 ± 0.002	0.007 ± 0.001	0.021 ± 0.003	0.099 ± 0.009
25%	75% So	0.001 ± 0.0002	0.064 ± 0.008	0.069 ± 0.008	2.581 ± 0.276	0.086 ± 0.008	0.006 ± 0.0005	0.018 ± 0.003	0.081 ± 0.009
25%	75% S5	---	0.018 ± 0.003	0.018 ± 0.004	0.964 ± 0.106	0.015 ± 0.003	0.005 ± 0.0005	0.015 ± 0.002	0.074 ± 0.007
50%	50% So	0.0005 ± 0.0003	0.043 ± 0.007	0.046 ± 0.005	1.721 ± 0.233	0.057 ± 0.006	0.005 ± 0.0005	0.012 ± 0.002	0.054 ± 0.006
50%	50% S5	---	0.012 ± 0.002	0.012 ± 0.002	0.643 ± 0.072	0.010 ± 0.001	0.003 ± 0.0005	0.011 ± 0.002	0.049 ± 0.006
75%	25% So	---	0.021 ± 0.005	0.023 ± 0.009	0.861 ± 0.084	0.028 ± 0.004	0.002 ± 0.0002	0.006 ± 0.001	0.027 ± 0.003
75%	25% S5	---	0.006 ± 0.002	0.006 ± 0.001	0.321 ± 0.019	0.005 ± 0.001	0.001 ± 0.0002	0.005 ± 0.001	0.024 ± 0.003
Looms									
100%		---	---	0.009 ± 0.001	0.095 ± 0.010	0.001 ± 0.0001	---	---	0.003 ± 0.0005
0%	100% So	---	0.003 ± 0.0005	0.045 ± 0.004	0.398 ± 0.040	0.008 ± 0.001	0.003 ± 0.0005	0.012 ± 0.002	0.010 ± 0.001
0%	100% S5	---	0.001 ± 0.0002	0.010 ± 0.002	0.375 ± 0.039	0.005 ± 0.001	0.001 ± 0.0002	0.009 ± 0.001	0.013 ± 0.002
25%	75% So	---	0.002 ± 0.0002	0.033 ± 0.003	0.298 ± 0.031	0.006 ± 0.001	0.002 ± 0.0002	0.009 ± 0.001	0.007 ± 0.001
25%	75% S5	---	0.001 ± 0.0002	0.007 ± 0.001	0.281 ± 0.026	0.004 ± 0.001	0.001 ± 0.0002	0.006 ± 0.001	0.009 ± 0.002
50%	50% So	---	0.015 ± 0.002	0.022 ± 0.003	0.199 ± 0.014	0.004 ± 0.001	0.001 ± 0.0002	0.006 ± 0.001	0.005 ± 0.001
50%	50% S5	---	0.005 ± 0.001	0.005 ± 0.001	0.187 ± 0.014	0.002 ± 0.0002	---	0.005 ± 0.001	0.006 ± 0.001
75%	25% So	---	0.001 ± 0.0002	0.011 ± 0.002	0.099 ± 0.011	0.002 ± 0.0002	---	0.003 ± 0.0005	0.002 ± 0.0005
75%	25% S5	---	---	0.002 ± 0.0005	0.093 ± 0.011	0.001 ± 0.0002	---	0.002 ± 0.0002	0.003 ± 0.0005
Leaves									
100%		---	---	0.001 ± 0.0002	0.004 ± 0.0005	0.001 ± 0.0002	---	---	---
0%	100%So	---	---	0.010 ± 0.002	0.012 ± 0.002	0.002 ± 0.0002	---	0.002 ± 0.0002	0.002 ± 0.0002
0%	100%S5	---	---	0.004 ± 0.001	0.009 ± 0.001	---	---	0.001 ± 0.0002	0.002 ± 0.0002
25%	75% So	---	---	0.007 ± 0.001	0.009 ± 0.001	0.001 ± 0.0002	---	0.001 ± 0.0002	0.001 ± 0.0002
25%	75% So	---	---	0.003 ± 0.0005	0.006 ± 0.001	---	---	0.001 ± 0.0002	0.001 ± 0.0002
50%	50% So	---	---	0.005 ± 0.001	0.006 ± 0.001	0.001 ± 0.0002	---	0.001 ± 0.0002	0.001 ± 0.0002
50%	50% S5	---	---	0.002 ± 0.0005	0.004 ± 0.0005	---	---	---	---
75%	25% So	---	---	0.002 ± 0.0005	0.003 ± 0.0005	---	---	---	---
75%	25% S5	---	---	0.001 ± 0.0002	0.002 ± 0.0005	---	---	---	---

Mean value of 20 samples ± standard deviation.

Table 6 Metal concentration (mg/g) in roots, looms and leaves in eggplant cultivation.

Control	Compost	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Roots									
100%		---	---	0.004 ± 0.0005	0.912 ± 0.094	0.018 ± 0.003	---	---	0.028 ± 0.004
0%	100%So	0.001 ± 0.0002	0.078 ± 0.011	0.090 ± 0.008	3.442 ± 0.310	0.105 ± 0.009	0.009 ± 0.001	0.025 ± 0.003	0.108 ± 0.011
0%	100%S5	---	0.019 ± 0.003	0.022 ± 0.003	1.286 ± 0.162	0.019 ± 0.003	0.005 ± 0.001	0.021 ± 0.003	0.089 ± 0.007
25%	75% So	0.001 ± 0.0002	0.058 ± 0.005	0.067 ± 0.007	2.581 ± 0.204	0.078 ± 0.008	0.006 ± 0.001	0.018 ± 0.003	0.081 ± 0.007
25%	75% S5	---	0.014 ± 0.003	0.018 ± 0.004	0.964 ± 0.091	0.014 ± 0.002	0.003 ± 0.0002	0.015 ± 0.002	0.066 ± 0.005
50%	50% So	0.001 ± 0.0002	0.039 ± 0.004	0.045 ± 0.005	1.721 ± 0.141	0.052 ± 0.005	0.004 ± 0.0005	0.012 ± 0.002	0.054 ± 0.005
50%	50% S5	---	0.010 ± 0.002	0.013 ± 0.002	0.643 ± 0.062	0.009 ± 0.001	0.002 ± 0.0002	0.011 ± 0.002	0.045 ± 0.004
75%	25% So	---	0.019 ± 0.003	0.022 ± 0.003	0.860 ± 0.077	0.026 ± 0.003	0.002 ± 0.0002	0.006 ± 0.001	0.027 ± 0.003
75%	25% S5	---	0.005 ± 0.001	0.006 ± 0.001	0.321 ± 0.019	0.004 ± 0.001	0.001 ± 0.0002	0.005 ± 0.001	0.022 ± 0.003
Looms									
100%		---	---	0.004 ± 0.001	0.101 ± 0.010	0.001 ± 0.0005	---	---	0.002 ± 0.0002
0%	100% So	0.001 ± 0.0002	0.003 ± 0.0005	0.035 ± 0.005	0.378 ± 0.017	0.008 ± 0.002	0.003 ± 0.0005	0.011 ± 0.002	0.011 ± 0.002
0%	100% S5	---	---	0.009 ± 0.002	0.375 ± 0.017	0.005 ± 0.001	---	0.005 ± 0.001	0.009 ± 0.001
25%	75% So	0.001 ± 0.0002	0.002 ± 0.0002	0.026 ± 0.003	0.283 ± 0.015	0.006 ± 0.001	0.002 ± 0.0002	0.008 ± 0.002	0.008 ± 0.001
25%	75% S5	---	---	0.006 ± 0.001	0.281 ± 0.015	0.004 ± 0.001	---	0.003 ± 0.001	0.006 ± 0.001
50%	50% So	0.001 ± 0.0002	0.001 ± 0.0002	0.017 ± 0.002	0.189 ± 0.013	0.004 ± 0.001	0.001 ± 0.0002	0.005 ± 0.001	0.005 ± 0.001
50%	50% S5	---	---	0.004 ± 0.001	0.187 ± 0.013	0.002 ± 0.0005	---	0.002 ± 0.0005	0.004 ± 0.0005
75%	25% So	---	0.001 ± 0.0002	0.008 ± 0.002	0.094 ± 0.009	0.002 ± 0.0005	0.001 ± 0.0002	0.002 ± 0.0005	0.003 ± 0.0005
75%	25% S5	---	---	0.002 ± 0.001	0.093 ± 0.09	0.001 ± 0.0002	---	0.001 ± 0.0002	0.002 ± 0.0002
Leaves									
100%		---	---	0.001 ± 0.0002	0.005 ± 0.001	0.001 ± 0.0002	---	---	0.001 ± 0.0002
0%	100%So	---	---	0.009 ± 0.001	0.012 ± 0.002	0.002 ± 0.0002	---	0.002 ± 0.0002	0.002 ± 0.0002
0%	100%S5	---	---	0.005 ± 0.001	0.009 ± 0.001	---	---	---	---
25%	75% So	---	---	0.005 ± 0.001	0.006 ± 0.001	---	---	---	---
25%	75% So	---	---	---	0.004 ± 0.0005	---	---	---	---
50%	50% So	---	---	0.005 ± 0.001	0.007 ± 0.001	0.001 ± 0.0002	---	0.001 ± 0.0002	0.001 ± 0.0002
50%	50% S5	---	---	0.003 ± 0.001	0.005 ± 0.001	---	---	---	---
75%	25% So	---	---	0.002 ± 0.001	0.004 ± 0.005	0.001 ± 0.0002	---	0.001 ± 0.0002	0.001 ± 0.0002
75%	25% S5	---	---	0.001 ± 0.0002	0.002 ± 0.0005	---	---	---	---

Mean value of 20 samples ± standard deviation.

looms > pepper looms > eggplant looms; oats leaves > pepper leaves = eggplant leaves.

Pb: oats roots > pepper roots > eggplant roots; oats looms > pepper looms > eggplant looms; oats leaves > pepper leaves > eggplant leaves.

Zn: oats roots > pepper roots > eggplant roots; oats looms > pepper looms > eggplant looms; oats leaves > pepper leaves > eggplant leaves.

The metal concentrations in the sewage sludge depend on several factors such as sewage origin, sewage treatment processes, and sludge treatment processes (Hue and Ranjith 1994). The bioavailability of the sludge-borne metals to soil is further influenced by soil properties such as pH, redox potential (Eh), sesquioxide content and organic matter, sludge application rate (Hue and Ranjith 1994), as well as metals speciation (Zorpas *et al.* 2008). Absorption, accumulation and tolerating ability of crops vary at different levels of sewage sludge amendment. Singh and Agrawal (2008) mention in there literature review that wide variations in heavy metal accumulation in crops grown on sludge-amended soil. Cd accumulation was highest in different species. With respect to species, the trend of accumulation was tobacco > lettuce > spinach > celery > cabbage for Cd; kale > rye grass > celery for Pb; sugar beet > some varieties of barley for Cu; sugarbeet > ryegrass > mangold > turnip for Ni; and sugarbeet > mangold > turnip for Zn. Alloway *et al.* (1990) found a trend of Cd uptake as lettuce > cabbage > radish > carrots. Cadmium generally tends to accumulate in leaves, and therefore is more risky especially for leafy vegetables grown on contaminated soils than in seed or root crops (Alloway *et al.* 1990). Mondy *et al*. (1984) also recorded a significant increase in concentrations of B, Cd, Cu, Ni, and Zn in potato tubers grown on sludge-amended soils, but no significant trend was observed for Co, Cr, Fe, Mn and Pb concentrations. Bioavailability of metals in sludge-amended soil has been reported for many years after application, giving anomalously high metal concentrations (Heckman *et al.* 1987). Heavy metal accumulation due to long-term sludge amendment affected the biological nitrogen fixation and VAM (vesicular arbuscular mycorrhiza) negatively (McGrath *et al.* 1994). Long-term sewage sludge application also caused a reduction in nitrogen fixation by free-living heterotrophic bacteria due to metal accumulation in soil (Lorenz *et al.* 1992).

Current legislation favours the diversion of organic wastes from landfill and composting of biosolids is seen as a process that stabilizes the organic matter content and reduces the volume and mass of the waste (Moreno *et al.* 1996; Breslin 1999). Application of composts to land presents a potential way to recover value and avoid disposal to landfill (Petersen *et al.* 2003). Important criteria used to determine if land application will be beneficial, or not, is the ability of the organic by-product to enhance, or at least have no deleterious effect on, soil productivity and the growth and/or yield of plants. Improvements in soil chemical properties have been reported for re-use of organic by-products and include increased soil pH (Ouedraogo *et al.* 2001), increased plant available potassium (Erhart and Hartl 2003) and plant available calcium and magnesium (Jakobsen 1996; Wen *et al.* 1999). Organic amendments can also promote plant health and increase yield of certain crops. Barley yields were increased to 50 t/ha MSW (Zhang *et al.* 2000). The influence of organic matter on soil properties depends on its amount and composition (Unsal and Ok 2001). Low quality compost essentially arises from an excess of heavy metals and salt and a low degree of stabilization (Murillo *et al.* 1995). Depending on feedstock, certain composts have been shown to contain elevated concentrations of metals including Pb, Cd, Cu, and Zn (Breslin 1999; Zheljazkov and Warman 2003). Also, land application of some compost can result in increased electrical conductivity (EC) due to high salt content and can restrict seedling performance (Hsiao-Lei Wang *et al.*1984). Consequently, the type of compost being used for land application will affect the overall impact on soil properties and crop growth and composts organic matter content, nutrient values and potential levels of metals are of concern (Courtney and Mullen 2005).

CONCLUSIONS

The final results indicate that the application of 25% (w/w) zeolite to the sewage sludge has the ability to take up a significant ($p<0.05$) amount of all heavy metals. Specifically 25% (w/w) of zeolite takes up 100% of Cd, 20% of Co, 36% of Cu, 12% of Cr, 10% of Mn, 40% of Fe and Zn, 32% of Pb and 53% of Ni. How ever the absorbance of heavy metal through the roots increases by increasing the addition of compost in pots. The application of compost in pepper, oats and eggplant cultivation seems to increases the final product while zeolite can retain the heavy metals without letting them pass from the roots to the final product.

Also, the phytotoxicity and the humics of the final product are presented as a function of evaluation. The substrate is characterized as non-phytotoxic after 80 days of maturity, which GI is 78, 75 and 72 for oats, eggplant and pepper seeds, respectively. Total humics are presented to low due to the low concentrations of lignin and cellulose in the initial sample.

REFERENCES

Adams DV (1990) *Water and Wastewater Examination Manual*, Michigan, U.S.A. Lewis Publishers INC, USA, pp 108-119, 132, 146-150, 186

Alloway BJ, Jackson AP, Morgan H (1990) The accumulation of cadmium by vegetables grown on soils contaminated from a variety of sources. *Science of the Total Environment* **91**, 223-236

Breslin V (1999) Retention of metals in agricultural soils after amending with MSW and MSW-biosolids compost. *Water Air and Soil Pollution* **109**, 163-178

Courtney RG, Mullen GJ (2005) Soil quality and barley growth as influenced by the land application of two compost types. *Bioresource Technology* **96**, 955-961

Erhart E, Hartl W (2003) Mulching with compost improves growth of blue spruce in Christmas tree plantations. *European Journal of Soil Biology* **39**, 149-156

Finstein MS, Miller FC, MacGregor ST, Psarianos KM (1992) The Rutgers Strategy for composting: Process design and control. *Acta Horticulturae* **302**, 75-86

Han FX, Kingery WL, Selim HM (2001) Accumulation, redistributions, transport and bioavailability of heavy metals in waste-amendment soils. In: Iskandar IK, Kirkham MB (Eds) *Trace Elements in Soil. Bioavailability, Flux and Transfer*, CRC Press LLC, Boca Raton, Florida, pp 145-173

Heckman JR, Angle JS, Chaney RL (1987) Residual effects of sewage sludge on soybean: I. Accumulation of heavy metals. *Journal of Environmental Quality* **16**, 113-114

Hsiao-Lei Wang S. Lohr VI, Coffey D (1984) Growth response of selected vegetable crops to spent mushroom compost application in a controlled environment. *Plant and Soil* **82**, 31-40

Hue NV, Ranjith SA (1994) Sewage sludges in Hawaii: chemical composition and reactions with soils and plants. *Water, Air and Soil Pollution* **72**, 265-283

Jakobsen ST (1996) Leaching of nutrients from pots with and without applied compost. *Resources Conservation and Recycling* **17**, 1-11

Lorenz SE, McGrath SP, Giller KE (1992) Assessment of free-living nitrogen fixation activity as a biological indicator of heavy metal toxicity in soil. *Soil Biology and Biochemistry* **24**, 601-606

McGrath SP, Chang AC, Page AL, Witter E (1994) Land application of sewage sludge: scientific perspectives of heavy metal loading limits in Europe and the United States. *Environmental Reviews* **2**, 108-118

Mendoza J, Garrido T, Castillo G, Martin N (2006) Metal availability and uptake by sorghum plants grown in soils amendment with sludge from different treatments. *Chemosphere* **65**, 2304-2312

Mondy NI, Naylor LM, Philips JC (1984) Total glycoalkaloid and mineral content of potatoes grown in soils amended with sewage sludge. *Journal of Agricultural and Food Chemistry* **32**, 1256-1260

Moreno JL, García C, Hernández T, Pascual J (1996) Transference of heavy metals from a calcareous soil amended with sewage-sludge compost to barley plants. *Bioresource Technology* **55**, 251-258

Murillo JM, Cabrera F, Lopez R, Martín-Olmedo P (1995) Testing low-quality urban composts for agriculture: germination and seedling performance of plants. *Agriculture, Ecosystems and Environment* **54**, 127-135

Oliver I, McLaughin MJ, Merrigton G (2005) Temporal trends of total and potentially available elements concentrations in sewage biosolids: a comparison of biosolid surveys conducted 18 years apart. *Science of the Total Environment* **337**, 139-145

Ouedraogo E, Mando A, Zombre NP (2001) Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa. *Agriculture Ecosystems and Environment* **84**, 259-266

Petersen SO, Henriksen K, Mortensen GK, Krogh PH, Brandt KK, Sørensen J, Madsen T, Petersen J, Grøn C (2003) Recycling of sewage sludge and household compost to arable land: fate and effects of organic contaminants, and impact on soil fertility. *Soil and Tillage Research* **72**, 139152

Schnitzer M (1982) *Methods of Soil Analysis* (Part 2, 9th Edn), Madison, USA, pp 581-594

Singh RP, Agrawal M (2008) Potential benefits and risks of land application of sewage sludge. *Waste Management* **28**, 347-358

Tiffany ME, McDowell LR, O Connor GA, Nguyen H, Martin FG, Wilkinson NS, Cardoso EC (2000) Effects of pasture-applied biosolids on forage and soil concentrations over a grazing season in North Florida. 1. Macrominerals, crude protein, and *in vitro* digestibility. *Communications in Soil Science and Plant Analysis* **31**, 201-213

Tiquia SM, Tam NFY (1998) Elimination of phytotoxicity during co-composting of spent pig-manure sawdust litter and pig sludge. *Bioresource Technology* **65**, 43-49

Tsitsishvili GV, Andronikashvili TG, Kirov GN, Filizova LD (1992) *Natural Zeolite*, Ellis Horwood Ltd, Chichester, West Sussex, England, pp 1, 64-66, 205-266

Unsal T, Ok SS (2001) Description of characteristics of humic substances from different waste materials. *Bioresource Technology* **78**, 239-242

Wagner DJ, Bacon GD, Knocke WR, Switzenbaum MS (1990) Changes and variability in concentration of heavy metals in sewage sludge during composting. *Environmental Technology* **11**, 949-960

Warman PR (1986) Effects of fertilizer, pig manure, and sewage sludge on timothy and soils. *Journal of Environmental Quality* **15**, 95-100

Warman PR, Termeer WC (2005) Evaluation of sewage sludge, septic waste and sludge compost applications to corn and forage: Ca, Mg, S, Fe, Mn, Cu, Zn and B content of crops and soils. *Bioresource Technology* **96**, 1029-1038

Wen G, Bates T, Voroney R, Winter J, Schellenberg M (1999) Influence of application of sewage sludges, and sludge and manure composts on plant Ca and Mg concentration and soil extractability in field experiments. *Nutrient Cycling in Agroecosystems* **55**, 51-61

Zhang M, Heaney D, Solberg E, Heriquez B (2000) The effect of Msw compost on metal uptake and yield of wheat, barley and canola in less productive farming soils of Alberta. *Compost Science and Utilization* **8**, 224-236

Zheljazkov VD, Warman PR (2003) Application of high Cu compost to Swiss chard and basil. *Science of the Total Environment* **302**, 13-26

Zorpas AA, Vlyssides AG, Loizidou M (1998) Physical and chemical characterization of anaerobically stabilized primary sewage sludge. *Fresinious Environmental Bulletin* **7**, 383-508

Zorpas AA (1999) Development of a methodology for the composting of sewage sludge using zeolite. PhD thesis, National Technical University of Athens, Athens, Greece, pp 107-118, 196-258

Zorpas AA, Kapetanios E, Vlyssides A, Zorpas GA, Karlis PK, Haralambous I, Loizidou M (2000) Compost produced from organic fraction of municipal solid waste, primary stabilized sewage sludge and natural zeolite. *Journal of Hazardous Material B* **77**, 149-159

Zorpas A, Inglezakis V, Loizidou M (2008) Heavy metals fractionation before, during and after composting of sewage sludge with natural zeolite. *Waste Management* **28**, 2054-2060