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Metal Transfer in Vermicomposting of Sewage Sludge and Plant Wastes

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Sewage sludge is the fluid sediment that settles out when sewage wastes are passed through a municipal treatment plant. These "raw" wastes are processed by anaerobic digestion to give a black fluid stabilized product that is relatively odorless or with a swampy odor.

Sewage sludge is an urban waste that has a potential nutrient value for recycling into food production. Major cities in Ontario like Toronto, London and Hamilton with mixed industrial and residential wastes incinerate their sludges. Other cities like Burlington, Kingston and Ottawa find their sludges unsuitable for land and dispose of them in landfill sites. Yet others like Stratford, St. Marys and Waterloo have good quality wastes and these are applied to agricultural lands.

A set of guidelines has been developed that prescribes the quality of sludge suitable for utilization on foodlands. Among several criteria is one that is based on the available nitrogen to metal ratio (O.M.A.F.-O.M.E. 1981). These guidelines have been phased in over a three year period and were fully implemented by early 1983.

A number of sewage sludges do not meet the criteria and are therefore not acceptable for direct foodland application. One of the options available for such sludges is the production of compost and one of these composting processes involves worms (vermicomposting). This study looks at a pilot vermicomposting operation and follows metal concentrations by batch lot from the sewage sludge to the final commercial product.

METHODS AND MATERIALS

A pilot vermicomposting operation was sampled at each step of the procedure in order to follow the metal concentrations through the whole process. Raw sewage sludge ca 75% moisture was treated at 170° before mechanical mixing with a raw vegetable-fruit mash of ca 97% moisture in the ratio of 7:4 by volume (ca 14-15:1 on dry weight basis). This resulting mixture, called a 'worm feed', was approximat 17% dry matter. Brandling worms (*Eisenia foetida*) were introduced to the mixture and for 27 days the worms ingested, digested and excreted worm castings. During this process the mixture dried out slightly dropping to about 60% moisture. At the end of this process worm cast ings were layered with a peat sand-filler of ca 40% moisture and mixe mechanically through a hammer mill shredder. After physical mixing, the product was bagged and sold as a commercial product called 'Terra Organica'.

The sewage sludge was obtained from a local water treatment plant in Mississauga and the filler was prepared by mixing seven parts of peat with two parts of sand by volume or ca 1:2 to 3 by dry weight.

A total of six batches were followed through the process. Between one and three composite samples were collected from each stage of each batch. The two basic ingredients, sewage sludge and vegetable-fruit mash and their mixture were sampled at the beginning of each batch by collecting subsamples from different parts of the batches as to give representative composite samples. Worms and worm castings were sampled in like manner one month into the process and filler and 'Terra Organica' were sampled at the end of the process. Samples were air dried before metal analyses were performed. Lettuce was seeded into the final product and after growing for several weeks plants were harvested for analysis.

Cd, Co, Cr, Cu, Ni, Pb, and Zn Analysis. A one gram oven-dried sample was digested with 10 ml of conc. HNO_3 by gently boiling for 5h; 20 ml of water were added, and the contents were warmed for 2h. The mixture was filtered through a coarse porosity, sintered glass filter and made up to 100 ml with distilled water. The metals were measured with a Techtron Model AA-5 atomic absorption spectrophotometer (AAS) with carbon rod atomizer (CRA-90), background corrector (BC-6) and a Varian Model G-2000 recorder. The method used was a slight modification of the procedure described by AMOS et al. (1971). The wavelengths used to measure the metals were Cd 228.8, Co 240.7, Cr 357.9, Cu 327.4, Ni 352.4, Pb 283.3, Zn 307.6 nm. High-purity nitrogen gas was used to protect the carbon rod at a flow rate of 3.5 liters/min.

Mo, As, and Se Analysis. For Mo 5 g samples were digested with 10 ml of aquaregia by gently boiling until the acid evaporated to 3 ml. For Se and As, a 1:2 mixture of H_2SO_4 and HNO_3 (15 ml) was gently boiled with the sample until white sulfurous fumes first evolved. This procedure avoided interferences of continued boiling reported by LANSFORD et al. (1974). The digested mixtures were filtered through coarse glass filters and made up to 50 ml using distilled water. Recoveries by the described method optimized extractions at 70% for Mo, 80% for Se and 85% for As without destruction of the soil lattice. Molybdenum was measured with the Varian Model 1200 flame AAS with a background corrector (Model BC-6) and using N_2O and C_2H_2 gases. As and Se were measured by flame AAS and background corrector fitted with a hybride generator kit (Model 64) and using H_2 and N_2 gases. The wavelengths used to measure the elements were: Mo 313.5, As 193.7, and Se 196.0 nm.

Total Hg Analysis. One gram of oven-dried sample was digested with 20 ml of concentrated sulfuric and nitric acids (4:1) for 1 h in a shaker bath at 60°C. The digested samples were cooled over ice and 25 ml of saturated potassium permanganate was slowly added until the color remained dark purple; and excess was then added. The contents were incubated for 2 h in a shaker at 60°C. A 0.1-or 0.2-g aliquot was made up to 100 ml with distilled water. Hydroxylamine sulfate

solution (2%) was added and the contents were allowed to stand until the color disappeared. Stannous sulfate solution (5 ml of 10%) was added and the effluent was passed through a mercury analyzer as a cold vapor. Mercury content was determined from peaks produced by an AAS set at 253.7 nm and attached to a recorder (HATCH and OTT 1968)

Organochlorine Analysis. All samples (25 g) except lettuce and worms were extracted by shaking for 2 h with 1:1 acetone: hexane followed by filtration, partitioning into hexane after dilution of acetone with water, and solvent reduction to ca 5 ml with rotary vacuum evaporation Lettuce and worms (25 g) were extracted by blending at high speed for 5 min with 2:1 - acetonitrile:water, filtration, partitioning into hexane and solvent evaporation to ca 5 ml. The concentrated extracts were cleaned up and fractionated on Florisil according to MILLS et al. (1972) and PCBs were isolated from organochlorine insecticides on charcoal according to the method of HOLDRINET (1974). Determinations were made by gas-liquid chromatography on a 1.8 m x 2 mm i.d. column packed with 1.5% OV-17/2.0% OV-210 on Gas Chrom Q and using electron capture detection.

RESULTS AND DISCUSSION

The production of 'Terra Organica' was carried out in three basic steps: 1) Mechanical mixing of sewage sludge and a fruit-vegetable mash (14 to 15:1 by dry weight); 2) Biological mixing by passage through worms; 3) Mechanical mixing of worm castings with a filler (1:13 to 14 by dry weight). The fate of eleven elements was followed through this system and the results appear in Table 1 and 2 as content on a dry weight basis.

Maximum acceptable metal concentrations for the eleven elements has been published for dried and composted sewage sludges sold in Ontario (O.M.A.F.-O.M.E. 1981). These are based on the dried or composted sludge containing 5% or less nitrate and ammonia nitrogen. The mean limits for metals are given in Table 1 and 2. The eleven elements in the described vermicomposting process conveniently divided into six above the limit (Table 1) and five below the limit (Table 2).

In one step, the addition of the fruit-vegetable mash with a very low metal content did little to ameliorate the high metal contents in the sewage sludge as can be observed by analysis of the mixture. This was due to the fact that only one part of dry matter in the mash was added to 14 to 15 of sewage sludge. Metal contents in sludge were very variable. This can be clearly seen from the Pb and Mo concentrations that were respectively 652 $\pm$ 239 and 32.3 $\pm$ 29.0 mg/kg. Levels found in sewage sludge and the mixture were similar for As, Cd, Cr, Cu, Pb, Se, and Zn and higher in the sludge with Co, Hg., Mo, and Ni. The Se reflect the difficulty in obtaining representative samples from such a variable waste.

The vermicomposting process appeared to increase the metal contents slightly in worm castings, except Cr and Zn over the "worm feed" mixture. This could be explained by the fact that organic matter

Table 1. Metal contents in the raw materials, the intermediates and the end products of a pilot vermicomposting process

Sample Type	Total No. analyses on 6 batches	Content in dried samples (mg/kg)											
		Cd		Cu		Mo		Ni		Pb		Zn	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Sewage sludge	6x3	16.7	4.8	888	284	32.3	29.0	213	80	652	239	2236	482
Fruit/Veg wastes	6x1.5	0.2	0.1	5	2	2.7	1.6	2	1	3	2	64	32
Mixture	6x1	16.6	6.5	863	117	25.1	4.9	183	47	675	263	2233	476
Worm	6x2.5	1.9	0.7	21	9	3.9	3.8	13	16	16	10	92	88
Worm castings	6x3	18.7	7.0	889	152	32.7	16.0	266	149	735	149	2216	593
Filler	6x3	1.0	0.6	24	17	7.0	5.3	10	5	16	14	49	38
'Terra Organica'	6x1	2.4	2.7	61	26	6.2	2.5	19	8	47	32	131	75
Lettuce tops	6x1	0.93	1.43	10.6	4.4	2.5	1.3	4.7	1.1	1.5	0.3	81	56
roots	6x1	2.26	3.80	36.5	12.8	1.4	0.1	14.7	19.3	9.7	12.2	141	114
Max. acceptable (OMAF-OME 1981)		10		750		20		160		450		1650	
Average soil level (FRANK et al. 1977)		0.8		25		2		16		15		55	
Calculated concentration for end product		2.2		85		8		23		62		207	

Table 2. Metal contents in the raw materials, the intermediates and the end products of a pilot vermicomposting process

Sample Type	Content in dried samples (mg/kg)										Dry Matter (%)
	As		Co		Cr		Hg		Se		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Sewage sludge	7.41	2.30	12.0	4.4	611	149	3.94	1.99	0.40	0.33	25±3
Fruit/Veg wastes	0.32	0.23	0.1	0.1	4	3	0.04	0.01	0.34	0.16	3±1
Mixture	7.00	1.04	9.6	3.1	645	170	2.81	1.30	0.40	0.16	17±2
Worms	2.65	1.38	0.5	2.9	21	18	0.73	1.62	0.22	0.14	
Worm castings	8.28	0.93	16.4	3.9	578	132	4.92	0.91	1.46	0.62	61±5
Filler	1.47	0.51	2.5	1.3	13	11	0.10	0.11	0.17	0.14	40±4
'Terra Organica'	2.03	0.60	4.3	1.3	40	19	0.38	0.37	0.16	0.06	51±5
Lettuce tops	0.47	0.26	0.13	0.17	3.0	0.8	0.06	0.01	0.06	0.07	3±.5
roots	1.54	0.65	0.49	0.05	14	18	0.08	0.01	0.69	0.35	
Maximum acceptable (OMAF-OME 1981)	70		150		1000		4		12		
Average soil level (FRANK et al. 1977)	7		5		15		0.1		0.4		
Calculated concentration for end product	1.8		3.2		55		0.4		0.2		

was being reduced on passage through the worms. In the process, worms did not appear to bioaccumulate metals within their tissues. With all elements, except Se, content in analyzed worms fell between the concentrations of the two raw materials, which was only a fraction of the concentrations found in the mixture. While worms contained higher concentrations than the fruit-vegetable mash, they did not approach the order of magnitude of concentrations in the sewage sludge. Accumulation of Se appeared to be higher than either raw material.

The addition of filler, a mixture of peat and sand, to the worm castings was a physical mixing process that drastically reduced the elemental concentrations found in the worm castings. In the case of Cr, Cu, Hg, Ni, Pb, and Zn, concentrations were reduced 92 to 94%, with Cd and Se reductions were 87 to 89%, with As and Mo, reductions were 79 and 81%, and with Co, the reduction was 76%.

'Terra Organica' contained elemental concentrations similar to the filler and these were of similar magnitude to the background contents of agricultural soils in southern Ontario (FRANK et al. 1976, 1979). 'Terra Organica' was therefore found to be well within the guidelines for composted sewage sludges (O.M.A.F.-O.M.E. 1981). The theoretically calculated elemental contents of 'Terra Organica' based on physical mixing, agreed closely with the actual levels recorded. These comparisons appear in Tables 1 and 2.

Each stage of the process was analyzed for organochlorine residues. The highest residues occurred in sludge and the lowest in the final product. PCB residues were higher than other organochlorines. Worms did not appear to accumulate organochlorine residues in their tissues (Table 3). No heptachlor, heptachlor epoxide, methoxychlor, endrin or mirex were identified in any components of the vermicomposting process.

Lettuce was grown on the 'Terra Organica' and lettuce tops had similar low concentrations as in the original fruit-vegetable mash used in the process. All metals except Mo were in higher concentration in lettuce roots than in tops; Mo was lower (Table 1 and 2).

Table 3. Organochlorine residues measured in components of vermicomposting process

Organochlorine	Mean and standard deviation (ug/kg)				
Compound	Sludge	Worms	Castings	Filler	'Terra Organica'
DDE	10±4	9±1	<5	<5	<5
TDE	12±3	<10	<10	<10	<10
DDT	20±17	<10	<10	<10	<10
Dieldrin	8±5	<5	<5	<5	<5
Chlordane	<5	9±1	<5	<5	<5
PCB	300±21	56±12	330±30	16±7	37±43

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