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Cadmium Accumulation by Earthworms Inhabiting Municipal Sludge-amended Soil

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Several million tons of sewage sludge are produced in the United States annually. Present methods of sludge disposal include ocean dumping, incineration, discard in landfills, as a fertilizer and soil conditioner on golf courses, parks, ornamentals and some farm lands and for reclamation of wasteland areas. The Environmental Protection Agency is proposing an end to ocean dumping and instead utilization of sludge as a widespread soil amendment in agriculture.

Municipal sludges comprise the bulk of the total produced throughout the nation. Owing to the concentration of urban industries, municipal sludges may typically contain high concentrations of heavy metals (FURR et al. 1976). Of the heavy metals present in it, cadmium is of most concern because of its toxicity, mobility and efficiency of deposition and long half-life in animal tissues. Crickets and spiders (VAN HOOK and YATES 1975) and earthworms (GISH et al. 1975) have been shown to accumulate cadmium from cadmium-contaminated environments. Earthworms are extremely important in digestion of soil organic matter and general maintenance of soil fertility. They also serve as a food source for birds. In the work reported, earthworms were collected from municipal sludge-amended soil and soil which had received an equal quantity of bull manure (control). Cadmium was then determined in intact worms, and in worms from which the digestive system had been removed.

MATERIALS AND METHODS

Municipal sludge was obtained from the Ley Creek Sewage Treatment Plant in Syracuse, New York. Wastewater entering this facility is treated to produce an anaerobically digested, waste activated sludge. No lime or other chemicals are added during the treatment process. This plant receives the effluents discharged by about 100 industries as well as domestic wastes. The industrial activities represented include welding, plating, foundry, printing, laundering, fat rendering and manufacture of steel and electrical products, china, paper board, chemicals, wood preservatives, beverage, dairy and other food products.

In September, 1979, 2.4 tons of the sludge (pH 6.9, 53.1% moisture) was trucked to Ithaca, New York, and applied to a 13

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by 80 foot plot of Hudson silt loam soil (fine, illitic, mesic glossaquic hapludalfs, pH 6.2, cation exchange capacity 16 meq/100 g and 4.1% organic matter). This was equivalent to 100 dry tons of sludge per acre (224 metric tons per hectare) or a layer of sludge about one inch deep covering the soil prior to incorporation. The sludge had been produced a year earlier during which time it had been allowed to weather to facilitate removal of excess soluble salts and decomposition of possible phytotoxic organic constituents. The sludge had a fertilizer equivalent of 1.4-1.3-0.1% (N-P-K) and contained 69.0% ash. The soil had been plowed and disced and after spreading the sludge evenly on the surface it was incorporated with 50 pounds of 15-6.5-12.5% (N-P-K) granular fertilizer by rotary cultivation. An identically sized plot of the same soil without sludge addition was used as the control area. The same quantity (2.4 tons) of bull manure (66% moisture) and fertilizer was incorporated into the control plot. The manure had a fertilizer equivalent of 1.6-1.0-2.9% (N-P-K) and contained 65% ash. The resulting pH of the control and sludge-amended soils, respectively, was 6.6 and 6.4. The following year (1980), tobacco was grown in both plots. In 1981, sugar beets were grown on both plots but no more sludge was applied.

In October, 1981, 50 earthworms (Lumbriscus terrestris) were sampled at random from the upper 10 inches of soil from each of the plots. External soil and debris were thoroughly removed from the worms by repeated rinsings with distilled water. The earthworms from each plot were divided into two size-matched groups of 25. The entire digestive system was removed by dissection from the 25 worms of one group from each plot. The remaining body was rinsed with distilled water. All groups of worms were then freeze-dried, milled to a powder, mixed and duplicate subsamples were taken for cadmium analysis. The samples were wet-ashed with nitric, sulfuric and perchloric acids. Cadmium was determined in the digest by conventional stripping voltammetry (GAJAN and LARRY 1972).

RESULTS AND DISCUSSION

The concentrations of cadmium found in the earthworm groups and growth media are listed in Table 1. The data indicates that earthworms may accumulate considerable concentrations of cadmium from sludge-amended soil but that a major portion may be associated with the digestive system. The average percentages of cadmium in the digestive system of the sludge and control worms were, respectively, 69 and 40.

Since birds such as robins consume earthworms, the total (undissected) cadmium concentration would have to be considered along with any cadmium-contaminated debris external to the earthworm which might be inadvertently ingested. A number of toxic effects from dietary cadmium in avian species have been reported. In the chicken, these have included anemia, enlarged heart, myocardial infarction (STURKIE 1973), lowered hematocrit, hemoglobin

TABLE 1

Cadmium concentration in earthworms, sludge, manure and soil.

Sample	Cadmium[1] ppm, dry wt
Whole worms (sludge)	60.6, 53.8
Whole worms (control)	5.8, 5.2
Dissected[2] worms (sludge)	17.1, 18.4
Dissected worms (control)	2.7, 3.9
Sludge	84.0
Manure	0.6
Soil	1.3

[1]Duplicate analyses

[2]With digestive system removed

and serum zinc concentration (FREELAND and COUSINS 1973), testicular hyperplasia, growth retardation, bone marrow hyperplasia, heart ventrical hypertrophy and small intestinal enteropathy (RICHARDSON et al. 1974). Testicular atrophy in mallard ducks has been reported (WHITE et al. 1978). Transfer of cadmium to chicken eggs is essentially negligible (SELL 1976). Importantly, these effects occur at dietary levels of added cadmium corresponding to those found in earthworms in this study. Potential hazard to wild birds would, of course, depend on what percent of their diet consisted of such cadmium-laden worms. The form of cadmium in earthworms would also be of importance as it determined the degree of cadmium assimilation or excretion. For instance, inducible cadmium-binding proteins resembling metallothionein have been reported in the earthworm (*Eisenia factida*) (SUZUKI et al. 1980). One might assume such sulfyhdryl-rich proteins would strongly bind cadmium and therefore favor fecal excretion. However, cadmium deposition in chicken tissues has been reported to be comparable whether dietary cadmium was in the form of the soluble acetate or bound to cystein (NEZEL et al. 1981). Of course, other possible modifying factors would include protective effects against cadmium toxicity exerted by dietary zinc (JOHNSON et al. 1970), ascorbic acid (FOX et al., 1971) and cysteine or selenium (GUNN et al. 1968).

The accumulation of cadmium by earthworms is not surprising since it has been estimated that up to 15 tons of dry earth per acre is annually digested by them (BRADY 1974). In this regard, the concentration of cadmium in the Syracuse sludge used in this study is typical of municipal sludges but others have been analyzed which are several-fold higher (FURR et al. 1976). It is estimated that the earthworms were about 25 times more plentiful and were generally larger in the control plot area than in the sludge area in this study. This may have been due to cadmium or general heavy metal toxicity. Refractory organic constituents in municipal sludge such as industrial cutting oils may repel earthworms but this requires further study.

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