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Toxicological Benchmarks for Potential Contaminants of Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process

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Toxicological Benchmarks for Potential Contaminants of Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process

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PREFACE

This report presents a standard method for deriving benchmarks for the purpose of "contaminant screening," performed by comparing measured ambient concentrations of chemicals. The work was performed under Work Breakdown Structure 1.4.12.2.3.04.07.02 (Activity Data Sheet 8304). In addition, this report presents sets of data concerning the effects of chemicals in soil on invertebrates and soil microbial processes, benchmarks for chemicals potentially associated with United States Department of Energy sites, and literature describing the experiments from which data were drawn for benchmark derivation.

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TABLES

ABBREVIATIONS

CCME	Canadian Council of Ministers of the Environment
CEC	Cation Exchange Capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	United States Department of Energy
EIV	Ecotoxicological Intervention Value
EPA	United States Environmental Protection Agency
ER-L	Effects Range Low
HCl	Hydrochloric Acid
LCT	Lowest Concentration Tested
LOEC	Lowest Observed Effect Concentration
NOEC	No Observed Effect Concentration
OECD	Organization for Economic Cooperation and Development
ORR	Oak Ridge Reservation
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
RC	Remediation Criteria
RIVM	National Institute of Public Health and Environmental Protection
USGS	United States Geological Survey

EXECUTIVE SUMMARY

One of the initial stages in ecological risk assessments for hazardous waste sites is the screening of contaminants to determine which of them are worthy of further consideration as "contaminants of potential concern." This process is termed "contaminant screening." It is performed by comparing measured ambient concentrations of chemicals to benchmark concentrations. Currently, no standard benchmark concentrations exist for assessing contaminants in soil with respect to their toxicity to soil- and litter-dwelling invertebrates, including earthworms, other micro- and macroinvertebrates, or heterotrophic bacteria and fungi. This report presents a standard method for deriving benchmarks for this purpose, sets of data concerning effects of chemicals in soil on invertebrates and soil microbial processes, and benchmarks for chemicals potentially associated with United States Department of Energy sites. In addition, literature describing the experiments from which data were drawn for benchmark derivation. Chemicals that are found in soil at concentrations exceeding both the benchmarks and the background concentration for the soil type should be considered contaminants of potential concern.

1. SCREENING BENCHMARKS IN ECOLOGICAL RISK ASSESSMENT

An important step in ecological risk assessments is screening the chemicals occurring on a site for contaminants of potential concern. Screening may be accomplished by comparing reported ambient concentrations to a set of toxicological benchmarks. Multiple endpoints for assessing risks posed by soil-borne contaminants to organisms directly impacted by them have been established. Benchmarks for toxic effects of contaminants on terrestrial plants are presented in a companion manuscript (Will and Suter, 1994). This report presents benchmarks for soil invertebrates and microbial processes and addresses only chemicals found at United States Department of Energy (DOE) sites. No benchmarks for pesticides are presented.

If a chemical's concentration or reported detection limit exceeds the screening benchmark, additional analysis may be needed to determine the hazards posed by that chemical (i.e., it is a contaminant of potential concern). However, if the chemical's concentration or detection limit falls below the proposed benchmark, the chemical may be ignored during further study unless public concern or ancillary evidence suggest that it should be retained.

Soil benchmarks are based on data provided by toxicity studies in the field or, more commonly, in laboratory settings. The reported toxic concentrations are not all equivalent to concentrations reported from field sites. Most of the soil concentrations of metals reported from waste sites are from extractions with hydrochloric acid (HCl) or other mineral acids which are intended to provide estimates of total concentrations. Similarly, concentrations of organic contaminants in waste site soils are total concentrations derived from rigorous extractions by solvents. In some cases, toxicity tests report contaminant concentrations extracted from soils, but various extractants are used that may not yield total concentrations. More commonly, the concentrations reported are nominal concentrations of a soluble form (i.e., a highly bioavailable form) of the chemical added to soil. We have chosen to use nominal concentrations from the literature to compare to the "total" extracted quantities of a chemical reported for waste sites.

These benchmarks are appropriate for contaminant screening purposes only. An assessor must realize that soil and invertebrate characteristics play a large part in toxicity and incorporate these site-specific considerations in the evaluation of the potential hazards of a chemical. If chemical concentrations reported in soils supporting many earthworms exceed one or more of the benchmarks presented in this report, or if a benchmark is exceeded by background soil concentrations, it is generally safe to assume that the benchmark is a poor measure of risk to earthworms at that site.

After discussing methods, this report presents the results of the literature reviews and benchmark derivation for toxicity to earthworms (Sect. 3), heterotrophic microbes and their processes (Sect. 4), and other invertebrates (Sect. 5). The final sections compare the benchmarks to other criteria and background and draw conclusions concerning the utility of the benchmarks.

2. METHODS

2.1 DATA

References on the toxicity of selected chemicals to soil and litter dwelling invertebrates, microbes, and microbial processes were obtained from searches of bibliographic data bases (BIOSIS, POL TOX I), review articles, and conventional literature searching. The target was reports of toxicity tests of individual chemicals in laboratory, greenhouse, or field settings. Data presented in this report were derived mainly from primary sources. More specific information on the types of effects data available for each group of organisms is given in the appropriate section of this report. The general criteria for inclusion of a study in the data set used to derive toxicity benchmarks follow.

1. Methodology was clearly stated (especially concentrations of applied chemicals) and followed in the experiment.

2. Results were quantified as measures of survivorship, growth, respiration, reproduction, substrate transformation, or enzyme activity.

3. Results were presented in numeric form, or graphical presentations of data were clearly interpretable.

4. An unambiguous reduction existed in the measured parameter within the range of applied concentrations of the chemical of interest.

The data selected for soil benchmarks using these criteria appear in Appendix A through Appendix C. Data were collected in the following categories for analysis:

1. Chemical—The effects of individual chemicals of interest were analyzed. In the case of metals, the metal itself is listed in the "Chemical" field. For organics, the compound is listed in the "Chemical" field.

2. Chemical Form—The form in which the chemical was added to the experimental medium (e.g., soluble salt, organic).

3. Growth Medium—Substrate in which organisms were kept during the experiment. The media included natural and artificial soil, manure, soil/litter microcosms, and other experimental substrates.

4. Cation exchange capacity is the sum of the exchangeable cations that a soil can adsorb, expressed as milliequivalents per 100 g of soil. Soil organic and inorganic constituents contain negatively charged sites that are the location of important interactions with positively charged ions in soil solution. These interactions affect the toxicity of many contaminants.

5. Organic matter—Soil organic matter is important in reactions of many contaminants in the soil. Percentage organic carbon, if given, was converted to the more frequently cited

measure of percentage organic matter by the equation (Nelson and Sommers, 1982):

$$\%\text{organic carbon} \times 2 = \%\text{organic matter}$$

6. Soil pH—The pH of the soil exerts control over chemical reactions that affect speciation and bioavailability of chemicals

7. Species—The species of earthworm, other invertebrate, or microorganism is necessary when provided. However, most microbiological experiments were conducted with an undefined, mixed native microflora.

8. Exposure duration—How long the organisms were exposed to the test chemical.

9. NOEC Applied—The no observed effect concentration (NOEC) is defined as the highest applied concentration of the chemical of interest causing a reduction of 20% or less in a measured response.

10. LOEC Applied—The lowest observed effect concentration (LOEC) is defined as the lowest applied concentration of the chemical of interest causing a greater than 20% reduction in a measured response. In some cases, the LOEC for the test was the lowest concentration tested (LCT) or the only concentration reported, as when the EC_{50} (or ED_{50}) was reported.

11. Growth parameter—Response varied with the type of organism and experiment.

12. Percent decrease—Percent decrease in measured parameter compared to control organism.

2.2 SELECTION OF LEVELS OF EFFECTS

Twenty percent reduction in growth, reproduction, or activity was used as the threshold for significant effects to be consistent with other screening benchmarks for ecological risk assessment and with current regulatory practice (Suter, 1992). In brief, most regulatory criteria are based on concentrations in toxicity tests that cause effects which are statistically significantly different from controls. On average, these concentrations correspond to greater than 20% effects. In addition, regulatory actions may be based on comparisons of biological parameters measured on contaminated sites to those from reference sites. Differences between sites generally must be greater than 20% to be reliably detected in such studies. Therefore, the 20% effects level is treated as a conservative approximation of the threshold for regulatory concern.

2.3 DERIVATION OF BENCHMARKS

Because of the diversity of soils, species, chemical forms, and test procedures, it is impossible to estimate concentrations that would constitute a threshold for toxic effects on the invertebrate communities at particular sites from published toxicity data. This situation is analogous to the problem of deriving benchmarks for sediments. In this report, the method used for deriving soil benchmarks is based on the National Oceanographic and Atmospheric Administration's method for deriving the Effects Range Low (ER-L) (Long and Morgan, 1990) which has been recommended as a sediment screening benchmark by the U.S. Environmental Protection Agency (EPA) Region IV.

The ER-L is the tenth percentile of the distribution of various toxic effects thresholds for various organisms in sediments.

This approach can be justified by assuming that the toxicity of a chemical in soil is a random variate, the toxicity of contaminated soil at a particular site is drawn from the same distribution, and the assessor should be 90% certain of protecting organisms growing in the site soil. Any bias in the data set would mitigate against that assumption. In this implementation of the approach, the bias most likely to be significant is the use of soluble salts of metals in the toxicity tests which are likely to be more toxic than the mixture of forms encountered in field soils. That bias would result in conservative benchmark values. Other possible sources of bias include the exclusion of synergistic and antagonistic effects resulting from interactions between chemicals, use of a limited number of test species that may not be representative of those in the field, use of artificial soils that may not be representative of soils in general, and other laboratory test conditions that may not be representative of field conditions. The direction and magnitude of these potential biases is unknown.

The toxicity benchmarks were derived by rank ordering the LOEC values and then picking a number that approximated the 10th percentile. As with the ER-Ls, statistical fitting was not used because there was seldom sufficient data and because these benchmarks are to be used as screening values and do not require the consistency and precision of regulatory criteria. If there were 10 or fewer values for a chemical, the lowest LOEC was used. If there were more than 10 values, the 10th percentile LOEC value was used. If the 10th percentile fell between LOEC values, a value was chosen by interpolation. Since these benchmarks are intended to be thresholds for significant effects on growth and production, test endpoints that indicate a high frequency of lethality are not appropriate. Therefore, when a benchmark is based on an LC_{50} or on some other endpoint that includes a 50% or greater reduction in survivorship, the value is divided by a factor of 5; this factor is based on the authors' expert judgment. Although no data exist for comparison of lethal and sublethal effects concentrations in tests conducted with the same species and soils, it is assumed that a factor of 5 can be used to approximate the ratio LC_{50}/EC_{20}.

In all cases, benchmark values were rounded down to one significant figure. This rounding was done for two reasons. First, it is not appropriate to ascribe greater precision to a number than it actually possesses; these benchmarks are very imprecise. Second, the rounding serves to emphasize the fact that the benchmarks are conceptually distinct from the test endpoint values from which they were derived. That is, an LOEC may be a precise estimate of the lowest toxic concentration for a particular plant variety in a particular test system, but when an LOEC is used as a benchmark for all plants in field soils, it is a qualitatively different and much more poorly defined value.

Benchmarks were derived in the previously described manner for earthworms and microbial heterotrophs. Insufficient information was available for establishing benchmarks for other invertebrates, as discussed in the appropriate section of this report. Proposed screening benchmarks for toxic effects of contaminants in soils are presented in Table 1 (earthworms) and Table 2 (microbial populations).

Table 1. Screening benchmark concentrations for the toxicity of chemicals to earthworms

CHEMICAL	SOIL (mg/kg)
Arsenic	60
Cadmium	20
Chromium	0.4
Copper	50
Lead	500
Mercury	0.1
Nickel	200
Selenium	70
Zinc	200
Chloroacetamide	2
3-chloroaniline	30
2,4-dichloroaniline	100
3,4-dichloroaniline	20
2,4,5-trichloroaniline	20
2,3,5,6-tetrachloroaniline	20
Pentachloroaniline	100
1,2-dichloropropane	700
Dimethylphthalate	200
Fluorene	30
N-nitrosodiphenylamine	20
Phenol	30
4-nitrophenol	7
3-chlorophenol	10
3,4-dichlorophenol	20
2,4,5-trichlorophenol	9
2,4,6-trichlorophenol	10
2,3,4,5-tetrachlorophenol	20
Pentachlorophenol	4
Chlorobenzene	40
1,4-dichlorobenzene	20
1,2,3-trichlorobenzene	20
1,2,4-trichlorobenzene	20
1,2,3,4-tetrachlorobenzene	10
Pentachlorobenzene	20
Nitrobenzene	40

Table 2. Screening benchmark concentrations for the toxicity of chemicals to soil microorganisms and microbial processes

CHEMICAL	SOIL (mg/kg)
Aluminum	600
Arsenic	100
Barium	3000
Boron	20
Cadmium	20
Chromium	10
Cobalt	1000
Copper	100
Fluorine	30
Iron	200
Lanthanum	50
Lead	900
Lithium	10
Manganese	100
Mercury	30
Molybdenum	200
Nickel	90
Selenium	100
Silver	50
Tin	2000
Titanium	1000
Tungsten	400
Vanadium	20
Zinc	100
Acrylonitrile	1000
Carbon tetrachloride	1000
Cis-1,4-dichloro-2-butene	1000
Hexachlorobenzene	1000
Nitrobenzene	1000
Phenol	100
Pentachlorophenol	50
Trans-1,4-dichloro-2-butene	1000

This method of deriving screening benchmarks for soil organisms may appear as insufficiently conservative. This impression might result from the fact that the derivation of the benchmark (like the derivation of the ER-L values) implies a significant effect on approximately 10% of the species. However, the method probably is sufficiently conservative for the following reasons. First, the benchmarks were derived for a community-level assessment endpoint. Given the water, nutrient, or physical limitations of most soil- and litter-dwelling communities, a reduction in survival, growth, or reproduction of 10% of earthworm species or reduction of the rates of 10% of microbial processes is likely to be acceptable. Second, the benchmarks derived by these methods have proved to be conservative in practice. In some cases, the benchmarks are lower than background concentrations (Sect. 7). It is believed that this is caused by the fact that the benchmarks are based on toxicity tests that dose growth substrates with soluble salts of metals which are more available than most naturally occurring metals and even metals at many, if not most, waste sites.

The authors have attempted to assign levels of confidence to the benchmarks; these are presented with the appropriate chemicals in Sect. 3. The criteria best reflecting that confidence are as follows:

1. Low Confidence—Benchmarks based on fewer than 10 literature values.

2. Moderate Confidence—Benchmarks based on 10 to 20 literature values.

3. High Confidence—Benchmarks based on more than 20 literature values.

High confidence in a benchmark based on more than 20 reported toxic concentrations may be reduced to moderate if the range of plant, earthworm, or microbial species tested is narrow (i.e., no tree species or only one family of plants was tested). Moderate or high confidence benchmarks were in some instances demoted one level if the value approximating the 10th percentile was the lowest concentration tested and caused a greater than 30% reduction in the measured growth parameter. These criteria may seem arbitrary, but the result is a confidence classification that fairly reflects the authors' professional judgment.

Any scheme for deriving a set of standard ecotoxicological benchmarks is based on assumptions that may be questioned by readers. The procedure used herein is consistent with current regulatory practice and contains a minimum of assumptions or factors. Readers who care to make other assumptions or add safety factors may make use of the data presented herein to calculate their own benchmarks.

3. EARTHWORMS

3.1 INTRODUCTION

Earthworms are probably the most important soil invertebrate in promoting soil fertility (Edwards, 1992). Their feeding and burrowing activities break down organic matter and release nutrients and improve aeration, drainage, and aggregation of soil. Earthworms are also important components of the diets of many higher animals.

Earthworms are known to take up many inorganic and organic soil contaminants. Availability of contaminants for uptake from the soil is controlled by soil characteristics. van Gestel (1992) concludes that, with the exception of extremes in pH, it is not possible to predict metal availability on the basis of soil variables. Availability of contaminants from plant litter in varying degrees of decomposition is also complex and poorly understood. The feeding and burrowing habits of earthworms determine their exposure to chemicals in soil and litter. Geophagus organisms (those taking in large amounts of soil during feeding on well-decomposed organic material) and those living on or near the soil surface may have greater exposure to organic chemicals than worms feeding on litter pulled down into burrows in the subsoil (Curl et al., 1987). Organic contaminants may undergo oxidation by the cytochrome P-450 and other enzyme systems within the earthworm. Earthworms also may bind xenobiotics and their metabolites in unextractable forms (Stenersen, 1992). Physiological response mechanisms to metals are species specific (Tomlin, 1992). Much of the ingested lead, cadmium, and zinc (the three most studied inorganic contaminants) is accumulated in chloragogenous tissue (intestinal wall) of the posterior alimentary canal (Morgan et al., 1993). Little is known about mechanisms of toxicity of chemicals in earthworms.

3.2 EARTHWORM DATA SELECTION

Information suitable for calculating screening benchmarks was available for a limited number of metals and a larger number of organic compounds. Toxic effects information on polychlorinated biphenyls (PCBs) is not available and is limited for polycyclic aromatic hydrocarbons (PAHs). The toxicity of many agricultural pesticides has been tested, but as stated previously, they will not be presented herein. Data on which the benchmarks are based are given in Appendix A; benchmarks are given in Table 1.

Only experiments in which earthworms were exposed to soil (natural or artificial mixture of natural components), soil/litter microcosms, or manure were considered for determining benchmark levels of contaminants in soils. The main alternative method is the contact filter paper test in which the organisms are placed on filter paper containing the chemical to be tested for toxicity. Results are presented as mg chemical per cm^2 filter paper and are therefore not comparable to results given as concentrations (mg per kg substrate). The test gives information about skin contact toxicity but not oral ingestion toxicity (Reinecke, 1992). Although uptake through the cuticle is considered an important uptake route for some organic chemicals (Stenersen, 1992), oral ingestion is an important uptake route for metals and organic compounds found in soil and litter. Heimbach (1988) reports that there is little correlation between contact paper test and OECD artificial soil test results. Good correlation between the OECD artificial soil test and field tests are reported for several pesticides (Heimbach, 1992).

Acute and chronic toxicity are tested for in experiments evaluating the effects of chemicals on earthworms. Mortality is the main endpoint in acute toxicity tests with results reported as the concentration causing death in 50% of the test population (LC_{50}). In the case of organic compounds, most of the literature reports LC_{50} values.

Change of individual body weight, which may indicate sublethal effects, can also be measured during acute toxicity tests. Endpoints that indicate effects important to population dynamics include cocoon production, cocoon hatching rates, and juvenile survival (Kokta, 1992). It should be noted that several researchers have found a negative correlation between adult body weight and reproduction (Kokta, 1992), and the conclusion is that these characteristics should be investigated together.

3.3 EARTHWORM TEST SPECIES

Experiments on the toxicity of chemicals to earthworms have been performed with representatives of three families (*Megascolecidae*, *Eudrilidae*, and *Lumbricidae*) and 12 species representing earthworms from Europe and North America, Africa, India, and Asia.

The most commonly used earthworm, *Eisenia fetida*, is a nonburrowing organism found in compost piles and other organic-rich environments (Lee, 1985). They belong to the epigeic ecological category of Bouche (1992). *Eisenia fetida* may be the most prolific of worms with a shorter lifespan than others of the *Lumbricidae* family. Its natural habitat may be under the bark of fallen trees, and protozoa may be an essential part of its diet (Lee, 1985). *Eisenia andrei* is considered a sibling species of *E. fetida* by most researchers (Bouche, 1992); however, it has been treated as a subspecies of *E. fetida* by others in the past (van Gestel and Ma, 1988). These earthworms are considered ideal for toxicity testing because of the ease with which populations are maintained in the laboratory. The short generation time of *E. fetida* allows investigation of effects of chemicals on reproduction and second generation survival.

Lumbricus rubellus is a shallow-burrowing lumbricid active in the surface and litter horizons of pastures and grasslands (Lee, 1985). It may forage for food, such as dead roots, in the subsurface horizon and dig deep burrows in which to rest during periods of environmental stress. In the litter layer, *L. rubellus* feeds on slightly decomposed plant remains, dung, and bacteria.

The genus *Allolobophora* is represented in the toxicity literature by three species. *Allolobophora chlorotica* is a shallow-burrowing lumbricid worm found in permanent pasture and other grasslands (Lee, 1985). It spends most of its life in the topsoil feeding on well-decomposed plant remains (humus). It is considered to be geophagus because it ingests a large quantity of soil during feeding. *Allolobophora caliginosa* and *Apporectodea caliginosa* are classified by Dindal (1990) as the same organism. It is similar to *A. chlorotica* in its burrowing and feeding habits and is common in alkaline soils of Egypt (Lee, 1985). No life history information was available on the species *A. tuberculata*.

Octolasium cyaneum is a burrowing lumbricid species that lives in the soil and feeds on dead roots (Lee, 1985). It is common in pasture lands where it creates deep horizontal burrows.

Dendrobaena rubida is an ubiquitous forest litter inhabiting lumbricid (Lee, 1985). It feeds on slightly decomposed leaf litter and does not burrow into the soil.

The *Eudrilidae* family is represented by *Eudrilus eugeniae*. This tropical species from west Africa is now widespread throughout tropical and temperate regions (Neuhauser et al., 1979). It is a common inhabitant of topsoils and prefers habitats with high concentrations of organic matter.

The *Megascolecidae* family is represented by three organisms for which little information is available. *Perionyx excavatus* is the Indian subcontinent equivalent of *Eisenia fetida*, preferring compost heaps and other accumulations of organic material (Lee, 1985). It is known to feed on animal dung. *Pheretima posthuma* is originally from east and southeast Asia. No life history information was found on *Octochaetus pattoni*; however, other members of the genus occur in New Zealand (Lee, 1985).

3.4 EARTHWORM DATA AND BENCHMARK DERIVATION

3.4.1 Inorganic Compounds

Arsenic. Fischer and Koszorus (1992) tested the effects of 68 ppm of arsenic (as potassium arsenate) on growth and reproduction of *Eisenia fetida* (average initial age of 5 weeks) when added to a combination of peaty marshland soil and horse manure (1:1). Number of survivors and their live mass and number of cocoons produced were measured. The number of cocoons produced per worm showed the highest sensitivity to arsenic with a 56% reduction at the test concentration.

The benchmark of 60 ppm arsenic is based on this study only. Because of the lack of data, confidence in this benchmark is low.

Cadmium. van Gestel and his colleagues in the Netherlands have established a fairly standard procedure for testing the toxicity of chemicals to earthworms in an artificial soil mixture made up of (by dry weight) 10% sphagnum peat, 20% kaolin clay, and 69% fine sand and $CaCO_3$ to adjust the pH to approximately 6 (OECD soil) (van Gestel et al., 1992). The work in this citation evaluated the effects of Cd, added to the soil as $CdCl_2$, on growth and reproduction (cocoons/worm/week, percent fertility of cocoons, juveniles/fertile cocoon, juveniles/worm/week) of *Eisenia andrei* after 21 days. The Cd was added in aqueous form and the resultant substrate added to 1 L glass jars. Approximately 5 g finely ground cow dung was added to a shallow hole in the middle of the substrate to serve as a food source for the 10 worms. A concentration of 18 ppm Cd was required to reduce the number of cocoons produced/week and the number of juveniles/worm (23 and 22%). Growth and reproduction were not affected at 10 ppm Cd. In other experiments by van Gestel et al. (1991a) using the same system but comparing the results from putting the food source in a hole with those from mixing it in with substrate, growth was reduced 44% by 100 ppm (32 ppm had no effect) in the former case and 40% by 32 ppm (10 ppm had no effect), in the latter. The EC_{50} for clitella development (indicating sexual maturity) was 108 ppm Cd for dung placed in a center hole in the substrate, and 27 ppm for dung mixed in with substrate.

Spurgeon et al. (1994) kept adult *E. fetida* in contaminated OECD artificial soil (pH 6.3) for 8 weeks to test the effects of Cd [as $Cd(NO_3)_2$] on survival and growth of the earthworms. Results were reported as LC_{50}s for mortality and EC_{50}s for effects on cocoon production. After 56 days, the calculated LC_{50} was greater than 300 ppm Cd. The EC_{50} for cocoon production was 46.3 ppm.

The effects of Cd added to horse manure (as Cd acetate) on *E. fetida* (initially less than 2 weeks old) was investigated by Malecki et al. (1982). Two growth periods were used, 8 and 20 weeks, and

survival, weight gain, and cocoon production were measured. The most sensitive parameter was cocoon production. In the 8-week test, the lowest concentration tested, 25 ppm Cd, caused a 52% decrease in cocoon production. In the 20-week test, the lowest concentration tested, 50 ppm Cd, caused a 24% decrease in cocoon production.

The previously described system (horse manure) was used by Neuhauser et al. (1984) to look at the effects of Cd added as various soluble salts on growth and reproduction of *E. fetida*. The authors report their results with pooled data from all forms of a metal. After 6 weeks, both growth (weight) and cocoon production were decreased (25 and 100%) by 100 ppm Cd, the lowest concentration tested.

Bengtsson et al. (1986) report the effects of Cd on reproduction in the earthworm *Dendrobaena rubida* when grown in substrate at varying acidity. The metal was added to a 1:2 (volume) combination of sandy soil and well-decomposed cattle dung with a resulting organic carbon of about 6%. After 4 months at pH 4.5, the number of cocoons produced per worm was reduced 62% by 100 ppm Cd, while 10 ppm had no effect. The percent hatched cocoons, hatchlings/cocoon, and total number of hatchlings were not affected. At pH 5.5, the number of cocoons produced per worm, hatchlings/cocoon, and total number of hatchlings were reduced 78, 71, and 74%, respectively, by 100 ppm Cd, while 10 ppm had no effect. The percent hatched cocoons was not affected. At pH 6.5, the percent hatched cocoons, hatchlings/cocoon, and total number of hatchlings were reduced 47, 38, and 30%, respectively, by 100 ppm Cd, while 10 ppm had no effect. The number of cocoons/worm was not affected.

van Gestel and van Dis (1988) conducted a series of experiments in a sandy soil (1.7% organic matter, CEC 5.5 meq/100 g soil) to investigate the effects of acidity on acute toxicity of Cd ($CdCl_2$) to adult *E. andrei*. The LC_{50} was between 320 and 560 ppm Cd after 14 days at pH 4.1 and >1000 (no effect) at pH 7. The LC50 concentration in OECD soil, with 10% organic matter at pH 7, was also >1000 (no effect).

Neuhauser et al. (1985) used OECD artificial soil (pH 6) to determine LC_{50} of Cd (added as Cd nitrate) for adult *E. fetida*. After 14 days, the LC_{50} was calculated to be 1843 ppm Cd.

In a study examining the effects of soil factors on Cd toxicity and uptake, Ma (1982) used a sandy loam soil (pH 7.3, 8% organic matter) spiked with $CdCl_2$ to determine the effects of Cd on survival of adult *Lumbricus rubellus*. After 12 weeks, 1000 ppm Cd caused an 82% decrease in survival while 150 ppm had no effect.

A benchmark of 20 ppm has been computed for Cd on the basis of the 16 available concentrations causing toxicity. Confidence in this benchmark is moderate.

Chromium. Abbasi and Soni (1983) worked with a system in which the earthworm *Octochaetus pattoni* was kept in concrete tanks containing a mixture of soil and animal dung for 60 days to assess the effect of Cr(VI), added as $K_2Cr_2O_7$, on survival and reproduction. Survival was the most sensitive measure with a 75% decrease resulting from 2 ppm Cr, the lowest concentration tested. The number of cocoons produced was not diminished until the concentration reached 20 ppm Cr (highest concentration tested); the number of juveniles produced was not affected.

These same researchers (Soni and Abbasi, 1981) found no survival of *Pheretima posthuma* after 61 days in a paddy soil to which 10 ppm Cr(VI) (lowest concentration tested) was added.

van Gestel et al. (1992), in the system described previously for Cd, also found growth of *E. andrei* to be more sensitive to Cr than reproduction. In this case, Cr(III) was added as chromic nitrate to OECD soil. A concentration of 32 ppm Cr reduced growth by 30% while cocoons/worm/week, percent fertile cocoons, and juveniles/worm/week were reduced 28, 22, and 51%, respectively, by 100 ppm Cr.

Molnar et al. (1989) examined the effects of Cr(III) and Cr(VI) on growth and reproduction of *Eisenia fetida* in an undefined substrate. Chromium (VI) was added as $K_2Cr_2O_7$ and Cr(III) as $KCr(SO_4)_2$. Reproduction after 8 weeks was the measure most sensitive to Cr(III) with a 55% decrease in the number of cocoons and hatchlings at 625 ppm Cr(III). The authors indicate that reproduction was also sensitive to Cr(VI) but no data were given. After 2 weeks, mass gain of juveniles was decreased 34% by 2,500 ppm Cr(III) (625 ppm had no effect) and 43% by 625 ppm Cr(VI) (lowest concentration tested). After 4 weeks, mass gain of juveniles was decreased 39% by 2,500 ppm Cr(III) (625 ppm had no effect), and Cr(VI) had no effect. Chromium(VI) at 1,250 ppm was ineffective when worms were introduced after the soil had equilibrated for 2 weeks, regardless of the length of exposure.

It is difficult to set a benchmark concentration for toxicity of Cr to earthworms. Survival may be more sensitive than reproduction to the metal when it is added to the earthworm substrate as a soluble salt. The relative toxicity of Cr(III) and Cr(VI) is not clear from these studies. Cr(VI) ions can pass through cell membranes with much greater ease than Cr(III) ions. However, it is thought that Cr(VI) is reduced to Cr(III) inside the cell (Molnar et al., 1989); this latter may be the final active form. Without a better understanding of Cr transformations in the soil, transport across earthworm cell membranes, and reactions within the cell, it is difficult to separate the effects of the two different forms.

The 0.4 ppm benchmark for Cr is based on the work of Abbasi and Soni (1983). A safety factor of 5 was applied to the 2 ppm LOEC because it caused a 75% reduction in earthworm survival.

Confidence in this benchmark is low because it is based on only five reported concentrations causing toxicity to earthworms.

Copper. Neuhauser et al. (1984) evaluated the effects of soluble forms of copper on growth and reproduction *E. fetida* as described for Cd. The authors report their results with pooled data from all forms of a metal. After 6 weeks, both growth (weight) and cocoon production were decreased (75 and 85%) by 2000 ppm Cu, while 1000 ppm had no effect.

Neuhauser et al. (1985) used the OECD artificial soil (pH 6) to estimate LC_{50} of Cu (added as Cu nitrate) for adult *E. fetida*. After 14 days, the LC_{50} was 643 ppm Cu.

Spurgeon et al. (1994) kept adult *E. fetida* in contaminated OECD artificial soil (pH 6.3) for 8 weeks to test the effects of Cu (as $Cu(NO_3)_2$) on survival and growth of the earthworms, as described for Cd. After 56 days, the calculated LC_{50} was 555 ppm, and the EC_{50} for cocoon production was 53.3 ppm.

The effects of Cu added to horse manure (as copper acetate) on *E. fetida* (initially less than 2 weeks old) was investigated by Malecki et al. (1982). Two growth periods were used, 8 and 20 weeks, and survival, weight gain, and cocoon production were measured. The most sensitive parameter was cocoon production. In the 8-week test, 500 ppm Cu caused a 24% decrease in cocoon

production, while 300 ppm had no effect. In the 20-week test, 1000 ppm Cu caused a 24% decrease in cocoon production, while 500 ppm had no effect.

Bengtsson et al. (1986) looked at the effects of copper on *Dendrobaena rubida* at different acidities in the same type of experiments described for Cd. After 4 months at pH 4.5, the number of cocoons produced per worm, hatchlings/cocoon, and total number of hatchlings were reduced 70, 64, and 74%, respectively, by 100 ppm Cu, the lowest concentration tested. The percent hatched cocoons was not affected. At pH 5.5, the number of cocoons produced per worm, hatchlings/cocoon, and percent hatched cocoons were reduced 96, 100, and 100%, respectively, by 500 ppm Cu, while 100 ppm had no effect. The total number of hatchlings was not affected. At pH 6.5, the number of cocoons produced per worm, hatchlings/cocoon, and percent hatched cocoons were reduced 90, 100, and 100%, respectively, by 500 ppm Cu, while 100 ppm had no effect. The total number of hatchlings was not affected.

In experiments by van Gestel et al. (1991b) using the same system described previously but with Cu ($CuCl_2$) mixed homogeneously with the OECD substrate, growth of *E. fetida* was reduced 32% by 100 ppm (32 ppm had no effect). The EC_{50} for clitella development (sexual development) was >100 ppm Cu.

In a study examining the effects of soil factors on Cu toxicity and uptake, Ma (1982) used a sandy loam soil (pH 7.3, 8% organic matter) spiked with $CuCl_2$ to determine the effects of Cu on survival of adult *Lumbricus rubellus*. After 12 weeks, 1000 ppm Cu caused an 82% decrease in survival while 150 ppm had no effect.

The effect of soil organic carbon on toxicity of Cu ($CuSO_4$) to the earthworm *Octolasium cyaneum* was evaluated by Streit and Jaggy (1983). They determined the 14-day LC_{50} in a Brown soil, a Rendzina soil, and a peat soil containing 3.2, 14, and 43% organic carbon, respectively. LC_{50} concentrations were 180, 850, and 2500 ppm, respectively.

van Rhee (1975) tested the effects of a single concentration of Cu added to a polder soil on body weight, number of cocoons produced per week, mortality and sexual development of *Allolobophora caliginosa*. After 60 days, number of cocoons produced was the only measure affected; it decreased by 27% in the presence of 110 ppm Cu.

Using the OECD artificial soil (pH 6) and 21-day test procedure, van Gestel et al. (1989) looked at the effects of Cu (as $CuCl_2$) on reproductive parameters of adult *E. andrei*. After 21 days, cocoon production was decreased 36% by the addition of 180 ppm Cu to the substrate, while 120 ppm had no effect. Cocoon hatchability and number of juveniles per cocoon were not affected.

The sublethal effects of Cu on *L. rubellus* were investigated with respect to mortality, growth, cocoon production, and litter breakdown activity (Ma, 1984). Loamy sand field soil (5.7% organic matter, pH 4.8), with Cu added as $CuCl_2$, was placed in bags with leaf litter added to the top. In an experiment lasting 6 weeks, the number of cocoons produced was decreased 42% by 131 ppm (HNO_3:H_2SO_4 extractable), while 54 ppm had no effect. In another study using this soil with the pH adjusted to between 4.8 and 7.1, Ma investigated at the effect of acidity on toxicity of Cu ($CuSO_4$) to *L. rubellus* growth and reproduction. At pH 4.8, 148 ppm Cu resulted in a 26% decrease in production (83 ppm had no effect). At pH 6, a 33% reduction in cocoon production resulted from 278 ppm Cu, while 148 ppm had no effect. In a 6-week experiment using a calcareous sandy loam

soil (pH 7.3, organic matter 3.4%), the number of cocoons produced was diminished 41% in cultures to which 63 ppm Cu were added as $CuCl_2$ (13 ppm had no effect).

The relative sensitivity of several lumbricid earthworms to Cu ($CuCl_2$) added to a sandy soil (pH 5, organic matter 5%) was investigated by Ma (1988). EC_{50}s for cocoon production of *L. rubellus*, *Aporrectodea caliginosa*, and *Allolobophora chlorotica* were 122, 68, and 51 ppm Cu.

The work of Streit and Jaggy (1983) and others shows that the organic carbon content of the soil is a strong determinant of the bioavailability and toxicity of copper. From the studies cited, it appears that low pH has a compounding effect, with an increase in Cu availability resulting from more acid conditions. Overall, reproduction is more sensitive than mortality, and there is no consistent evidence that one genus of earthworms is any less tolerant to Cu under a given set of conditions than another genus.

The benchmark for Cu was established at 50 ppm. Confidence in this benchmark is moderate.

Lead. Bengtsson et al. (1986) examined the effects of lead on *Dendrobaena rubida* at different acidities in the same type of experiments as those described for Cd. After 4 months at pH 4.5, the number of cocoons produced per worm, hatchlings/cocoon, and percent hatched cocoons were reduced 75, 100, and 100%, respectively, by 500 ppm Pb, while 100 ppm had no effect. At pH 5.5 and 6.5, Pb had no effect at any level on any of the measures.

Spurgeon et al. (1994) kept adult *E. fetida* in contaminated OECD artificial soil (pH 6.3) for 8 weeks to examine the effects of Pb (as $Pb(NO_3)_2$) on survival and growth of the earthworms as described for Cd. After 56 days, the calculated LC_{50} was 3760 ppm, and the EC_{50} for cocoon production was 1940 ppm.

The effects of Pb added to horse manure (as lead acetate) on *E. fetida* was investigated by Malecki et al. (1982), as described above for Cd. The most sensitive parameter was cocoon production. In the 8-week test, 4000 ppm Pb caused a 50% decrease in cocoon production, while 2000 ppm had no effect. In the 20-week test, 5000 ppm Pb caused a 28% decrease in cocoon production, while 1000 ppm had no effect.

Neuhauser et al. (1985) used the OECD artificial soil (pH 6) to determine LC_{50} of Pb [added as Pb (NO_3)] for adult *E. fetida*. After 14 days, the LC_{50} was calculated to be 5941 ppm Pb.

Neuhauser et al. (1984) evaluated the effects of soluble forms of lead on growth and reproduction of *E. fetida* as described for Cd. The authors report their results with pooled data from all forms of a metal. After 6 weeks, cocoon production was decreased 80% by 5000 ppm Pb, the lowest concentration tested. Growth was not affected until 40,000 ppm was added to the substrate.

A benchmark of 500 ppm has been established for Pb based on the work of Bengtsson et al. (1986) which showed inhibition of reproduction at this concentration. Confidence in this benchmark is low because of the limited amount of data.

Mercury. Abbasi and Soni (1983) worked with *Octochaetus pattoni* in a system described previously for Cd. They assessed the effect of Hg(II), added as $HgCl_2$, on survival and reproduction. Survival and cocoon production were reduced 65 and 40% at 0.5 ppm Hg, the lowest concentration tested. The number of juveniles produced was not affected.

The effect of methyl mercury on survival and segment regeneration of *E. fetida* was investigated by Beyer et al. (1985). Methyl mercury chloride was added to an undefined potting soil in which the earthworms were cultured for 84 days. A concentration of 12.5 ppm Hg reduced survival by 21%, and the ability to regenerate excised segments was reduced by 69%. Methyl mercury at 2.5 ppm had no effect.

It is not possible to evaluate the relative toxicity of forms of Hg based on these two studies which used different systems and evaluated two different families of earthworms.

A benchmark of 0.1 ppm was established for Hg based on the work of Abbasi and Soni (1983). A safety factor of 5 was applied to the 0.5 ppm LOEC because it caused a 65% reduction in earthworm survival. Confidence in this benchmark is low because of the limited amount of data.

Nickel. The effects of Ni (added to horse manure as Ni acetate) on *E. fetida* were investigated by Malecki et al. (1982), as described for Cd. The most sensitive parameter was cocoon production. In the 8-week test, 300 ppm Ni caused a 41% decrease in cocoon production, while 200 ppm had no effect. In the 20-week test, 200 ppm Ni caused a 23% decrease in cocoon production, while 100 ppm had no effect.

Neuhauser et al. (1985) used the OECD artificial soil (pH 6) to determine LC_{50} of Ni (added as Ni nitrate) for adult *E. fetida*. After 14 days, the LC_{50} was calculated to be 757 ppm Ni.

Neuhauser et al. (1984) evaluated the effects of soluble forms of nickel on growth and reproduction *E. fetida* as described for Cd. The authors report their results with pooled data from all forms of a metal. After 6 weeks, cocoon production was decreased 33% by 250 ppm Ni, the lowest concentration tested. Growth was not affected until 500 ppm was added to the substrate.

In a study examining the effects of soil factors on Ni toxicity and uptake, Ma (1982) used a sandy loam soil (pH 7.3, 8% organic matter) spiked with $NiCl_2$ to determine the effects of Ni on survival of adult *Lumbricus rubellus*. After 12 weeks, 1000 ppm Cd caused a 31% decrease in survival while 150 ppm had no effect.

A benchmark of 200 ppm has been established for Ni based on the work of Malecki et al. (1982) which showed inhibition of reproduction at this concentration. Confidence in this benchmark is low because of the limited amount of data.

Selenium. Fischer and Koszorus (1992) tested the effects of 77 ppm of selenium (as sodium arsenite) on growth and reproduction of *Eisenia fetida* when added to a combination of peaty marshland soil and horse manure (1:1). Number of survivors and their live mass and number of cocoons produced were measured. The number of cocoons produced per worm showed the highest sensitivity to selenium with a 69% reduction at the test concentration.

The benchmark of 70 ppm is based on this study. Confidence in this benchmark is low.

Zinc. van Gestel et al. (1993) evaluated the effect of zinc added as $ZnCl_2$ to OECD artificial soil (pH 6.2), on the growth and reproduction of *E. andrei*. The numbers of cocoons and juveniles produced were reduced 31 and 42% by 560 ppm, while 320 ppm had no effect. The percent fertile cocoons and number of juveniles per fertile cocoon were not affected until Zn was added to a concentration of 1000 ppm Zn, and percent growth of individuals increased with increasing Zn concentration.

Spurgeon et al. (1994) kept adult *E. fetida* in contaminated OECD artificial soil (pH 6.3) for 8 weeks to test the effects of Zn (as $Zn(NO_3)_2$) on survival and growth of the earthworms as described for Cd. After 56 days, the calculated LC_{50} was 745 ppm, and the EC_{50} for cocoon production was 276 ppm.

Neuhauser et al. (1985) used the OECD artificial soil (pH 6) to determine LC_{50} of Zn [added as Zn (NO_3)] for adult *E. fetida*. After 14 days, the LC_{50} was calculated to be 662 ppm Zn.

van Rhee (1975) tested the effects of one concentration of Zn (1100 ppm) added to a polder soil on body weight, number of cocoons produced per week, mortality and sexual development of *Allolobophora caliginosa*. After 60 days, there was a 53% loss of body weight and a 22% increase in mortality; clitellum development and cocoon production were completely inhibited.

Neuhauser et al. (1984) evaluated the effects of soluble forms of zinc on growth and reproduction *E. fetida* as described for Cd. The authors report their results with data pooled from all forms of a metal. After 6 weeks, cocoon production was decreased 50% by 2500 ppm Zn, while 1000 ppm had no effect. Growth was not affected until 5000 ppm was added to the substrate.

The effects of Zn added to horse manure (as zinc acetate) on *E. fetida was* investigated by Malecki et al. (1982), as described for Cd. The most sensitive parameter was cocoon production. In the 8-week test, 2000 ppm Zn caused a 36% decrease in cocoon production, while 1000 ppm had no effect. In the 20-week test, 5000 ppm Zn caused a 53% decrease in cocoon production, while 2500 ppm had no effect.

The EC_{50} value of 276 (Spurgeon et al., 1994) was the lowest toxic concentration of the seven reported. Confidence in the benchmark of 200 ppm Zn is low because of the limited amount of data.

3.4.2 Organic Compounds

A small number of research groups have been conducting experiments on the toxicity of organic compounds and pesticides to earthworms. As a result, there are a limited number of experimental designs in use, and data are mainly in the form of LC_{50}s. The following review describes the experimental designs of the various groups; the reader is directed to Appendix A for complete data.

Chloroacetamide. van Gestel and van Dis (1988) evaluated the effects of soil pH and organic matter content on toxicity of chloroacetamide to survival of adult *E. andrei*. The LC_{50} (14 d) in a sandy soil (1.7% organic matter) at pH 4.1 and 7 was determined. Clearly, pH had an effect in this soil with higher LC_{50} values at pH 7. In the OECD artificial soil (7.7% organic matter) at pH 7, the LC_{50} was similar to that in the sandy soil at the same pH. It appears that differences in the organic matter content in this range were not determining the toxicity of this compound.

Heimbach (1984) also used the OECD artificial soil (pH 7) to evaluate the effects of this compound on the survival of *E. fetida* after 28 days. He found an LC_{50} of 24 ppm.

The effect of chloroacetamide on growth and reproduction of *E. fetida* after 56 days of growth in horse manure was assessed by Neuhauser and Callahan (1990). A concentration of 500 ppm had no effect on the earthworms, but 1000 ppm caused 100% mortality.

The LC_{50} value between 10 and 18 (van Gestel and van Dis, 1988) was the lowest toxic concentration of the five reported. A safety factor of 5 was applied to the lower bound on the LC_{50} to obtain the benchmark of 2 ppm chloroacetamide. Confidence in this benchmark is low because of the limited amount of data.

3-chloroaniline. van Gestel and Ma (1993) investigated the effects of soil pH and organic matter content on the toxicity of this compound to two earthworms, *E. andrei* and *L. rubellus*. In a sandy soil with pH 4.8 and 3.7% organic matter, LC_{50} values were lower for both earthworm species than it was in the OECD artificial soil with pH 5.9 and 8.1% organic matter. The authors conclude that, with this narrow a range of pH values, it is likely that the difference in organic matter is responsible for the results.

The LC_{50} value of 195 (van Gestel and Ma, 1993) was the lowest toxic concentration of the four reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 30 ppm 3-chloroaniline. Confidence in this benchmark is low.

2,4-dichloroaniline. van Gestel et al. (1989) used the OECD artificial soil (pH 6) to determine the effects of this compound on growth and reproduction of *E. andrei*. After 21 days, cocoon production was reduced 23% by 100 ppm, while 56 ppm had no effect. Cocoon fertility and number of juveniles per cocoon were not affected by concentrations up to 180 ppm, the highest concentration tested.

van Gestel and Ma (1990) investigated the effects of soil pH and organic matter content on the toxicity of this compound to two earthworms, *E. andrei* and *L. rubellus*. Two sandy soils had similar pH values (5.3 and 5.6) but different organic matter levels (3.7 and 6.1%). The OECD artificial soil had a pH of 5.9 and 8.1% organic matter. A peaty soil also used had a pH of 4 and organic matter content of 15.6%. The LC_{50} values for 2-4-dichloroaniline ranged from 145 to 824 ppm, with organic matter being the more important determinant of bioavailability of this compound within the narrow pH range of soils used.

The 100 ppm benchmark is based on the work of van Gestel et al. (1989) which showed inhibition of reproduction at this concentration. This test endpoint is chosen as more appropriate than lethality (LC_{50}). Confidence in the benchmark is low because of the few data available.

3,4-dichloroaniline. van Gestel and van Dis (1988) investigated the effects of soil pH and organic matter content on the toxicity of this compound to *E. fetida*. A sandy soil (1.7% organic matter) was tested at pH 4.1 and 7. The OECD artificial soil had a pH of 7 and 7.7% organic matter. The LC_{50} values ranged from 140 to 250 ppm increased with increasing organic matter content. No difference related to pH was seen in the sandy soil.

The LC_{50} value of 140 (van Gestel and van Dis, 1988) was the lowest toxic concentration of the three reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 20 ppm 3,4-dichloroaniline. Confidence in this benchmark is low.

2,4,5-trichloroaniline. van Gestel and Ma (1993) evaluated the effects of this compound on the earthworms *E. andrei* and *L. rubellus* as described for 3-chloroaniline. As was the case for that compound, it is likely that the difference in organic matter is responsible for the results.

The lowest LC_{50} value of 134 derives from this work. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 20 ppm 2,4,5-trichloroaniline. Confidence in this benchmark is low.

2,3,5,6-tetrachloroaniline. van Gestel and Ma (1993) evaluated the effects of this compound on the earthworms *E. andrei* and *L. rubellus* as described for 3-chloroaniline. There is not much difference in the results under different pH and organic matter conditions, and it is not clear that organic matter affecting the bioavailability as in the case of 3-chloroaniline and 2,4,5-trichloroaniline.

The lowest LC_{50} value of 116 ppm derives from this work. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 20 ppm 2,3,5,6-tetrachloroaniline. Confidence in this benchmark is low.

Pentachloroaniline. van Gestel and Ma (1993) evaluated the effects of this compound on the earthworms *E. andrei* and *L. rubellus* as described previously. There is considerable difference in the LC_{50}s but no discernible pattern was evident based on soil characteristics or species of earthworm tested.

The lowest LC_{50} value of 825 derives from this work. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 100 ppm pentachloroaniline. Confidence in this benchmark is low.

1,2-dichloropropane. Neuhauser et al. (1986) used the OECD artificial soil (pH 6) to assess the effects of this compound on survival of adults of four earthworms, *Perionyx excavatus*, *Eudrilus eugeniae*, *Eisenia fetida*, and *Allolobophora tuberculata*. They determined the LC_{50} after 14 days and found less than two-fold difference in sensitivity among the worms; sensitivity decreased in the order *P. excavatus>E. fetida>A. tuberculata>E. eugeniae*.

Neuhauser and Callahan (1990) investigated the effect of this compound on growth and reproduction of *E. fetida* after 56 days of growth in horse manure. A concentration of 80,800 ppm had no effect on the earthworms, but 92,300 ppm caused 100% mortality.

The LC_{50} value of 3880 (Neuhauser et al., 1986) was the lowest toxic concentration of the five reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 700 ppm 1,2-dichloropropane. Confidence in this benchmark is low.

Dimethylphthalate. Neuhauser et al. (1986) used the OECD artificial soil (pH 6) to assess the effects of this compound on survival of adults of four species of earthworms, as described previously. The LC_{50}s after 14 days showed a three-fold difference in sensitivity among the worms; sensitivity decreased in the order *P. excavatus>E. eugeniae>E. fetida>A. tuberculata.*

Neuhauser and Callahan (1990) evaluated the effect of this compound on growth and reproduction of *E. fetida* after 56 days of growth in horse manure. A concentration of 47,200 ppm had no effect on the earthworms, but 70,800 ppm caused a 62% reduction in cocoon production.

The LC_{50} value of 1064 (Neuhauser et al., 1986) was the lowest toxic concentration of the three reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 200 ppm dimethylphthalate. Confidence in this benchmark is low.

Fluorene. Neuhauser et al. (1986) used the OECD artificial soil (pH 6) to assess the effects of this compound on survival of adults of four earthworms, as described previously. The LC_{50}s after 14 days showed little difference in sensitivity among the worms; sensitivity decreased in the order *P. excavatus>E. fetida>E. eugeniae>A. tuberculata.*

Neuhauser and Callahan (1990) investigated the effect of this compound on growth and reproduction of *E. fetida* after 56 days of growth in horse manure. A concentration of 500 ppm had no effect on the earthworms, but 750 ppm caused a 49% reduction in cocoon production.

The LC_{50} value of 170 (Neuhauser et al., 1986) was the lowest toxic concentration of the five reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 30 ppm fluorene. Confidence in this benchmark is low.

N-nitrosodiphenylamine. Neuhauser et al. (1986) used the OECD artificial soil (pH 6) to assess the effects of this compound on survival of adults of four earthworms, as described previously. The LC_{50}s after 14 days showed little difference in sensitivity among the worms; sensitivity decreased in the order *E. eugeniae>P. excavatus>E. fetida>A. tuberculata.*

Neuhauser and Callahan (1990) looked at the effect of this compound on growth and reproduction of *E. fetida* after 56 days of growth in horse manure. A concentration of 1400 ppm (lowest concentration tested) caused a 37% reduction in cocoon production.

The LC_{50} value of 109 (Neuhauser et al., 1986) was the lowest toxic concentration of the five reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 20 ppm N-nitrosodiphenylamine. Confidence in this benchmark is low.

Phenol. Neuhauser et al. (1986) used OECD artificial soil (pH 6) to assess the effects of this compound on survival of adults of four species of earthworms, as described previously. The LC_{50}s after 14 days showed a less than three-fold difference in sensitivity among the worms; sensitivity decreased in the order *E. eugeniae>P. excavatus>E. fetida>A. tuberculata.*

Neuhauser and Callahan (1990) assessed the effect of this compound on growth and reproduction of *E. fetida* after 56 days of growth in horse manure. A concentration of 3900 ppm had no effect on the earthworms, but 4900 ppm caused a 26% reduction in cocoon production.

The LC_{50} value of 188 (Neuhauser et al., 1986) was the lowest toxic concentration of the five reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 30 ppm phenol. Confidence in this benchmark is low.

4-nitrophenol. Neuhauser et al. (1986) used the OECD artificial soil (pH 6) to assess the effects of this compound on survival of adults of four species of earthworms, as described previously. The LC_{50}s after 14 days showed little difference in sensitivity among the worms; sensitivity decreased in the order *E. fetida>E. eugeniae>P. excavatus>A. tuberculata.*

Neuhauser and Callahan (1990) looked at the effect of this compound on growth and reproduction of *E. fetida* after 56 days of growth in horse manure. A concentration of 600 ppm (the lowest concentration tested) caused a 39% reduction in cocoon production.

The LC_{50} value of 38 (Neuhauser et al., 1986) was the lowest toxic concentration of the five reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 7 ppm 4-nitrophenol. Confidence in this benchmark is low.

3-chlorophenol. van Gestel and Ma (1990) investigated the effects of soil pH and organic matter content on the toxicity of this compound to two earthworms, *E. andrei* and *L. rubellus*. Two sandy

soils had similar pH values (5.3 and 5.6) but different organic matter levels (3.7 and 6.1%). The OECD artificial soil had a pH of 5.9 and 8.1% organic matter. A peaty soil also used had a pH of 4 and organic matter content of 15.6%. The LC_{50} values ranged from 75 to 633 ppm, with organic matter being the more important determinant of bioavailability of this compound within the narrow pH range of soils used.

van Gestel and Ma (1988) looked at the effects of this compound on survival of *L. rubellus* and *E. andrei* in two humic sand soils of differing organic matter content (3.7 and 6.1%) but similar pH (5 and 5.6). These investigators found a three-fold difference between the highest and lowest values with no strong trend in relation to earthworm species or soil factors.

The benchmark for this compound has been established at 10 ppm. The LC_{50} of 75 from the work of van Gestel and Ma (1990) approximates the 10th percentile. A safety factor of 5 was applied to this value to obtain the benchmark. Confidence in this benchmark is low because all 12 values of the data set are LC_{50}s.

3,4-dichlorophenol. van Gestel and Ma (1990) investigated the effects of soil pH and organic matter content on the toxicity of this compound to two earthworms, *E. andrei* and *L. rubellus*, as described previously. The LC_{50} values ranged from 134 to 680 ppm, with a trend of organic matter being more important than pH as a determinant of bioavailability for this compound.

van Gestel and Ma (1988) assessed at the effects of this compound on survival of *L. rubellus* and *E. andrei* in two humic sand soils of differing organic matter content but similar with respect to pH, as described previously. There was about a three-fold difference between the highest and lowest values with no strong trend in relation to earthworm species or soil factors.

The benchmark for this compound was established at 20 ppm. The LC_{50} of 134 from the work of van Gestel and Ma (1990) approximates the 10th percentile. A safety factor of 5 was applied to this value to obtain the benchmark. Confidence in this benchmark is low because all 12 values of the data set are LC_{50}s.

2,4,5-trichlorophenol. van Gestel and Ma (1990) investigated the effects of soil pH and organic matter content on the toxicity of this compound to two earthworm species, *E. andrei* and *L. rubellus*, as described previously. The LC_{50} values ranged from 46 to 875 ppm, with a trend of organic matter being more important than pH as a determinant of bioavailability within earthworm type. *E. andrei* appears to be more sensitive than *L. rubellus* to this compound.

van Gestel and Ma (1988) assessed the effects of this compound on survival of *L. rubellus* and *E. andrei* in two humic sand soils of differing organic matter content but similar pH, as described previously. The LC_{50} values ranged from 52 to 290 ppm, with a trend of organic matter being the more important determinant of bioavailability within earthworm type. *E. andrei* again appears to be more sensitive to this compound than *L. rubellus*.

The benchmark for this compound was established at 9 ppm. The LC_{50} of 46 from the work of van Gestel and Ma (1990) approximates the 10th percentile. A safety factor of 5 was applied to this value to obtain the benchmark. Confidence in this benchmark is low because all 12 values of the data set are LC_{50}s.

2,4,6-trichlorophenol. Neuhauser et al. (1986) used the OECD artificial soil (pH 6) to assess the effects of this compound on survival of adults of four earthworms, as described previously. The LC_{50}s after 14 days showed little difference in sensitivity among the worms; sensitivity decreased in the order *E. fetida>P. excavatus>E. eugeniae>A. tuberculata.*

Neuhauser and Callahan (1990) assessed the effect of this compound on growth and reproduction of *E. fetida* after 56 days of growth in horse manure. A concentration of 100 ppm (lowest concentration tested) caused a 28% reduction in cocoon production.

The LC_{50} value of 58 (Neuhauser et al., 1986) was the lowest toxic concentration of the five reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 10 ppm for 2,4,6-trichlorophenol. Confidence in this benchmark is low.

2,3,4,5-tetrachlorophenol. van Gestel and Ma (1990) investigated the effects of soil pH and organic matter content on the toxicity of this compound to two earthworms, *E. andrei* and *L. rubellus*, as described previously. The LC_{50} values ranged from 117 to 875 ppm, with a trend of organic matter being more important that pH as a determinant of bioavailability within earthworm species. *E. andrei* appears to be more sensitive than *L. rubellus* to this compound.

van Gestel and Ma (1988) looked at the effects of this compound on survival of *L. rubellus* and *E. andrei* in two humic sand soils of differing organic matter content but similar pH, as described previously. The LC_{50} values ranged from 116 to 828 ppm, with a trend of organic matter being the more important determinant of bioavailability within earthworm type. *E. andrei* again appears to be more sensitive to this compound than *L. rubellus*.

The LC_{50} value of 116 (van Gestel and Ma, 1990) was the lowest toxic concentration of the eight reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 20 ppm 2,3,4,5-tetrachlorophenol. Confidence in this benchmark is low.

Pentachlorophenol. van Gestel and van Dis (1988) investigated the effects of soil pH and organic matter content on the toxicity of this compound to *E. fetida.* A sandy soil (1.7% organic matter) was tested at pH 4.1 and 7. The OECD artificial soil had a pH of 7 and 7.7% organic matter. There was no strong trend related to organic matter, but the highest LC_{50} occurred in the more acid soil.

van Gestel et al. (1989) used the OECD artificial soil (pH 6) to determine the effects of this compound on the growth and reproduction of *E. andrei.* After 21 days, percent cocoon hatching success was reduced 50% by 32 ppm, while 10 ppm had no effect. Cocoon production and number of juveniles per cocoon were not affected until 100 ppm was added.

Heimbach (1984) used the OECD artificial soil (pH 7) to evaluate the effects of this compound on survival of *E. fetida* after 28 days. He found an LC_{50} of 87 ppm.

van Gestel and Ma (1990) investigated the effects of soil pH and organic matter content on the toxicity of this compound to two earthworms, *E. andrei* and *L. rubellus*, as described previously. The LC_{50} values ranged from 83 to 2298 ppm, with the highest value occurring in soil with the highest organic matter content for each earthworm species. *E. andrei* appears to be more sensitive than *L. rubellus* to this compound.

van Gestel and Ma (1988) investigated the effects of this compound on survival of *L. rubellus* and *E. andrei* in two humic sand soils of differing organic matter content but similar pH, as described previously. The LC_{50} values ranged from 94 to 1094 ppm, with no strong trend related to organic matter. *E. andrei* again appears to be more sensitive to this compound than *L. rubellus*.

The 10th percentile of the data lay between LC_{50} values of 16 and 29 (van Gestel and van Dis, 1988). A safety factor of 5 was applied to the geometric mean of these two values (21.5) to obtain the benchmark of 4 ppm pentachlorophenol. Confidence in this benchmark is low because all but one of the 17 values in the data set are LC_{50}s.

Chlorobenzene. van Gestel et al. (1991b) investigated the effects of soil pH and organic matter content on the toxicity of this compound to two earthworms species, *E. andrei* and *L. rubellus*. In a sandy soil with pH 4.8 and 3.7% organic matter and OECD artificial soil (pH 5.9 and 8.1% organic matter), LC_{50} values were lower for *E. fetida* than for *L. rubellus*. Values ranged from 240 to 1107 ppm.

The LC_{50} value of 240 (van Gestel et al., 1991b) was the lowest toxic concentration of the four reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 40 ppm chlorobenzene. Confidence in this benchmark is low.

1,4-dichlorobenzene. van Gestel et al. (1991b) investigated the effects of soil pH and organic matter content on the toxicity of this compound to two earthworms species, *E. andrei* and *L. rubellus*. In a sandy soil with pH 4.8 and 3.7% organic matter and the OECD artificial soil (pH 5.9 and 8.1% organic matter), LC_{50} values were lower in the soil with a lower percentage of organic matter. LC_{50} values ranged from 128 to 615 ppm.

The LC_{50} value of 128 (van Gestel et al., 1991b) was the lowest toxic concentration of the four reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 20 ppm 1,4-dichlorobenzene. Confidence in this benchmark is low.

1,2,3-trichlorobenzene. van Gestel and Ma (1990) investigated the effects of soil pH and organic matter content on the toxicity of this compound to two earthworms species, *E. andrei* and *L. rubellus*, as described previously. The LC_{50} values ranged from 115 to 563 ppm, with the highest LC_{50} occurring in soil with the highest organic matter content. No trend in sensitivity of earthworm species was evident.

The LC_{50} value of 115 (van Gestel and Ma, 1990) was the lowest toxic concentration of the eight reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 20 ppm 1,2,3-trichlorobenzene. Confidence in this benchmark is low because of the limited amount of data.

1,2,4-trichlorobenzene. Neuhauser et al. (1986) used the OECD artificial soil (pH 6) to assess the effects of this compound on survival of adults of four earthworms species, as described previously. The LC_{50}s after 14 days showed little difference in sensitivity among the worms; sensitivity decreased in the order *E. eugeniae>P. excavatus>E. fetida>A. tuberculata.*

The LC_{50} value of 127 ppm (Neuhauser et al., 1986) was the lowest toxic concentration of the four reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 20 ppm 1,2,4-trichlorobenzene. Confidence in this benchmark is low.

1,2,3,4-tetrachlorobenzene. van Gestel et al. (1991b) investigated the effects of soil pH and organic matter content on the toxicity of this compound to two earthworms species, *E. andrei* and *L. rubellus*. In a sandy soil with pH 4.8 and 3.7% organic matter and the OECD artificial soil (pH 5.9 and 8.1% organic matter), LC_{50} values were lower in the soil with less organic matter. The LC_{50} values ranged from 75 to 223 ppm.

The LC_{50} value of 75 (van Gestel et al., 1991b) was the lowest toxic concentration of the five reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 10 ppm 1,2,3,4-tetrachlorobenzene. Confidence in this benchmark is low.

Pentachlorobenzene. van Gestel et al. (1991a) investigated the effects of soil pH and organic matter content on the toxicity of this compound to two earthworms species, *E. andrei* and *L. rubellus*, as described previously. In a sandy soil and the OECD artificial soil, LC_{50} values were lower in the soil with a lower percentage of organic matter. LC_{50} values ranged from 72 to 223 ppm.

The LC_{50} value of 115 (van Gestel et al., 1991b) was the lowest toxic concentration of the four reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 20 ppm pentachlorobenzene. Confidence in this benchmark is low.

Nitrobenzene. Neuhauser et al. (1986) used the OECD artificial soil (pH 6) to assess the effects of this compound on survival of adults of four earthworms species, as described previously. The LC_{50}s after 14 days showed little difference in sensitivity among the worms; sensitivity decreased in the order *E. eugeniae>E. fetida>P. excavatus>A. tuberculata.*

The LC_{50} value of 226 (Neuhauser et al., 1986) was the lowest toxic concentration of the four reported. A safety factor of 5 was applied to this LC_{50} to obtain the benchmark of 40 ppm nitrobenzene. Confidence in this benchmark is low.

4. MICROBIAL HETEROTROPHS AND PROCESSES

4.1 INTRODUCTION

Soil microorganisms play a critical role in nutrient cycling. As primary consumers of soil organic matter, soil microbes convert nutrients to plant-available forms and serve as a food source for higher trophic levels. The soil microbiota is a heterogeneous collection of highly adaptable organisms exploiting the many micro-niches in the soil. The effect of contaminants may be to change the microbial community structure without overall changes in the functional ability of the community. The authors' assessment endpoint, however, is microflora community functioning. This is measured as effects on C mineralization, N transformation, and enzyme activities.

Little information is available on the mechanisms of toxicity of contaminants to soil microorganisms. Some metal ions may inhibit enzyme reactions by complexing with enzyme substrates, combining with the protein active group of the enzyme, or reacting with the enzyme-substrate complex (Juma and Tabatabai, 1977).

As with the others benchmarks, much of the variance is due to the variance in soil characteristics that influence toxicity. These characteristics control bioavailability to all soil-dwelling organisms, with pH and organic matter content being among those that are very important.

4.2 MICROBE DATA SELECTION

Toxic response data were collected for inorganic elements and organic compounds. Measures of effects of soil-borne chemicals on microorganisms include growth, respiration, nitrogen transformation reactions (denitrification, mineralization, and nitrification), C mineralization, P mineralization, cellulolytic activity, oxidation of hydrogen gas, alpha-glucosidase synthesis, and other enzyme activities.

Many enzymes that are produced by plants and microbes can exist and function extracellularly in the soil for varying periods of time, depending on soil micro-environmental factors (Tabatabai, 1982). For this reason, it may not be appropriate to interpret measured effects of chemicals on soil enzyme activities as representing effects on soil microbial populations. Soil enzymes do, however, give valuable information about the functioning of the soil in organic matter degradation. These enzymes include urease which catalyzes the hydrolysis of urea to CO_2 and NH_3; phosphatases which catalyze the hydrolysis of phospho esters and anhydrides; arylsulfatase which catalyzes the hydrolysis of the arylsulfate ion; amidase, which catalyzes the hydrolysis of acid amides with the release of NH_3; amylases, enzymes which catalyze the hydrolysis of starch and glycogen; and dehydrogenases, a group of enzymes which catalyze the dehydrogenation of many organic compounds. Dehydrogenase activity is considered by some to provide an overall estimate of microbial activity. None of these activities is accepted as adequate for characterizing the response of the soil microbial community to toxic stress because of the many soil and microbial factors affecting them at the micro-environment level. However, it is often the case that benchmarks are based on the effects of a chemical on a single activity (e.g., reduction of phosphatase activity) because of lack of other data.

Most of the research used to establish benchmarks was conducted in the laboratory with native soil microflora in small samples of soil or soil/litter microcosms. Exposure durations ranged from one and one-half hours to one and one-half years. The chemicals tested were mixed into the soil in the form of salts. Bacteria, actinomycetes, and fungi are included and evaluated together. Tests conducted in culture media are not included because they are not directly relevant to the soil environment.

4.3 MICROBE DATA AND BENCHMARK DERIVATION

A short review of the available literature is discussed in the following text. Data are summarized in Appendix B, and benchmarks are given in Table 2.

4.3.1 Inorganic Chemicals

Aluminum. The effects of soil characteristics on effects of Al (as $AlCl_3$) on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979). Soils were chosen with a range in pH, organic matter, and clay contents (6.2 to 7.6; 5.4 to 10.6%; 26 to 34%). Air-dried, sieved soil samples were placed in flasks with the test chemical added in solution. The samples were incubated for 90 minutes before microbial activity was stopped and arylsulfatase activity measured. In all soils, a concentration of 675 ppm Al reduced the enzyme activity between 24 and 43%. The least inhibition occurred in the soil with the highest contents of organic matter and clay.

Juma and Tabatabai (1977) used essentially the same system and three of the same soils to evaluate the effects of several metals on soil acid and alkaline phosphatase activities. Three soils were used to test effects and acid phosphatase activity with pH, organic matter, and clay ranging from 5.8 to 7.8, 5.2 to 11%, and 23 to 30%. Alkaline phosphatase activity was not tested in the most acid soil. For Al in a loam soil (pH 5.8; percent organic matter 5.2) acid phosphatase activity was reduced, and alkaline phosphatase activity was reduced in another loam soil (pH 7.4, percent organic matter 11) by a concentration of 675 ppm Al. Aluminum had no effect on the activity of either enzyme in an alkaline soil (pH 7.8, percent organic matter 7.4).

The benchmark of 600 ppm of Al was derived from the previously described studies. Confidence in the benchmark is low because of the limited amount and type of data available.

Arsenic. Juma and Tabatabai (1977) used the system described for Al to evaluate the effects of two forms of As on soil acid and alkaline phosphatase activities. Arsenic (III) had no effect on acid phosphatase activity in any of the three soils. At a concentration of 1875 ppm As (lowest concentration tested), alkaline phosphatase activity was reduced in a loam soil (pH 7.8; percent organic matter 7.4). Arsenic (V) was more toxic than As(III) to both enzyme complexes. Alkaline and acid phosphatase activities were reduced by as little as 187.5 ppm As(V) (lowest concentration tested) in soils of pH 5.8 to 7.4 and percent organic matter 5.2 to 11.

Frankenberger and Tabatabai (1981) investigated the effect of As(III) on amidase activity in three soils in shaker flask assays as described previously. After 2 1/2 hrs, amidase activity was reduced in all three soils. Activity was almost totally inhibited in the soil with the soils tested with a lowest concentration of 1873 ppm.

The effective concentration of 187 ppm (Frankenberger and Tabatabai, 1981) is the lowest of the eight reported. Confidence in the benchmark of 100 ppm is low because of the limited amount and type of data available.

Barium. The influence of soil characteristics on effects of Ba on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) using methods described for Al. A reduction in activity was measured in only one of the four soils, having the lowest pH and organic matter content. A 22% reduction in activity was caused by 3433 ppm Ba (only concentration tested).

The benchmark of 3000 ppm is based on this study. Confidence in the benchmark is low because of the limited amount of data available.

Boron. The influence of soil characteristics on effects of B on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) using methods described for Al. Approximately the same degree of reduction in activity was measured in all soils at 270 ppm, and at 27 ppm in a loam (pH 6.5, percent organic matter 5.8) There was no clear relationship between magnitude of reduction in activity and soil pH and organic matter.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effects of B on soil acid and alkaline phosphatase activities. Acid phosphatase activity was not affected in the soil with the highest pH. It was reduced in the other two soils at a concentration of 270 ppm. Alkaline phosphatase activity was not affected by B in the soils tested.

The effective concentration of 27 ppm (Al-Khafaji and Tabatabai, 1979) is the lowest of the six reported. Confidence in the benchmark of 20 ppm is low because of the limited amount and type of data available.

Cadmium. The influence of soil characteristics on effects of Cd on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) using methods described for Al. A reduction in activity was measured in all four soils (23 to 55%) at 2810 ppm Cd, with the greatest reduction in the soil with the lowest clay content.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effects of Cd on soil acid and alkaline phosphatase activities. Acid phosphatase activity was reduced in all three of the soils (44 to 51%) at 2810 ppm. Alkaline phosphatase activity was reduced 27% in the loam soil at a concentration of 281 ppm and 78% at 2810 ppm in a clay loam soil in which this was the only concentration tested.

Haanstra and Doelman (1991) investigated short- and long-term effects of metals on arylsulfatase activity, urease activity (Doelman and Haanstra, 1986), and total phosphatase activity (Doelman and Haanstra, 1989) by native soil microflora in five soils (sand, sandy loam, silt loam, clay, and sandy peat) of varying characteristics. Soil pH ranged from 7.7 to 4, organic matter content from 1.6 to 12.8%, and clay from 2 to 60%. Metals were added as salts to the sieved soils in flasks, and enzyme activity was measured after a 6-week or 18-month study. Results were reported as EC_{50}. In the 6-week incubation study on the effects of Cd, data from the sandy loam soil were not available. Data for the effects on phosphatase activity were also not available for sandy peat. For all three enzyme systems, the highest EC_{50}s were found in the soil with the highest clay content (9520, 9779, and 4460 ppm for arylsulfatase, phosphatase, and urease activities, respectively). The lowest EC_{50}s were 1888 ppm for arylsulfatase, and 840 and 340 ppm in the sand for phosphatase and urease

activities. In the 18-month study, data from the sandy peat soil were not available for arylsulfatase and phosphatase. The highest EC_{50}s were 230 ppm in the soil with the highest pH for phosphatase, 30 ppm Cd in the sandy loam soil for urease, and 121 ppm in the sand (lowest pH, organic matter, and clay) for arylsulfatase.

The effects of several elements on dehydrogenase activity of the native soil microflora in a composite soil sample from the Rocky Mountain Arsenal was assessed by Rogers and Li (1985). Soil was amended with glucose and alfalfa, with the metal salts added in solution. After 6 days, a concentration of 30 ppm Cd (lowest concentration tested), added as cadmium nitrate, reduced dehydrogenase activity by 47%.

Lighthart and Bond (1976) investigated the effects of Cd (as $CdCl_2$) added to a small (600 ml) soil and litter microcosm. Soil was homogenized and sieved and the overlying plant litter layer was sieved. The Cd (0.006 or 6.1 ppm Cd) was introduced into the microcosm by injecting an aqueous solution into the soil and litter with a syringe. After 24 days, the native soil and litter microflora exhibited a 43% reduction in respiration (O_2 uptake) in microcosms inoculated with 6.1 ppm Cd.

Threshold levels of Cd (as cadmium acetate) for soil respiration of native microflora in three soils were determined by Reber (1989). The soils ranged in pH from 5.6 to 7, percent organic matter 1.7 to 2.6, and percent clay 3.2 to 21.3. There was no clear relationship between these soil characteristics and the magnitude of reduction in soil respiration at the concentrations tested. The highest LOEC concentration (56.3 ppm) for Cd was associated with the soil containing the lowest percentage of organic matter and the lowest pH.

Liang and Tabatabai (1977) investigated the effects of various metals on N mineralization by native soil microflora in four soils varying in pH from 6 to 7.8, clay from 23 to 34%, and organic matter content from 6 to 11%. Only one concentration of each metal was tested and was added to the soil as a salt solution. Cadmium reduced N mineralization in two soils at 562 ppm but no relationship between soil characteristics and effects of Cd could be discerned.

Bollag and Barabasz (1979) evaluated the effects of several metals on denitrification in autoclaved soil by three species of soil-dwelling *Pseudomonas* species of bacteria andon denitrification in soil by native soil microflora. The silt loam soil was autoclaved to kill the majority of its microflora, inoculated with individual metals and bacterial populations, and incubated 4 days under anaerobic conditions. The same soil was used to determine the effects of metals on denitrification by the native soil microflora after 21-day incubation under anaerobic conditions. In the autoclaved soil, two of the three *Pseudomonas* species had reductions in activity at 50 ppm Cd, while the third was more sensitive to the toxic effects of this metal (and Cu and Zn) on denitrification. The native soil population in unautoclaved soil was more tolerant of the Cd, with reductions in activity at 100 ppm Cd. It is not clear whether this difference is due to changes in the chemical and physical nature of the soil during autoclaving or to other organisms in the natural soil being more tolerant to Cd.

Khan and Frankland (1984) used a dyed cellophane film technique to evaluate the effects of Cd on cellulolytic activity of native soil microflora in a Brown earth soil (pH 4.6). The film was encased in nylon mesh, buried in the potted soils containing Cd added as $CdCl_2$, and allowed to equilibrate for 15 days. After a further 30 days past the equilibrium period, the film was retrieved and analyzed for dye release. A 35% reduction in percent cellulose decomposition was measured in pots containing 100 ppm Cd, while 50 ppm had no effect.

Lighthart et al. (1977) evaluated the effects of a number of metals at single concentrations on respiration of native soil microflora in small coniferous forest soil/litter microcosms. Metals in solution form were mixed into the soil and litter which were then layered in the microcosm. Cadmium at 920 ppm reduced respiration 61%.

In a study on the effects of Cd on N mineralization and nitrification by native soil microflora in a moderately acid soil, Bewley and Stotzky (1983) found N mineralization to be unaffected by Cd levels up to 1000 ppm, the highest concentration tested. Nitrification was reduced 62% by 1000 ppm.

The effects of Cd as $CdCl_2$ on carbon and nitrogen mineralization and nitrogen transformations in alfalfa-amended sieved soil were determined by Suter and Sharples (1984). The silt loam soil had a pH of 4.7. At 3 days, respiration was reduced by 20% at 500 ppm, but at later dates no significant reduction occurred. Ammonia levels were increased (by as much as a factor of 12) on days 22 to 53 at 50 ppm Cd and higher. Nitrate levels were reduced by >21% on days 25, 32, and 39 at 50 ppm Cd and higher, but on days 46 and 53 significant effects occurred at only 100 ppm and higher. These results suggest that nitrification is highly sensitive to Cd relative to C mineralization and may be chronically reduced at 50 ppm.

A benchmark of 20 ppm Cd was established as the 10th percentile of the 47 reported effective values. Confidence in this benchmark is high because of the relatively large amount of data available for a variety of functional measures.

Chromium. Liang and Tabatabai (1977) investigated the effects of various metals on N mineralization by native soil microflora in four soils, as described for Cd. Chromium(III) at 260 ppm reduced N mineralization in the soil containing the highest organic matter content. This same soil showed an effect of added Cu.

The effects of Cr(III) on dehydrogenase activity of the native soil microflora in soil from the Rocky Mountain Arsenal was assessed by Rogers and Li (1985) as described previously for Cd. After 6 days, a concentration of 30 ppm Cr (the lowest concentration tested) reduced dehydrogenase activity by 54%.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effect of Cr on soil acid and alkaline phosphatase activities. Acid and alkaline phosphatase activities were affected at 1635 ppm in all three soils to about the same degree, but greater inhibition of alkaline phosphatase activity occurred in the soil with the greatest content of organic matter and clay.

Ross et al. (1981) evaluated the relative toxicities of forms of Cr to respiration of native soil microflora in a loam and a sandy loam soil. After 22 days, Cr (III), tested at only 100 ppm, caused reductions in both soils of 41 and 48%. A concentration of 10 ppm (the lowest concentration tested) Cr (VI) caused reductions in both soils (27 and 33%). In this experiment, Cr(VI) was more toxic than Cr(III) to soil respiration.

Premi and Cornfield (1969, 1969/1970) investigated the effects of Cr added to a sandy loam soil on nitrogen transformations by native soil microflora. In a 21-day experiment (1969), nitrification was severely inhibited at 1000 ppm Cr (added as sulfate salt), but was unaffected at 100 ppm. In an 8-week experiment (1969/1970) with sucrose and ammonium nitrate added to the soil, nitrification was not affected by 10,000 ppm Cr, the highest concentration tested. Possible

reasons for the differences in results for the two sets of experiments are differences in exposure duration and effects of amendments.

Bhuiya and Cornfield (1976) investigated the effects of several metals on N mineralization and nitrification by native soil microflora in a sandy soil at different pH levels. Metals were added to the soil as oxides to achieve a concentration of 1000 ppm, and the pH was adjusted to 7 (or left at the natural pH 6) before a 2-month equilibration period. After an additional 6 or 12 weeks past the equilibrium period, N transformation measures were made. After 6 weeks, both mineralization and nitrification were reduced by 1000 ppm Cr at pH 7, but not at pH 6. After 12 weeks, neither mineralization nor nitrification was affected by Cr at either pH.

The effects of soil characteristics on toxicity of Cr to arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) using methods described for Al. Activity was reduced in all soils at 1300 ppm Cr. Magnitude of reduction was inversely related to soil organic C content.

Haanstra and Doelman (1991) investigated short- and long-term effects of Cr on arylsulfatase activity, urease activity (Doelman and Haanstra, 1986), and total phosphatase activity (Doelman and Haanstra, 1989) by native soil microflora in five soils, as described for Cd. In the 6-week incubation study on the effects of Cr, data from the silt loam soil were not available for arylsulfatase activity and not available from the sandy loam soil for urease. The highest EC_{50}s were 3203, 5512, and 4470 ppm, respectively, for arylsulfatase, phosphatase, and urease activities found in different soils. The lowest was 17 ppm in the sand for arylsulfatase and 1170 and 490 ppm in the clay for phosphatase and urease. In an 18-month study, the highest EC_{50}s were 1798, 20020, and 1110 ppm Cr, respectively, for arylsulfatase, phosphatase, and urease activities found in different soils. The lowest were 12 and <1 ppm in the clay for arylsulfatase and urease activities and 2692 ppm in the sandy loam for phosphatase activity.

The benchmark for Cr was established at 10 ppm because the 10th percentile lies between the EC_{50} values of 12 and 15 ppm from the work of Haanstra and Doelman (1991). Confidence in this benchmark is high because of the relatively large amount of data available for a variety of functional measures.

Cobalt. Lighthart et al. (1977) evaluated the effects of Co at a single concentration on respiration of native soil microflora in soil/litter microcosms, as described for Cd. Co at 1362 ppm reduced respiration 23%.

The benchmark of 1000 ppm comes from this study. Confidence in the benchmark is low because of the limited amount of data available.

Copper. Liang and Tabatabai (1977) investigated the effects of various metals on N mineralization by native soil microflora in four soils, as described for Cd. Copper at 320 ppm severely reduced N mineralization in one soil. This same soil showed an effect of added Cr(III).

The effects of Cu on dehydrogenase activity of the native soil microflora in soil from the Rocky Mountain Arsenal was assessed by Rogers and Li (1985) using methods described for Cd. A concentration of 30 ppm Cu (the lowest concentration tested) Cu reduced dehydrogenase activity by 28%.

Bollag and Barabasz (1979) evaluated the effects of Cu on denitrification by three species of soil-dwelling *Pseudomonas* species of bacteria in autoclaved soil and by native soil microflora, as described for Cd. In the autoclaved soil, there was a range of sensitivities of the *Pseudomonas* species to Cu. LOECs ranged from 10 (lowest concentration tested) to 250 ppm (highest concentration tested). The organism most sensitive to the effects of Cd and Zn was also more sensitive to the toxic effects of Cu on denitrification. Denitrification by the native soil population was reduced 44% by 250 ppm Cu.

The effects of adding Cu, as $CuSO_4$, to a sandy loam adjusted to three pH levels on N mineralization during a 21-day incubation was assessed by Quraishi and Cornfield (1973). Mineralization was decreased by 1000 ppm Cu at all three pH levels (5.1, 5.9, and 7.3) with inhibitory effect increasing with decreasing pH from 39% to 100%.

Premi and Cornfield (1969, 1969/1970) investigated the effects of several metals added to a sandy loam soil on nitrogen transformations by native soil microflora. In a 21-day experiment (1969), nitrification was severely inhibited at 10,000 ppm Cu, added as $CuSO_4$, but unaffected at 1000 ppm. Copper added in carbonate form was ineffective at 10,000 ppm (highest concentration tested), probably because of the increase in soil pH caused by addition of this form. In an 8-week experiment (1969/1970) with sucrose and ammonium nitrate added to the soil, nitrification was decreased at 1000 ppm Cu but unaffected at 100 ppm. Possible reasons for the differences in results between the two experiments are differences in exposure duration and effects of amendments.

Bhuiya and Cornfield (1972) assessed the effects of several metals on C mineralization by native microflora in a sandy soil, with or without added organic matter. Metals were added to the soil as oxides to achieve a concentration of 1000 ppm and a small amount of ground oat straw was added to part of the soil before a 2-month equilibration period. After a further 12 weeks, soil respiration was reduced in the Cu-treated soil with amendment but not in the unamended soil.

The influence of soil characteristics on effects of Cu on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) using methods described previously for Al. In the soil with the highest pH (7.6), Cu had no effect. Arylsulfatase activity in the other three soils was reduced by Cu at a concentration of 1590 ppm. Reductions were the least severe in the soil having the highest organic carbon and clay content.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effects of two forms of Cu on soil acid and alkaline phosphatase activities. Acid phosphatase activity was affected by Cu(I) and Cu(II) in all three soils about equally at a concentration of 1590 Cu (lowest concentration tested). The greatest reduction occurred in the soil with the lowest pH and the lowest contents of organic matter and clay. Alkaline phosphatase activity was more sensitive to Cu(I) than Cu(II).

Haanstra and Doelman (1991) investigated short- and long-term effects of Cu on arylsulfatase activity, urease activity (Doelman and Haanstra, 1986), and total phosphatase activity (Doelman and Haanstra, 1989) for native soil microflora in five soils, as described for Cd. In the 6-week study, data were not available for phosphatase activity in the sandy loam or for urease activity in the silt loam. The highest EC_{50}s for arylsulfatase and phosphatase activities (14,946 and 6424 ppm) was found in the soil with the highest pH (silt loam). The highest EC_{50} for urease activity (4200 ppm) was found in the soil with the greatest content of organic matter and the lowest pH (sandy peat). The lowest EC_{50}s, all found in the sand, were 390, 140, and 260 ppm for arylsulfatase, phosphatase, and urease. In the 18-month incubation study, the highest EC_{50}s were 6996 and 4200 ppm Cu in the soil with the

greatest percentage organic matter for arylsulfatase and urease activities and 2773 ppm for phosphatase in the clay soil. Lowest EC_{50}s were 203, 170, and 680 ppm in the sand for arylsulfatase, phosphatase, and urease activities, respectively.

The effects of Cu (as $CuCl_2$) on carbon and nitrogen mineralization and nitrogen transformations in alfalfa-amended sieved soil were determined by Suter and Sharples (1984). The silt loam soil had a pH of 4.7. At 10 days, respiration was reduced by 24% at 100 ppm, but significant reductions occurred at 500 ppm on days 3 and 14 and at 1000 ppm on all dates. Ammonia concentration was decreased significantly by 58% on days 4 and 11 at 10 ppm, but there was no increase of effects with concentration on those dates, and ammonia concentrations were unchanged or increased at those concentrations on later dates. Ammonia concentrations were significantly increased at 500 and 1000 ppm from day 18 to 53, and after day 18 there were regular patterns of increasing ammonia at increasing Cu levels. Nitrate levels were reduced by 21% on day 4 at a concentration of 10 ppm, but not on later dates. On day 11, nitrate concentrations were significantly reduced to 50–1000 ppm (but increased at 10 ppm), and on days 18 to 53, they were significantly reduced only at 500 and 1000 ppm Cu. These results suggest that nitrification is highly sensitive to Cu, relative to C and N mineralization. If the chronic response is used as the basis for the benchmark, the threshold for significant effects in this test is 500 ppm Cu.

The benchmark for Cu has been established at 100 ppm. Confidence in this benchmark is high.

Fluoride. The effects of fluoride, added as potassium fluoride to poplar litter, on nitrogen and phosphorus mineralization by native microflora was investigated by van Wensem and Adema (1991). The newly fallen (2 months old) litter was air-dried, cut into small pieces, and rewetted with KF solutions of varying concentrations. After 9 weeks, K mineralization was reduced 22% in litter treated with 32.3 ppm F, the lowest concentration tested. Nitrogen mineralization was reduced 26% by 100.7 ppm, while 32.3 ppm had no effect.

The effects of F on dehydrogenase activity of the native soil microflora in soil from the Rocky Mountain Arsenal was assessed by Rogers and Li (1985) as described previously for Cd. A concentration of 5000 ppm F reduced dehydrogenase activity by 30% (3000 ppm had no effect).

The toxic concentration of 32 ppm (van Wensem and Adema, 1991) is the lowest of the two reported. Confidence in the benchmark of 30 ppm is low because of the limited amount and type of data available.

Iron. Liang and Tabatabai (1977) investigated the effects of Fe on N mineralization by native soil microflora in four soils, as described for Cd. Iron(III) reduced N mineralization in one soil at 280 ppm. This same soil showed an effect of added Cd.

The influence of soil characteristics on effects of Fe(III) on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) as described previously for Al. In the soil with the highest pH (7.6), Fe(III) had no effect. Activity was reduced in all other soils at 1398 ppm Fe. The magnitude of reduction generally was inversely related to soil pH.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effects of Fe(II) and Fe(III) on soil acid and alkaline phosphatase activities. Iron(II) reduced acid phosphatase activity at 1398 ppm in only the soil with the lowest pH and organic matter and clay contents. Iron(III) reduced activity to a greater degree in this soil and also in the soil with the second lowest

pH (but highest organic matter and clay contents). Iron(II) inhibited alkaline phosphatase activity in one of the soils tested and Fe(III) in the soil in which both forms of Fe inhibited acid phosphatase activity.

The effective concentration of 280 ppm (Liang and Tabatabai, 1977) is the lowest of the nine reported. Confidence in the benchmark of 200 ppm is low because of the limited amount and type of data available.

Lanthanum. Lighthart et al. (1977) evaluated the effects of La (as $LaCl_2$) at a single concentration on respiration of native soil microflora in soil/litter microcosms, as described for Cd. After 23 days, lanthanum at 57 ppm reduced respiration by 22%.

The benchmark of 50 ppm (Al-Khafaji and Tabatabai, 1979) is based on this work. Confidence in the benchmark is low because of the limited amount of data available.

Lead. Khan and Frankland (1984) used a dyed cellophane film technique to evaluate the effects of Pb on cellulolytic activity of native soil microflora in a Brown earth soil (pH 4.6), as described previously for Cd. A 23% reduction in percent cellulose decomposition was measured in pots containing 1000 ppm Pb, while 500 ppm had no effect.

The mediating influence of clay on effects of lead on soil respiration was assessed by Debosz et al. (1985). The sandy loam soil (9% clay) was amended with glucose and Pb acetate in solution. After 15 days, respiration was reduced 29% by 10,000 ppm Pb (1000 ppm had no effect). In the same soil amended with either 9% by weight kaolinite or montmorillonite, Pb up to 10,000 ppm had no effect.

Cole (1977) assessed the effects of various carbohydrate additions and Pb compounds on amylase synthesis and activity by native soil microflora in a silt loam soil. Carbohydrates were added to the soil in solution and Pb in dry salt form. With the addition of glucose and lead acetate, amylase activity was more sensitive than synthesis, with a 74% reduction at the lowest concentration tested (2000 ppm). With the addition of starch, amylase activity was reduced less by $PbCl_2$ than with lead acetate and lead sulfate. With the addition of lead acetate, amylase activity was more sensitive with the addition of starch than with glucose. Cole also investigated the effect of Pb acetate on alpha-glucosidase synthesis and bacterial population size. Both were reduced by the addition of 2000 ppm Pb (lowest concentration tested).

Liang and Tabatabai (1977) investigated the effects of Pb on N mineralization by native soil microflora in four soils, as described for Cd. Lead reduced N mineralization in one soil at 1035 ppm. This same soil showed an effect of added Cd.

Bhuiya and Cornfield (1972) assessed the toxic effects of Pb on C mineralization by native microflora in a sandy soil, with or without added organic matter, as described for Cu. After 12 weeks, soil respiration was reduced in the Pb-treated soil without oat straw, but not in the straw-amended soil.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effects of two forms of Pb (acetate and nitrate) to soil acid and alkaline phosphatase activities. The two forms had equal effect on acid phosphatase activity at 5175 ppm and that only in the soil with the lowest pH and organic matter and clay contents. They had equal effects on alkaline phosphatase activity at this

concentration in one of the soils tested, and only Pb acetate was inhibitory in the soil with the highest organic matter and clay contents.

Haanstra and Doelman (1991) investigated short- and long-term effects of Pb on arylsulfatase activity, urease activity (Doelman and Haanstra, 1986), and total phosphatase activity (Doelman and Haanstra, 1989) by native soil microflora in five soils, as described for Cd. In the 6-week study on the effects of Pb, data from the sandy loam, clay, and sandy peat soils were not available for arylsulfatase, the sand, sandy loam and peat for phosphatase, and the sand for urease. The highest EC_{50}s for arylsulfatase and phosphatase activities (9138 and 1168 ppm) were found in the clay soil. The highest EC_{50} for urease activity (7190 ppm) was found in the silt loam (highest pH). The lowest were 8288, 8184, and 50 60 ppm Pb for arylsulfatase, phosphatase, and urease activities. In the 18-month study, data from the sandy peat soil were not available for arylsulfatase and phosphatase and from the clay and sandy loam for phosphatase. The highest EC_{50}s were 12,411 ppm in the soil with the highest clay for arylsulfatase, 78,943 ppm for phosphatase in the sand, and 8130 in the silt loam for urease. The lowest EC_{50}s were 3004, 7604, and 1340 ppm, in different soils.

Doelman and Haanstra (1979) evaluated the effects of Pb on soil respiration and dehydrogenase activity in several soils. After 24 hours, respiration in a sand (pH 5.7, percent organic matter 3) was reduced by 750 ppm Pb, the lowest concentration tested. Dehydrogenase activity was not affected at this concentration. After 40 months, respiration in this soil was reduced to approximately the same degree at 1500 ppm, the lowest concentration tested. Dehydrogenase activity was not evaluated. In another sandy soil, (pH 5.4, percent organic matter 6.7), dehydrogenase activity was severely inhibited by 1500 ppm, but not at 750 ppm Pb after 24 hours. Respiration was not affected at this concentration. In a clay soil, dehydrogenase activity was inhibited by 375 ppm, the lowest concentration tested. Respiration was not evaluated.

The benchmark of 900 ppm Pb is the 10th percentile of the 36 reported effective values. Confidence in this benchmark is high because of the relatively large amount of data available for a variety of functional measures.

Lithium. Lighthart et al. (1977) evaluated the effects of Li at a single concentration on respiration of native soil microflora in soil/litter microcosms, as described for Cd. Lithium at 17 ppm reduced respiration 43%.

The effective concentration of 10 ppm was derived from this study. Confidence in the benchmark is low because of the limited amount of data available.

Manganese. Liang and Tabatabai (1977) investigated the effects of Mn on N mineralization by native soil microflora in four soils, as described for Cd. Manganese at 275 ppm reduced N mineralization in one soil. This same soil showed an effect of added Cd.

Premi and Cornfield (1969) investigated the effects of Mn added to a sandy loam soil on nitrogen transformations by native soil microflora. In a 21-day experiment, nitrification was severely inhibited at 100 ppm, added as sulfate salt, the lowest concentration tested.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effect of Mn on soil acid and alkaline phosphatase activities. Acid phosphatase activity was affected at 1375 ppm only in the soil with the lowest pH and organic matter and clay contents. Alkaline phosphatase activity was reduced in one of the soils tested by this same concentration.

The effective concentration of 100 ppm (Premi and Cornfield, 1969) the lowest of the four reported. Confidence in the benchmark of 100 ppm is low because of the limited amount and type of data available.

Mercury. van Fanssen (1973) investigated the effects of an inorganic and an organic mercury compound on N mineralization and nitrification by native soil microflora in two alkaline soils: a dune sand with 2% organic matter and a mix of two clay soils with 6% organic matter. Little information was provided concerning the experimental design. In the clay soil, both $HgCl_2$ and phenylmercury acetate reduced nitrification at 100 ppm Hg (10 ppm had no effect), but the organic form was more inhibitory than the inorganic form. Mineralization was not affected by the inorganic form but was decreased by phenylmercury acetate. In the dune sand, $HgCl_2$ severely reduced nitrification at 100 ppm (10 ppm had no effect) and phenylmercury acetate reduced nitrification at 10 ppm Hg (lowest concentration tested). Mineralization was not affected by the organic form but was decreased by $HgCl_2$ at 100 ppm Hg. This work indicates that the relative toxicity of various forms of Hg can be influenced by soil characteristics.

Landa and Fang (1978) investigated the effects of mercuric chloride (up to 100 ppm Hg) on carbon mineralization by native soil microflora in five agricultural topsoils varying in pH and organic matter content. The magnitude of effects varied greatly among the soils and were not related to those two soil characteristics. Effects ranged from an 87% reduction at 0.1 ppm (the lowest concentration tested) in one of the soils to no effect at 100 ppm in another soil.

Bremner and Douglas (1971) evaluated the effects of several metals on urease activity in two soils with similar pH, organic matter, and clay content characteristics. Metals were added individually in solution at a concentration of 50 ppm, and urease activity was determined after 5 hours. Mercury, added either as the chloride or sulfate salt, decreased urease activity by 36 to 42% in both soils.

Liang and Tabatabai (1977) investigated the effects of Hg on N mineralization by native soil microflora in four soils, as described for Cd. Mercury reduced N mineralization in all soils at 1003 ppm. The greatest magnitude of the toxic effect was seen in the soil having the lowest pH and organic matter and clay contents.

The influence of soil characteristics on effects of Hg on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) as described previously for Al. In two soils tested with a lowest concentration of 502 ppm, arylsulfatase activity was greatly reduced. In the two soils tested with a lowest concentration of 5015 ppm, arylsulfatase activity was inhibited almost totally. No clear differences between the soils with regard to effects on toxicity of Hg could be discerned.

Frankenberger and Tabatabai (1981) investigated the effect of Hg on amidase activity in three soils in shaker flask assays as described previously. After 2 1/2 hours, amidase activity was reduced in all three soils at 5015 ppm. The greatest reduction occurred in the soil with the lowest pH and organic matter and clay contents.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effect of Hg on soil acid and alkaline phosphatase activities. Acid and alkaline phosphatase activities were affected at 5015 ppm in all three soils to about the same degree.

The benchmark of 30 ppm Hg is the 10th percentile of the 27 reported effective values. Confidence in this benchmark is high because of the relatively large amount of data available for a variety of functional measures.

Molybdenum. Liang and Tabatabai (1977) investigated the effects of Mo on N mineralization by native soil microflora in four soils, as described for Cd. Molybdenum reduced N mineralization in three of the soils at 480 ppm. No toxic effect was seen in the soil having the lowest pH and organic matter and clay contents. No clear relationship between soil characteristics and magnitude of effects of Mo could be discerned.

The influence of soil characteristics on effects of Mo on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) as described previously for Al. In the soil with the highest clay and organic matter contents, Mo had no effect. Activity was severely reduced at 2398 ppm (lowest concentration tested) in the soil with the lowest pH and organic matter content. It is possible that activity in this soil would have been inhibited to a somewhat lesser degree by 240 ppm Mo, as it was in the two remaining soils.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effect of Mo on soil acid and alkaline phosphatase activities. Acid phosphatase activity in all three soils was reduced at 2398 ppm. In the soil with the lowest pH, and organic matter and clay contents, it was also inhibited at 240 ppm Mo. Alkaline phosphatase activity in both soils tested was reduced about the same degree at this concentration.

The benchmark for Mo was established at 200 ppm based on the work of Al-Khafaji and Tabatabai (1979). Confidence in this benchmark is moderate.

Nickel. The effects of Ni, as nickel sulfate, on dehydrogenase activity of the native soil microflora in soil from the Rocky Mountain Arsenal was assessed by Rogers and Li (1985) as described previously for Cd. After 6 days, a concentration of 30 ppm (lowest concentration tested) Ni reduced dehydrogenase activity by 39%.

Babich and Stotzky (1982) evaluated the effects of two forms of Ni on mycelial growth rate of a number of soil-dwelling fungi inoculated individually into autoclaved sandy loam soil. The concentrations at which growth was reduced ranged from 50 to 750 ppm for Ni (added in chloride or sulfate form).

Giashuddin and Cornfield assessed the effect of Ni added in oxide (1979) and sulfate (1978) forms on N and C mineralization by native soil microflora in a sandy soil. The metal salts were mixed into the soil in dry form. After 42 days incubation, soil respiration (C mineralization) was reduced in soil containing 10 ppm Ni from Ni sulfate (lowest concentration tested), and N mineralization was affected at 100 ppm. Soil respiration was reduced in soil containing 50 ppm Ni from Ni oxide (lowest concentration tested), and N mineralization was affected at 1000 ppm. Because of the test concentrations used, it is difficult to assess the relative toxicity of these two forms of Ni to C mineralization. When the soil pH was raised to 6.9 (from its normal 5.9), soil respiration was reduced in soil containing 250 ppm Ni from Ni oxide (lowest concentration tested), and N mineralization was affected at 1000 ppm. The effect of Ni from Ni sulfate was not tested at the higher pH. Raising the pH appeared to affect soil respiration but not N mineralization.

Bhuiya and Cornfield (1974) assessed the effects of Ni on C mineralization by native microflora in a sandy soil, with or without added organic matter, as described for Cu. After 12 weeks, soil respiration was reduced in the Ni-treated soil with or without oat straw, but to a greater degree in the straw-amended soil.

The influence of soil characteristics on effects of Ni on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) as described previously for Al. In only one soil was the highest concentration tested, 1468 ppm, found to reduce arylsulfatase activity. This soil had the lowest pH and organic matter content of the four soils tested.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effect of Ni on soil acid and alkaline phosphatase activities. Acid phosphatase activity was not affected at 1468 ppm only in the soil with the highest pH. Alkaline phosphatase activity was reduced in one of the soils tested by this same concentration.

Haanstra and Doelman (1991) investigated short- and long-term effects of Ni on arylsulfatase activity, urease activity (Doelman and Haanstra, 1986), and total phosphatase activity (Doelman and Haanstra, 1989) by native soil microflora in five soils, as described for Cd. In the 6-week study on the effects of Ni, data from the sandy peat soil were not available for arylsulfatase and phosphatase activities. The highest EC_{50}s (5659, 6516, and 3380 ppm for arylsulfatase, phosphatase, and urease activities) were found in the soil with the highest clay content. The lowest were 2119, 1109, and 100 ppm, for arylsulfatase, phosphatase, and urease activities found in the sand. In the 18-month study, data from the sandy loam soil were not available for arylsulfatase activity nor from clay and sandy peat for phosphatase activities. The highest EC_{50}s were 8101, 8042, and 2790 ppm Ni for arylsulfatase, phosphatase, and urease activities in different soils. The lowest LC_{50}s, 92, 769, and 370 ppm, were found in the sand.

A benchmark of 90 ppm Ni was established based on the 56 reported effective values. Confidence in this benchmark is high because of the relatively large amount of data available for a variety of functional measures.

Selenium. Lighthart et al. (1977) evaluated the effects of using methods at a single concentration on respiration of native soil microflora in soil/litter microcosms, as described for Cd. Selenium at 484 ppm reduced respiration 43%.

The influence of soil characteristics on effects of Se on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) as described previously for Al. In the soil with the lowest clay content, activity was reduced by 198 ppm. In the other soils, arylsulfatase activity was reduced by 1975 ppm with the greatest reduction in the soil with the lowest pH and organic matter content.

Frankenberger and Tabatabai (1981) investigated the effect of Se on amidase activity in three soils in shaker-flask assays as described previously. After 2 1/2 hours, amidase activity was reduced in only one soil at 1975 ppm. This soil had the lowest pH and organic matter and clay contents of the soils tested.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effect of Se(IV) to soil acid and alkaline phosphatase activities. Acid phosphatase activity in all three soils was reduced at 1975 ppm. Alkaline phosphatase activity in both soils tested was reduced about the same degree at this concentration.

The effective concentration of 198 ppm (Al-Khafaji and Tabatabai, 1979) is the lowest of the 10 reported. Confidence in the benchmark of 100 ppm is moderate.

Silver. Bremner and Douglas (1971) evaluated the effects of Ag on urease activity in two soils, as described for Hg. After 5 hours, silver, added as either nitrate or sulfate salt, decreased urease activity by 60 to 65% in both soils.

Liang and Tabatabai (1977) investigated the effects of Ag on N mineralization by native soil microflora in four soils, as described for Cd. Silver at 540 ppm reduced N mineralization in all soils. The greatest magnitude of the inhibitory effect was seen in the soil having the lowest pH and organic matter and clay contents.

The influence of soil characteristics on effect of Ag on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) as described previously for Al. In two soils tested with a lowest concentration of 270 ppm, arylsulfatase activity was greatly reduced. In the two soils tested with a lowest concentration of 2698 ppm, arylsulfatase activity was almost totally inhibited.

Frankenberger and Tabatabai (1981) investigated the effect of Ag on amidase activity in three soils in shaker-flask assays as described previously. After 2 1/2 hours, amidase activity was severely reduced in all three soils at 2698 ppm. The greatest reduction occurred in the soil with the lowest pH and organic matter and clay contents.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effect of silver on soil acid and alkaline phosphatase activities. Acid phosphatase activity was affected at 2698 ppm only in the soil with the highest pH (7.8). Alkaline phosphatase activity was reduced 28% in the loam soil at an Ag concentration of 270 ppm and 93% at 2698 ppm in a clay loam soil.

A benchmark of 50 ppm Ag was established based on the 17 reported effective values. Confidence in this benchmark is moderate.

Tin. The influence of soil characteristics on effect of Sn on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) as described previously for Al. In the soil with the highest pH (7.6), Sn had no effect. Arylsulfatase activity in the other three soils was reduced by 2968 ppm Sn. The reductions were the least severe in the soil having the highest organic C and clay content.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effect of Sn on soil acid and alkaline phosphatase activities. Acid phosphatase activity was affected at 2968 ppm only in the soil with the lowest pH and organic matter and clay contents. Alkaline phosphatase activity was reduced in both soils tested by this same concentration.

The effective concentration of 2968 ppm (Al-Khafaji and Tabatabai, 1979) is the lowest of the seven reported. Confidence in the benchmark of 2000 ppm is low because of the limited amount and type of data available.

Titanium. The influence of soil characteristics on effect of Ti (as $TiSO_4$) to arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) as described previously for Al. In two soils tested with a lowest concentration, arylsulfatase activity was reduced by 1198 ppm. These two soils had the lowest pH and organic matter and clay contents of the four tested.

The effective concentration of 1198 ppm (Al-Khafaji and Tabatabai, 1979) is the lowest of the two reported. Confidence in the benchmark of 1000 ppm is low because of the limited amount and type of data available.

Tungsten. The influence of soil characteristics on effects of tungsten (W) (Na_2WO_4) on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) as described previously for Al. In the soil with the highest clay and organic matter contents, W had no effect. Activity was reduced in all other soils at 4598 ppm, with the greatest reduction in the soil with the lowest clay content.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effect of tungsten on soil acid and alkaline phosphatase activities. Acid phosphatase activity in all three soils was reduced at 4598 ppm. In the soil with the lowest pH and organic matter and clay content, it was also inhibited at 460 ppm W. Alkaline phosphatase activity in both soils tested was reduced about the same amount at this concentration.

The effective concentration of 460 ppm (Juma and Tabatabai, 1977) is the lowest of the seven reported. Confidence in the benchmark of 400 ppm is low because of the limited amount and type of data available.

Vanadium. Tyler (1976) evaluated the effect of V, added in a solution of sodium vanadate to fresh needles from a white pine stand, on acid phosphatase activity of the native microflora. After 3 hours of exposure, activity was reduced 40% by 50 ppm V, while 30 ppm had no effect.

The influence of soil characteristics on effect of V on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) as described previously for Al. In two soils tested with a lowest concentration of 127 ppm, arylsulfatase activity was reduced with the greatest reduction in the soil with the lowest clay content. In the two soils tested with a lowest concentration of 1273 ppm, arylsulfatase activity was severely inhibited.

Juma and Tabatabai (1977) used the system described for Al to evaluate the effect of V on soil acid and alkaline phosphatase activities. Acid phosphatase activity in all three soils was reduced about the same degree at 1273 ppm. In the soil with the lowest pH and organic matter and clay contents, it was also inhibited at 127.3 ppm V. Alkaline phosphatase activity in both soils tested was reduced about the same degree at 1273 ppm. In the soil with the highest organic matter and clay contents, it was also inhibited at 127.3 ppm V.

Lighthart et al. (1977) evaluated the effects of V at a single concentration on respiration of native soil microflora in soil/litter microcosms, as described for Cd. Vanadium at 23 ppm reduced respiration 21%.

The effective concentration of 23 ppm (Lighthart et al., 1977) is the lowest of the 10 reported. Confidence in the benchmark of 20 ppm is moderate.

Zinc. Wilson (1977) evaluated the effect of Zn, as zinc sulfate solution, on nitrification by native soil microflora in three soils. The soils ranged in pH from 5.1 to 6.2, percent organic matter from 1.1 to 2.4, and percent clay from 2 to 28. After 49 days, nitrification was severely inhibited in all three soils (98 to 100%) by 1000 ppm Zn, while Zn at 100 ppm had no effect.

Haanstra and Doelman (1991) investigated short- and long-term effects of Zn on arylsulfatase activity, urease activity (Doelman and Haanstra, 1986), and total phosphatase activity (Doelman and Haanstra, 1989) by native soil microflora in five soils, described for Cd. In the 6-week study on the effects of Zn, data from the sandy peat soil were not available for any of the enzymes. The highest EC_{50}s were 5559, 3623, and 1780 ppm for arylsulfatase, phosphatase, and urease activities, all in the soil with the greatest content of clay. The lowest EC_{50}s of 909, 220, and 420 ppm Zn were all found in the sand. In the 18-month study, data were not available from the sandy peat for phosphatase or the silt loam for urease. The highest EC_{50}s were 9679, 4872, and 290 ppm Zn in different soils. The lowest EC_{50}s were 375, 170, and 70 ppm in different soils.

Juma and Tabatabai (1977) used the system described for Al to evaluate the toxicity of Zn to soil acid and alkaline phosphatase activities. Acid and alkaline phosphatase activities were affected at 1635 ppm in all three soils to about the same degree, except increased inhibition of alkaline phosphatase activity in the soil with the highest pH.

The influence of soil characteristics on effects of Zn on arylsulfatase activity was evaluated by Al-Khafaji and Tabatabai (1979) as described previously for Al. A reduction in activity was measured in two soils tested at a concentration of 1635 ppm. No clear differences between the soils with regard to influence on effects of Zn could be discerned.

Bhuiya and Cornfield (1974) investigated the effects of Zn on N mineralization and nitrification by native soil microflora in a sandy soil at different pH levels, as described for Cr. After 12 weeks, both mineralization and nitrification were reduced by 1000 ppm Zn at pH 7, but not at pH 6. After 6 weeks, neither mineralization nor nitrification was affected by Zn at either pH.

Bhuiya and Cornfield (1974) investigated the effects of 1000 ppm Zn added as Zn oxide to a sandy soil at three pH levels on nitrogen mineralization by native soil microflora. After 42 days, N mineralization was reduced in the pH 7.7 soil but not in soils at pH 6 and 7.

The effects of Zn on dehydrogenase activity of the native soil microflora in soil from the Rocky Mountain Arsenal was assessed by Rogers and Li (1985) as described previously for Cd. A concentration of 300 ppm Zn reduced dehydrogenase activity by 30%; Zn at 150 ppm had no effect.

Laskowski et al. (1994) looked at the effects of several metals at low to moderate levels on the respiration rate of acid-mixed forest litter. The fresh litter was treated with solutions of $CdCl_2$ (up to 250 ppm Cd), $Pb(NO_3)_2$ (up to 2500 ppm Pb), or $ZnCl_2$. Only zinc had an effect at the concentrations tested. A concentration of 1000 ppm Zn reduced respiration by 26%; Zn at 200 ppm had no effect.

The effect of Cd and Zn on respiration of soil microflora in field-collected black oak forest soil/litter microcosms was evaluated by Chaney et al. (1978). The metals, in solutions of chloride salts, were sprinkled over the litter layer of the chamber. After 23 days, Cd at a concentration up to 6 ppm had no effect. Respiration was decreased 21% by Zn at 479 ppm; Zn at 47 ppm had no effect.

Bollag and Barabasz (1979) evaluated the effects of Zn on denitrification by three soil-dwelling *Pseudomonas* (bacteria) in autoclaved soil and by native soil microflora, as described for Cd. In the autoclaved soil, two of the three species had reductions in activity at 250 ppm Cd, while the organism most sensitive to the effects of Cd and Cu was also more sensitive to the toxic effects of Zn on denitrification. Denitrification by the native soil population was reduced 31% by 250 ppm Zn.

Lighthart et al. (1977) evaluated the effects of Zn at a single concentration on respiration of native soil microflora in soil/litter microcosms, as described for Cd. Zinc at 3600 ppm reduced respiration 66%.

Premi and Cornfield (1969, 1969/1970) investigated the effects of Zn added to a sandy loam soil on nitrogen transformations by native soil microflora. In a 21-day experiment (1969), nitrification was severely inhibited at 100 ppm Zn, added as sulfate salt, the lowest concentration tested. Zinc added in carbonate form was ineffective at 10,000 ppm (highest concentration tested), probably because of the increase in soil pH caused by addition of this form. In the 8-week experiment (1969/1970) with sucrose and ammonium nitrate added to the soil, nitrification was decreased only slightly less at 100 ppm Zn than it was in the 21-day study.

Leita et al. (1995) evaluated the effect of Zn [$Zn(SO_4)_2$] on microbial biomass of native microflora ina surface soil (pH 6, 2% organic carbon, and 18% clay). After 56 d, the 600 ppm single treatment level nitrification reduced biomass 31%.

The benchmark of 100 ppm Zn is the 10th percentile of the 47 reported effective values. Confidence in this benchmark is high because of the relatively large amount of data available for a variety of functional response factors.

4.3.2 Organic Chemicals

Acrylonitrile. The effects of several organic compounds on respiration of native soil microflora in a sandy loam and a silt loam soil were evaluated by Walton et al. (1989). Both soils were acid (pH 4.9 and 5.3) and low in organic matter (1.4 and 3%) but differed with respect to amounts of clay (5% vs and 30%). Respiration was measured after 6-day exposure to 1000 ppm of each chemical. Chemicals tested at 1000 ppm had no effect and include methyl ethyl ketone, benzene, toluene, p-xylene, chlorobenzene, chloroform, and other chlorinated benzenes. Acrylonitrile reduced respiration by 59% in the sandy loam soil and 41% in the silt loam. Clay appeared to have an ameliorating influence on the effects of acrylonitrile.

The benchmark of 1000 ppm is based on this work. Confidence in the benchmark is low because of the limited amount and type of data available.

Carbon tetrachloride. The effects of 1000 ppm carbon tetrachloride on respiration of native soil microflora in a sandy loam and a silt loam soil was evaluated by Walton et al. (1989) as described for acrylonitrile. Carbon tetrachloride reduced respiration by 21% in the sandy loam but did not lower respiration in the silt loam soil. Clay may have had an ameliorating influence on the effects of this compound.

The benchmark of 1000 ppm is based on this work. Confidence in the benchmark is low because of the limited amount and type of data available.

Cis-1,4-dichloro-2-butene. The effects of cis-1,4-dichloro-2-butene on respiration of native soil microflora in a sandy loam and a silt loam soil was evaluated by Walton et al. (1989) as described for acrylonitrile. Cis-1,4-dichloro-2-butene reduced respiration by 48% in the sandy loam soil and 44% in the silt loam by 1000 ppm. Clay did not appear not to have an ameliorating influence on the effects of this compound.

The benchmark of 1000 ppm is based on this work. Confidence in the benchmark is low because of the limited amount and type of data available.

Hexachlorobenzene. The effects of 1000 ppm hexachlorobenzene on respiration of native soil microflora in a sandy loam and a silt loam soil was evaluated by Walton et al. (1989) as described for acrylonitrile. Hexachlorobenzene reduced respiration by 37% in the silt loam but did not lower respiration in the sandy loam soil. Clay did not appear to have an ameliorating effect on the toxicity of this compound.

The benchmark of 1000 ppm is based on this work. Confidence in the benchmark is low because of the limited amount and type of data available.

Nitrobenzene. The effects of 1000 ppm nitrobenzene on respiration of native soil microflora in a sandy loam and a silt loam soil was evaluated by Walton et al. (1989) as described for acrylonitrile. Nitrobenzene reduced respiration by 61% in the sandy loam soil and by 22% in the silt loam. Clay appears to have an ameliorating influence on the effect of nitrobenzene.

The benchmark of 1000 ppm is based on this work. Confidence in the benchmark is low because of the limited amount and type of data available.

Pentachlorophenol. van Beelen and Fleuren-Kemila (1993) evaluated the effect of pentachlorophenol (PCP) on mineralization of added acetate by native soil microflora in an acid agricultural soil and an acid dune sand. After 1.8 days, CO_2 evolved was reduced 50% (EC_{50}) by 460 ppm in the agricultural soil (percent organic matter, 10.4; percent clay, 5) and by 1500 ppm in the dune sand (percent organic matter, 1.2; percent clay, 0.4).

van Beelen et al. (1994) evaluated the effect of PCP on mineralization of added acetate by native soil microflora in an alkaline polder agricultural soil (pH 8, % organic matter 1; % clay 1) and an acid soil (pH 4, % organic matter 5; % clay 1). The calculated EC_{50} was 57 ppm in the polder soil and 1207 ppm in the soil containing a greater amount of organic matter.

The benchmark of 50 ppm for PCP is based on the work of van Beelen et al. (1994). Confidence in the benchmark is low because of the limited amount and type of data available.

Phenol. Effects of phenol on carbon and nitrogen mineralization and nitrogen transformations in alfalfa-amended, sieved soil were determined by Suter and Sharples (1984). The silt loam soil had a pH of 4.7. Carbon dioxide production was increased at 10 ppm and 100 ppm on days 1 and 7 but not on later dates or at higher concentrations. CO_2 production was decreased at 1000 ppm phenol on day 1, but not thereafter, and at 5000 ppm phenol on days 1 through 55. On all dates (days 7 through 42), ammonia concentrations were significantly increased and nitrate significantly decreased by 1000 and 5000 ppm phenol. At 10 and 100 ppm on day 7 and at 100 ppm on day 42, but not on intermediate dates, ammonia was significantly increased and nitrate decreased. If the lowest chronic response is used as the basis for the benchmark, the threshold for significant effects in this test is 100 ppm phenol.

The benchmark of 100 ppm is based on this work. Confidence in the benchmark is low because of the limited amount and type of data available.

Trans-1,4-dichloro-2-butene. The effects of 1000 ppm trans-1,4-dichloro-2-butene on respiration of native soil microflora in a sandy loam and a silt loam soil was evaluated by Walton et al. (1989) as described for acrylonitrile. Trans-1,4-dichloro-2-butene reduced respiration by 44% in the sandy loam soil and 58% in the silt loam. Clay did not appear not to have an ameliorating influence on the effect of this compound.

The benchmark of 1000 ppm is based on this work. Confidence in the benchmark is low because of the limited amount and type of data available.

5. INVERTEBRATES OTHER THAN EARTHWORMS AND MICROBIAL HETEROTROPHS

5.1 INTRODUCTION

Interest in the toxic effects of soil pollutants on soil and litter dwelling invertebrates other than earthworms and microorganisms stems from concern for negative effects on nutrient cycling and availability and quality of food for animals feeding on soil and litter dwelling invertebrates. In general, the most important route for assimilation of metals by soil invertebrates is through the digestive tract (Beeby, 1991). Assimilation of toxic metals depends on diet and the animal's essential metal demand. In general, invertebrates with a high calcium demand tend to accumulate higher concentrations of toxic metals. The metals are often bound in intracellular granules, structural tissues, and membrane-bound vesicles. There is no clear relationship between the bioconcentration potential of a species and its susceptibility to metal intoxication (van Straalen, 1991).

Toxic effects of metals on invertebrates result in part from their interactions with nutritionally significant metals. van Straalen et al. (1989) suggest that the negative impact of cadmium on mite (*Platynothrus peltifer*) egg production results from disruption of the role of zinc in reproductive metabolism. Cadmium also blocks the calcium current of *Helix* neurons (Akaike et al., 1978), possibly leading to tissue damage and reduced reproduction (Russell et al., 1981). The interrelationships between metals, both essential and nonessential, appear to be quite complex and variable among species of invertebrates. Other effects may result from the binding of metals to proteins and enzymes with consequent functional disruption.

5.2 INVERTEBRATE DATA SELECTION

The experimental approaches are too diverse, and the data too meager to allow for the establishment of benchmarks for the toxicity of contaminants in soil to soil-dwelling invertebrates other than earthworms. Most experiments evaluating the effects on nematodes are conducted in solution because these organisms inhabit the water films around soil particles and roots. The experiments using Collembola and mites are often conducted by feeding the organisms on algae that were reared on contaminated media. Perhaps the most common method for other organisms is to surface apply a solution, or soluble powder, of the chemical to the organic substrate on which it is to feed during the experiment. At most contaminated sites, soil concentrations are available while soil algae, litter, and pore water concentrations are not. Surface applied chemicals are only appropriate when evaluating sites where deposition of air-borne contaminants onto vegetation and litter is the only route by which these food sources become contaminated. The bioavailability of chemicals introduced to food by these methods is not directly comparable to that of chemicals bound in organic form inside plant material or microflora. Furthermore, it would be difficult to assess the food preferences of these diverse and opportunistic organisms in any specific field situation (Hopkin, 1989) to allow appropriate sampling and analysis.

For the previously described reasons, no benchmarks have been set for these organisms. The information in this part of the document is provided as reference and support material. Experimental data are given in Appendix C.

5.3 INVERTEBRATE TEST SPECIES

The literature on toxicity of chemicals to soil and litter-dwelling invertebrates presents experimental results using microarthropods, macroarthropods, nematodes, and terrestrial gastropods and crustaceans. These organisms represent diverse morphological, physiological, and behavioral groups. The following general information is derived mainly from works edited by Dindal (1990) and Dickinson and Pugh (1974).

Collembola (springtails) are small, wingless microarthropods that live mainly in the soil litter layer. With the mites, springtails make up the majority of the soil litter arthropod fauna. Most soil forms live on partially decomposed vegetation or microflora, especially fungi. The importance of Collembola to soil organic matter breakdown and nutrient cycling results from the comminution of organic matter fragments, feeding on humus and feces in the litter, and on decaying roots. Collembola commonly used as test species are *Folsomia candida*, *Onychiurus armatus*, and *Orchesella cincta*. *Folsomia candida* is considered well-suited for the study of effects of contaminants on population parameters because it is easy to culture and has a relatively short generation time. This allows the study of individual and population parameters in the same experiment (Crommentuijn et al., 1993).

The Acarina (mites) are a diverse group of arthropods in the suborders *Prostigmata*, *Mesostigmata*, *Astigmata*, and *Oribatida*. Each suborder contains representatives living in a wide range of habitats. In the soil and litter, mites may be detritivores eating dead plant material, predatory, or fungivores/algivores. Oribatid mites are found in large numbers in organic horizons of soils. They are represented in toxicity tests by *Platynothrus peltifer*. Like the springtails, mites act to increase the rate of organic matter decomposition by reducing the size of organic matter fragments and feeding on microflora involved in decomposition. Mites, especially oribatids, are considered suitable for the study of effects of contaminants on population parameters because they are easy to culture and have a relatively short generation time (1 per year), although it is longer than that of the Collembola (2 per year).

Terrestrial crustaceans are represented in the toxicity literature by woodlice, also known as pill bugs (Isopoda, *Porcellio scaber* and *Oniscus asellus*). They are common in deciduous woodland living in the litter layer and on decaying wood. Woodlice are omnivorous, feeding mainly on dead and decaying plants. They increase organic matter decomposition by comminuting the fragments and feeding on microflora involved in primary decomposition. As leaf litter feeders, isopods are considered good candidates for standard organisms in ecotoxicological testing (van Wensem, 1989). *Porcellio scaber* is common in many countries and is easy to maintain in the laboratory.

The snail *Helix aspersa* and the slug *Arion ater* represent terrestrial gastropods. They are generalized feeders (living and dead plant materials) inhabiting the soil surface, the litter layer, and standing vegetation. Their use in ecotoxicological testing stems from their potential importance for accumulation of contaminants in the food chain (Russell et al., 1981).

Nematodes (roundworms) are significantly different from other soil and litter-dwelling organisms discussed herein because they require a continuous water film for survival. They feed on a wide variety of foods although some are specialized parasites. The effects of chemicals on fungivores, bactivores, herbivores, and omnivores/predators have been evaluated. *Caenorhabditis elegans* used in experiments is a widespread free-living, soil-dwelling nematode. Nematodes have

been used in ecotoxicological work for a number of reasons. They are abundant, easily retrieved from soil, and reared in the laboratory. Nematodes live in the interstitial water of the soil so experiments can be conducted in water. They may be exposed to higher concentrations of contaminants by this route than earthworms and other invertebrates not constantly in contact with the soil solution. Uptake of chemicals is mainly through the cuticle, and differences in cuticle permeability are thought to be the primary source of variability in response of various nematodes to toxic chemicals (Kammenga et al., 1994).

5.4 OTHER INVERTEBRATES LITERATURE REVIEW

Cadmium. Kammenga et al. (1994) compared the acute toxicity of Cd ($CdCl_2$) to seven terrestrial nematode species belonging to different taxonomic and ecological groups. The nematodes were extracted from the surface horizon of an arable soil and a forest floor and identified and selected on the basis of different trophic levels: *Rhabditis* species and *Diplogasteritus* species; *Cephalobus persegnis*, *Acrobeloides buetschlii*, and *Caenorhabditis elegans*, bacteria feeders; *Aphelenchus avenae*, fungus feeder; and *Tylenchus elegans*, plant feeder. Solutions were mixed to mimic the mineral concentrations of soil solution in a sandy forest surface soil plus Cd at different concentrations. LC_{50} values were determined after 72 hours. The nematodes *T. elegans* and *A. avenae* had LC_{50} values of greater than 90 ppm after 96 hours (termination of experiment); that is, they were essentially unaffected by the experimental treatment. Among the bacterial feeders the LC_{50} ranged from approximately 3 to 60 ppm Cd after 72 hours.

The nematode *C. elegans* was used by van Kessel et al. (1989) to test the effects of Cd (as $CdCl_2$) on growth (length) and reproduction (number of juveniles per adult) of this soil-dwelling group. Juvenile (J-1) nematodes were cultured for 168 hours in microtiter plates containing solutions with different levels of Cd. Reproduction, the more sensitive parameter, was reduced 36% by 3.6 ppm.

The influence of Cd (as $CdCl_2$) on life-history characteristics of the collembolan *Folsomia candida* was investigated by Crommentuijn et al. (1993). One-week old animals were placed on OECD artificial soil (containing, in percent dry weight, 10 sphagnum peat, 20 kaolin clay, 70 quartz sand; pH 6) containing a series of concentrations of Cd and fed baker's yeast. Number and weight of adults and number of offspring were determined. A soil concentration ($HCl+HNO_3$ extractable) of 326 ppm Cd reduced the number of offspring produced by 21% after 42 days. Weight of the individual animals was not affected at this concentration.

Representatives of Collembola and mites were used by van Straalen et al. (1989) to assess the effect of Cd in diets of soil microarthropods on population growth rates. Three-day old *Orchesella cincta* (Collembola) were fed green algae containing Cd ($CdSO_4$). A concentration of 15 ppm Cd caused an approximate 56% reduction in calculated population growth rate after 61 days, while 4.7 ppm had no effect. Adult mites (*P. peltifer*) fed the same diet for 84 days experienced a 23% reduction in population growth rate at a concentration of 9 ppm Cd, while 3 ppm had no effect.

Hopkin and Hames (1994) investigated the effects of Cd (as $CdNO_3$) in food on survival and reproduction of the terrestrial isopod *Porcellio scaber*. Leaves of field maple (*Acer campestre*) were sprayed with solutions containing Cd and placed in plastic containers with juvenile woodlice. After 360 days, the number of surviving isopods and the number of juveniles were determined. The

number of juveniles produced was decreased 47% by 10 ppm Cd (lowest concentration tested) while 50 ppm was required to reduce total survival.

The effects of Cd on individual weight, new shell growth, and reproductive behavior of the snail *Helix aspersa* was evaluated by Russell et al. (1981). The diet fed to the sub-adult (4-month- old) snails for 30 days was ground Purina Lab Chow (for rats, mice, and hamsters) with Cd (as $CdCl_2$) added. Snails were raised in plastic containers with sand bottoms. Reproductive activity, as measured by the number of individuals mating or with spermatophores in place, was reduced 28% by 25 ppm Cd while 10 ppm had no effect. New shell growth and weight were not affected at this concentration.

The experimental approaches described in the previous paragraphs are too diverse to allow comparison of results, as discussed in the Introduction. There is agreement between the two studies on the effects of Cd on nematodes in that approximately 3 ppm in solution is detrimental to the organisms. This number may be useful when soil solution concentration values for Cd are available.

The one study conducted in soil yielded a toxic concentration of 326 ppm, which is higher than the earthworm and microbe benchmarks for soil (Tables 1 and 2).

Copper. The acute toxicity of Cu to the nematode *C. elegans* in four soils and in solution was evaluated by Donkin and Dusenbery (1993). The soils included two silt loams, a loam, and a clay loam. Adult nematodes were placed in the soil with Cu added as $CuCl_2$ and native soil organic matter as food. After 24 hours, surviving animals were counted, and an LC_{50} concentration calculated. Toxicity was also tested in solutions containing Cu. A concentration of 105 ppm Cu in solution caused 50% mortality while at least 400 ppm (sandy loam soil) was required in soil. The highest LC_{50} (1061 ppm) was associated with the highest percentage organic matter in the loam soil.

Parmalee et al. (1993) used a soil microcosm to test the effects of Cu on survival of nematodes and microarthropods feeding on native soil organic matter. Cu was added as $CuSO_4$ to the A horizon of an acid sandy forest soil where native soil nematode and microarthropod populations were exposed for 7 days. There was an average reduction of approximately 70% in number of individuals of most categories of nematodes (fungivores, bactivores, herbivores, hatchlings) at 400 ppm total Cu, while 185 ppm had no effect. The number of individuals of the omnivores/predators category was reduced 85% by the lowest concentration of Cu tested, 72 ppm. Total microarthropod numbers were reduced about 50% by 400 ppm. The oribatid and Mesostigmata mites appeared to be more sensitive, and the Collembola population was too small to evaluate.

Hopkin and Hames (1994) investigated the effects of Cu (as $CuNO_3$) in food on survival and reproduction of the terrestrial isopod *Porcellio scaber*. The experimental design used by the authors is described in the discussion of the effects of Cd on this animal. After 360 days, the number of surviving isopods and the number of juveniles were determined. The number of juveniles produced was decreased 53% by 50 ppm Cu while 100 ppm of Cu was required to reduce total survival.

The slug, *Arion ater*, was used as the test organism by Marigomez et al. (1986) to determine the effects of several pollutants on terrestrial mollusks. Slugs collected from the field were reared in plastic boxes and fed a diet of a pulverized mixture of lettuce, apple, carrot, and pumpkin mixed with $CuSO_4$. After 27 days on this diet, the animals experienced a 55% decrease in growth at 1000 ppm Cu, while 300 ppm had no effect.

The studies of Donkin and Dusenbery (1993) and Parmalee et al. (1993) taken together show a higher concentration in soil than in solution is required to affect the survival of nematodes. Differences among groups of nematodes in sensitivity to Cu is shown by Parmalee et al. (1993). The application of soluble form of Cu to food material by Hopkin and Hames (1994) and Marigomez et al. (1986) show very distinct sensitivities of woodlice and slugs to Cu.

The lowest toxic concentration reported in these two studies (72 ppm Cu) is higher than the benchmarks for earthworms (50 ppm) and microbes (30 ppm).

Iron. The effect of iron on the Collembola *Orchesella cincta* was investigated by Nottrot et al. (1987). The springtails were grown in plastic dishes and fed green algae (*Pleurococcus* spp.) containing various concentrations of Fe for 21 days. Percent growth, feeding activity, and molting were determined. Growth of the springtails was reduced 42% by a diet of 7533 ppm, while 3515 ppm had no effect.

Lead. Bengtsson et al. (1983) evaluated the effects of lead, in the fungus *Verticillium bulbillosum*, on growth rate of a fungus-feeding collembolan, *O. armatus*. Adult springtails were fed the fungus for 125 days and their lengths were recorded for calculation of growth rate. Lead at 3089 ppm in the fungus caused a 25% reduction in *O. armatus* growth rate. fungus.

Hopkin and Hames (1994) investigated the effects of Pb (as $PbNO_3$) in food on survival and reproduction of the terrestrial isopod *Porcellio scaber*. The experimental design used by the authors is described in the discussion of the effects of Cd on this animal. After 360 days, the number of surviving isopods and the number of juveniles were determined. Survival and the number of juveniles produced were decreased 100% by 2000 ppm Pb while 1000 ppm had no effect.

Beyer and Anderson (1985) also used *Porcellio scaber* in experiments to determine the effect of Pb, added as PbO to ground deciduous leaf litter, on several population parameters. The woodlice were reared in plastic containers and fed this diet for 448 days. During this time, the following were measured: lifespan of generation 1, maximum number of individuals in generation 2, and survival of generation 2. These parameters were decreased 27, 68, and 84%, respectively, by 12,800 ppm Pb in the diet, while 6400 ppm had no effect.

The slug, *Arion ater*, was used as the test organism by Marigomez et al. (1986) to determine the effect of lead on terrestrial mollusks. Field collected slugs were reared in plastic boxes and fed a diet of a pulverized mixture of lettuce, apple, carrot, and pumpkin mixed with $PbNO_3$. After 27 days on this diet, the animals experienced a 51% decrease in growth at 1000 ppm Pb, while 300 ppm had no effect.

The studies indicate a high tolerance to Pb in the diets of the tested woodlouse, springtail, and slug species. The discrepancy between the Hopkin and Hames (1994) and Beyer and Anderson (1985) levels of Pb required to affect the woodlouse may be due to differences in bioavailability of the added Pb compounds.

Mercury. The slug, *Arion ater*, was used as the test organism by Marigomez et al. (1986) to determine the effect of mercury (as $HgCl_2$) on terrestrial mollusks, as described for Pb. After 27 days on this diet, the animals experienced a 26% decrease in growth at 1000 ppm Hg, while Hg at 300 ppm had no effect.

Zinc. Hopkin and Hames (1994) investigated the effects of Zn (as $ZnNO_3$) in food on survival and reproduction of the terrestrial isopod *Porcellio scaber*. The experimental design used by the authors is described in the discussion of the effects of Cd on this animal. After 360 days, the number of surviving isopods and number of juveniles were determined. Survival and number of juveniles produced were decreased 100% by 1000 ppm Zn while 500 ppm had no effect.

Zinc (as ZnO) was added to litter from the O2 layer under woodlands to evaluate the effects of that metal on *Porcellio scaber* (Beyer et al., 1984). Adult animals kept in plastic boxes were fed this diet for 56 days before survival was determined. The only concentration tested, 5000 ppm, caused a 26% decrease in survival.

Beyer and Anderson (1985) also used *Porcellio scaber* in experiments to determine the effect of Zn, added ZnO to ground deciduous leaf litter, on several population parameters. The woodlice were reared in plastic containers and fed this diet for 448 days. During this time the following were measured: lifespan of generation 1, maximum number of individuals in generation 2, and survival of generation 2. The maximum number of individuals in generation 2 and the survival rate for generation 2 were decreased 22 and 27% by 1600 ppm Zn in the diet, while 800 ppm had no effect.

The slug, *Arion ater*, was used as the test organism by Marigomez et al. (1986) to determine the effect of Zn (as $ZnCl_2$) on terrestrial mollusks, as described previously. After 27 days on this diet the animals experienced a 38% decrease in growth at 10 ppm Zn, the lowest concentration tested.

The experiments evaluating the toxicity of Zn to the woodlouse *Porcellio scaber* show a high tolerance to the metal when it is added to the food in soluble form. The work with *Arion ater* (Marigomez et al., 1986) indicates that this organism is more sensitive than *P. scaber* to Zn. On the other hand, growth of individual woodlice was not evaluated and may be more sensitive than survival and reproduction.

Benzo(a)pyrene (BaP). The woodlouse *P. scaber* was chosen by van Straalen and Verweij (1991) to determine the effects of this PAH on the soil invertebrate community. Polynuclear aromatic hydrocarbons are strongly sorbed onto soil organic matter which serves as the main food for many of these organisms. Adult woodlice were reared in plastic boxes for 28 days and fed ground poplar leaf litter mixed with benzo(a)pyrene. Growth efficiency was determined as dry weight increase divided by net food consumption (consumption minus defecation). Respiration, food consumption, and food assimilation were also measured. Growth efficiency of the males of the group was reduced 82% by 125 ppm BaP in the food, while 25 ppm had no effect. Growth efficiency of the females, respiration, food consumption, and food assimilation were not affected.

Two isopods, *Porcellio scaber* and *Oniscus asellus*, were used by van Brummelen and Stuijfzand (1993) to determine the effects of BaP on litter layer-dwelling soil invertebrates. Weight and length changes and energy reserves were measured in individuals reared in plastic boxes and fed a combination of ground poplar leaves and ground dog food spiked with BaP for 63 days. Dry weight of *P. scaber* was reduced 30% with a diet containing 100 ppm BaP, while 32 ppm had no effect. Length and energy reserves (lipids+glycogen+protein) were not affected. Dry weight and length of *O. asellus* were reduced 58 and 48% with a diet containing 316 ppm BaP, while 100 ppm had no effect. Energy reserves were not affected.

These experiments with woodlice indicate that growth may be affected by BaP at concentrations of about 100 ppm applied to food.

p-nitrophenol (PNP). Parmalee et al. (1993) tested the effects of PNP on survival of nematodes and microarthropods in soil microcosms, as described for Cu. There was an average reduction of approximately 55% in number of individuals of most categories of nematodes (fungivores, herbivores, herbivores/predators, and hatchlings) at 40 ppm total PNP, while 20 ppm had no effect. The number of individuals of the bacterivore category was reduced 40% by the lowest concentration of PNP tested, 20 ppm. Total microarthropod numbers were reduced about 35% by 176 ppm, mainly as the result of reductions in oribatids. P-nitrophenol up to 176 ppm had no effect on numbers of Mesostigmata or unclassified microarthropods, and there were no Collembola were present.

Pentachlorophenol. Kammenga et al. (1994) compared the acute toxicity of PCP in solution culture to seven terrestrial nematode species belonging to different taxonomic and ecological groups. The nematodes and experimental design are the same as described previously for Cd. *Aphelenchus avenae*, *Caenorhabditis elegans*, and *Acrobeloides beutschlii* had LC_{50} values greater than 9 ppm after 96 hours (that is, experimental concentrations killed fewer than half of the nematodes). LC_{50} values for the remaining nematodes ranged from approximately 1 to 7 ppm PCP.

Trinitrotoluene (TNT). Parmalee et al. (1993) used a soil microcosm to test the effects of TNT on survival of nematodes and microarthropods in soil microcosms, as described previously for Cu. Trinitrotoluene additions up to 200 ppm had no effect on numbers of nematodes. Total microarthropod numbers were reduced about 58% by 200 ppm, while 100 ppm had no effect. Trinitrotoluene up to 200 ppm had no effect on numbers of Mesostigmata, Collembola, or unclassified microarthropods.

6. RELATIONSHIP BETWEEN SOIL TOXICITY BENCHMARKS AND OTHER ECOTOXICOLOGICAL CRITERIA

6.1 COMPARISON OF TOXICITY BENCHMARKS FOR CONTAMINANTS IN SOIL TO CANADIAN ENVIRONMENTAL QUALITY CRITERIA FOR CONTAMINATED SITES

The Canadian Council of Ministers of the Environment has developed Environmental Quality Criteria for contaminated sites. These are "numerical limits for contaminants in soil and water intended to maintain, improve, or protect environmental quality and human health at contaminated sites in general" (CCME, 1991). Remediation criteria are presented for comparison to the toxicity benchmarks presented herein because they represent levels considered generally protective of human health and the environment for specified uses of soil (in this case the most conservative use—which is agriculture—has been chosen) without taking into account site-specific conditions. If contaminant concentrations exceed the remediation criteria for a current or future land use, further investigation or remediation is needed. These criteria have an interim status, and their derivation is in the process of refinement. They have been adopted from several Canadian jurisdictions and many lack supporting rationale (CCME, 1991). The remediation criteria are not strictly comparable to the toxicity benchmarks developed herein because they also take into account human health and, presumably, plants and the entire food web dependent upon the soil. New CCME Soil Quality Guidelines are being developed and will be made available in late 1995. A comparison of the toxicity benchmarks presented in this report with the CCME Remediation Criteria is given in Table 3.

For 7 of 18 chemicals, one or both of the soil toxicity benchmarks derived by the method used in this report is lower than the CCME criterion. There is no indication in the source publication as to the level of protection being afforded by the CCME Remediation Criteria. However, because human health is considered in the conservative agriculture land-use scenario, one would expect it to be high. This is seen in the organic chemicals which are known to be toxic to mammals at relatively low levels.

6.2 COMPARISON OF TOXICITY BENCHMARKS FOR CONTAMINANTS IN SOIL TO RIVM (NETHERLANDS) ECOTOXICOLOGICAL INTERVENTION VALUES FOR CONTAMINANTS IN SOILS

The Dutch National Institute of Public Health and Environmental Protection (RIVM) developed Ecotoxicological Intervention Values (EIVs) that represent concentrations of contaminants in soil causing 50% of the species potentially present in an ecosystem to experience adverse effects (van den Berg et al., 1993). The EIVs take into account plants, soil fauna, and microorganisms. The method for deriving the EIVs is described by Denneman and van Gestel in several RIVM publications in Dutch. To take the influence of soil characteristics on the bioavailability of compounds, data were adjusted for organic matter and clay content as described by van den Berg et al. (1993). Risks resulting from biomagnification were included.

Although these EIVs are based on purely "ecological" endpoints, they take into account many more types of organisms than the authors' earthworm and microbe toxicity benchmarks. For metals, benchmarks presented herein are more conservative than the RIVM EIVs in about half of the cases. For organic chemicals, most of benchmarks presented herein for earthworms are in fairly good agreement with the RIVM values. Differences here may stem from the RIVM report of values for undefined compounds of particular classes rather than for particular compounds.

Table 3. Comparison of screening benchmark concentrations for the toxicity to earthworms and soil microbes of chemicals in soil to CCME remediation criteria (RC), RIVM ecotoxicological intervention values (EIV's), arithmetic means of elements in uncontaminated soils of the Oak Ridge Reservation (ORR), and geometric means of elements in soils and surficial materials of the eastern U.S.

CHEMICAL	EARTHWORM BENCHMARK (mg/kg)	MICROBIAL BENCHMARK (mg/kg)	CCME RC[a] (mg/kg)	RIVM EIVs (mg/kg)	OAK RIDGE RESERVATION (mg/kg)	EASTERN U.S. (mg/kg)
Aluminum	---	600	---	---	15700	33000
Arsenic	60	100	20	40	9.7	4.8
Barium	---	3000	750	625	87.9	290
Boron	---	20	2[b]	---	10.4	---
Cadmium	20	20	3	12	0.22	---
Chromium	0.4	10	750[c]	230	24	33
Cobalt	---	1000	40	240	15.6	5.9
Copper	50	100	150	190	11.2	13
Fluorine	---	30	200	---	---	130
Iron	---	200	---	---	22650	14000
Lanthanum	---	50	---	---	---	29
Lead	500	900	375	290	26.8	14
Lithium	---	10	---	---	9.4	17
Manganese	---	100	---	---	1318	260
Mercury	0.1[d]	30	0.8[e]	10[e]	0.20[e]	0.08[e]
Molybdenum	---	200	5	<480	3.9	0.32
Nickel	200	90	150	210	15.1	11
Selenium	70	100	2	---	0.73	0.3
Silver	---	50	20	---	1.22	---
Tin	---	2000	2	---	---	0.86
Titanium	---	1000	---	---	---	2800
Vanadium	---	20	200	---	32.3	43
Zinc	200	100	600	720	46.2	40
Phenol	30	100	0.01[f]	40	---	---

Table 3. (continued)

CHEMICAL	EARTHWORM BENCHMARK (mg/kg)	MICROBIAL BENCHMARK (mg/kg)	CCME RC[a] (mg/kg)	RIVM EIVs (mg/kg)	OAK RIDGE RESERVATION (mg/kg)	EASTERN U.S. (mg/kg)
4-nitrophenol	7	---	0.01[f]	---	---	---
3-chlorophenol	10	---	0.05[g]	10[i]	---	---
3,4-dichlorophenol	20	---	0.05[g]	10[i]	---	---
2,4,5-trichlorophenol	9	---	0.05[g]	10[i]	---	---
2,4,6-trichlorophenol	10	---	0.05[g]	10[i]	---	---
2,3,4,5-tetrachlorophenol	20	---	0.05[g]	10[i]	---	---
Pentachlorophenol	4	50	0.05[g]	5	---	---
Chlorobenzene	40	---	0.1	30	---	---
1,4,-dichlorobenzene	20	---	0.1	30[j]	---	---
1,2,3-trichlorobenzene	20	---	0.05[h]	30[j]	---	---
1,2,4-trichlorobenzene	20	---	0.05[h]	30[j]	---	---
1,2,3,4-tetrachlorobenzene	10	---	0.05[h]	30[j]	---	---
Pentachlorobenzene	20	---	0.05[h]	30	---	---
Hexachlorobenzene	---	1000	0.05	30	---	---

[a] Agricultural land-use context
[b] Hot water soluble B
[c] Total Cr. Criterion for Cr (VI) is 8 ppm
[d] Combined inorganic and organic forms of Hg
[e] Does not indicate form (organic or inorganic)

[f] Each unspecified non-chlorinated phenolic compound is not to exceed 0.1 ppm
[g] Each unspecified chlorinated phenolic compound is not to exceed 0.05 ppm
[h] Each unspecified tri-, tetra-, and pentachlorinated benzene is not to exceed 0.05 ppm
[i] Unspecified chlorinated phenols
[j] Unspecified chlorinated benzenes

7. COMPARISON OF TOXICITY BENCHMARKS FOR CONTAMINANTS IN SOIL TO CONCENTRATIONS OF CHEMICALS IN UNPOLLUTED SOILS

7.1 COMPARISON TO USGS ELEMENT CONCENTRATIONS IN SOILS AND OTHER SURFICIAL MATERIALS OF THE EASTERN UNITED STATES

To place the four sets of critical values into a broader perspective, soil chemical concentrations are presented herein as reported by the United States Geological Survey (USGS) in a survey of soils of the eastern United States (Shacklette and Boerngen, 1984) (Table 3). These samples were collected and analyzed by the USGS to represent, as far as possible, soils that supported native plants and which were altered very little from their natural condition.

It is interesting to compare the levels of elements cited in the literature as toxic against concentrations of those same elements found in natural (i.e., not known to be polluted) soils. This comparison is reasonable in most cases because benchmarks generally were based on nominal soil concentrations (i.e., those added to the soil by the experimenter) as opposed to a measure of either total concentration or of the bioavailable quantity of the element in the soil. Seldom was the background level of the "contaminant" element in the soil measured, the assumption being that very little of the element existed naturally in the soil compared to treatment levels added. This is often, but not always, a reasonable assumption. The USGS compilation contains concentrations of elements derived mainly from strong-acid extractions, although in the case of uranium, neutron activation was used to measure a true total concentration. Values for the eastern United States were used because surficial deposits of the western United States, especially in arid and mountainous regions, may contain unusually high concentrations of naturally-occurring trace elements.

For several of the metals, our toxicity benchmarks were below (Al, Cr, F, Fe, Mn, Ti, and V) or about equal to (Li) the geometric mean for the element in soils and surficial deposits in the eastern United States. The large difference between the USGS soil Fe and Al values and the low microbial benchmark based on a quantity of Fe or Al added to soil is likely due to the strong extractant used in the USGS study. The form of the element added or some other aspect of the experimental design may account for other low benchmark concentrations as compared to mean levels in soils.

7.2 COMPARISON TO DOE OAK RIDGE RESERVATION BACKGROUND SOIL CHARACTERIZATION ELEMENT CONCENTRATIONS IN SOILS

The Background Soil Characterization Project (BSCP) at the ORR was established to determine the background concentrations of organics, metals, and radionuclides in natural soils that are important to environmental restoration projects (Watkins et al., 1993). Soils were sampled, field classified, and analyzed for chemicals using several methods. The data presented in Table 3 show the arithmetic means of elements from 46 sampling sites. The elements were extracted from the soil samples using nitric acid and hydrogen peroxide (EPA, 1986). This standard EPA acid digestion for sediments, sludges, and soils is not explicitly meant to extract total elements from a sample. A comparison with total soil concentrations of elements measured by neutron activation analysis (NAA) shows that for many elements (e.g., Sb, As, Cr, Co, Mn, Si, V, Zn) the HNO_3-

H_2O_2 extraction method was adequate for most of the elements in question (Watkins et al., 1993). Unfortunately, not all elements are amenable to measurement by NAA.

A large discrepancy was found between the BSCP soil Fe and Al values and the low soil toxicity benchmarks, based on a quantity of Fe or Al added to soil. At least one of our benchmarks is lower than background soil concentrations in the case of Cr, Mn, and V, and about equal for Li and Hg. The form of the element added or some other aspect of the experimental design may account for these differences.

8. RECOMMENDATIONS AND CONCLUSIONS

The values presented in Tables 1 and 2 are intended for use in contaminant screening during the hazard identification (problem formulation) phase of ecological risk assessments. Chemicals with soil concentrations that exceed both the toxicity benchmarks for soil and the background soil concentration for the soil type are contaminants of potential concern. Background soil concentrations have been derived for the ORR and should be generated for other Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) sites as well.

For baseline ecological risk assessments, and other assessments that may lead to regulatory actions, assessors should consult the primary sources of toxicity data and then determine the applicability of the data to their specific site. In addition, assessments should not rely on laboratory toxicity data only. Where toxicity to soil invertebrates is suspected, toxicity tests should be performed with the contaminated soil. In addition, the abundance of earthworms in the soil of a particular site, determined during collection of earthworms for chemical analysis, may provide a rough indication of the likelihood of soil toxicity.

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Appendix A

TOXICITY DATA FOR EARTHWORMS

Table A.1 Toxicity Data for Earthworms

Chemical concentrations are mg of element/kg of growth medium

%OC - % organic carbon

% DEC - % decrease in measured parameter at LOEC as compared to controls.

OECD soil (% dry weight): sphagnum peat, 10; kaolin clay, 20; fine sand, 69; CaCO3, 1; pH 6.0

CHEMICAL / FORM		EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
As	KH2AsO4	Eisenia fetida	soil & manure			56	cocoons/worm		68LCT	56	Fischer & Koszorus. 1992.
Cd	CdCl2	Eisenia andrei	OECD soil	6	5	21	cocoons/worm; juveniles/worm	10	18	23,22	van Gestel, et al. 1992.
Cd	C4H6CdO4	Eisenia fetida	horse manure			56	cocoon production		25LCT	52	Malecki et al. 1982.
Cd	CdCl2	Eisenia andrei	OECD soil	6	5	84	sexual development EC50		27	50	van Gestel et al. 1991a.
Cd	CdCl2	Eisenia andrei	OECD soil	6	5	84	growth	10	32	40	van Gestel et al. 1991a.
Cd	Cd(NO3)2	Eisenia fetida	OECD soil	6		56	cocoon production EC50		46.3	50	Spurgeon et al. 1994.
Cd	C4H6CdO4	Eisenia fetida	horse manure			140	cocoon production		50LCT	24	Malecki et al. 1982.
Cd	Soluble forms	Eisenia fetida	horse manure			42	growth;cocoon production		100 LCT	25,100	Neuhauser et al. 1984.
Cd	CdCl2	Eisenia andrei	OECD soil	6	5	84	growth	32	100	44	van Gestel et al. 1991a.

Table A.1 (continued)

CHEMICAL / FORM		EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
Cd		Dendrobaena rubida	soil & dung	5	5.7	120	cocoons/worm	10	100	62	Bengtsson et al. 1986.
Cd		Dendrobaena rubida	soil & dung	6	5.7	120	cocoons/worm; hatchlings/cocoon	10	100	78,71	Bengtsson et al. 1986.
							total hatchlings			74	
Cd		Dendrobaena rubida	soil & dung	7	5.7	120	% cocoon hatching success	10	100	47	Bengtsson et al. 1986.
							hatchlings/coc; total hatchlings			38,30	Bengtsson et al. 1986.
Cd	CdCl2	Eisenia andrei	OECD soil	6	5	84	sexual development EC50		108	50	van Gestel et al. 1991a.
Cd	CdCl2	Eisenia fetida	sandy soil	4	0.9	14	survival LC50		440	50	van Gestel & van Dis.1988
Cd	CdCl2	Lumbricus rubellas	sandy loam	7	4	84	survival	150	1000	82	Ma. 1982.
Cd	CdNO3	Eisenia fetida	OECD soil	6	5	14	survival LC50		1843	50	Neuhauser et al. 1985
Cr	K2Cr2O7	Octochaetus pattoni	soil & dung			60	survival		2LCT	75	Abbasi & Soni. 1983.
Cr	K2Cr2O7	Pheretima posthuma	paddy soil			61	survival		10LCT	100	Soni & Abbasi. 1981.
Cr	Cr(NO3)3	Eisenia andrei	OECD soil	6	5	21	growth	10	32	30	van Gestel et al. 1992.

Table A.1 (continued)

CHEMICAL / FORM		EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
Cr	KCr(SO4)2	Eisenia fetida	soil & manure			56	number cocoons and hatchlings		625 LCT	55	Molnar et al. 1989.
Cr	K2Cr2O7	Eisenia fetida	soil & manure			14	weight gain of juveniles		625 LCT	43	Molnar et al. 1989.
Cu	CuCl2	Allolobophora chlorotica	sandy loam	5	2.5		cocoon production		51	50	Ma. 1988.
Cu	Cu(NO3)2	Eisenia fetida	OECD soil	6		56	cocoon production EC50		53.3	50	Spurgeon et al. 1994.
Cu	CuCl2	Lumbricus rubellus	sandy loam	7	1.7	42	cocoon production	13	63	41	Ma. 1984.
Cu	CuCl2	Apporectodea caliginosa	sandy loam	5	2.5		cocoon production		68	50	Ma. 1988.
Cu		Dendrobaena rubida	soil & dung	5	5.7	120	cocoons/worm; hatchlings/cocoon; total hatchlings		100 LCT	70 64 74	Bengtsson et al. 1986.
Cu	CuCl2	Eisenia andrei	OECD soil	6	5	84	growth	32	100	32	van Gestel et al. 1991a.
Cu		Allolobophora caliginosa	polder soil			60	cocoon production		110 LCT	27	van Rhee. 1975.
Cu	CuCl2	Lumbricus rubellus	sandy loam	5	2.5		cocoon production		122	50	Ma. 1988.
Cu	CuCl2	Lumbricus rubellus	loamy sand	5	2.9	42	cocoon production	54	131	42	Ma. 1984.
Cu	CuSO4	Lumbricus rubellus	loamy sand	5	2.9	18	cocoon production	83	148	26	Ma. 1984.

Table A.1 (continued)

CHEMICAL / FORM		EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
Cu	CuSO4	Octolasium cyaneum	Brown soil		3	14	survival LC50		180	50	Streit & Jaggy. 1983.
Cu	CuCl2	Eisenia fetida	OECD soil	6	5	21	cocoon production	120	180	36	van Gestel et al. 1989.
Cu	CuSO4	Lumbricus rubellus	loamy sand	6	2.9	18	cocoon production	148	278	33	Ma. 1984.
Cu		Dendrobaena rubida	soil & dung	6	5.7	120	cocoons/worm; hatchlings/cocoon; % hatching success	100	500	96 100 100	Bengtsson et al. 1986.
Cu		Dendrobaena rubida	soil & dung	7	5.7	120	cocoons/worm; hatchlings/cocoon; % hatching success	100	500	90 100 100	Bengtsson et al. 1986.
Cu	C4H6CuO4	Eisenia fetida	horse manure			56	cocoon production	300	500	24	Malecki et al. 1982
Cu	CuNO3	Eisenia fetida	OECD soil	6	5	14	survival LC50		643	50	Neuhauser et al. 1985.
Cu	CuSO4	Octolasium cyaneum	Rendzina soil		14	14	survival LC50		850	50	Streit & Jaggy. 1983.
Cu	C4H6CuO4	Eisenia fetida	horse manure			140	cocoon production	500	1000	24	Malecki et al. 1982.
Cu	CuCl2	Lumbricus rubellus	sandy loam	7	4	84	survival	150	1000	82	Ma. 1982.
Cu	Soluble forms	Eisenia fetida	horse manure			42	growth;cocoon production	1000	2000	27,85	Neuhauser et al. 1984.
Cu	CuSO4	Octolasium cyaneum	Peat soil		43	14	survival LC50		2500	50	Streit & Jaggy. 1983.

Table A.1 (continued)

CHEMICAL / FORM		EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
Pb		Dendrobaena rubida	soil & dung	5	5.7	120	cocoons/worm; hatchlings/cocoon; % hatching success	100	500	75 100 100	Bengtsson et al. 1986.
Pb	Pb(NO3)2	Eisenia fetida	OECD soil	6		56	cocoon production EC50		1940	50	Spurgeon et al. 1994.
Pb	C4H6O4Pb	Eisenia fetida	horse manure			56	cocoon production	2000	4000	50	Malecki et al. 1982.
Pb	C4H6O4Pb	Eisenia fetida	horse manure			140	cocoon production	1000	5000	28	Malecki et al. 1982.
Pb	PbNO3	Eisenia fetida	OECD soil	6	5	14	survival LC50		5941	50	Neuhauser et al. 1985.
Pb	Soluble forms	Eisenia fetida	horse manure			42	cocoon production		5000 LCT	80	Neuhauser et al. 1984.
Hg	HgCl2	Octochaetus pattoni	soil & dung			60	survival;cocoon production		0.5LCT	65,40	Abbasi & Soni. 1983.
Hg	CH3HgCl	Eisenia fetida	potting soil			84	survival;segment regeneration	2.5	12.5	21,69	Beyer et al. 1985.
Ni	C4H6NiO4	Eisenia fetida	horse manure			140	cocoon production	100	200	23	Malecki et al. 1982.
Ni	Soluble forms	Eisenia fetida	horse manure			42	cocoon production		250 LCT	33	Neuhauser et al. 1984.
Ni	C4H6NiO4	Eisenia fetida	horse manure			56	cocoon production	200	300	41	Malecki et al. 1982.
Ni	NiNO3	Eisenia fetida	OECD soil	6	5	14	survival LC50		757	50	Neuhauser et al. 1985.

Table A.1 (continued)

CHEMICAL / FORM		EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
Ni	NiCl2	Lumbricus rubellus	sandy loam	7	4	84	survival	150	1000	31	Ma. 1982.
Se	Na2SeO3	Eisenia fetida	soil & manure			56	cocoons/worm		77LCT	69	Fischer & Koszorus. 1992.
Zn	Zn(NO3)2	Eisenia fetida	OECD soil	6		56	cocoon production EC50		276	50	Spurgeon et al. 1994.
Zn	ZnCl2	Eisenia andrei	OECD soil	6	5	21	cocoons/worm; juveniles/worm	320	560	31,42	van Gestel et al. 1993.
Zn	ZnNO3	Eisenia fetida	OECD soil			14	survival LC50		662	50	Neuhauser et al. 1985.
Zn		Allolobophora caliginosa	polder soil				body weight; cocoon production; mortality; sexual development		1100 LCT	53,100, 22, 100	van Rhee. 1975.
Zn	C4H6O4Zn	Eisenia fetida	horse manure			56	cocoon production	1000	2000	36	Malecki et al. 1982.
Zn	Soluble forms	Eisenia fetida	horse manure			42	cocoon production	1000	2500	50	Neuhauser et al. 1984.
Zn	C4H6O4Zn	Eisenia fetida	horse manure			140	cocoon production	2500	5000	53	Malecki et al. 1982.
Chloroacetamide		Eisenia andrei	sandy soil	4	0.9	14	survival LC50		>10<18	50	van Gestel & van Dis. 1988
Chloroacetamide		Eisenia fetida	artificial soil	7		28	survival LC50		24	50	Heimbach 1984.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
Chloroacetamide	Eisenia andrei	sandy soil	7	0.9	14	survival LC50		>32<56	50	van Gestel & van Dis. 1988
Chloroacetamide	Eisenia andrei	OECD soil	7	3.9	14	survival LC50		40	50	van Gestel & van Dis. 1988
Chloroacetamide	Eisenia fetida	horse manure			56	growth	500	1000	100	Neuhauser & Callahan. 1990
3-chloroaniline	Lumbricus rubellus	sandy soil	5	1.9	14	survival LC50		195	50	van Gestel & Ma. 1993.
3-chloroaniline	Eisenia andrei	sandy soil	5	1.9	14	survival LC50		220	50	van Gestel & Ma. 1993.
3-chloroaniline	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		332	50	van Gestel & Ma. 1993.
3-chloroaniline	Eisenia andrei	OECD soil	6	4	14	survival LC50		448	50	van Gestel & Ma. 1993.
2,4-dichloroaniline	Eisenia andrei	OECD soil	6	5	21	cocoon production	56	100	23	van Gestel et al. 1989.
2,4-dichloroaniline	Eisenia andrei	sandy soil	5	1.9	14	survival LC50		142	50	van Gestel & Ma. 1990.
2,4-dichloroaniline	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		190	50	van Gestel & Ma. 1990.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
2,4-dichloroaniline	Lumbricus rubellus	sandy soil	5	1.9	14	survival LC50		201	50	van Gestel & Ma. 1990.
2,4-dichloroaniline	Eisenia andrei	sandy soil	6	3	14	survival LC50		285	50	van Gestel & Ma. 1990.
2,4-dichloroaniline	Lumbricus rubellus	sandy soil	6	3	14	survival LC50		304	50	van Gestel & Ma. 1990.
2,4-dichloroaniline	Eisenia andrei	OECD soil	6	4	14	survival LC50		319	50	van Gestel & Ma. 1990.
2,4-dichloroaniline	Lumbricus rubellus	peaty soil	4	7.8	14	survival LC50		580	50	van Gestel & Ma. 1990.
2,4-dichloroaniline	Eisenia andrei	peaty soil	4	7.8	14	survival LC50		824	50	van Gestel & Ma. 1990.
3,4-dichloroaniline	Eisenia andrei	sandy soil	7	0.9	6	survival LC50		140	50	van Gestel & van Dis. 1988
3,4-dichloroaniline	Eisenia andrei	sandy soil	4	0.9	6	survival LC50		140	50	van Gestel & van Dis. 1988
3,4-dichloroaniline	Eisenia andrei	OECD soil	7	3.9	11	survival LC50		250	50	van Gestel & van Dis. 1988
2,4,5-trichloroaniline	Eisenia andrei	sandy soil	5	1.9	14	survival LC50		134	50	van Gestel & Ma. 1993.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
2,4,5-trichloroaniline	Lumbricus rubellus	sandy soil	5	1.9	14	survival LC50		174	50	van Gestel & Ma. 1993.
2,4,5-trichloroaniline	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		213	50	van Gestel & Ma. 1993.
2,4,5-trichloroaniline	Eisenia andrei	OECD soil	6	4	14	survival LC50		233	50	van Gestel & Ma. 1993.
2,3,5,6-tetrachloro-aniline	Eisenia andrei	sandy soil	5	1.9	14	survival LC50		116	50	van Gestel & Ma. 1993.
2,3,5,6-tetrachloro-aniline	Eisenia andrei	OECD soil	6	4	14	survival LC50		133	50	van Gestel & Ma. 1993.
2,3,5,6-tetrachloro-aniline	Lumbricus rubellus	sandy soil	5	1.9	14	survival LC50		159	50	van Gestel & Ma. 1993.
2,3,5,6-tetrachloro-aniline	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		179	50	van Gestel & Ma. 1993.
Pentachloroaniline	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		825	50	van Gestel & Ma. 1993.
Pentachloroaniline	Lumbricus rubellus	sandy soil	5	1.9	14	survival LC50		825	50	van Gestel & Ma. 1993.
Pentachloroaniline	Eisenia andrei	sandy soil	5	1.9	14	survival LC50		1014	50	van Gestel & Ma. 1993.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
Pentachloroaniline	Eisenia andrei	OECD soil	6	4	14	survival LC50		>3200	50	van Gestel & Ma. 1993.
1,2-dichloropropane	Perionyx excavatus	OECD soil	6	5	14	survival LC50		3880	50	Neuhauser et al. 1986.
1,2-dichloropropane	Eisenia fetida	OECD soil	6	5	14	survival LC50		4240	50	Neuhauser et al. 1986.
1,2-dichloropropane	Allolobophora tuberculata	OECD soil	6	5	14	survival LC50		4272	50	Neuhauser et al. 1986.
1,2-dichloropropane	Eudrilus eugeniae	OECD soil	6	5	14	survival LC50		5300	50	Neuhauser et al. 1986.
1,2-dichloropropane	Eisenia fetida	horse manure			56	growth	80800	92300	death	Neuhauser & Callahan. 1990
Dimethylphthalate	Perionyx excavatus	OECD soil	6	5	14	survival LC50		1064	50	Neuhauser et al. 1986.
Dimethylphthalate	Eudrilus eugeniae	OECD soil	6	5	14	survival LC50		2000	50	Neuhauser et al. 1986.
Dimethylphthalate	Eisenia fetida	OECD soil	6	5	14	survival LC50		3160	50	Neuhauser et al. 1986.
Dimethylphthalate	Allolobophora tuberculata	OECD soil	6	5	14	survival LC50		3335	50	Neuhauser et al. 1986.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
Dimethylphthalate	Eisenia fetida	horse manure			56	cocoon production	4720	70800	62	Neuhauser & Callahan. 1990
Fluorene	Perionyx excavatus	OECD soil	6	5	14	survival LC50		170	50	Neuhauser et al. 1986.
Fluorene	Eisenia fetida	OECD soil	6	5	14	survival LC50		173	50	Neuhauser et al. 1986.
Fluorene	Eudrilus eugeniae	OECD soil	6	5	14	survival LC50		197	50	Neuhauser et al. 1986.
Fluorene	Allolobophora tuberculata	OECD soil	6	5	14	survival LC50		206	50	Neuhauser et al. 1986.
Fluorene	Eisenia fetida	horse manure			56	cocoon production	500	750	49	Neuhauser & Callahan. 1990
N-nitrosodiphenylamine	Eudrilus eugeniae	OECD soil	6	5	14	survival LC50		109	50	Neuhauser et al. 1986.
N-nitrosodiphenylamine	Perionyx excavatus	OECD soil	6	5	14	survival LC50		128	50	Neuhauser et al. 1986.
N-nitrosodiphenylamine	Eisenia fetida	OECD soil	6	5	14	survival LC50		151	50	Neuhauser et al. 1986.
N-nitrosodiphenylamine	Allolobophora tuberculata	OECD soil	6	5	14	survival LC50		155	50	Neuhauser et al. 1986.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
N-nitrosodiphenylamine	Eisenia fetida	horse manure			56	cocoon production		1400 LCT	37	Neuhauser & Callahan. 1990
Phenol	Eudrilus eugeniae	OECD soil	6	5	14	survival LC50		188	50	Neuhauser et al. 1986.
Phenol	Perionyx excavatus	OECD soil	6	5	14	survival LC50		258	50	Neuhauser et al. 1986.
Phenol	Eisenia fetida	OECD soil	6	5	14	survival LC50		401	50	Neuhauser et al. 1986.
Phenol	Allolobophora tuberculata	OECD soil	6	5	14	survival LC50		450	50	Neuhauser et al. 1986.
Phenol	Eisenia fetida	horse manure			56	cocoon production	3900	4900	26	Neuhauser & Callahan. 1990
4-nitrophenol	Eisenia fetida	OECD soil	6	5	14	survival LC50		38	50	Neuhauser et al. 1986.
4-nitrophenol	Eudrilus eugeniae	OECD soil	6	5	14	survival LC50		40	50	Neuhauser et al. 1986.
4-nitrophenol	Perionyx excavatus	OECD soil	6	5	14	survival LC50		44	50	Neuhauser et al. 1986.
4-nitrophenol	Allolobophora tuberculata	OECD soil	6	5	14	survival LC50		56	50	Neuhauser et al. 1986.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
4-nitrophenol	Eisenia fetida	horse manure			56	cocoon production		600 LCT	39	Neuhauser & Callahan. 1990
3-chlorophenol	Eisenia andrei	sandy soil	5	1.9	14	survival LC50		75	50	van Gestel & Ma. 1990.
3-chlorophenol	Eisenia andrei	humic sand	5	1.9	14	survival LC50		78	50	van Gestel & Ma. 1988.
3-chlorophenol	Eisenia andrei	OECD soil	6	4	14	survival LC50		130	50	van Gestel & Ma. 1990.
3-chlorophenol	Eisenia andrei	sandy soil	6	3	14	survival LC50		134	50	van Gestel & Ma. 1990.
3-chlorophenol	Eisenia andrei	humic sand	6	3	14	survival LC50		140	50	van Gestel & Ma. 1988.
3-chlorophenol	Lumbricus rubellus	humic sand	5	1.9	14	survival LC50		150	50	van Gestel & Ma. 1988.
3-chlorophenol	Lumbricus rubellus	sandy soil	5	1.9	14	survival LC50		150	50	van Gestel & Ma. 1990.
3-chlorophenol	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		247	50	van Gestel & Ma. 1990.
3-chlorophenol	Lumbricus rubellus	humic sand	6	3	14	survival LC50		296	50	van Gestel & Ma. 1988.
3-chlorophenol	Lumbricus rubellus	sandy soil	6	3	14	survival LC50		342	50	van Gestel & Ma. 1990.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
3-chlorophenol	Eisenia andrei	peaty soil	4	7.8	14	survival LC50		423	50	van Gestel & Ma. 1990.
3-chlorophenol	Lumbricus rubellus	peaty soil	4	7.8	14	survival LC50		633	50	van Gestel & Ma. 1990.
3,4-dichlorophenol	Eisenia andrei	sandy soil	5	1.9	14	survival LC50		134	50	van Gestel & Ma. 1990.
3,4-dichlorophenol	Eisenia andrei	humic sand	5	1.9	14	survival LC50		140	50	van Gestel & Ma. 1988.
3,4-dichlorophenol	Eisenia andrei	OECD soil	6	4	14	survival LC50		172	50	van Gestel & Ma. 1990.
3,4-dichlorophenol	Eisenia andrei	sandy soil	6	3	14	survival LC50		240	50	van Gestel & Ma. 1990.
3,4-dichlorophenol	Eisenia andrei	humic sand	6	3	14	survival LC50		250	50	van Gestel & Ma. 1988.
3,4-dichlorophenol	Lumbricus rubellus	humic sand	5	1.9	14	survival LC50		303	50	van Gestel & Ma. 1988.
3,4-dichlorophenol	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		322	50	van Gestel & Ma. 1990.
3,4-dichlorophenol	Lumbricus rubellus	sandy soil	5	1.9	14	survival LC50		352	50	van Gestel & Ma. 1990.
3,4-dichlorophenol	Eisenia andrei	peaty soil	4	7.8	14	survival LC50		423	50	van Gestel & Ma. 1990.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
3,4-dichlorophenol	Lumbricus rubellus	sandy soil	6	3	14	survival LC50		486	50	van Gestel & Ma. 1990.
3,4-dichlorophenol	Lumbricus rubellus	humic sand	6	3	14	survival LC50		486	50	van Gestel & Ma. 1988.
3,4-dichlorophenol	Lumbricus rubellus	peaty soil	4	7.8	14	survival LC50		680	50	van Gestel & Ma. 1990.
2,4,5-trichlorophenol	Eisenia andrei	sandy soil	5	1.9	14	survival LC50		46	50	van Gestel & Ma. 1990.
2,4,5-trichlorophenol	Eisenia andrei	humic sand	5	1.9	14	survival LC50		52	50	van Gestel & Ma. 1988.
2,4,5-trichlorophenol	Eisenia andrei	OECD soil	6	4	14	survival LC50		63	50	van Gestel & Ma. 1990.
2,4,5-trichlorophenol	Eisenia andrei	sandy soil	6	3	14	survival LC50		76	50	van Gestel & Ma. 1990.
2,4,5-trichlorophenol	Eisenia andrei	humic sand	6	3	14	survival LC50		90	50	van Gestel & Ma. 1988.
2,4,5-trichlorophenol	Eisenia andrei	peaty soil	4	7.8	14	survival LC50		164	50	van Gestel & Ma. 1990.
2,4,5-trichlorophenol	Lumbricus rubellus	humic sand	5	1.9	14	survival LC50		201	50	van Gestel & Ma. 1988.
2,4,5-trichlorophenol	Lumbricus rubellus	sandy soil	5	1.9	14	survival LC50		235	50	van Gestel & Ma. 1990.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
2,4,5-trichlorophenol	Lumbricus rubellus	humic sand	6	3	14	survival LC50		290	50	van Gestel & Ma. 1988.
2,4,5-trichlorophenol	Lumbricus rubellus	sandy soil	6	3	14	survival LC50		316	50	van Gestel & Ma. 1990.
2,4,5-trichlorophenol	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		362	50	van Gestel & Ma. 1990.
2,4,5-trichlorophenol	Lumbricus rubellus	peaty soil	4	7.8	14	survival LC50		875	50	van Gestel & Ma. 1990.
2,4,6-trichlorophenol	Eisenia fetida	OECD soil	6	5	14	survival LC50		58	50	Neuhauser et al. 1986.
2,4,6-trichlorophenol	Perionyx excavatus	OECD soil	6	5	14	survival LC50		78	50	Neuhauser et al. 1986.
2,4,6-trichlorophenol	Eudrilus eugeniae	OECD soil	6	5	14	survival LC50		85	50	Neuhauser et al. 1986.
2,4,6-trichlorophenol	Eisenia fetida	horse manure			56	cocoon production		100 LCT	28	Neuhauser & Callahan. 1990
2,4,6-trichlorophenol	Allolobophora tuberculata	OECD soil	6	5	14	survival LC50		108	50	Neuhauser et al. 1986.
2,3,4,5-tetrachloro-phenol	Eisenia andrei	humic sand	5	1.9	14	survival LC50		116	50	van Gestel & Ma. 1988.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
2,3,4,5-tetrachloro-phenol	Eisenia andrei	sandy soil	5	1.9	14	survival LC50		117	50	van Gestel & Ma. 1990.
2,3,4,5-tetrachloro-phenol	Eisenia andrei	sandy soil	6	3	14	survival LC50		166	50	van Gestel & Ma. 1990.
2,3,4,5-tetrachloro-phenol	Eisenia andrei	humic sand	6	3	14	survival LC50		176	50	van Gestel & Ma. 1988.
2,3,4,5-tetrachloro-phenol	Lumbricus rubellus	humic sand	5	1.9	14	survival LC50		514	50	van Gestel & Ma. 1988.
2,3,4,5-tetrachloro-phenol	Lumbricus rubellus	sandy soil	5	1.9	14	survival LC50		515	50	van Gestel & Ma. 1990.
2,3,4,5-tetrachloro-phenol	Lumbricus rubellus	humic sand	6	3	14	survival LC50		828	50	van Gestel & Ma. 1988.
2,3,4,5-tetrachloro-phenol	Lumbricus rubellus	sandy soil	6	3	14	survival LC50		875	50	van Gestel & Ma. 1990.
Pentachlorophenol	Eisenia andrei	sandy soil	7	0.9	14	survival LC50		16	50	van Gestel & van Dis. 1988
Pentachlorophenol	Eisenia andrei	OECD soil	7	3.9	14	survival LC50		29	50	van Gestel & van Dis. 1988
Pentachlorophenol	Eisenia andrei	OECD soil	6	5	21	% cocoon hatch success	10	32	50	van Gestel et al. 1989.
Pentachlorophenol	Eisenia andrei	sandy soil	4	0.9	14	survival LC50		52	50	van Gestel & van Dis. 1988

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
Pentachlorophenol	Eisenia andrei	OECD soil	6	4	14	survival LC50		83	50	van Gestel & Ma. 1990.
Pentachlorophenol	Eisenia andrei	sandy soil	5	1.9	14	survival LC50		84	50	van Gestel & Ma. 1990.
Pentachlorophenol	Eisenia fetida	artificial soil	7		28	survival LC50		87	50	Heimbach 1984.
Pentachlorophenol	Eisenia andrei	humic sand	5	1.9	14	survival LC50		94	50	van Gestel & Ma. 1988.
Pentachlorophenol	Eisenia andrei	sandy soil	6	3	14	survival LC50		142	50	van Gestel & Ma. 1990.
Pentachlorophenol	Eisenia andrei	humic sand	6	3	14	survival LC50		143	50	van Gestel & Ma. 1988.
Pentachlorophenol	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		362	50	van Gestel & Ma. 1990.
Pentachlorophenol	Eisenia andrei	peaty soil	4	7.8	14	survival LC50		502	50	van Gestel & Ma. 1990.
Pentachlorophenol	Lumbricus rubellus	humic sand	6	3	14	survival LC50		883	50	van Gestel & Ma. 1988.
Pentachlorophenol	Lumbricus rubellus	sandy soil	6	3	14	survival LC50		1013	50	van Gestel & Ma. 1990.
Pentachlorophenol	Lumbricus rubellus	humic sand	5	1.9	14	survival LC50		1094	50	van Gestel & Ma. 1988.
Pentachlorophenol	Lumbricus rubellus	sandy soil	5	1.9	14	survival LC50		1206	50	van Gestel & Ma. 1990.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
Pentachlorophenol	Lumbricus rubellus	peaty soil	4	7.8	14	survival LC50		2298	50	van Gestel & Ma. 1990.
Chlorobenzene	Eisenia fetida	sandy soil	5	1.8	14	survival LC50		240	50	van Gestel et al. 1991b.
Chlorobenzene	Eisenia fetida	OECD soil	6	4	14	survival LC50		446	50	van Gestel et al. 1991b.
Chlorobenzene	Lumbricus rubellus	sandy soil	5	1.8	14	survival LC50		547	50	van Gestel et al. 1991b.
Chlorobenzene	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		1107	50	van Gestel et al. 1991b.
1,4-dichlorobenzene	Eisenia fetida	sandy soil	5	1.8	14	survival LC50		128	50	van Gestel et al. 1991b.
1,4-dichlorobenzene	Lumbricus rubellus	sandy soil	5	1.8	14	survival LC50		184	50	van Gestel et al. 1991b.
1,4-dichlorobenzene	Eisenia fetida	OECD soil	6	4	14	survival LC50		229	50	van Gestel et al. 1991b.
1,4-dichlorobenzene	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		615	50	van Gestel et al. 1991b.
1,2,3-trichlorobenzene	Lumbricus rubellus	sandy soil	5	1.9	14	survival LC50		115	50	van Gestel & Ma. 1990.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
1,2,3-trichlorobenzene	Eisenia andrei	OECD soil	6	4	14	survival LC50		133	50	van Gestel & Ma. 1990.
1,2,3-trichlorobenzene	Eisenia andrei	sandy soil	5	1.9	14	survival LC50		134	50	van Gestel & Ma. 1990.
1,2,3-trichlorobenzene	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		195	50	van Gestel & Ma. 1990.
1,2,3-trichlorobenzene	Lumbricus rubellus	sandy soil	6	3	14	survival LC50		200	50	van Gestel & Ma. 1990.
1,2,3-trichlorobenzene	Eisenia andrei	sandy soil	6	3	14	survival LC50		240	50	van Gestel & Ma. 1990.
1,2,3-trichlorobenzene	Eisenia andrei	peaty soil	4	7.8	14	survival LC50		547	50	van Gestel & Ma. 1990.
1,2,3-trichlorobenzene	Lumbricus rubellus	peaty soil	4	7.8	14	survival LC50		563	50	van Gestel & Ma. 1990.
1,2,4-trichlorobenzene	Eudrilus eugeniae	OECD soil	6	5	14	survival LC50		127	50	Neuhauser et al. 1986.
1,2,4-trichlorobenzene	Perionyx excavatus	OECD soil	6	5	14	survival LC50		180	50	Neuhauser et al. 1986.
1,2,4-trichlorobenzene	Eisenia fetida	OECD soil	6	5	14	survival LC50		197	50	Neuhauser et al. 1986.
1,2,4-trichlorobenzene	Allolobophora tuberculata	OECD soil	6	5	14	survival LC50		251	50	Neuhauser et al. 1986.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
1,2,3,4-tetrachloro-benzene	Eisenia fetida	sandy soil	5	1.8	14	survival LC50		75	50	van Gestel et al. 1991b.
1,2,3,4-tetrachloro-benzene	Lumbricus rubellus	sandy soil	5	1.8	14	survival LC50		112	50	van Gestel et al. 1991b.
1,2,3,4-tetrachloro-benzene	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		201	50	van Gestel et al. 1991b.
1,2,3,4-tetrachloro-benzene	Eisenia fetida	OECD soil	6	4	14	survival LC50		223	50	van Gestel et al. 1991b.
Pentachlorobenzene	Lumbricus rubellus	sandy soil	5	1.8	14	survival LC50		115	50	van Gestel et al. 1991b.
Pentachlorobenzene	Eisenia fetida	sandy soil	5	1.8	14	survival LC50		134	50	van Gestel et al. 1991b.
Pentachlorobenzene	Lumbricus rubellus	OECD soil	6	4	14	survival LC50		201	50	van Gestel et al. 1991b.
Pentachlorobenzene	Eisenia fetida	OECD soil	6	4	14	survival LC50		238	50	van Gestel et al. 1991b.
Nitrobenzene	Eudrilus eugeniae	OECD soil	6	5	14	survival LC50		226	50	Neuhauser et al. 1986.
Nitrobenzene	Eisenia fetida	OECD soil	6	5	14	survival LC50		319	50	Neuhauser et al. 1986.

Table A.1 (continued)

CHEMICAL / FORM	EARTHWORM SPECIES	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC APPL	LOEC APPL	% DEC	REFERENCE
Nitrobenzene	Perionyx excavatus	OECD soil	6	5	14	survival LC50		343	50	Neuhauser et al. 1986.
Nitrobenzene	Allolobophora tuberculata	OECD soil	6	5	14	survival LC50		362	50	Neuhauser et al. 1986.

Appendix B

TOXICITY DATA FOR MICROORGANISMS

Table B.1 Toxicity Data for Microorganisms

Chemical concentrations are mg of element/kg of growth medium

% DEC - % decrease in measured parameter at LOEC as compared to controls.

EXP DUR (D) - exposure duration in days

GROWTH MEDIUM: Montmorill = mont = montmorillonite clay;
Kaol = kaolinite clay

%OC - % organic carbon in growth medium

CEC = cation exchange capacity of growth medium (milliequivalents/100 g)

* denotes phenylmercury acetate

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Aluminum	AlCl3	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		675 LCT	43	Al-Khafaji & Tabatabai. 1979.
Aluminum	AlCl3	native soil microflora	loam	7	5.3	0.1	Arylsulfatase activity		675 LCT	24	Al-Khafaji & Tabatabai. 1979.
Aluminum	AlCl3	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity	67.5	675	34	Al-Khafaji & Tabatabai. 1979.
Aluminum	AlCl3	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity	67.5	675	42	Al-Khafaji & Tabatabai. 1979.
Aluminum	AlCl3	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	67.5	675	34	Juma & Tabatabai. 1977.
Aluminum	AlCl3	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	67.5	675	25	Juma & Tabatabai. 1977.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Arsenic	NaAsO2	native soil microflora	surface soil	6	2.6	0.1	Amidase activity		187.3 LCT	32	Frankenberger& Tabatabai. 1981
Arsenic	Na2HAsO4	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity		187.3 LCT	33	Juma & Tabatabai. 1977.
Arsenic	Na2HAsO4	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity		187.3 LCT	32	Juma & Tabatabai. 1977.
Arsenic	NaAsO2	native soil microflora	clay loam	8	3.2	0.1	Amidase activity		1873 LCT	98	Frankenberger& Tabatabai. 1981
Arsenic	NaAsO2	native soil microflora	loam	7	4.7	0.1	Amidase activity		1873 LCT	97	Frankenberger& Tabatabai. 1981
Arsenic	NaAsO2	native soil microflora	clay loam	8	3.7	0.1	Alkaline phosphatase activity		1875 LCT	35	Juma & Tabatabai. 1977.
Arsenic	Na2HAsO4	native soil microflora	clay loam	8	3.7	0.1	Alkaline & acid phosphatase activities		1875 LCT	75, 39	Juma & Tabatabai. 1977.
Arsenic	Na2HAsO4	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		1875 LCT	62	Juma & Tabatabai. 1977.
Barium	BaCl2	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		3433 LCT	24	Al-Khafaji & Tabatabai. 1979.
Boron	Na2B4O7	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity		27 LCT	31	Al-Khafaji & Tabatabai. 1979.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Boron	Na2B4O7	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		270 LCT	22	Juma & Tabatabai. 1977.
Boron	Na2B4O7	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		270 LCT	70	Al-Khafaji & Tabatabai. 1979.
Boron	Na2B4O7	native soil microflora	loam	7	5.3	0.1	Arylsulfatase activity		270 LCT	60	Al-Khafaji & Tabatabai. 1979.
Boron	Na2B4O7	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity	27	270	65	Al-Khafaji & Tabatabai. 1979.
Boron	Na2B4O7	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	27	270	33	Juma & Tabatabai. 1977.
Cadmium	CdCl2	native soil microflora	soil/litter microcosm			24	Respiration	.006	6.1	43	Lighthart & Bond. 1976.
Cadmium	Cd(NO3)2	Pseudomonas sp.	silt loam	7	2	4	Denitrification		10 LCT	23	Bollag & Barabasz. 1979.
Cadmium	C4H6CdO4	native soil microflora	phaeosem	7	1	84	Respiration	7	14	22	Reber. 1989.
Cadmium	C4H6CdO4	native soil microflora	sandy hortisol	7	1.5	84	Respiration	7	14	23	Reber. 1989.
Cadmium	CdCl2	native soil microflora	sandy loam	6	3	548	Urease activity		30 ED50	50	Doelman & Haanstra. 1986.
Cadmium	CdNO4	native soil microflora	surface soil		1.3	1	Dehydrogenase activity		30 LCT	47	Rogers & Li. 1985.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Cadmium	Cd(NO3)2	Pseudomonas denitrificans	silt loam	7	2	4	Denitrification	10	50	22	Bollag & Barabasz. 1979.
Cadmium	Cd(NO3)2	Pseudomonas aeruginosa	silt loam	7	2	4	Denitrification	10	50	25	Bollag & Barabasz. 1979.
Cadmium	CdCl2	native soil microflora	silt loam	5			Nitrification		50	>20	Suter and Sharples. 1984.
Cadmium	C4H6CdO4	native soil microflora	acid cambisol	6	1	84	Respiration	28	56	23	Reber. 1989.
Cadmium	CdCl2	native soil microflora	brown earth	5		30	Cellulolytic activity	50	100	35	Khan & Frankland. 1984.
Cadmium	Cd(NO3)2	native soil microflora	silt loam	7	2	21	Denitrification	50	100	27	Bollag & Barabasz. 1979.
Cadmium	CdCl2	native soil microflora	sandy soil	7	1	548	Urease activity		120 ED50	50	Doelman & Haanstra. 1986.
Cadmium	CdCl2	native soil microflora	sandy soil	7	1	548	Arylsulfatase activity		121 ED50	50	Haanstra & Doelman. 1991.
Cadmium	CdCl2	native soil microflora	silty loam	8	1	548	Arylsulfatase activity		137 ED50	50	Haanstra & Doelman. 1991.
Cadmium	CdCl2	native soil microflora	silty loam	8	1	548	Phosphatase activity		230 ED50	50	Doelman & Haanstra. 1989.
Cadmium	CdSO4	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity		281 LCT	27	Juma & Tabatabai. 1977.
Cadmium	CdCl2	native soil microflora	sandy soil	7	1	548	Phosphatase activity		330 ED50	50	Doelman & Haanstra. 1989.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Cadmium	CdCl2	native soil microflora	sandy soil	7	1	42	Urease activity		340 ED50	50	Doelman & Haanstra. 1986.
Cadmium	CdCl2	native soil microflora	sandy peat	4	6.5	548	Urease activity		490 ED50	50	Doelman & Haanstra. 1986.
Cadmium	CdCl2	native soil microflora	silty loam	8	1	548	Urease activity		520 ED50	50	Doelman & Haanstra. 1986.
Cadmium	CdCl2	native soil microflora	clay	8	1.5	548	Urease activity		520 ED50	50	Doelman & Haanstra. 1986.
Cadmium	CdSO4	Native soil microflora	silty clay	7	3	20	N mineralization		562 LCT	27	Liang & Tabatabai. 1977.
Cadmium	CdSO4	native soil microflora	clay loam	8	4	20	N mineralization		562 LCT	39	Liang & Tabatabai. 1977.
Cadmium	CdCl2	native soil microflora	sandy soil	7	1	42	Phosphatase activity		840 ED50	50	Doelman & Haanstra. 1989.
Cadmium	CdCl2	native soil microflora	soil/litter microcosm				Respiration		920 LCT	61	Lighthart et al. 1977.
Cadmium	CdCl2	native soil microflora	silty loam	8	1	42	Urease activity		970 ED50	50	Doelman & Haanstra. 1986.
Cadmium	CdSO4	native soil microflora	surface soil	6	2.9	35	Nitrification	500	1000	62	Bewley & Stotzky. 1983.
Cadmium	CdCl2	native soil microflora	clay	8	1.5	548	Arylsulfatase activity		1016 ED50	50	Haanstra & Doelman. 1991.
Cadmium	CdCl2	native soil microflora	sandy loam	6	3	548	Arylsulfatase activity		1798 ED50	50	Haanstra & Doelman. 1991.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Cadmium	CdCl2	native soil microflora	silt loam	8	1	42	Arylsulfatase activity		1888 ED50	50	Haanstra & Doelman. 1991.
Cadmium	CdCl2	native soil microflora	sandy soil	7	1	42	Arylsulfatase activity		2214 ED50	50	Haanstra & Doelman. 1991.
Cadmium	CdSO4	native soil microflora	clay loam	8	3.7	0.1	Alkaline & acid phosphatase activities		2810 LCT	78, 51	Juma & Tabatabai. 1977.
Cadmium	CdSO4	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		2810 LCT	48	Juma & Tabatabai. 1977.
Cadmium	CdSO4	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		2810 LCT	27	Al-Khafaji & Tabatabai. 1979.
Cadmium	CdSO4	native soil microflora	loam	7	5.3	0.1	Arylsulfatase activity		2810 LCT	42	Al-Khafaji & Tabatabai. 1979.
Cadmium	CdSO4	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	281	2810	44	Juma & Tabatabai. 1977.
Cadmium	CdSO4	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity	281	2810	55	Al-Khafaji & Tabatabai. 1979.
Cadmium	CdSO4	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity	281	2810	23	Al-Khafaji & Tabatabai. 1979.
Cadmium	CdCl2	native soil microflora	sandy peat	4	6.5	42	Arylsulfatase activity		3192 ED50	50	Haanstra & Doelman. 1991.
Cadmium	CdCl2	native soil microflora	sandy peat	4	6.5	42	Urease activity		3260 ED50	50	Doelman & Haanstra. 1986.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Cadmium	CdCl2	native soil microflora	clay	8	1.5	42	Urease activity		4460 ED50	50	Doelman & Haanstra. 1986.
Cadmium	CdCl2	Native soil microflora	clay	8	1.5	548	Phosphatase activity		5305 ED50	50	Doelman & Haanstra. 1989.
Cadmium	CdCl2	Native soil microflora	Silty loam	8	1	42	Phosphatase activity		5485 ED50	50	Doelman & Haanstra. 1989.
Cadmium	CdCl2	native soil microflora	clay	8	1.5	42	Arylsulfatase activity		9520 ED50	50	Haanstra & Doelman. 1991.
Cadmium	CdCl2	Native soil microflora	clay	8	1.5	42	Phosphatase activity		9779 ED50	50	Doelman & Haanstra. 1989.
Cadmium	CdCl2	native soil microflora	sandy loam	6	3	548	Phosphatase activity		9869 ED50	50	Doelman & Haanstra. 1989.
Chromium	CrCl3	native soil microflora	sandy loam	6	3	548	Urease activity		<1 ED50	50	Doelman & Haanstra. 1986.
Chromium	K2Cr2O7	native soil microflora	sandy loam	6		22	Respiration		10 LCT	33	Ross et al. 1981.
Chromium	K2Cr2O7	native soil microflora	loam	6		22	Respiration		10 LCT	27	Ross et al. 1981.
Chromium	CrCl3	native soil microflora	sandy loam	6	3	548	Arylsulfatase activity		12 ED50	50	Haanstra & Doelman. 1991.
Chromium	CrCl3	native soil microflora	sandy soil	7	1	42	Arylsulfatase activity		17 ED50	50	Haanstra & Doelman. 1991.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Chromium	CrSO4	native soil microflora	surface soil		1.3	1	Dehydrogenase activity		30 LCT	54	Rogers & Li. 1985.
Chromium	CrCl3	native soil microflora	sandy loam	6		22	Respiration		100 LCT	48	Ross et al. 1981.
Chromium	CrCl3	native soil microflora	loam	6		22	Respiration		100 LCT	41	Ross et al. 1981.
Chromium	CrCl3	native soil microflora	sandy soil	7	1	548	Arylsulfatase activity		203 ED50	50	Haanstra & Doelman. 1991.
Chromium	CrCl3	native soil microflora	loam	6	3	20	N mineralization		260 LCT	20	Liang & Tabatabai. 1977.
Chromium	CrCl3	native soil microflora	silty clay loam	7	6	20	N mineralization		260 LCT	24	Liang & Tabatabai. 1977.
Chromium	CrCl3	native soil microflora	clay	8	1.5	42	Arylsulfatase activity		281 ED50	50	Haanstra & Doelman. 1991.
Chromium	CrCl3	native soil microflora	sandy loam	6	3	42	Arylsulfatase activity		309 ED50	50	Haanstra & Doelman. 1991.
Chromium	CrCl3	native soil microflora	silty loam	8	1	548	Arylsulfatase activity		411 ED50	50	Haanstra & Doelman. 1991.
Chromium	CrCl3	native soil microflora	clay	8	1.5	548	Urease activity		420 ED50	50	Doelman & Haanstra. 1986.
Chromium	CrCl3	native soil microflora	clay	8	1.5	42	Urease activity		490 ED50	50	Doelman & Haanstra. 1986.
Chromium	CrCl3	native soil microflora	clay	8	1.5	548	Arylsulfatase activity		575 ED50	50	Haanstra & Doelman. 1991.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Chromium	CrCl3	native soil microflora	sandy soil	7	1	548	Urease activity		630 ED50	50	Doelman & Haanstra. 1986.
Chromium	CrO	native soil microflora	sandy soil	7		42	N mineralization & nitrification		1000 LCT	22, 24	Bhuiya & Cornfield. 1976.
Chromium	CuSO4	native soil microflora	sandy loam	7	2	21	Nitrification	100	1000	67	Premi & Cornfield. 1969.
Chromium	CrCl3	native soil microflora	silty loam	8	1	548	Urease activity		1110 ED50	50	Doelman & Haanstra. 1986.
Chromium	CrCl3	native soil microflora	clay	8	1.5	42	Phosphatase activity		1170 ED50	50	Doelman & Haanstra. 1989.
Chromium	CrCl3	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		1300 LCT	54	Al-Khafaji & Tabatabai. 1979.
Chromium	CrCl3	native soil microflora	loam	7	5.3	0.1	Arylsulfatase activity		1300 LCT	32	Al-Khafaji & Tabatabai. 1979.
Chromium	CrCl3	native soil microflora	clay loam	8	3.7	0.1	Alkaline & acid phosphatase activity		1300 LCT	27, 25	Juma & Tabatabai. 1977.
Chromium	CrCl3	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		1300 LCT	27	Juma & Tabatabai. 1977.
Chromium	CrCl3	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity	130	1300	43	Al-Khafaji & Tabatabai. 1979.
Chromium	CrCl3	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity	130	1300	35	Al-Khafaji & Tabatabai. 1979.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Chromium	CrCl3	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	130	1300	30	Juma & Tabatabai. 1977.
Chromium	CrCl3	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	130	1300	39	Juma & Tabatabai. 1977.
Chromium	CrCl3	native soil microflora	sandy peat	4	6.5	42	Urease activity		1360 ED50	50	Doelman & Haanstra. 1986.
Chromium	CrCl3	native soil microflora	clay	8	1.5	548	Phosphatase activity		2652 ED50	50	Doelman & Haanstra. 1989.
Chromium	CrCl3	native soil microflora	sandy loam	6	3	548	Phosphatase activity		2792 ED50	50	Doelman & Haanstra. 1989.
Chromium	CrCl3	native soil microflora	sandy peat	4	6.5	548	Arylsulfatase activity		3203 ED50	50	Haanstra & Doelman. 1991.
Chromium	CrCl3	native soil microflora	sandy soil	7	1	42	Phosphatase activity		3208 ED50	50	Doelman & Haanstra. 1989.
Chromium	CrCl3	native soil microflora	sandy peat	4	6.5	42	Phosphatase activity		3208 ED50	50	Doelman & Haanstra. 1989.
Chromium	CrCl3	native soil microflora	silty loam	8	1	42	Phosphatase activity		3728 ED50	50	Doelman & Haanstra. 1989.
Chromium	CrCl3	native soil microflora	sandy soil	7	1	42	Urease activity		3970 ED50	50	Doelman & Haanstra. 1986.
Chromium	CrCl3	native soil microflora	silty loam	8	1	548	Phosphatase activity		4139 ED50	50	Doelman & Haanstra. 1989.
Chromium	CrCl3	native soil microflora	silty loam	8	1	42	Urease activity		4470 ED50	50	Doelman & Haanstra. 1986.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Chromium	CrCl3	native soil microflora	sandy loam	6	3	42	Phosphatase activity		5512 ED50	50	Doelman & Haanstra. 1989.
Chromium	CrCl3	native soil microflora	sandy peat	4	6.5	42	Arylsulfatase activity		5928 ED50	50	Haanstra & Doelman. 1991.
Chromium	CrCl3	native soil microflora	sandy soil	7	1	548	Phosphatase activity		20020 ED50	50	Doelman & Haanstra. 1989.
Cobalt	CoCl2	native soil microflora	soil/litter microcosm				Respiration		1362 LCT	23	Lighthart et al. 1977.
Copper	Cu(NO3)2	Pseudomonas sp.	silt loam	7	2	4	Denitrification		10 LCT	53	Bollag & Barabasz. 1979.
Copper	CuSO4	native soil microflora	surface soil		1.3	1	Dehydrogenase activity		30 LCT	28	Rogers & Li. 1985.
Copper	Cu(NO3)2	Pseudomonas aeruginosa	silt loam	7	2	4	Denitrification	10	50	43	Bollag & Barabasz. 1979.
Copper	CuSO4	native soil microflora	sandy loam	5	2	21	N mineralization		100 LCT	20	Quraishi & Cornfield. 1973.
Copper	CuCl2	native soil microflora	sandy soil	7	1	42	Phosphatase activity		140 ED50	50	Doelman & Haanstra. 1989.
Copper	CuCl2	native soil microflora	sandy soil	7	1	548	Phosphatase activity		170 ED50	50	Doelman & Haanstra. 1989.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Copper	Cu(NO3)2	native soil microflora	silt loam	7	2	21	Denitrification	100	250	44	Bollag & Barabasz. 1979.
Copper	Cu(NO3)2	Pseudomonas denitrificans	silt loam	7	2	4	Denitrification	100	250	22	Bollag & Barabasz. 1979.
Copper	CuCl2	native soil microflora	sandy soil	7	1	42	Urease activity		260 ED50	50	Doelman & Haanstra. 1986.
Copper	CuCl2	native soil microflora	sandy soil	7	1	548	Arylsulfatase activity		287 ED50	50	Haanstra & Doelman. 1991.
Copper	CuSO4	native soil microflora	silty clay loam	7	6	20	N mineralization		320 LCT	82	Liang & Tabatabai. 1977.
Copper	CuCl2	native soil microflora	sandy soil	7	1	42	Arylsulfatase activity		391 ED50	50	Haanstra & Doelman. 1991.
Copper	CuCl2	native soil microflora	silt loam	5			Nitrification		500	>2	Suter and Sharples. 1984.
Copper	CuCl2	native soil microflora	sandy loam	6	3	548	Arylsulfatase activity		548 ED50	50	Haanstra & Doelman. 1991.
Copper	CuCl2	native soil microflora	sandy loam	6	3	42	Urease activity		570 ED50	50	Doelman & Haanstra. 1986.
Copper	CuCl2	native soil microflora	sandy soil	7	1	548	Urease activity		680 ED50	50	Doelman & Haanstra. 1986.
Copper	CuCl2	native soil microflora	silty loam	8	1	548	Phosphatase activity		744 ED50	50	Doelman & Haanstra. 1989.
Copper	CuCl2	native soil microflora	silty loam	8	1	548	Arylsulfatase activity		763 ED50	50	Haanstra & Doelman. 1991.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Copper	CuCl2	native soil microflora	sandy loam	6	3	42	Arylsulfatase activity		967 ED50	50	Haanstra & Doelman. 1991.
Copper	CuO	native soil microflora	sandy soil	6	2	84	C mineralization		1000 LCT	33	Bhuiya & Cornfield. 1972.
Copper	CuSO4	native soil microflora	sandy loam	8	2	56	Nitrification	100	1000	38	Premi & Cornfield. 1969/1970.
Copper	CuSO4	native soil microflora	sandy loam	6	2	21	N mineralization	100	1000	75	Quraishi & Cornfield. 1973.
Copper	CuSO4	native soil microflora	sandy loam	5	2	21	N mineralization	100	1000	100	Quraishi & Cornfield. 1973.
Copper	CuSO4	native soil microflora	sandy loam	7	2	21	N mineralization	100	1000	39	Quraishi & Cornfield. 1973.
Copper	CuCl2	native soil microflora	clay	8	1.5	548	Urease activity		1080 ED50	50	Doelman & Haanstra. 1986.
Copper	CuCl2	native soil microflora	clay	8	1.5	42	Urease activity		1370 ED50	50	Doelman & Haanstra. 1986.
Copper	CuSO4	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		1590 LCT	22	Al-Khafaji & Tabatabai. 1979.
Copper	CuCl2	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		1590 LCT	43	Juma & Tabatabai. 1977.
Copper	CuSO4	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		1590 LCT	36	Juma & Tabatabai. 1977.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Copper	CuCl2	native soil microflora	clay loam	8	3.7	0.1	Alkaline & acid phosphatase activity		1590 LCT	30, 28	Juma & Tabatabai. 1977.
Copper	CuSO4	native soil microflora	clay loam	8	3.7	0.1	Acid phosphatase activity		1590 LCT	26	Juma & Tabatabai. 1977.
Copper	CuSO4	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity	159	1590	26	Al-Khafaji & Tabatabai. 1979.
Copper	CuSO4	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity	159	1590	32	Al-Khafaji & Tabatabai. 1979.
Copper	CuCl2	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	159	1590	51	Juma & Tabatabai. 1977.
Copper	CuSO4	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	159	1590	44	Juma & Tabatabai. 1977.
Copper	CuCl2	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	159	1590	32	Juma & Tabatabai. 1977.
Copper	CuSO4	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	159	1590	23	Juma & Tabatabai. 1977.
Copper	CuCl2	native soil microflora	sandy loam	6	3	548	Phosphatase activity		1895 ED50	50	Doelman & Haanstra. 1989.
Copper	CuCl2	native soil microflora	sandy peat	4	6.5	548	Urease activity		1970 ED50	50	Doelman & Haanstra. 1986.
Copper	CuCl2	native soil microflora	silty loam	8	1	548	Urease activity		1990 ED50	50	Doelman & Haanstra. 1986.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Copper	CuCl2	native soil microflora	sandy peat	4	6.5	548	Phosphatase activity		2442 ED50	50	Doelman & Haanstra. 1989.
Copper	CuCl2	native soil microflora	sandy peat	4	6.5	42	Phosphatase activity		2639 ED50	50	Doelman & Haanstra. 1989.
Copper	CuCl2	native soil microflora	clay	8	1.5	42	Phosphatase activity		2722 ED50	50	Doelman & Haanstra. 1989.
Copper	CuCl2	native soil microflora	clay	8	1.5	42	Arylsulfatase activity		2722 ED50	50	Haanstra & Doelman. 1991.
Copper	CuCl2	native soil microflora	clay	8	1.5	548	Phosphatase activity		2754 ED50	50	Doelman & Haanstra. 1989.
Copper	CuCl2	native soil microflora	sandy peat	4	6.5	42	Urease activity		4200 ED50	50	Doelman & Haanstra. 1986.
Copper	CuCl2	native soil microflora	clay	8	1.5	548	Arylsulfatase activity		4853 ED50	50	Haanstra & Doelman. 1991.
Copper	CuCl2	native soil microflora	silty loam	8	1	42	Phosphatase activity		6424 ED50	50	Doelman & Haanstra. 1989.
Copper	CuCl2	native soil microflora	sandy peat	4	6.5	548	Arylsulfatase activity		6996 ED50	50	Haanstra & Doelman. 1991.
Copper	CuCl2	native soil microflora	sandy peat	4	6.5	42	Arylsulfatase activity		8904 ED50	50	Haanstra & Doelman. 1991.
Copper	CuSO4	native soil microflora	sandy loam	7	2	21	Nitrification	1000	10000	75	Premi & Cornfield. 1969.
Copper	CuCl2	native soil microflora	silty loam	8	1	42	Arylsulfatase activity		14946 ED50	50	Haanstra & Doelman. 1991.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Fluoride	KF	native soil microflora	leaf litter			63	P mineralization		32 LCT	22	van Wensem & Adema. 1991.
Fluoride	NaF	native soil microflora	surface soil		1.3	1	Dehydrogenase activity	3000	5000	30	Rogers & Li. 1985.
Iron	FeCl3	native soil microflora	clay loam	8	4	20	N mineralization		280 LCT	22	Liang & Tabatabai. 1977.
Iron	FeCl3	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		1398 LCT	59	Al-Khafaji & Tabatabai. 1979.
Iron	FeCl3	native soil microflora	loam	7	5.3	0.1	Arylsulfatase activity		1398 LCT	23	Al-Khafaji & Tabatabai. 1979.
Iron	FeSO4	native soil microflora	clay loam	8	3.7	0.1	Alkaline phosphatase activity		1398 LCT	22	Juma & Tabatabai. 1977.
Iron	FeCl2	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		1398 LCT	26	Juma & Tabatabai. 1977.
Iron	FeCl3	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity	139.8	1398	45	Al-Khafaji & Tabatabai. 1979.
Iron	FeSO4	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	139.8	1398	27	Juma & Tabatabai. 1977.
Iron	FeCl2	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	139.8	1398	40	Juma & Tabatabai. 1977.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Iron	FeCl2	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	139.8	1398	32	Juma & Tabatabai. 1977.
Lanthanum	LaCl3	native soil microflora	soil/litter microcosm				Respiration		57 LCT	22	Lighthart et al. 1977.
Lead	PbCl2	native soil microflora	clay	8	1.5	1	Dehydrogenase activity		375 LCT	29	Doelman & Haanstra. 1979.
Lead	PbCl2	native soil microflora	sandy soil	6	1.5	1	Respiration	375	750	35	Doelman & Haanstra. 1979.
Lead	PbC4H6O4	native soil microflora	silt loam			2	Amylase activity	450	900	31	Cole. 1977.
Lead	PbCl2	native soil microflora	silt loam			2	Amylase activity	450	900	21	Cole. 1977.
Lead	PbO	native soil microflora	sandy soil	6	2	84	C mineralization		1000 LCT	22	Bhuiya & Cornfield. 1972.
Lead	PbCl2	native soil microflora	brown earth	5		30	Cellulolytic activity	500	1000	23	Khan & Frankland. 1984.
Lead	PbC4H6O4	native soil microflora	clay loam	8	4	20	N mineralization		1035 LCT	28	Liang & Tabatabai. 1977.
Lead	PbCl2	native soil microflora	clay	8	1.5	548	Urease activity		1340 ED50	50	Doelman & Haanstra. 1986.
Lead	PbCl2	native soil microflora	sandy soil	6	1.5	1217	Respiration		1500 LCT	30	Doelman & Haanstra. 1979.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Lead	PbCl2	native soil microflora	sandy soil	5	3	1	Dehydrogenase activity	750	1500	78	Doelman & Haanstra. 1979.
Lead	PbCl2	native soil microflora	sandy soil	7	1	548	Urease activity		1590 ED50	50	Doelman & Haanstra. 1986.
Lead	PbS	native soil microflora	silt loam			2	Amylase activity	900	1800	58	Cole. 1977.
Lead	PbC4H6O4	native soil microflora	silt loam			4	alpha-glucosidase synthesis		2000 LCT	38	Cole. 1977.
Lead	PbC4H6O4	native soil microflora	silt loam			2	Amylase activity		2000 LCT	74	Cole. 1977.
Lead	PbC4H6O4	native soil microflora	silt loam			5	Bacterial population size		2000 LCT	37	Cole. 1977.
Lead	PbCl2	native soil microflora	sandy loam	6	3	548	Urease activity		2870 ED50	50	Doelman & Haanstra. 1986.
Lead	PbCl2	native soil microflora	sandy loam	6	3	548	Arylsulfatase activity		3004 ED50	50	Haanstra & Doelman. 1991.
Lead	PbCl2	native soil microflora	silty loam	8	1	548	Arylsulfatase activity		4538 ED50	50	Haanstra & Doelman. 1991.
Lead	PbCl2	native soil microflora	sandy loam	6	3	42	Urease activity		5060 ED50	50	Doelman & Haanstra. 1986.
Lead	PbC4H6O4	native soil microflora	clay loam	8	3.7	0.1	Alkaline phosphatase activity		5175 LCT	33	Juma & Tabatabai. 1977.
Lead	PbNO3	native soil microflora	clay loam	8	3.7	0.1	Alkaline phosphatase activity		5175 LCT	38	Juma & Tabatabai. 1977.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Lead	PbNO3	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	517.5	5175	26	Juma & Tabatabai. 1977.
Lead	PbC4H6O4	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	517.5	5175	24	Juma & Tabatabai. 1977.
Lead	PbC4H6O4	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	517.5	5175	21	Juma & Tabatabai. 1977.
Lead	PbCl2	native soil microflora	clay	8	1.5	42	Urease activity		5730 ED50	50	Doelman & Haanstra. 1986.
Lead	PbCl2	native soil microflora	sandy peat	4	6.5	42	Urease activity		6230 ED50	50	Doelman & Haanstra. 1986.
Lead	PbCl2	native soil microflora	sandy peat	4	6.5	548	Urease activity		7050 ED50	50	Doelman & Haanstra. 1986.
Lead	PbCl2	native soil microflora	silty loam	8	1	548	Phosphatase activity		7604 ED50	50	Doelman & Haanstra. 1989.
Lead	PbCl2	native soil microflora	silty loam	8	1	42	Urease activity		7190 ED50	50	Doelman & Haanstra. 1986.
Lead	PbCl2	native soil microflora	silty loam	8	1	548	Urease activity		8130 ED50	50	Doelman & Haanstra. 1986.
Lead	PbCl2	native soil microflora	sandy soil	7	1	42	Arylsulfatase activity		8288 ED50	50	Haanstra & Doelman. 1991.
Lead	PbCl2	native soil microflora	sandy soil	7	1	548	Arylsulfatase activity		8785 ED50	50	Haanstra & Doelman. 1991.
Lead	PbCl2	native soil microflora	silty loam	8	1	42	Arylsulfatase activity		9138 ED50	50	Haanstra & Doelman. 1991.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Lead	Pb(NO3)2	native soil microflora	sandy loam	5		15	Respiration	1000	10000	29	Debosz et al. 1985.
Lead	PbCl2	native soil microflora	clay	8	1.5	42	Phosphatase activity		11168 ED50	50	Doelman & Haanstra. 1989.
Lead	PbCl2	native soil microflora	clay	8	1.5	548	Arylsulfatase activity		12411 ED50	50	Haanstra & Doelman. 1991.
Lead	PbCl2	native soil microflora	sandy soil	7	1	548	Phosphatase activity		78943 ED50	50	Doelman & Haanstra. 1989.
Lithium	LiCl	native soil microflora	soil/litter microcosm				Respiration		17 LCT	43	Lighthart et al. 1977.
Manganese	MnSO4	native soil microflora	sandy loam	7	2	21	Nitrification		100 LCT	67	Premi & Cornfield. 1969.
Manganese	MnCl2	native soil microflora	clay loam	8	4	20	N mineralization		275 LCT	26	Liang & Tabatabai. 1977.
Manganese	MnCl2	native soil microflora	clay loam	8	3.7	0.1	Alkaline phosphatase activity		1375 LCT	25	Juma & Tabatabai. 1977.
Manganese	MnCl2	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	137.5	1375	62	Juma & Tabatabai. 1977.
Mercury	HgCl2	native soil microflora	clay loam	8	2	28	C mineralization		0.1 LCT	87	Landa & Fang. 1978.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Mercury	PMA*	native soil microflora	dune sand	8	1		Nitrification		10 LCT	57	van Faassen. 1973.
Mercury	HgCl2	native soil microflora	clay loam	7	3	0.2	urease activity		50 LCT	38	Bremner & Douglas. 1971.
Mercury	HgSO4	native soil microflora	clay loam	7	3	0.2	urease activity		50 LCT	36	Bremner & Douglas. 1971.
Mercury	HgCl2	native soil microflora	silty clay loam	7	2.2	0.2	urease activity		50 LCT	42	Bremner & Douglas. 1971.
Mercury	HgSO4	native soil microflora	silty clay loam	7	2.2	0.2	urease activity		50 LCT	46	Bremner & Douglas. 1971.
Mercury	HgCl2	native soil microflora	clay loam	8	2	28	C mineralization	10	100	45	Landa & Fang. 1978.
Mercury	HgCl2	native soil microflora	silty clay	7	7	28	C mineralization	10	100	28	Landa & Fang. 1978.
Mercury	HgCl2	native soil microflora	clay	8	3		Nitrification	10	100	40	van Faassen. 1973.
Mercury	PMA*	native soil microflora	clay	8	3		Nitrification & ammonification	10	100	94, 42	van Faassen. 1973.
Mercury	HgCl2	native soil microflora	dune sand	8	1		Nitrification & ammonification	10	100	95, 34	van Faassen. 1973.
Mercury	HgCl2	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity		501.5 LCT	39	Al-Khafaji & Tabatabai. 1979.
Mercury	HgCl2	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity		501.5 LCT	34	Al-Khafaji & Tabatabai. 1979.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Mercury	HgCl2	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity		501.5 LCT	34	Al-Khafaji & Tabatabai. 1979.
Mercury	HgCl2	native soil microflora	loam	6	3	20	N mineralization		1003 LCT	73	Liang & Tabatabai. 1977.
Mercury	HgCl2	native soil microflora	silty clay	7	3	20	N mineralization		1003 LCT	39	Liang & Tabatabai. 1977.
Mercury	HgCl2	native soil microflora	clay loam	8	4	20	N mineralization		1003 LCT	35	Liang & Tabatabai. 1977.
Mercury	HgCl2	native soil microflora	silty clay loam	7	6	20	N mineralization		1003 LCT	32	Liang & Tabatabai. 1977.
Mercury	HgCl2	native soil microflora	clay loam	8	3.2	0.1	Amidase activity		5015 LCT	30	Frankenberger& Tabatabai. 1981
Mercury	HgCl2	native soil microflora	loam	7	4.7	0.1	Amidase activity		5015 LCT	27	Frankenberger& Tabatabai. 1981
Mercury	HgCl2	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		5015 LCT	96	Al-Khafaji & Tabatabai. 1979.
Mercury	HgCl2	native soil microflora	loam	7	5.3	0.1	Arylsulfatase activity		5015 LCT	86	Al-Khafaji & Tabatabai. 1979.
Mercury	HgCl2	native soil microflora	clay loam	8	3.7	0.1	Alkaline & acid phosphatase activities		5015 LCT	53, 52	Juma & Tabatabai. 1977.
Mercury	HgCl2	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		5015 LCT	53	Juma & Tabatabai. 1977.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Mercury	HgCl2	native soil microflora	surface soil	6	2.6	0.1	Amidase activity	501.5	5015	46	Frankenberger& Tabatabai. 1981
Mercury	HgCl2	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	501.5	5015	63	Juma & Tabatabai. 1977.
Mercury	HgCl2	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	501.5	5015	41	Juma & Tabatabai. 1977.
Molybdenum	H2MoO4	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity		239.8 LCT	40	Al-Khafaji & Tabatabai. 1979.
Molybdenum	H2MoO4	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity		239.8 LCT	26	Al-Khafaji & Tabatabai. 1979.
Molybdenum	H2MoO4	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity		239.8 LCT	69	Juma & Tabatabai. 1977.
Molybdenum	H2MoO4	native soil microflora	silty clay	7	2	20	N mineralization		480 LCT	22	Liang & Tabatabai. 1977.
Molybdenum	H2MoO4	native soil microflora	clay loam	8	4	20	N mineralization		480 LCT	22	Liang & Tabatabai. 1977.
Molybdenum	H2MoO4	native soil microflora	silty clay loam	7	6	20	N mineralization		480 LCT	54	Liang & Tabatabai. 1977.
Molybdenum	H2MoO4	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		2398 LCT	63	Al-Khafaji & Tabatabai. 1979.
Molybdenum	H2MoO4	native soil microflora	clay loam	8	3.7	0.1	Alkaline & acid phosphatase activities		2398 LCT	25, 41	Juma & Tabatabai. 1977.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Molybdenum	H2MoO4	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		2398 LCT	68	Juma & Tabatabai. 1977.
Molybdenum	H2MoO4	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	239.8	2398	22	Juma & Tabatabai. 1977.
Nickel	NiSO4	native soil microflora	sand	6	2	42	Respiration		10 LCT	22	Giashuddin & Cornfield. 1979.
Nickel	NiSO4	native soil microflora	surface soil		1.3	1	Dehydrogenase activity		30 LCT	39	Rogers & Li. 1985.
Nickel	NiO	native soil microflora	sand	6	2	42	Respiration		50 LCT	22	Giashuddin & Cornfield. 1979.
Nickel	NiCl2	Aspergillus clavatus	sandy loam	5	3	7	Growth rate	10	50	36	Babich & Stotzky. 1982.
Nickel	NiCl2	native soil microflora	silt loam	8	1.2	548	Arylsulfatase activity		92 ED50	50	Haanstra & Doelman. 1991.
Nickel	NiCl2	native soil microflora	sand	7	0.8	548	Arylsulfatase activity		99 ED50	50	Haanstra & Doelman. 1991.
Nickel	NiSO4	Agrobacteerium radiobacter	sandy loam	5	3	7	Growth		250 LCT	98	Babich & Stotzky. 1982.
Nickel	NiSO4	Proteus vulgaris	sandy loam	5	3	7	Growth		250 LCT	54	Babich & Stotzky. 1982.
Nickel	NiSO4	Bacillus megaterium	sandy loam	5	3	7	Growth		250 LCT	100	Babich & Stotzky. 1982.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Nickel	NiSO4	Cryptococcus terreus	sandy loam	5	3	7	Growth		250 LCT	73	Babich & Stotzky. 1982.
Nickel	NiSO4	Torulopsis glabrata	sandy loam	5	3	7	Growth		250 LCT	84	Babich & Stotzky. 1982.
Nickel	NiO	native soil microflora	sand	7	2	42	Respiration	50	250	33	Giashuddin & Cornfield. 1979.
Nickel	NiCl2	Aspergillus flavus	sandy loam	5	3	7	Growth rate	100	250	30	Babich & Stotzky. 1982.
Nickel	NiCl2	Penicillium vermiculatum	sandy loam	5	3	7	Growth rate	100	250	41	Babich & Stotzky. 1982.
Nickel	NiCl2	Aspergillus flavipes	sandy loam	5	3	7	Growth rate	250	500	98	Babich & Stotzky. 1982.
Nickel	NiCl2	Aspergillus niger	sandy loam	5	3	7	Growth rate	250	500	42	Babich & Stotzky. 1982.
Nickel	NiCl2	Rhizopus stolonifer	sandy loam	5	3	7	Growth rate	250	500	84	Babich & Stotzky. 1982.
Nickel	NiCl2	Gliocladium sp.	sandy loam	5	3	7	Growth rate	250	500	23	Babich & Stotzky. 1982.
Nickel	NiSO4	Serratia marcescens	sandy loam	5	3	7	Growth	250	500	87	Babich & Stotzky. 1982.
Nickel	NiSO4	Nocardia rhodochrous	sandy loam	5	3	7	Growth	250	500	25	Babich & Stotzky. 1982.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Nickel	NiSO4	Aspergillus flavipes	sandy loam+ montmorill	6	2.5	7	Growth		750 LCT	44	Babich & Stotzky. 1982.
Nickel	NiSO4	Aspergillus clavatus	sandy loam+ mont	6	2.5	7	Growth		750 LCT	31	Babich & Stotzky. 1982.
Nickel	NiSO4	Penicillium vermiculatum	sandy loam+ mont	6	2.5	7	Growth		750 LCT	27	Babich & Stotzky. 1982.
Nickel	NiSO4	Trichoderma viride	sandy loam+ mont	6	2.5	7	Growth		750 LCT	40	Babich & Stotzky. 1982.
Nickel	NiSO4	Aspergillus flavipes	sandy loam+ kaol	6	2.5	7	Growth		750 LCT	64	Babich & Stotzky. 1982.
Nickel	NiSO4	Aspergillus clavatus	sandy loam+ kaol	6	2.5	7	Growth		750 LCT	64	Babich & Stotzky. 1982.
Nickel	NiSO4	Rhizopus stolonifer	sandy loam+ kaol	6	2.5	7	Growth		750 LCT	54	Babich & Stotzky. 1982.
Nickel	NiSO4	Penicillium vermiculatum	sandy loam+ kaol	6	2.5	7	Growth		750 LCT	89	Babich & Stotzky. 1982.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Nickel	NiSO4	Trichoderma viride	sandy loam+ kaol	6	2.5	7	Growth		750 LCT	73	Babich & Stotzky. 1982.
Nickel	NiSO4	Aspergillus flavipes	sandy loam	5	3	7	Growth rate		750 LCT	93	Babich & Stotzky. 1982.
Nickel	NiSO4	Aspergillus clavatus	sandy loam	5	3	7	Growth rate		750 LCT	84	Babich & Stotzky. 1982.
Nickel	NiSO4	Rhizopus stolonifer	sandy loam	5	3	7	Growth rate		750 LCT	78	Babich & Stotzky. 1982.
Nickel	NiSO4	Penicillium vermiculatum	sandy loam	5	3	7	Growth rate		750 LCT	82	Babich & Stotzky. 1982.
Nickel	NiSO4	Trichoderma viride	sandy loam	5	3	7	Growth rate		750 LCT	85	Babich & Stotzky. 1982.
Nickel	NiSO4	Gliocladium sp.	sandy loam	5	3	7	Growth rate		750 LCT	52	Babich & Stotzky. 1982.
Nickel	NiSO4	Bacillus cereus	sandy loam	5	3	7	Growth	500	750	32	Babich & Stotzky. 1982.
Nickel	NiSO4	Rhodotorula rubra	sandy loam	5	3	7	Growth	500	750	29	Babich & Stotzky. 1982.
Nickel	NiCl2	Trichoderma viride	sandy loam	5	3	7	Growth rate	500	750	85	Babich & Stotzky. 1982.
Nickel	NiCl2	native soil microflora	sand	7	0.8	548	Phosphatase activity		769 ED50	50	Doelman & Haanstra. 1989.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Nickel	NiSO4	Bacillus megaterium	sandy loam	8	1		Growth	750	1000	22	Babich & Stotzky. 1982.
Nickel	NiSO4	Cryptococcus terreus	sandy loam	8	1		Growth	750	1000	21	Babich & Stotzky. 1982.
Nickel	NiCl2	native soil microflora	sand	7	0.8	42	Phosphatase activity		1109 ED50	50	Doelman & Haanstra. 1989.
Nickel	NiCl2	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		1468 LCT	26	Al-Khafaji & Tabatabai. 1979.
Nickel	NiCl2	native soil microflora	clay loam	8	3.7	0.1	Alkaline phosphatase activity		1468 LCT	22	Juma & Tabatabai. 1977.
Nickel	NiCl2	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		1468 LCT	21	Juma & Tabatabai. 1977.
Nickel	NiCl2	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	146.8	1468	23	Juma & Tabatabai. 1977.
Nickel	NiCl2	native soil microflora	sand	7	0.8	42	Arylsulfatase activity		2119 ED50	50	Haanstra & Doelman. 1991.
Nickel	NiCl2	native soil microflora	silt loam	8	1.2	548	Phosphatase activity		2131 ED50	50	Doelman & Haanstra. 1989.
Nickel	NiCl2	native soil microflora	sandy loam	6	2.8	42	Arylsulfatase activity		2348 ED50	50	Haanstra & Doelman. 1991.
Nickel	NiCl2	native soil microflora	clay	8	1.6	548	Arylsulfatase activity		2436 ED50	50	Haanstra & Doelman. 1991.
Nickel	NiCl2	native soil microflora	silt loam	8	1.2	42	Phosphatase activity		4232 ED50	50	Doelman & Haanstra. 1989.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Nickel	NiCl2	native soil microflora	silt loam	8	1.2	42	Arylsulfatase activity		5400 ED50	50	Haanstra & Doelman. 1991.
Nickel	NiCl2	native soil microflora	sandy loam	6	2.8	42	Phosphatase activity		5688 ED50	50	Doelman & Haanstra. 1989.
Nickel	NiCl2	native soil microflora	clay	8	1.6	42	Phosphatase activity		6516 ED50	50	Doelman & Haanstra. 1989.
Nickel	NiCl2	native soil microflora	sandy loam	6	2.8	548	Phosphatase activity		8042 ED50	50	Doelman & Haanstra. 1989.
Nickel	NiCl2	native soil microflora	sandy peat	4	6.4	548	Arylsulfatase activity		8101 ED50	50	Haanstra & Doelman. 1991.
Selenium	H2SeO3	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity		197.5 LCT	21	Al-Khafaji & Tabatabai. 1979.
Selenium	SeO2	native soil microflora	soil/litter microcosm				Respiration		484 LCT	43	Lighthart et al. 1977.
Selenium	H2SeO3	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		1975 LCT	32	Al-Khafaji & Tabatabai. 1979.
Selenium	H2SeO3	native soil microflora	loam	7	5.3	0.1	Arylsulfatase activity		1975 LCT	26	Al-Khafaji & Tabatabai. 1979.
Selenium	H2SeO3	native soil microflora	clay loam	8	3.7	0.1	Alkaline & acid phosphatase activities		1975 LCT	30, 39	Juma & Tabatabai. 1977.
Selenium	H2SeO3	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		1975 LCT	34	Juma & Tabatabai. 1977.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Selenium	H2SeO3	native soil microflora	surface soil	6	2.6	0.1	Amidase activity	197.5	1975	27	Frankenberger& Tabatabai. 1981
Selenium	H2SeO3	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity	197.5	1975	26	Al-Khafaji & Tabatabai. 1979.
Selenium	H2SeO3	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	197.5	1975	24	Juma & Tabatabai. 1977.
Selenium	H2SeO3	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	197.5	1975	35	Juma & Tabatabai. 1977.
Silver	AgSO4	native soil microflora	clay loam	7	3	0.2	urease activity		50 LCT	61	Bremner & Douglas. 1971.
Silver	AgNO3	native soil microflora	silty clay loam	7	2.2	0.2	urease activity		50 LCT	65	Bremner & Douglas. 1971.
Silver	AgSO4	native soil microflora		7	2.2	0.2	urease activity		50 LCT	63	Bremner & Douglas. 1971.
Silver	AgNO3	native soil microflora	clay loam	7	3	0.2	urease activity		50 LCT	60	Bremner & Douglas. 1971.
Silver	AgSO4	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity		269.8 LCT	53	Al-Khafaji & Tabatabai. 1979.
Silver	AgSO4	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity		269.8 LCT	80	Al-Khafaji & Tabatabai. 1979.
Silver	AgSO4	native soil microflora	loam	6	3	20	N mineralization		540 LCT	73	Liang & Tabatabai. 1977.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Silver	AgSO4	native soil microflora	silty clay	7	3	20	N mineralization		540 LCT	41	Liang & Tabatabai. 1977.
Silver	AgSO4	native soil microflora	clay loam	8	4	20	N mineralization		540 LCT	59	Liang & Tabatabai. 1977.
Silver	AgSO4	native soil microflora	silty clay loam	7	6	20	N mineralization		540 LCT	52	Liang & Tabatabai. 1977.
Silver	AgSO4	native soil microflora	loam	7	4.7	0.1	Amidase activity		2698 LCT	50	Frankenberger& Tabatabai. 1981
Silver	AgSO4	native soil microflora	clay loam	8	3.2	0.1	Amidase activity		2698 LCT	53	Frankenberger& Tabatabai. 1981
Silver	AgSO4	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		2698 LCT	94	Al-Khafaji & Tabatabai. 1979.
Silver	AgSO4	native soil microflora	loam	7	5.3	0.1	Arylsulfatase activity		2698 LCT	95	Al-Khafaji & Tabatabai. 1979.
Silver	AgSO4	native soil microflora	clay loam	8	3.7	0.1	Alkaline & acid phosphatase activities		2698 LCT	93, 38	Juma & Tabatabai. 1977.
Silver	AgSO4	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity		2698 LCT	28	Juma & Tabatabai. 1977.
Silver	AgSO4	native soil microflora	surface soil	6	2.6	0.1	Amidase activity	269.8	2698	62	Frankenberger& Tabatabai. 1981
Tin	SnCl2	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		2968 LCT	60	Al-Khafaji & Tabatabai. 1979.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Tin	SnCl2	native soil microflora	loam	7	5.3	0.1	Arylsulfatase activity		2968 LCT	32	Al-Khafaji & Tabatabai. 1979.
Tin	SnCl2	native soil microflora	clay loam	8	3.7	0.1	Alkaline phosphatase activity		2968 LCT	25	Juma & Tabatabai. 1977.
Tin	SnCl2	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		2968 LCT	21	Juma & Tabatabai. 1977.
Tin	SnCl2	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity	296.8	2968	45	Al-Khafaji & Tabatabai. 1979.
Tin	SnCl2	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	296.8	2968	41	Juma & Tabatabai. 1977.
Tin	SnCl2	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	296.8	2968	38	Juma & Tabatabai. 1977.
Titanium	TiSO4	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		1198 LCT	33	Al-Khafaji & Tabatabai. 1979.
Titanium	TiSO4	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity	119.8	1198	31	Al-Khafaji & Tabatabai. 1979.
Tungsten	Na2WO4	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity		459.8 LCT	75	Juma & Tabatabai. 1977.
Tungsten	Na2WO4	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		4598 LCT	23	Al-Khafaji & Tabatabai. 1979.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Tungsten	Na2WO4	native soil microflora	clay loam	8	3.7	0.1	Alkaline & acid phosphatase activities		4598 LCT	29, 45	Juma & Tabatabai. 1977.
Tungsten	Na2WO4	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		4598 LCT	69	Juma & Tabatabai. 1977.
Tungsten	Na2WO4	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity	459.8	4598	38	Al-Khafaji & Tabatabai. 1979.
Tungsten	Na2WO4	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity	459.8	4598	25	Al-Khafaji & Tabatabai. 1979.
Tungsten	Na2WO4	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	459.8	4598	32	Juma & Tabatabai. 1977.
Vanadium	V2O5	native soil microflora	soil/litter microcosm				Respiration		23 LCT	21	Lighthart et al. 1977.
Vanadium	NaVO3	native soil microflora	Forest mor (litter)		46	0.1	Acid phosphatase activity	30	50	40	Tyler. 1976.
Vanadium	VSO4	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity		127.3 LCT	76	Al-Khafaji & Tabatabai. 1979.
Vanadium	VSO4	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity		127.3 LCT	32	Al-Khafaji & Tabatabai. 1979.
Vanadium	VSO4	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity		127.3 LCT	30	Juma & Tabatabai. 1977.
Vanadium	VSO4	native soil microflora	clay loam	6	2.7	0.1	Arylsulfatase activity		1273 LCT	87	Al-Khafaji & Tabatabai. 1979.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Vanadium	VSO4	native soil microflora	loam	7	5.3	0.1	Arylsulfatase activity		1273 LCT	85	Al-Khafaji & Tabatabai. 1979.
Vanadium	VSO4	native soil microflora	clay loam	8	3.7	0.1	Alkaline & acid phosphatase activities		1273 LCT	61, 45	Juma & Tabatabai. 1977.
Vanadium	VSO4	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		1273 LCT	55	Juma & Tabatabai. 1977.
Vanadium	VSO4	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	127.3	1273	60	Juma & Tabatabai. 1977.
Zinc	Zn(NO3)2	Pseudomonas sp.	silt loam	7		4	Denitrification	10	50	29	Bollag & Barabasz. 1979.
Zinc	ZnCl2	native soil microflora	sandy peat	4	6.5	548	Urease activity		70 ED50	50	Doelman & Haanstra. 1986.
Zinc	ZnCl2	native soil microflora	clay	8	1.5	548	Urease activity		90 ED50	50	Doelman & Haanstra. 1986.
Zinc	ZnSO4	native soil microflora	sandy loam	7	2	21	Nitrification		100 LCT	57	Premi & Cornfield. 1969.
Zinc	ZnSO4	native soil microflora	sandy loam	8	2	56	Nitrification		100 LCT	43	Premi & Cornfield. 1969/1970.
Zinc	ZnCl2	native soil microflora	sandy loam	6	3	548	Urease activity		110 ED50	50	Doelman & Haanstra. 1986.
Zinc	ZnCl2	native soil microflora	sandy soil	7	1	548	Phosphatase activity		170 ED50	50	Doelman & Haanstra. 1989.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Zinc	ZnCl2	native soil microflora	sandy soil	7	1	42	Phosphatase activity		220 ED50	50	Doelman & Haanstra. 1989.
Zinc	Zn(NO3)2	native soil microflora	silt loam	7		21	Denitrification	100	250	31	Bollag & Barabasz. 1979.
Zinc	Zn(NO3)2	Pseudomonas denitrificans	silt loam	7		4	Denitrification	100	250	22	Bollag & Barabasz. 1979.
Zinc	Zn(NO3)2	Pseudomonas aeruginosa	silt loam	7		4	Denitrification	100	250	35	Bollag & Barabasz. 1979.
Zinc	ZnCl2	native soil microflora	sandy soil	7	1	548	Urease activity		290 ED50	50	Doelman & Haanstra. 1986.
Zinc	ZnSO4	native soil microflora	surface soil		1.3	1	Dehydrogenase activity	150	300	30	Rogers & Li. 1985.
Zinc	ZnCl2	native soil microflora	sandy soil	7	1	548	Arylsulfatase activity		375 ED50	50	Haanstra & Doelman. 1991.
Zinc	ZnCl2	native soil microflora	sandy soil	7	1	42	Urease activity		420 ED50	50	Doelman & Haanstra. 1986.
Zinc	ZnCl2	native soil microflora	soil/litter microcosm			23	Respiration	47	479	21	Chaney et al. 1978.
Zinc	ZnCl2	native soil microflora	sandy loam	6	3	42	Urease activity		480 ED50	50	Doelman & Haanstra. 1986.
Zinc	Zn(SO4)2	native soil microflora	surface soil	6	2	56	Biomass		600 LCT	31	Leita et al.1995
Zinc	ZnCl2	native soil microflora	sandy soil	7	1	42	Arylsulfatase activity		909 ED50	50	Haanstra & Doelman. 1991.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Zinc	ZnCl2	native soil microflora	sandy loam	6	3	548	Arylsulfatase activity		948 ED50	50	Haanstra & Doelman. 1991.
Zinc	ZnO	native soil microflora	sandy soil	7		84	N mineralization & nitrification		1000 LCT	28, 31	Bhuiya & Cornfield. 1976.
Zinc	ZnO	native soil microflora	sandy soil	8		42	N mineralization		1000 LCT	32	Bhuiya & Cornfield. 1974.
Zinc	ZnCl2	native soil microflora	Forest mor (litter)	4		30	Respiration	200	1000	26	Laskowski et al. 1994.
Zinc	ZnSO4	native soil microflora	clay loam	6	1.2	49	Nitrification	100	1000	99	Wilson. 1977.
Zinc	ZnSO4	native soil microflora	sandy loam	6	0.8	49	Nitrification	100	1000	98	Wilson. 1977.
Zinc	ZnSO4	native soil microflora	loamy sand	5	0.6	49	Nitrification	100	1000	100	Wilson. 1977.
Zinc	ZnCl2	native soil microflora	silty loam	8	1	42	Urease activity		1030 ED50	50	Doelman & Haanstra. 1986.
Zinc	ZnCl2	native soil microflora	silty loam	8	1	42	Arylsulfatase activity		1295 ED50	50	Haanstra & Doelman. 1991.
Zinc	ZnSO4	native soil microflora	clay loam	8	3.7	0.1	Alkaline & acid phosphatase activities		1635 LCT	59, 32	Juma & Tabatabai. 1977.
Zinc	ZnSO4	native soil microflora	loam	7	5.5	0.1	Acid phosphatase activity		1635 LCT	33	Juma & Tabatabai. 1977.
Zinc	ZnCl2	native soil microflora	loam	7	2.9	0.1	Arylsulfatase activity	163.5	1635	33	Al-Khafaji & Tabatabai. 1979.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Zinc	ZnCl2	native soil microflora	clay loam	8	3.2	0.1	Arylsulfatase activity	163.5	1635	36	Al-Khafaji & Tabatabai. 1979.
Zinc	ZnSO4	native soil microflora	loam	6	2.6	0.1	Acid phosphatase activity	163.6	1635	30	Juma & Tabatabai. 1977.
Zinc	ZnSO4	native soil microflora	loam	7	5.5	0.1	Alkaline phosphatase activity	163.5	1635	28	Juma & Tabatabai. 1977.
Zinc	ZnCl2	native soil microflora	clay	8	1.5	42	Urease activity		1780 ED50	50	Doelman & Haanstra. 1986.
Zinc	ZnCl2	native soil microflora	sandy loam	6	3	42	Arylsulfatase activity		2184 ED50	50	Haanstra & Doelman. 1991.
Zinc	ZnCl2	native soil microflora	clay	8	1.5	548	Arylsulfatase activity		2838 ED50	50	Haanstra & Doelman. 1991.
Zinc	ZnCl2	native soil microflora	clay	8	1.5	548	Phosphatase activity		2845 ED50	50	Doelman & Haanstra. 1989.
Zinc	ZnCl2	native soil microflora	silty loam	8	1	42	Phosphatase activity		2963 ED50	50	Doelman & Haanstra. 1989.
Zinc	ZnCl2	native soil microflora	sandy loam	6	3	548	Phosphatase activity		2969 ED50	50	Doelman & Haanstra. 1989.
Zinc	ZnCl2	native soil microflora	sandy loam	6	3	42	Phosphatase activity		3342 ED50	50	Doelman & Haanstra. 1989.
Zinc	ZnCl2	native soil microflora	soil/litter microcosm				Respiration		3600 LCT	66	Lighthart et al. 1977.
Zinc	ZnCl2	native soil microflora	clay	8	1.5	42	Phosphatase activity		3623 ED50	50	Doelman & Haanstra. 1989.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
Zinc	ZnCl2	native soil microflora	silty loam	8	1	548	Arylsulfatase activity		4349 ED50	50	Haanstra & Doelman. 1991.
Zinc	ZnCl2	native soil microflora	silty loam	8	1	548	Phosphatase activity		4872 ED50	50	Doelman & Haanstra. 1989.
Zinc	ZnCl2	native soil microflora	clay	8	1.5	42	Arylsulfatase activity		5559 ED50	50	Haanstra & Doelman. 1991.
Zinc	ZnCl2	native soil microflora	sandy peat	4	6.5	548	Arylsulfatase activity		9679 ED50	50	Haanstra & Doelman. 1991.
acrylonitrile		native soil microflora	silt loam	5	1.5	4	Respiration		1000 LCT	41	Walton et al. 1989.
acrylonitrile		native soil microflora	sandy loam	5	0.7	4	Respiration		1000 LCT	59	Walton et al. 1989.
carbon tetrachloride		native soil microflora	sandy loam	5	0.7	4	Respiration		1000 LCT	21	Walton et al. 1989.
cis-1,4-dichloro-2-butene		native soil microflora	silt loam	5	1.5	4	Respiration		1000 LCT	44	Walton et al. 1989.
cis-1,4-dichloro-2-butene		native soil microflora	sandy loam	5	0.7	4	Respiration		1000 LCT	48	Walton et al. 1989.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
hexachlorobenzene		native soil microflora	silt loam	5	1.5	4	Respiration		1000 LCT	37	Walton et al. 1989.
nitrobenzene		native soil microflora	silt loam	5	1.5	4	Respiration		1000 LCT	22	Walton et al. 1989.
nitrobenzene		native soil microflora	sandy loam	5	0.7	4	Respiration		1000 LCT	61	Walton et al. 1989.
pentachlorophenol		native soil microflora	surface soil	5	5.2	1.8	Respiration		460 EC50	50	vanBeelen&Fleurin-Kemila.1993
pentachlorophenol		native soil microflora	dune sand	4	0.6	3	Respiration		800 EC50	50	vanBeelen&Fleurin-Kemila.1993.
pentachlorophenol		native soil microflora	polder soil	8	0.6		Respiration		57 EC50	50	vanBeelen et al.1994.
pentachlorophenol		native soil microflora	surface soil	4	2.6		Respiration		1207 EC50	50	vanBeelen et al.1994.
phenol		native soil microflora	silt loam	5			Nitrification		100	>20	Suter and Sharples. 1984.
trans-1,4-dichloro-2-butene		native soil microflora	silt loam	5	1.5	4	Respiration		1000 LCT	58	Walton et al. 1989.

Table B.1 (continued)

CHEMICAL	CHEMICAL FORM	ORGANISMS	GROWTH MEDIUM	pH	%OC	EXP (D)	RESPONSE PARAMETER	NOEC	LOEC	% DEC	REFERENCE
trans-1,4-dichloro-2-butene		native soil microflora	sandy loam	5	0.7	4	Respiration		1000 LCT	44	Walton et al. 1989.

Appendix C

TOXICITY DATA FOR OTHER SOIL AND LITTER INVERTEBRATES

Table C.1 Toxicity Data for Other Soil and Litter Invertebrates

Chemical concentrations are mg of element/kg of food or substrate

EXP (D) - exposure duration in days

LCT - lowest concentration tested

LC50 - concentration causing 50%mortality

% DEC - % decrease in measured parameter at LOEC as compared to controls.

CHEMICAL	FORM	SPECIES	FOOD	EXP (D)	RESPONSE	NOEC APPLIED	LOEC APPLIED	% DEC	REFERENCE
Cadmium	CdCl2	Diplogasteritus spp.	solution	3	survival LC50		3.3	50	Kammenga et al. 1994.
Cadmium	CdCl2	Caenorhabditis elegans	solution	7	reproduction	1.1	3.6	36	van Kessel et al. 1989.
Cadmium	CdCl2	Cephalobus persegnis	solution	3	survival LC50		9.3	50	Kammenga et al. 1994.
Cadmium	CdCl2	Rhabditis species	solution	3	survival LC50		14.1	50	Kammenga et al. 1994.
Cadmium	CdCl2	Caenorhabditis elegans	solution	3	survival LC50		14.7	50	Kammenga et al. 1994.
Cadmium	CdCl2	Acrobeloides buetschlii	solution	3	survival LC50		59.3	50	Kammenga et al. 1994.
Cadmium	CdNO3	Porcellio scaber-juv.	maple leaves	360	number of offspring		10LCT	47	Hopkin and Hames. 1994.
Cadmium	CdSO4	Orchesella cincta	green algae	61	population growth rate	4.7	15	56	van Straalen et al. 1989.
Cadmium	CdCl2	Folsomia candida	Baker's yeast	42	number of offspring	148	326	21	Crommentuijn et al. 1993.
Cadmium	CdSO4	Platynothrus peltifer	green algae	61	population growth rate	3	9	23	van Straalen et al. 1989.

Table C.1 (continued)

CHEMICAL	FORM	SPECIES	FOOD	EXP (D)	RESPONSE	NOEC APPLIED	LOEC APPLIED	% DEC	REFERENCE
Cadmium	CdCl2	Helix aspersa	Lab Chow	30	reproductive behavior	10	25	28	Russell et al. 1981.
Copper	CuSO4	nema-omnivore/ predator	soil OM	7	survival		72 LCT	85	Parmalee et al. 1993.
Copper	CuCl2	Caenorhabditis elegans	solution	1	survival LC50		105	50	Donkin and Dusenbery. 1993.
Copper	CuSO4	nematode-fungivores	soil OM	7	survival	185	400	65	Parmalee et al. 1993.
Copper	CuSO4	nematode-bacterivores	soil OM	7	survival	185	400	80	Parmalee et al. 1993.
Copper	CuSO4	nematode-herbivores	soil OM	7	survival	185	400	57	Parmalee et al. 1993.
Copper	CuSO4	nematode-hatchlings	soil OM	7	survival	185	400	75	Parmalee et al. 1993.
Copper	CuCl2	Caenorhabditis elegans	soil OM	1	survival LC50		413	50	Donkin and Dusenbery. 1993.
Copper	CuCl2	Caenorhabditis elegans	soil OM	1	survival LC50		534	50	Donkin and Dusenbery. 1993.
Copper	CuCl2	Caenorhabditis elegans	soil OM	1	survival LC50		629	50	Donkin and Dusenbery. 1993.
Copper	CuCl2	Caenorhabditis elegans	soil OM	1	survival LC50		1061	50	Donkin and Dusenbery. 1993.
Copper	CuNO3	Porcellio scaber-juv.	maple leaves	360	number of offspring	20	50	53	Hopkin and Hames. 1994.

Table C.1 (continued)

CHEMICAL	FORM	SPECIES	FOOD	EXP (D)	RESPONSE	NOEC APPLIED	LOEC APPLIED	% DEC	REFERENCE
Copper	CuSO4	Mesostigmata	soil OM	7	survival		72 LCT		Parmalee et al. 1993.
Copper	CuSO4	Oribatida	soil OM	7	survival		72 LCT	48	Parmalee et al. 1993.
Copper	CuSO4	Prostigmata	soil OM	7	survival	185	400	37	Parmalee et al. 1993.
Copper	CuSO4	other microarthropods	soil OM	7	survival	185	400	60	Parmalee et al. 1993.
Copper	CuSO4	Arion ater	fruit & veg	27	percent growth	300	1000	55	Marigomez et al. 1986.
Iron	FeSO4	Orchesella cincta	green algae	21	percent growth	3515	7533	42	Nottrot et al. 1987.
Lead	PbO	Porcellio scaber	O1+O2 litter	448	gen 1 survival & repro; gen 2 survival	6400	12800	27,6884	Beyer and Anderson. 1985.
Lead	PbNO3	Porcellio scaber-juv.	maple leaves	360	survival; number of offspring	1000	2000	100, 100	Hopkin and Hames. 1994.
Lead		Onychiurus armatus	fungus	125	growth rate		3089 LCT	25	Bengtsson et al. 1983.
Lead	PbNO3	Arion ater	fruit & veg	27	percent growth	300	1000	51	Marigomez et al. 1986.
Mercury	HgCl2	Arion ater	fruit & veg	27	percent growth	300	1000	26	Marigomez et al. 1986.

Table C.1 (continued)

CHEMICAL	FORM	SPECIES	FOOD	EXP (D)	RESPONSE	NOEC APPLIED	LOEC APPLIED	% DEC	REFERENCE
Zinc	ZnNO3	Porcellio scaber-juv.	maple leaves	360	survival;	500	1000	100	Hopkin and Hames. 1994.
Zinc	ZnO	Porcellio scaber	O1+O2 litter	448	gen 2 population size; generation 2 survival	800	1600	22,27	Beyer and Anderson. 1985.
Zinc	ZnO	Porcellio scaber	O2 litter	56	survival		5000 LCT	26	Beyer et al. 1984.
Zinc	ZnCl2	Arion ater	fruit & veg	27	percent growth		10 LCT	38	Marigomez et al. 1986.
benzo[a]pyrene		Porcellio scaber	leaf&dog food	63	change in dry weight	31.6	100	30	vanBrummelen &Stuijfzand.1993
benzo[a]pyrene		Porcellio scaber	poplar leaves	28	% growth efficiency	25	125	82	van Straalen and Verweij. 1991
benzo[a]pyrene		Oniscus asellus	leaf&dog food	63	change in dry weight and length	100	316	58,48	vanBrummelen &Stuijfzand. 1993
p-nitrophenol		nematode-bacterivores	soil OM	7	survival		20LCT	40	Parmalee et al. 1993.
p-nitrophenol		nematode-fungivores	soil OM	7	survival	20	40	55	Parmalee et al. 1993.
p-nitrophenol		nematode-herbivores	soil OM	7	survival	20	40	51	Parmalee et al. 1993.
p-nitrophenol		nema-omnivore/ predator	soil OM	7	survival	20	40		Parmalee et al. 1993.

Table C.1 (continued)

CHEMICAL	FORM	SPECIES	FOOD	EXP (D)	RESPONSE	NOEC APPLIED	LOEC APPLIED	% DEC	REFERENCE
p-nitrophenol		nematode-hatchlings	soil OM	7	survival	20	40	61	Parmalee et al. 1993.
p-nitrophenol		nematode-total	soil OM	7	survival	20	40	56	Parmalee et al. 1993.
p-nitrophenol		Prostigmata	soil OM	7	survival	40	80	24	Parmalee et al. 1993.
p-nitrophenol		Oribatida	soil OM	7	survival	80	160	26	Parmalee et al. 1993.
p-nitrophenol		total microarthropods	soil OM	7	survival	80	160	35	Parmalee et al. 1993.
pentachlorophenol		Tylenchus elegans	solution	3	survival LC50		1.2	50	Kammenga et al. 1994.
pentachlorophenol		Rhabditis species	solution	3	survival LC50		2.4	50	Kammenga et al. 1994.
pentachlorophenol		Cephalobus persegnis	solution	3	survival LC50		2.6	50	Kammenga et al. 1994.
pentachlorophenol		Diplogasteritus spp.	solution	3	survival LC50		6.8	50	Kammenga et al. 1994.
trinitrotoluene		Prostigmata	soil OM	7	survival	100	200	71	Parmalee et al. 1993.
trinitrotoluene		Oribatida	soil OM	7	survival	100	200	58	Parmalee et al. 1993.
trinitrotoluene		total	soil OM	7	survival	100	200	58	Parmalee et al. 1993.

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