# FIGURES

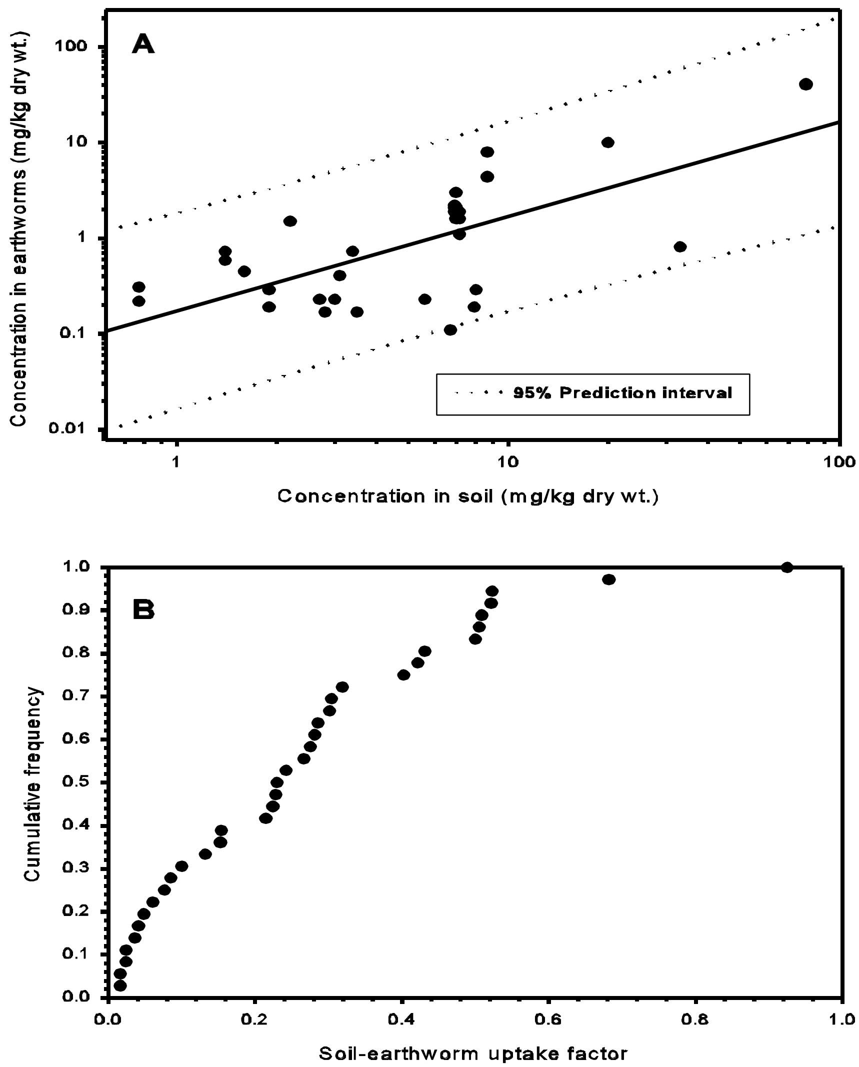


**Figure 1. Literature-derived data on accumulation of As by earthworms. A) log-log scatterplot of As concentration in soil versus As concentration in depurated earthworms. Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix A.**

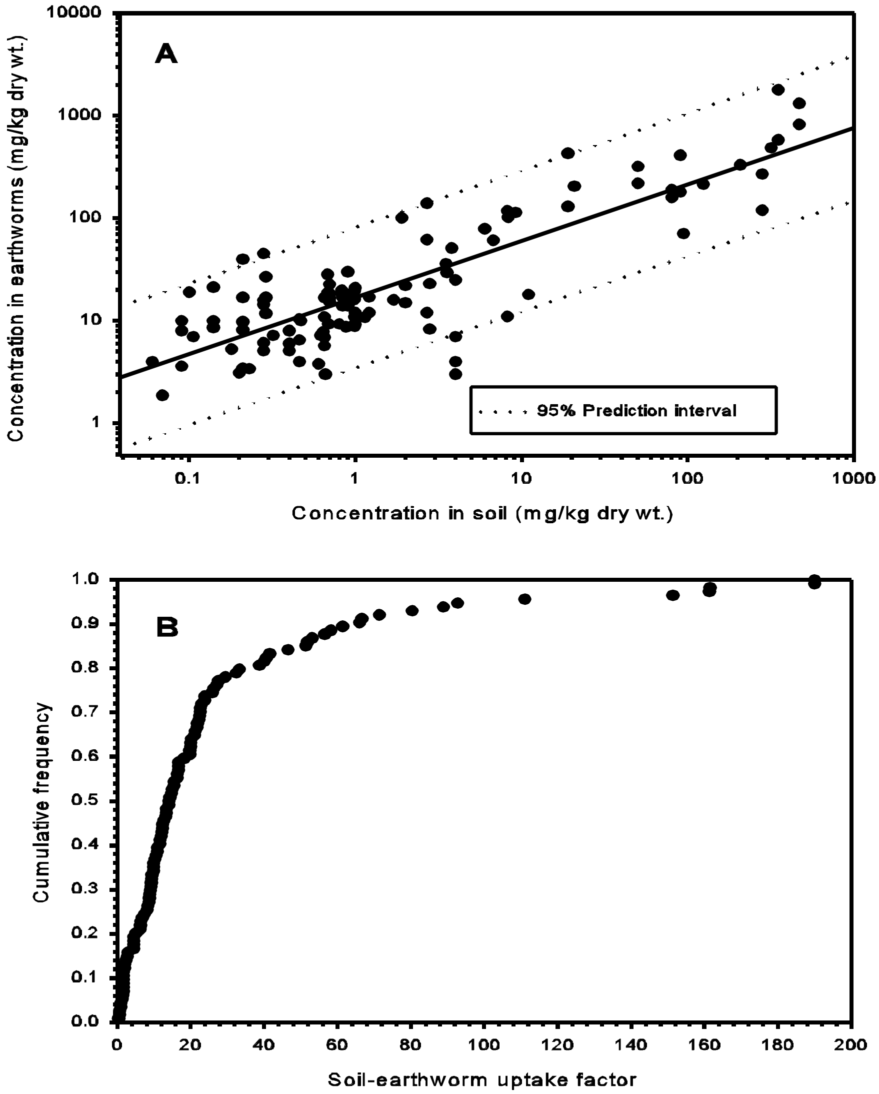


**Figure 2. Literature-derived data on accumulation of Cd by earthworms. A) log-log scatterplot of Cd concentration in soil versus Cd concentration in depurated earthworms. Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7.Summary of studies considered to evaluate accumulation is presented in Appendix A.**

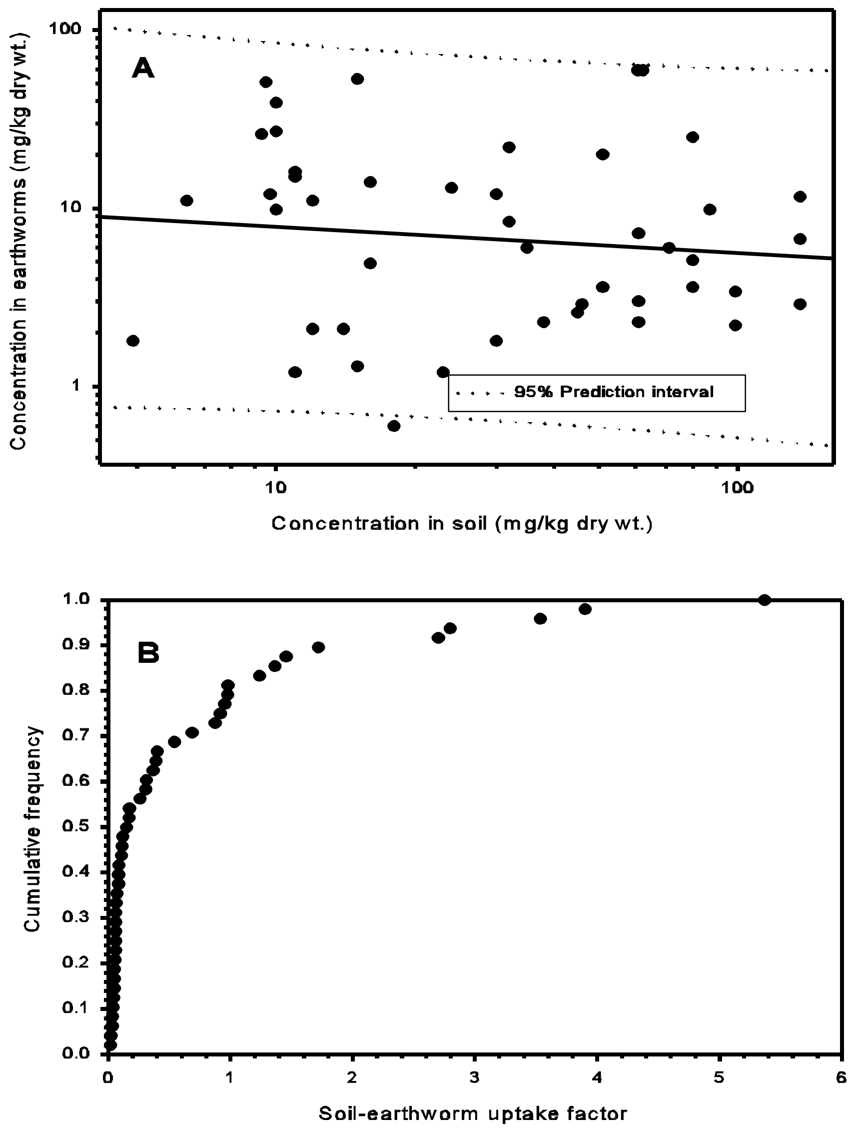


**Figure 3. Literature-derived data on accumulation of Cr by earthworms. A) log-log scatterplot of Cr concentration in soil versus Cr concentration in depurated earthworms. Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix A.**

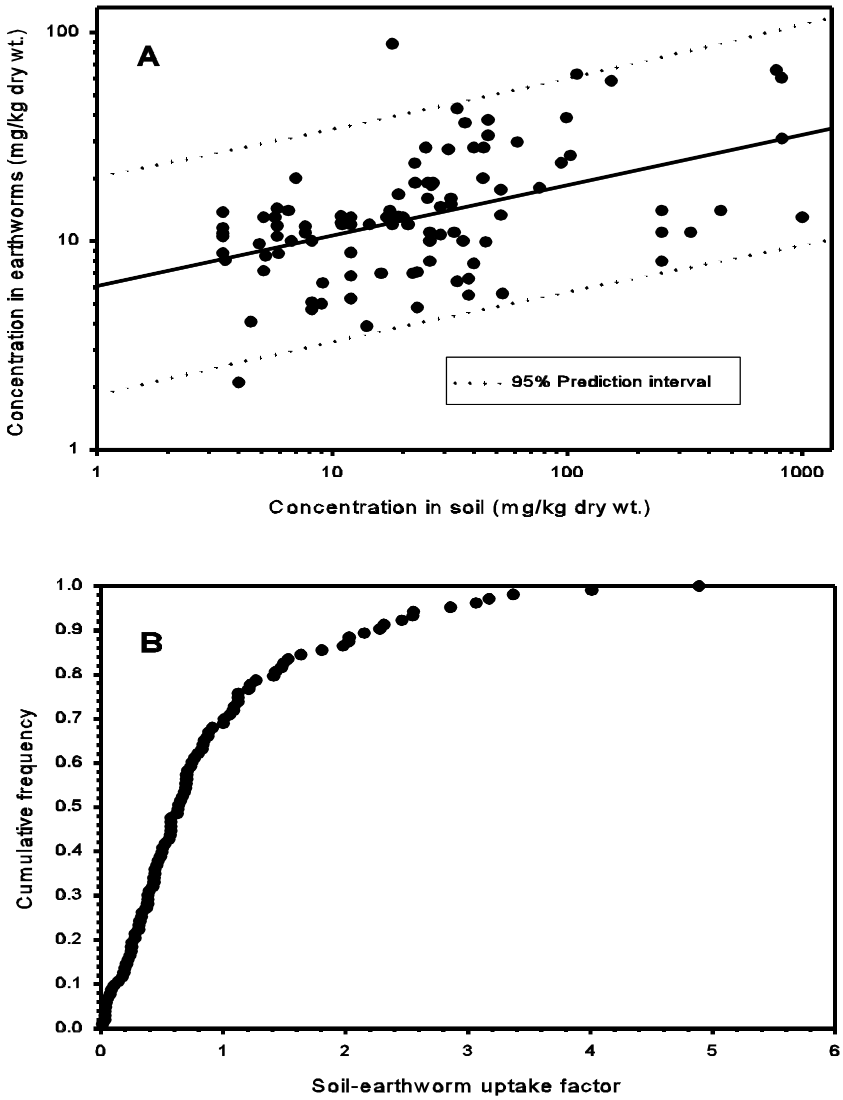


**Figure 4. Literature-derived data on accumulation of Cu by earthworms. A) log-log scatterplot of Cu concentration in soil versus Cu concentration in depurated earthworms. Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix A.**

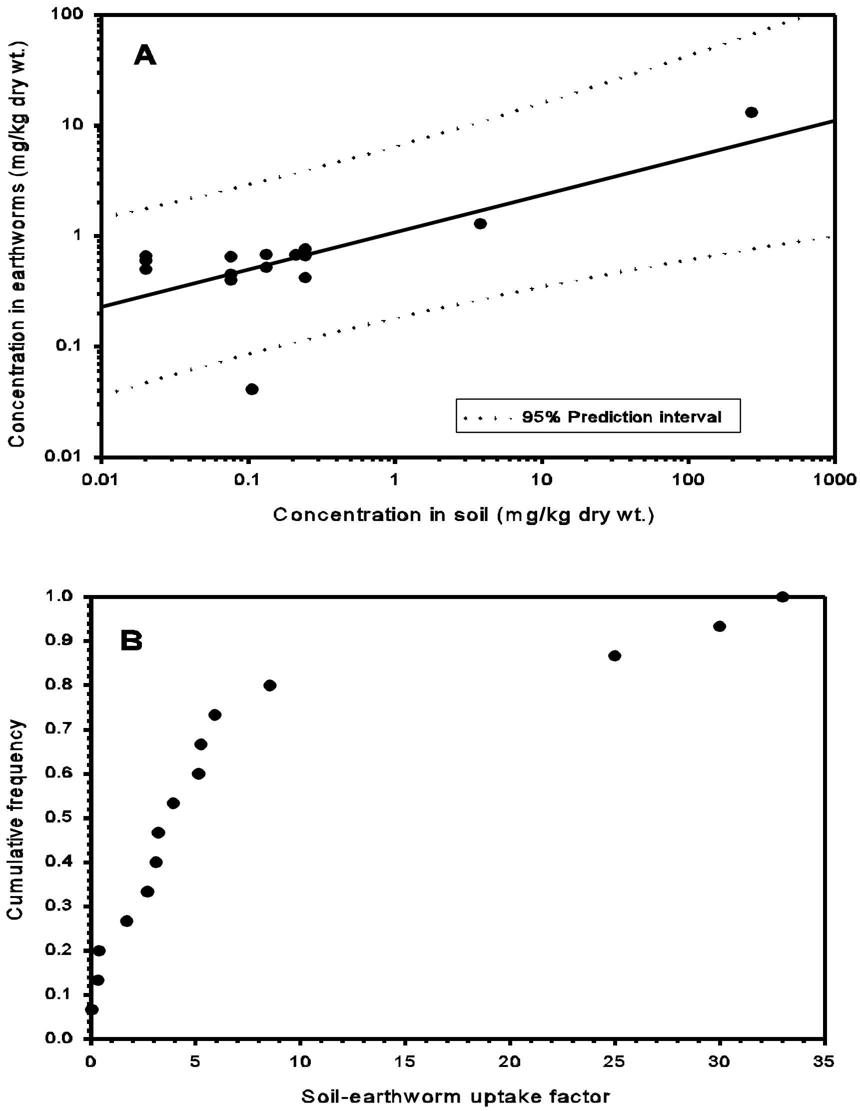


**Figure 5. Literature-derived data on accumulation of Hg by earthworms. A) log-log scatterplot of Hg concentration in soil versus Hg concentration in depurated earthworms. Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix A.**

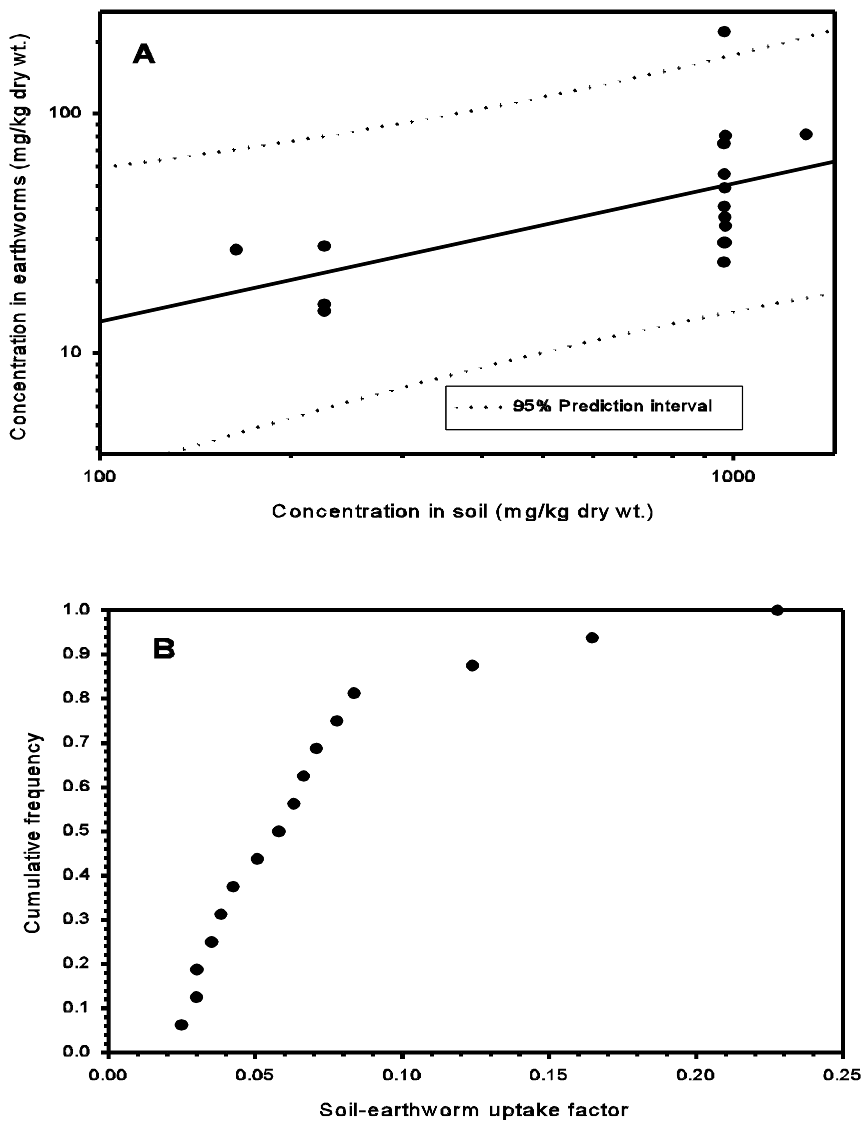


**Figure 6. Literature-derived data on accumulation of Mn by earthworms. A) log-log scatterplot of Mn concentration in soil versus Mn concentration in depurated earthworms. Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix A.**

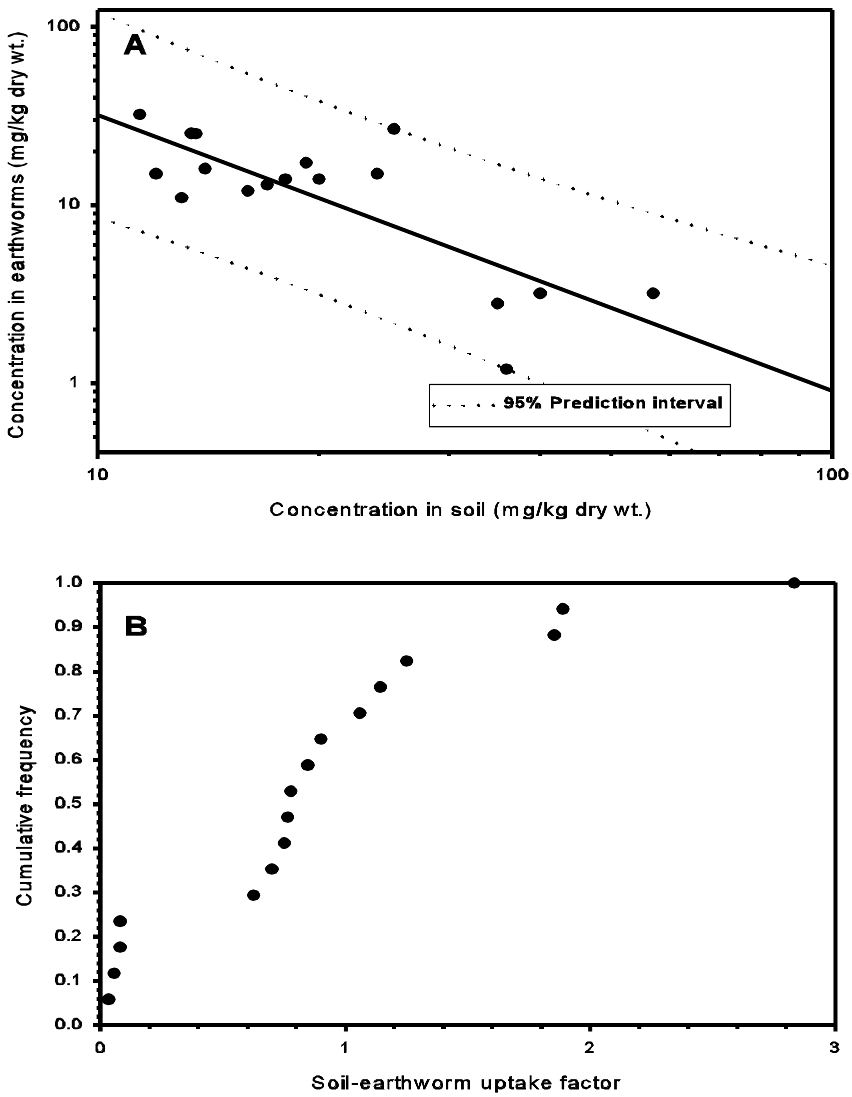


**Figure 7. Literature-derived data on accumulation of Ni by earthworms. A) log-log scatterplot of Ni concentration in soil versus Ni concentration in depurated earthworms. Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix A.**

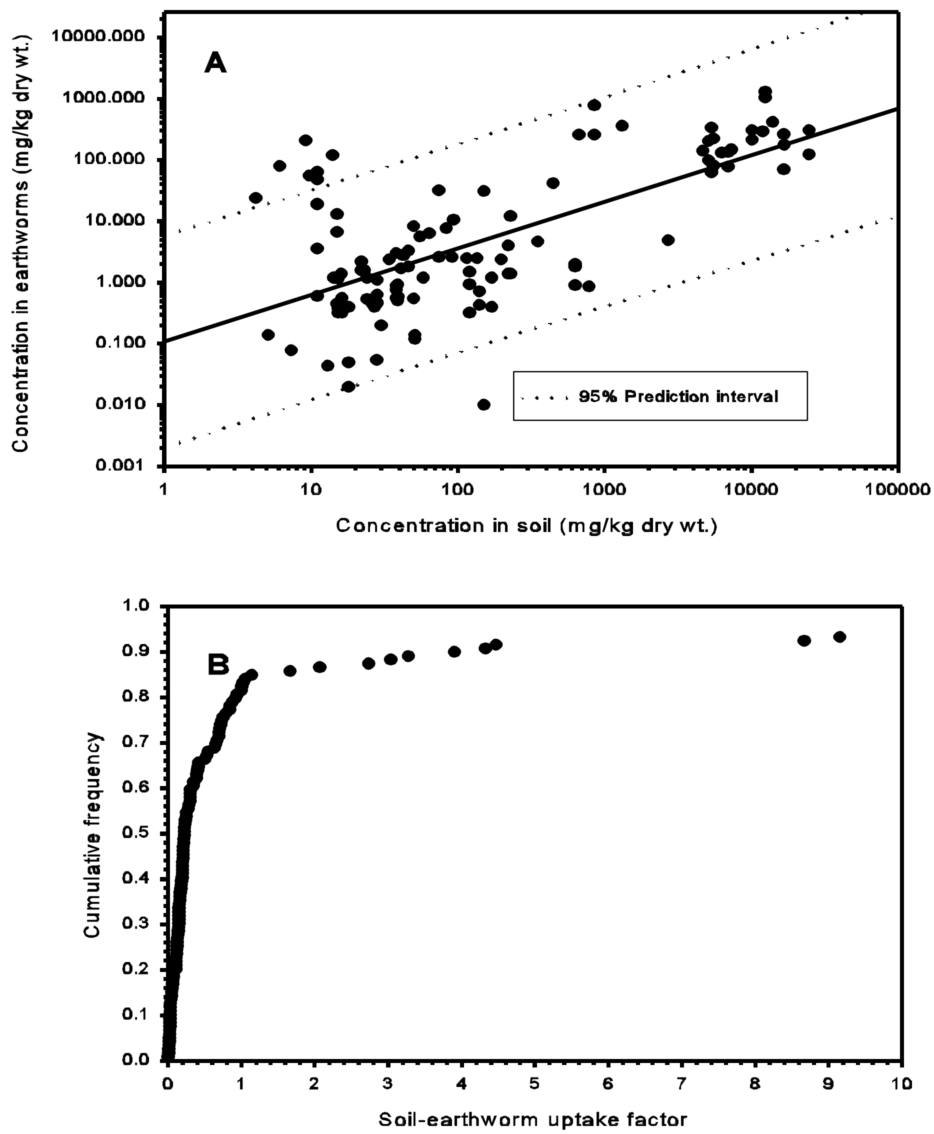


**Figure 8. Literature-derived data on accumulation of Pb by earthworms. A) log-log scatterplot of Pb concentration in soil versus Pb concentration in depurated earthworms. Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Plot truncated at UF=10. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix A.**

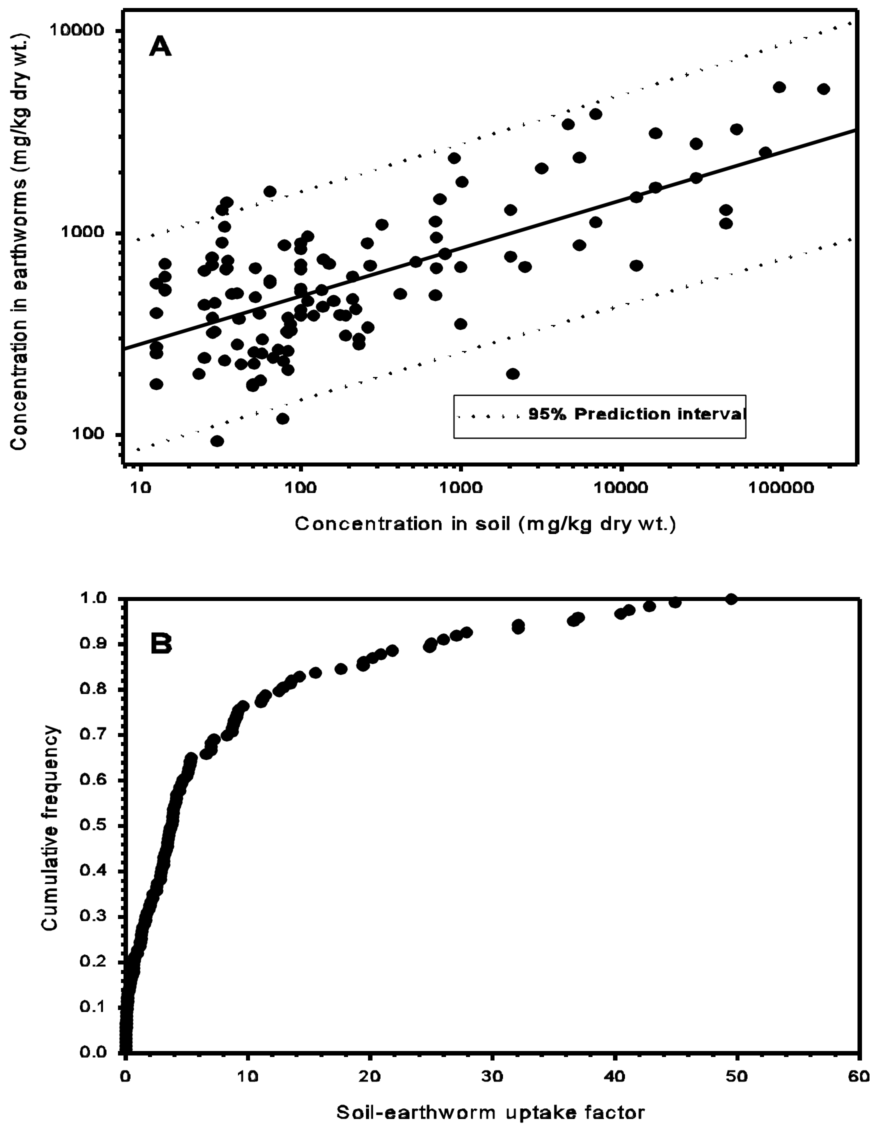


**Figure 9. Literature-derived data on accumulation of Zn by earthworms. A) log-log scatterplot of Zn concentration in soil versus Zn concentration in depurated earthworms. Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix A.**

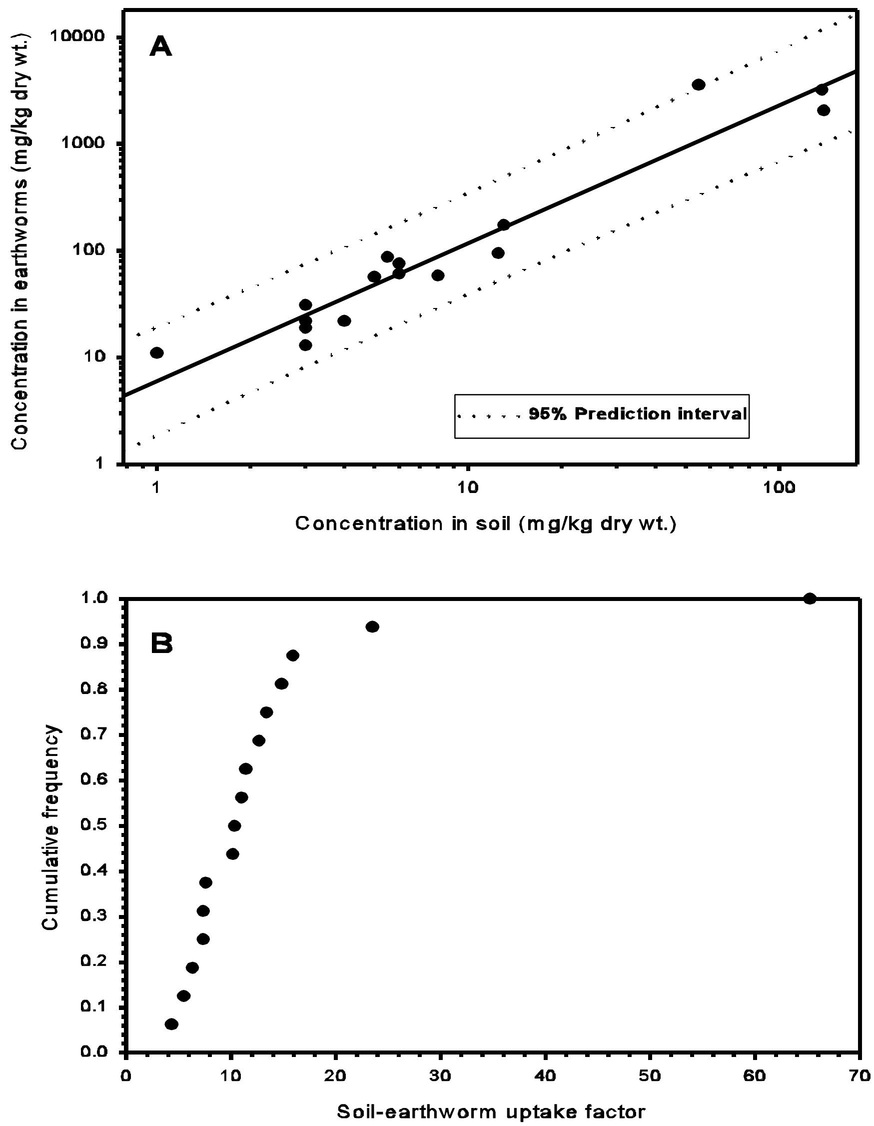


**Figure 10. Literature-derived data on accumulation of PCBs by earthworms. A) log-log scatterplot of PCBs concentration in soil versus PCBs concentration in depurated earthworms. Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix A.**

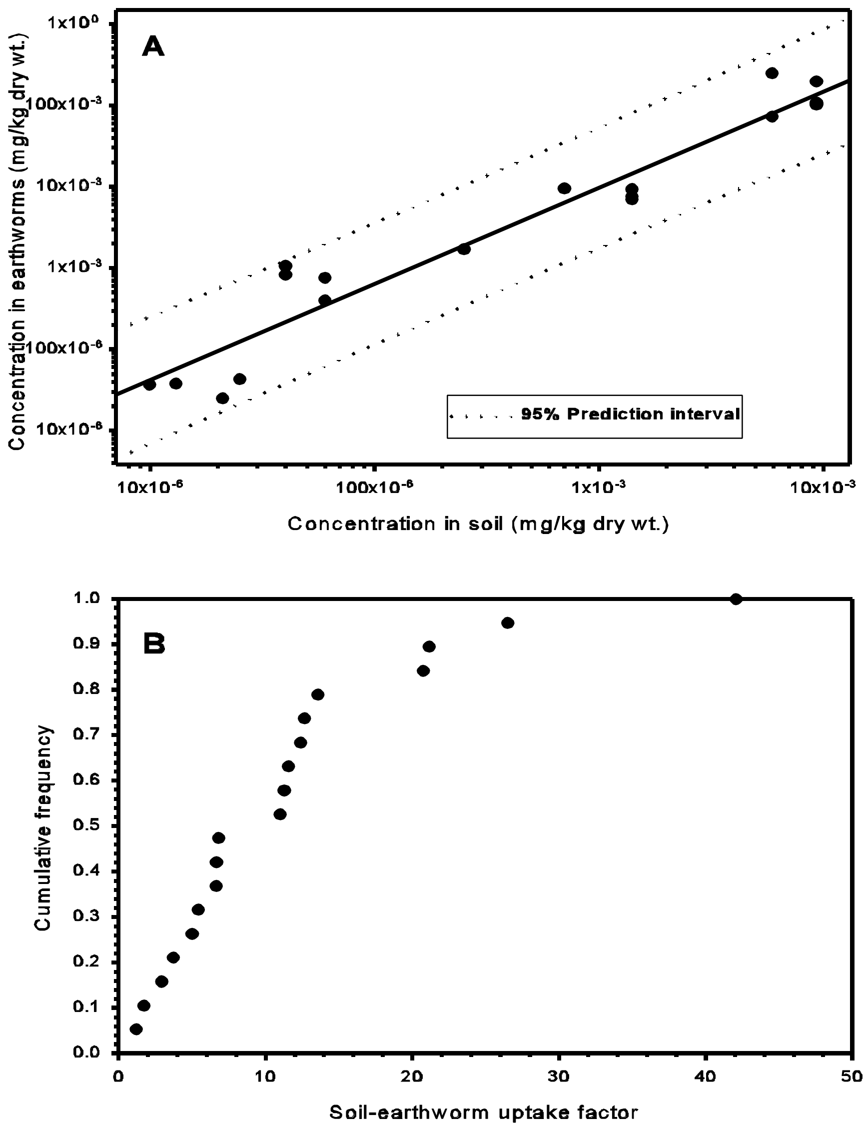


**Figure 11. Literature-derived data on accumulation of 2,3,7,8 TCDD by earthworms. A) log-log scatterplot of 2,3,7,8 TCDD concentration in soil versus 2,3,7,8 TCDD concentration in depurated earthworms. Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix A.**

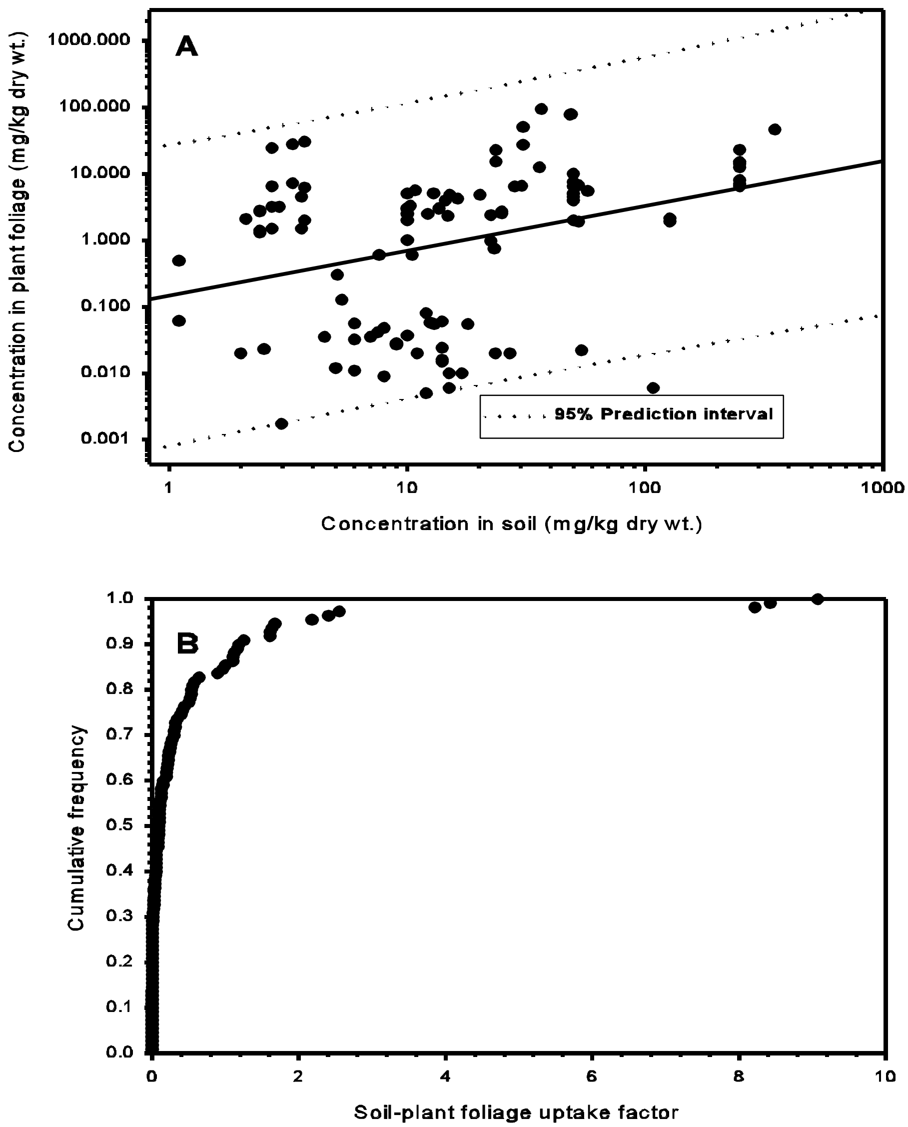


**Figure 12. Literature-derived data on accumulation of As by terrestrial plants. A) log-log scatterplot of As concentration in soil versus As concentration in above ground tissues (excluding fruits or seeds). Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix B.**

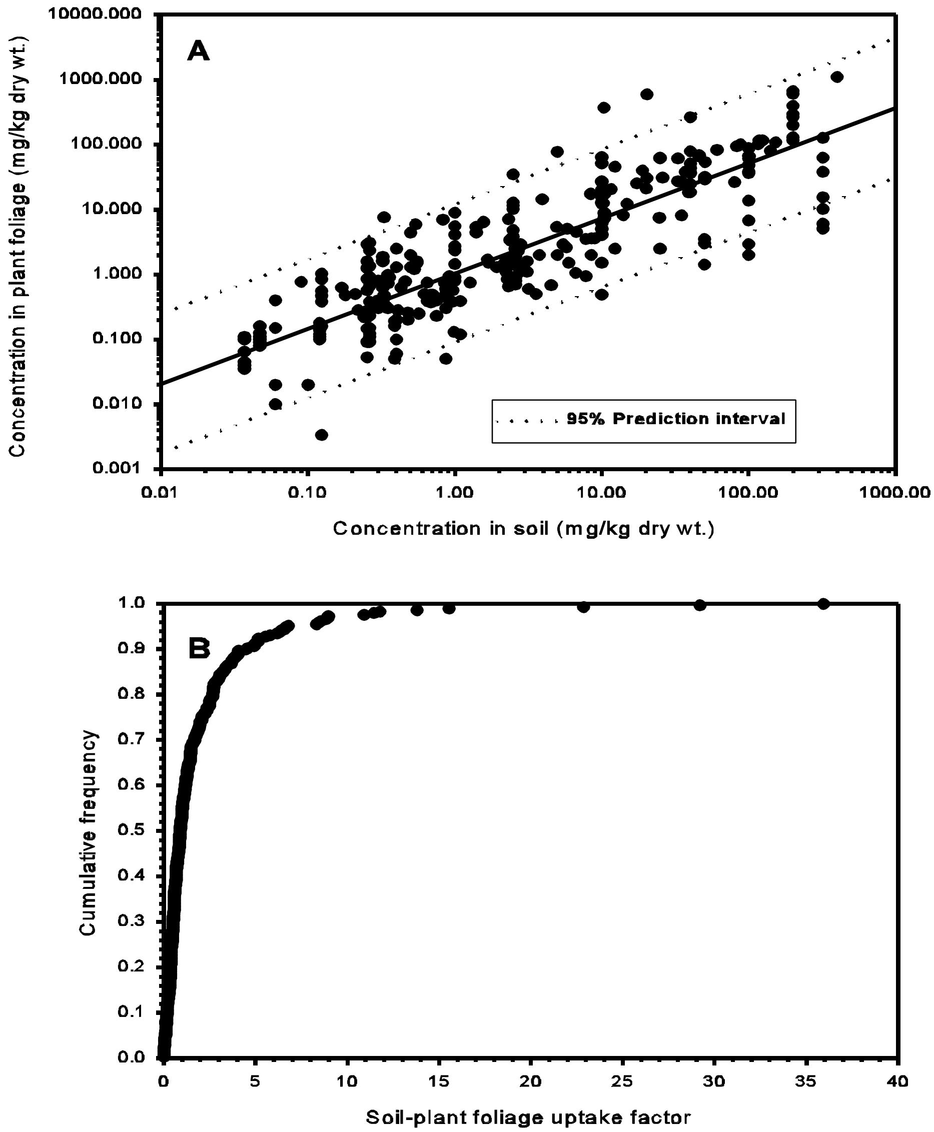


**Figure 13. Literature-derived data on accumulation of Cd by terrestrial plants. A) log-log scatterplot of Cd concentration in soil versus Cd concentration in above ground tissues (excluding fruits or seeds). Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix B.**

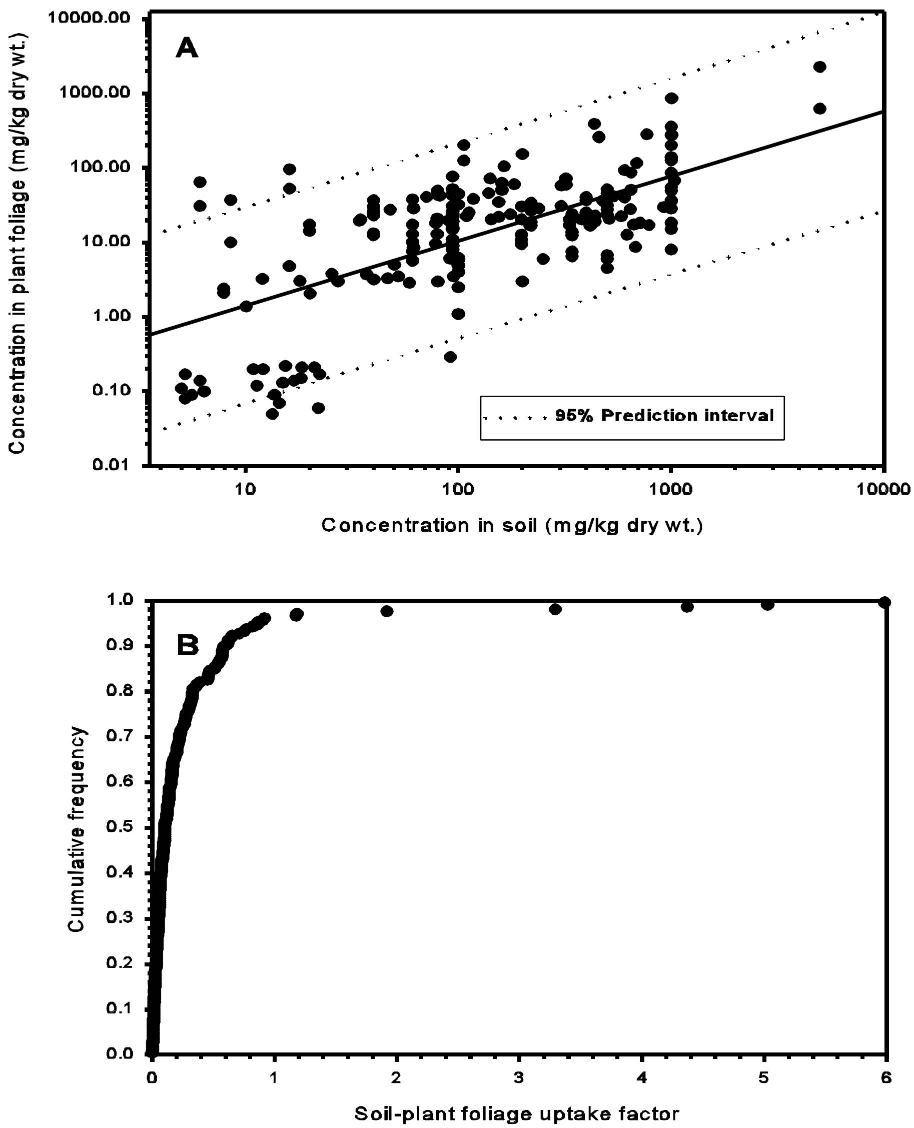


**Figure 14. Literature-derived data on accumulation of Pb by terrestrial plants. A) log-log scatterplot of Pb concentration in soil versus Pb concentration in above ground tissues (excluding fruits or seeds). Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix B.**

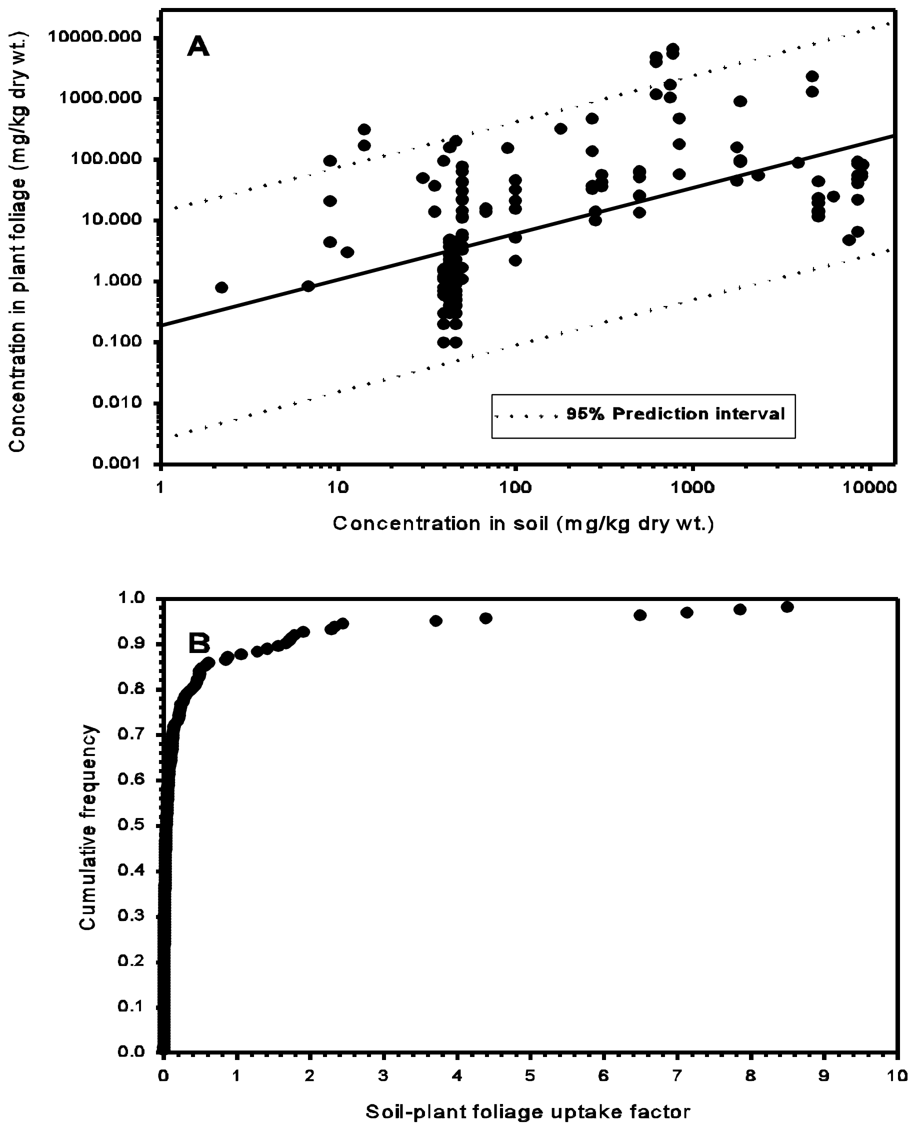


**Figure 15. Literature-derived data on accumulation of Ni by terrestrial plants. A) log-log scatterplot of Ni concentration in soil versus Ni concentration in above ground tissues (excluding fruits or seeds). Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix B.**

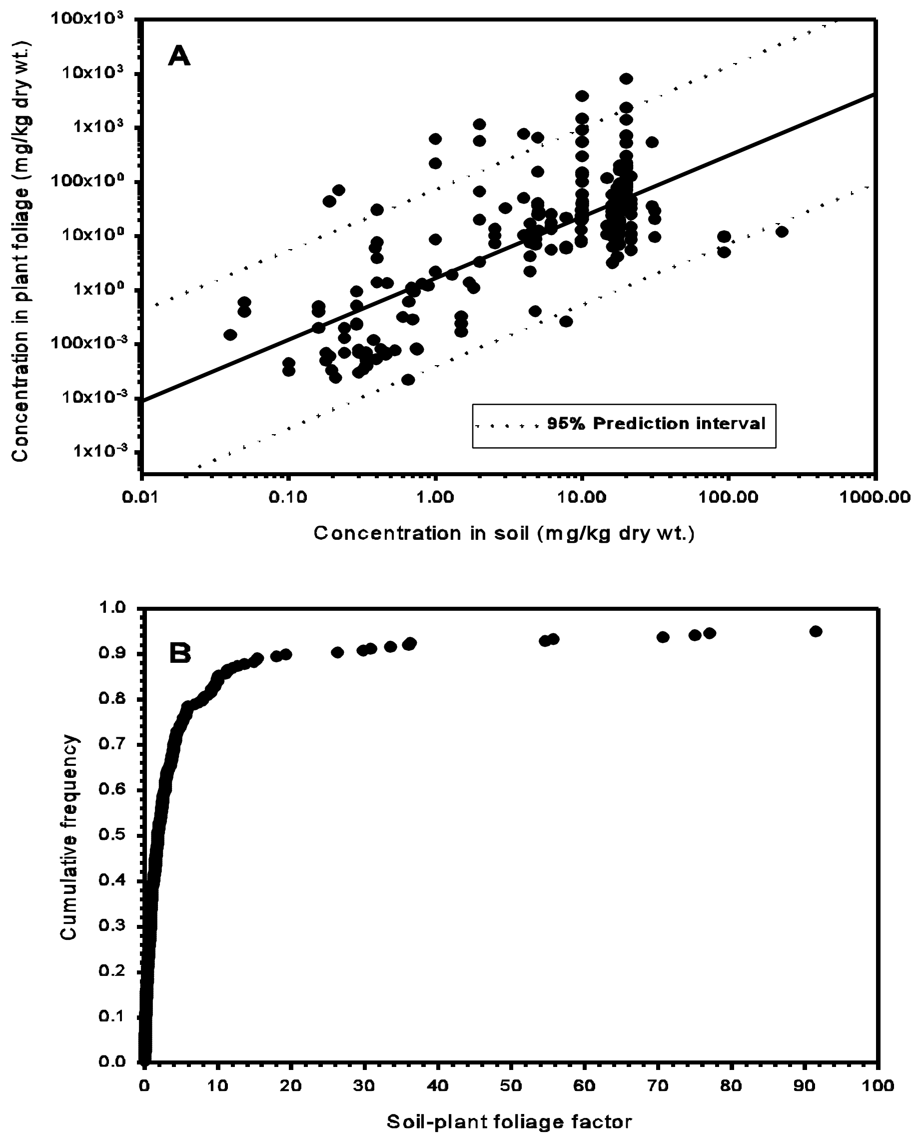


**Figure 16. Literature-derived data on accumulation of Se by terrestrial plants. A) log-log scatterplot of Se concentration in soil versus Se concentration in above ground tissues (excluding fruits or seeds). Line represents regression fit to natural-log transformed data (see Table 8). B) Cumulative frequency distribution for UFs. Summary statistics for UFs are presented in Table 7. Summary of studies considered to evaluate accumulation is presented in Appendix B.**

# APPENDIX A.

## SUMMARY OF CONTAMINANT UPTAKE LITERATURE FOR EARTHWORMS

**Reference:** Andersen 1979
**Analytes considered**: Pb and Cd
**Species**: *A. chlorotica, A. caliginosa, A. longa, A. rosea, and L. terrestris*
**Geographic location of study:** Denmark
**Exposure duration:** Resident
**Worms depurated:** yes
**Analytical method:** Atomic absorption (AA) spectroscopy
**Soil extraction method**: Nitric and perchloric acid
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: pH only
**Purpose of study**: To evaluate the population parameters and uptake of metals by earthworms in areas treated with municipal sewage sludge.
**Study conclusions:** Uptake of lead appears to be related to Ca content of soil.

**Reference:** Andersen and Laursen 1982
**Analytes considered**: Ca, Cd, Fe, Pb, Mn, and Zn
**Species**: *Lumbricus terrestris* and *Aporrectodea longa*
**Geographic location of study:** Denmark
**Exposure duration:** Resident
**Worms depurated:** yes
**Analytical method:** Atomic absorption/x-ray fluorescence
**Soil extraction method**: Nitric/perchloric acid digestions
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: no
**Purpose of study**: To evaluate heavy metal accumulation and distribution throughout earthworm body.
**Study conclusions:** Pb and Cd accumulate in the gut wall and are then transferred to the waste nodules. In *L. terrestris,* more Pb than Cd was transferred to waste nodules. Large amounts of Zn also accumulated in the gut wall. In *L. terrestris* the calciferous glands play a large role in regulation and excretion of heavy metals.

**Reference:** Beyer et al. 1982
**Analytes considered**: Pb, Cd, Cu, Ni, and Zn
**Species**: Not stated
**Geographic location of study:** Pennsylvania
**Exposure duration:** Resident
**Worms depurated:** Yes (mostly–authors estimate that ~75% soil removed from gut)
**Analytical method:** AA spectroscopy
**Soil extraction method**: Nnitric/hydrochloric acid
**Soil characteristics (pH, CEC, % OM, % clay, etc.) presented**: pH, CEC, and % OM
**Purpose of Study**: To evaluate the uptake of metals by earthworms in soils treated with sewage sludge
**Study conclusions:** Earthworm concentrations of Cd and Zn relative to soil, but not Cu, Pb, or Ni. High Zn concentrations in soil were negatively correlated with Cd concentrations in earthworms.

**Reference:** Beyer et al. 1985
**Analytes considered**: Pb, Cd, Cu, and Zn

**Species**: *Dendrobaena rubida and Eisenoides carolinensis*
**Geographic location of study:** Pennsylvania
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectroscopy
**Soil extraction method**: Acid
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: pH, % OM and CEC
**Purpose of study**: To evaluate the uptake and transfer of metals by biota in the vicinity of two zinc smelters.
**Study conclusions:** Metals are accumulated to higher levels by biota nearer the smelters.

**Reference:** Beyer and Cromartie 1987
**Analytes considered**: Pb, Cu, Zn, Cd, Cr, As, and Se
**Species**: Mixed
**Geographic location of study:** Maryland, Pennsylvania, and Virginia
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** Atomic absorption
**Soil extraction method**: Concentrated HCl and $HNO_3$
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: yes
**Purpose of study**: To determine how concentrations in earthworms compare to that in soils from diverse sites.
**Study conclusions:** Correlations between concentrations in soil and those in worms were low. The authors suggest that if worms are to be used as indicators of contamination, it is important to identify worm species, report soil characteristics, and collect similar worms from similar but uncontaminated locations.

**Reference:** Bull et al. 1977
**Analytes considered**: Mercury
**Species**: *Lumbricus terrestris*
**Geographic location of study**: Great Britain
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method**: AA spectroscopy
**Soil extraction method**: Nitric/perchloric acid
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: no
**Purpose of study**: To evaluate the uptake and transfer of mercury in the foodweb near a chlor-alkali plant.
**Study conclusions:** Mercury was found at higher levels in worms near the plant. Methyl mercury concentrations in worms varied from 8 to 13%.

**Reference:** Carter 1983
**Analytes considered**: Cd, Cu, and Zn
**Species**: *A. chlorotica and L. rubellus*
**Geographic location of study:** British Columbia
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectroscopy
**Soil extraction method**: Nitric/hydrochloric acid
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: pH only

**Purpose of study**: To evaluate the uptake and transfer of metals through a pasture food web.
**Study conclusions:** Cd was concentrated by earthworms, invertebrate predators, and herbivorous slugs over that in their foods. Millipedes concentrated Cu and Zn but not Cd.

**Reference:** Corp and Morgan 1991
**Analytes considered**: Cd, Cu, Pb, and Zn
**Species**: *Lumbricus rubellus*
**Geographic location of study:** Great Britain
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectrometry
**Soil extraction method**: $HNO_3$ digestion
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: only pH
**Purpose of study**: compare patterns of metal accumulation in field-collected earthworms at nine contaminated field sites to that in "clean" worms added to soil from the sites. Only data from field-collected worms were used in development of an uptake factor in this report.
**Study conclusions:** (1) Pb, Zn, and Cd concentrations were higher in field-collected worms than in laboratory worms; (2) the relationship between tissue and soil metal concentrations was similar between the two groups of worms; and (3) high soil organic matter reduced Pb bioavailability while low pH increased bioavailability.

**Reference:** Czarnowska and Jopkiewicz 1978
**Analytes considered**: Cd, Cu, Pb, and Zn
**Species**: *Lumbricus terrestris*
**Geographic location of study:** Warsaw, Poland
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectroscopy
**Soil extraction method**: Concentrated acid digestion
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: pH, % OM
**Purpose of study**: To study the uptake heavy metals in worms at increasing distances from Warsaw streets.
**Study conclusions:** Earthworms accumulated all four metals, Cd in particular.

**Reference:** Diercxsens et al. 1985
**Analytes considered**: Polychlorinated biphenyls (PCBs) and Cd, Cr, Cu, Pb, Mn, and Zn
**Species**: not stated
**Geographic location of study:** Germany
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:**
**Soil extraction method**: Aqua regia digestion
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: pH only
**Purpose of study**: To study metal accumulation in earthworms at a nature reserve and at site treated with sewage sludge.
**Study conclusions:** PCB concentrations in worm tissue and gut contents were greater than that in soil. Congener profiles in worm tissue and soil differed. Cd and Zn were also found to be accumulated.

**Reference:** ERT 1987
**Analytes considered**: 2,3,7,8-TCDD and 2,3,7,8-TCDF
**Species**: Not stated
**Geographic location of study:** Wisconsin
**Exposure duration:** Resident
**Worms depurated:** No
**Analytical method:** Mass spectroscopy
**Soil extraction method**:
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: none
**Purpose of study**: To evaluate the uptake of TCDD by earthworms in forests treated with paper mill sludge.
**Study conclusions:** Earthworm abundance was greater in sludge treated plots than in untreated plots. In treated plots, TCDD was accumulated to levels 3.3 times (on average) greater than that in soil.

**Reference:** Fisher and Koszorus 1992
**Analytes considered**: As, Hg, and Se
**Species**: *Eisnia fetida*
**Geographic location of study:** Laboratory
**Exposure duration:** 8 weeks
**Worms depurated:** Yes
**Analytical method:** X-ray spectrometry
**Soil extraction method**: Not stated
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: no
**Purpose of study**: To evaluate sublethal effects, uptake, and elimination of contaminants by earthworms.
**Study conclusions:** In general, accumulation rates decreased as soil concentrations increased.

**Reference:** Gish and Christensen 1973
**Analytes considered**: Cd, Ni, Pb, and Zn
**Species**: Mixed species, not differentiated
**Geographic location of study:** Maryland, near Washington DC
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectrometry
**Soil extraction method**: HCl digestion
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: yes
**Purpose of study**: To determine whether earthworms near roads are accumulating heavy metals.
**Study conclusions:** Metal accumulations were higher where traffic volume was greatest. Metal residues in soils were positively correlated to soil organic matter. Accumulations of Pb and Zn were sufficiently high to be potentially toxic to worm predators.

**Reference:** Helmke et al. 1979
**Analytes considered**: 29 elements
**Species**: *Aporrectodea tuberculata*
**Geographic location of study:** Wisconsin
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** Neutron Activation
**Soil extraction method**: Not stated

**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: range of pHs in soil only
**Purpose of study**: To evaluate the uptake of contaminants by earthworms in sewage sludge amended soils.
**Study conclusions:** Concentrations of Cd, Cu, and Zn increase with increasing sludge application rate while Se concentrations decrease. Cd appeared to be readily accumulated. Concentrations of Hg and Cr in casts increased with increasing soil concentration while tissue concentrations did not, suggesting that these elements were not bioavailable.

**Reference:** Hendriks et al. 1995
**Analytes considered**: Cd, Cu, Mn, Ni, Pb, and Zn
**Species**: *Lumbricus rubellus*
**Geographic location of study:** Netherlands
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectroscopy
**Soil extraction method**: Nitric acid digestion
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: not stated
**Purpose of study**: To evaluate the uptake and transfer of contaminants in the Rhine river floodplain.
**Study conclusions:** Accumulation of metals by worms was comparable to that seen in other studies.

**Reference:** Ireland 1979
**Analytes considered**: Ca, Cd, Cu, Pb, Mn, and Zn
**Species**: *Lumbricus rubellus, Dendobaena veneta,* and *Eiseniella tetraedra*
**Geographic location of study:** Great Britain
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectrometry
**Soil extraction method**: $HNO_3$ digestion
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) pPresented**: none
**Purpose of study**: To study metal accumulation in earthworms at metal contaminated sites.
**Study conclusions:** *Lumbricus rubellus* accumulated and retained Pb. Cu, Zn, and Mn appeared to be regulated by the worms irrespective of soil concentrations.

**Reference:** Kreis et al. 1987
**Analytes Considered**: PCBs
**Species**: *Nicodrilus*
**Geographic Location of Study:** Switzerland
**Exposure Duration:** Resident
**Worms Depurated:** yes
**Analytical Method:** GC
**Soil Extraction Method**:
**Soil Characteristics (pH, CEC, % OM, % Clay, etc.) Presented** :
**Purpose of Study**: to evaluate PCB uptake at sites treated with sewage sludge.

**Reference:** Ma 1982
**Analytes considered**: Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn
**Species**: *Allolobophora caliginosa*
**Geographic location of study:** Netherlands

**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectroscopy
**Soil extraction method**: HCl digestion
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: pH, CEC, % OM
**Purpose of study**: To study the role of soil physicochemical properties on bioavailability of heavy metals to earthworms.
**Study conclusions:** The order in which *A. caliginosa* accumulated metals was Cr<Mn≤Fe<Ni<Pb≤Cu<Zn<Cd. The ratio of concentrations in worms to that in soil was negatively correlated to CEC for Cd, Cu, Fe, Mn, Ni, Pb, and Zn but not for Cr, which was poorly taken up. There was a negative pH effect on the uptake of Cd, Zn, and Pb. Soil pH was more important than CEC for Cd and Zn; pH and CEC were equally important for Pb. Cu uptake was affected by CEC but not by pH; soil Cu was the most important factor affecting the level of Cu in worms.

**Reference:** Ma 1987
**Analytes considered**: Cd, Cu, Pb, and Zn
**Species**: *Lumbricus rubellus*
**Geographic location of study:** Netherlands
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectroscopy
**Soil extraction method**: HCl digestion
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: pH, CEC, % OM
**Purpose of study**: To study the uptake and transfer of heavy metals from soil through earthworms to moles.
**Study conclusions:** Accumulated levels in earthworms and moles do not consistently reflect metal levels in soil. In acidic, sandy soils, Cd may accumulate in worms, and critical levels to moles may be exceeded even when the soil levels are relatively low. Pb is also more readily accumulated by worms and moles associated with acidic soils than limed soils. There is no evidence to suggest that Cd, Pb, or Zn have any influence on Cu tissue levels in either worms or moles.

**Reference:** Martinucci et al. 1983
**Analytes considered**: 2,3,7,8-TCDD
**Species**: *A. rosea and A. caliginosa*
**Geographic location of study:** Seveso, Italy
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:**
**Soil extraction method**: Not stated
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: no
**Purpose of study**: To evaluate the uptake of TCDD by earthworms.
**Study conclusions:** Earthworms accumulated TCDD to levels 14.5 times (on average) higher than that in soil. No interspecies differences in accumulation were observed. Earthworm activity may serve to bring TCDD back to the soil surface. Tissue levels generally do not appear to be toxic to the worms.

**Reference:** Morgan and Morgan 1991
**Analytes considered**: Ca, Cd, Pb, and Zn
**Species**: *Lumbricus rubellus*

*Dendrodrilus rubidus*
**Geographic location of study:** Great Britain (England and Wales)
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA
**Soil extraction method**: Concentrated $HNO_3$
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: no
**Purpose of study**: To determine if there are interspecies differences in accumulation in two sympatric, ecologically similar species at ten different locations.
**Study conclusions:** *L. rubellus* contained higher Zn and Ca and lower Pb and Cd than *D. rubidus*. Pb accumulation by both species was higher in soils with lower Ca.

**Reference:** Morgan and Morris 1982
**Analytes considered**: Ca, Cd, Pb, and Zn
**Species**: *Lumbricus rubellus and Dendrobaena rubidus*
**Geographic location of study:** Abandoned lead mine in Wales, Great Britain
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectrometry
**Soil extraction method**: $HNO_3$ digestion
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: only pH
**Purpose of study**: Determine internal distribution of heavy metals in the earthworm.
**Study conclusions:** The two worm species accumulate metals to different degrees.

**Reference:** Pietz et al. 1984
**Analytes considered**: Pb, Cd, Cr, Cu, Ni, and Zn
**Species**: Mix of species
**Geographic location of study:** Fulton Co., IL
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectroscopy
**Soil extraction method**: Nitric/sulfuric acid
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: pH presented (but insufficient information to relate values to correct sample locations).
**Purpose of study**: To evaluate the uptake of metals by earthworms at mine sites amended with sewage sludge.
**Study conclusions:** Cd and Zn were accumulated to levels greater than that in soil; Cr, Cu, Ni, and Pb were not. Cr in earthworms was negatively related to soil pH.

**Reference:** Pizl and Josens 1995
**Analytes considered**: Pb, Cd, Cu, and Zn
**Species**: *A. chlorotica, A. caliginosa, A. icterica, A. rosea, L. castanea, L. rubellus, and L. terrestris*
**Geographic location of study:** Brussels Belgium
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectroscopy
**Soil extraction method**: Nitric acid

**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: pH, P, K, Mg, Na, and Ca
**Purpose of study**: To evaluate the population parameters and uptake of metals by earthworms along a gradient of urbanization.
**Study conclusions:** Earthworm density was negatively correlated to soil Cd and Mg concentrations. Biomass was negatively correlated with Pb, Cu, and Zn and positively with distance from city center. Intergeneric differences in accumulation were observed: *Aporrectodea* spp. accumulated Cd and Pb more readily than did *Lumbricus* spp.

**Reference:** Talmage and Walton 1993
**Analytes considered**: Hg
**Species**: Not stated
**Geographic location of study:** East Tennessee (Oak Ridge Reservation)
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** X-ray fluorescence, neutron activation, and AA spectroscopy, depending on concentration
**Soil extraction method**: Nitric/perchloric acid
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: no
**Purpose of study**: To evaluate the uptake, transfer, and toxicity of inorganic mercury at a contaminated site.
**Study conclusions:** Small amounts of mercury were taken up by earthworms. Hg accumulation by shrews approached nephrotoxic levels.

**Reference:** Van Hook 1974
**Analytes considered**: Cd, Pb, and Zn
**Species**: *Alabophera spp., Lumbricus spp.,* and *Octalasium*. Species not differentiated.
**Geographic location of study:** East Tennessee (Oak Ridge Reservation)
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** Isotope dilution spark source mass spectrometry
**Soil extraction method**: Aqua regia
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) pPresented**: no
**Purpose of study**: To evaluate the differential accumulation of Cd, Pb, and Zn from six soil types in East Tennessee.
**Study conclusions:** The earthworm species studied accumulated Cd and Zn to levels higher than that in soil but not Pb.

**Reference:** Van Rhee 1977
**Analytes considered**: Cu
**Species**: Mix of species
**Geographic location of study:** Netherlands
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** AA spectroscopy
**Soil extraction method**: Not stated
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: no
**Purpose of study**: To evaluate the uptake of Cu by earthworms in pastures treated with Cu-contaminated pig wastes.

**Study conclusions:** Earthworm density was not related to soil Cu, but Cu in worm tissue was highly correlated to that in soil.

**Reference:** Yeates et al. 1994
**Analytes considered**: As, Cr, and Cu
**Species**: *A. rosea and L. rubellus*
**Geographic location of study:** New Zealand
**Exposure duration:** Resident
**Worms depurated:** Yes
**Analytical method:** X-ray fluorescence spectroscopy
**Soil extraction method**: Not stated
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented**: pH only
**Purpose of dtudy**: To evaluate effects of surface runoff from a CCA wood-treatment plant on soil biota.
**Study conclusions:** Earthworms were absent from the site with the highest CCA concentrations. Bioconcentration of As, Cr, or Cu was not observed in either worm species (tissue levels were lower than soil levels).

# APPENDIX B.

## SUMMARY OF CONTAMINANT UPTAKE LITERATURE FOR PLANTS

**Reference:** Burton et al. 1984
**Analytes considered:** Cd, Cu, and Pb
**Species:** Sitka spruce (*Picea sitchensis*) seedlings
**Category of species (Grass, Herb, Shrub, Tree):** Tree
**Geographic location of study:** Greenhouse using acidic peaty gley soils from South Wales, with quartz sand added
**Exposure duration:** 0, 3, 17, 31, 59, 100 days
**Soil extraction and analytical method:** Perchloric-nitric acid mixture, and flame atomic absorption
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH, C content, total N, extractable ammonium N, extractable nitrate N
**Plant extraction and analytical method:** Nnitric/perchloric acid and flame atomic absorption
**Plant part analyzed:** Roots and shoots
**Purpose of study:** To investigate uptake and toxicity of heavy metals on sitka spruce.
**Study conclusions:** Uptake of Cd and Pb by roots and shoots increased with increasing concentrations in soil, but copper uptake appeared to be independent of soil concentration. No metal interactions were observed.

**Reference:** Carlson and Bazzaz 1977
**Analytes considered:** Pb and Cd
**Species:** American sycamore (*Plantanus occidentalis* L.)
**Category of species (Grass, Herb, Shrub, Tree):** Tree
**Geographic location of study:** University of Illinois experimental farms at Urbana, 3-L pots containing Drummer silty clay loam with one part "Perlite" per six parts soil
**Exposure duration:** 90 days
**Soil extraction and analytical method:** Known metal additions
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** None (that could be obtained from the University of Illinois)
**Plant extraction and analytical method:** AA
**Plant part analyzed:** Foliage, new stems, and woody stems
**Purpose of study:** To investigate the accumulation and toxicity of Cd and Pb in sycamore, as well as the interaction of the metals.
**Study conclusions:** "Heavy metal accumulation by plant parts increased with soil treatment levels but was much lower than values previously reported in the literature."

**Reference:** Carlson and Rolfe 1979
**Analytes considered:** Cd, Pb
**Species:** Rye grass (*Lolium perenne* L.) and red fescue (*Festuca rubra* L.)
**Category of species (Grass, Herb, Shrub, Tree):** Grass
**Geographic location of study:** Pot study in glass house in Illinois
**Exposure duration:** 10, 20, 30 days
**Soil extraction and analytical method:** Known treatment additions
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH and CEC
**Plant extraction and analytical method:** HCL and AA methods

**Plant part analyzed:** Clippings 2.5 cm aboveground
**Purpose of study:** To investigate the accumulation and effects of Cd and Pb on growth of rye grass and red fescue, the interaction of the metals, and the effects of fertilization.
**Study conclusions:** The accumulation of Cd in plants treated with two metals was greater than that of plants to which Cd only was added, while the addition of Cd did not increase uptake of Pb by plants. Fertilization increased uptake of Cd in both plant species but reduced the uptake of Pb in rye.

**Reference:** Gildon and Tinker 1983
**Analytes considered:** Cd and Zn
**Species:** White clover, [onion (*Allium cepa* $F_1$ hybrid var. Hygro) in paper but not uptake statistics]
**Category of species (Grass, Herb, Shrub, Tree):** Grass and root vegetable
**Geographic location of study:** Pots at Woburn farm of Rothamsted Experimental Station, UK
**Exposure duration:** 5 or 10 weeks
**Soil extraction and analytical method:** Known additions, also 0.5 M acetic acid extractions, and AA spectroscopy
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:**
**Plant extraction and analytical method:** AA spectroscopy
**Plant part analyzed:** Shoots and roots
**Purpose of study:** To examine the effects of heavy metals on infection of onions with vesicular-arbuscular mycorrhizal fungus. Secondarily, uptake of cadmium by white clover was measured in the absence of the fungi.
**Study conclusions:** Uptake of Cd increased with Cd concentration in soil, but not linearly.

**Reference:** He and Singh 1994
**Analytes considered:** Cd
**Species:** Oat (*Avena sativa L.*), ryegrass (*Lolium multiflorum L.*), carrot (*Daucus carota L.*), and spinach (*Spinacia oleracea L.*)
**Category of species (Grass, Herb, Shrub, Tree):** Grass and herb
**Geographic location of study:** Pots containing soil collected from Aas and Elverum, southeastern Norway
**Exposure duration:** 55 to 73 days
**Soil extraction and analytical method:**
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH range created by liming, % C, % clay, % silt, % sand, P
**Plant extraction and analytical method:**
**Plant part analyzed:** Oat straw and grain, ryegrass, carrot tubers and leaves, and spinach tops
**Purpose of study:** To investigate the uptake of Cd by various crops in the presence of different P fertilizers.
**Study conclusions:** Cd concentrations in crops generally increased with decreasing pH. Cd-containing NPK fertilizers increased the Cd concentration in plants. Crop yield was not affected much by fertilization or liming.

**Reference:** Haghiri, F. 1973
**Analytes considered:** Cd
**Species:** Lettuce (*Latuca sativa* L.), celery (*Apium graveolens* L.), green pepper (*Capsicum frutescens* L.), radish (*Raphanus sativus* L.), soybean (*Glycine max* L.), and wheat (*Triticum aestivum* L.)
**Category of species (Grass, Herb, Shrub, Tree):** Herb and grass
**Geographic location of study:** Pots containing Marengo silty clay loam, probably from Ohio
**Exposure duration:** 5 weeks

**Soil extraction and analytical method:** Known quantity of Cd added
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH, organic matter content and CEC
**Plant extraction and analytical method:** $HClO_4/HNO_3$, AA spectroscopy
**Plant part analyzed:** Soybean and wheat tops
**Purpose of study:** To investigate the uptake of Cd by agricultural plants.
**Study conclusions:** Cd accumulation by plant tops increased and yield decreased with increasing concentrations of Cd in soil. In the vegetables tested, Cd uptake was highest for lettuce, then radish tops, celery stalks, celery leaves, green pepper, and radish roots. In soybean tops and beans, Cd accumulation was highest in the stem, followed by leaves, pods, and beans.

**Reference:** Heggo et al. 1990
**Analytes considered:** Zn, Cu, Zn, Mn, and Fe
**Species:** Soybean (*Glycine max* L. Merr. "Essex")
**Category of species (Grass, Herb, Shrub, Tree):** Herb
**Geographic location of study:** Pots containing silt loam soils in greenhouse near Zn smelter at Palmerton, PA
**Exposure duration:** 6 weeks
**Soil extraction and analytical Method:** Nitric/perchloric acid and AA (DTPA extractions also available)
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH
**Plant extraction and analytical method:** Sulfuric/perchloric acid
**Plant part analyzed:** Leaves, stems, and roots
**Purpose of study:** To study the effect of mycorrhizal fungi on the uptake of metals from soils near a zinc smelter by soybeans. Treatments included sterilization with fungi added, with soil bacteria added, or with no additions. Data used for uptake factor calculations were from sterilized soil.
**Study conclusions:** The mycorrhizae treatment led to decreased concentrations of Zn, Cd, and Mn in plant leaves at high soil concentrations. The fungi increased foliar concentrations of the metals in low-metal soils. The presence of mycorrhizae increased plant biomass and concentrations of P and N in leaves.

**Reference:** Hutchinson et al. 1974
**Analytes considered:** Pb, Cd, Zn, Cu, and Ni
**Species:** Lettuce, radish, corn, oat, onion, carrot, and parsnip
**Category of species (Grass, Herb, Shrub, Tree):** Herb and grass
**Geographic location of study:** Holland Marsh muck soil area, Ontario
**Exposure duration:** Harvest maturity
**Soil extraction and analytical method:** Nitric/perchloric acid, AA
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:**
**Plant extraction and analytical meNhod:** nitric/perchloric acid, AA
**Plant part analyzed:** Shoot and root
**Purpose of study:** To determine the uptake of several metals from a muck soil by crops and human growers.
**Study conclusions:** Copper was less bioavailable than other metals, with the order being Cu, Ni, Pb, Zn, and Cd. The foliage of salad and leaf crops accumulated the most Cd and Pb.

**Reference:** Jiang and Singh 1994
**Analytes considered:** As (sodium arsenite, disodium hydrogen arsenate)
**Species:** Ryegrass (*Lolium perenne L.*) And barley (*Hordeum vulgare L.*)
**Category of species (Grass, Herb, Shrub, Tree):** Agricultural herb and grass
**Geographic location of study:** Greenhouse using soils collected from Aas, Norway

**Exposure duration:** < 1 year
**Soil extraction and analytical method:** no As extracted, backgound below detection
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH, clay organic carbon, Fe, Al, and P
**Plant analytical method:** Gutzeit method: reaction of H and As (with Zn as catalyst) to produce arsine
**Plant part analyzed:** Straw and grains
**Purpose of study:** As the authors state, "this work was undertaken to study: (1) the effect of arsenite and arsenate forms of As on crop yield and the As uptake by ryegrass . . . and barley . . . grown in two soils of different texture; (2) the residual effect of the As forms initially applied; (3) As uptake by these crops from a NPK fertilizer containing varying levels of As as influenced by liming, soils texture, and P application."
**Study conclusions:** Arsenic uptake by crops was much higher in sand than in loam. Arsenic concentration in barley straw was much higher **than** in barley grain. The availability of As to crops tended to decrease with aging of the chemical in years two and three. Under some conditions, As uptake by barley was higher when arsenite was the source rather than arsenate. Added P significantly increased uptake of As by ryegrass but not by barley. High rates of As application caused a yield reduction in crops, especially of barley in the sand.

**Reference:** John 1973
**Analytes considered:** Cd
**Species:** Broccoli/cauliflower (*Brassica oleracea* L.), oat (*Avena sativa* L.), leaf lettuce (*Lactuca sativa* L., cv. crispa), spinach (*Spinacia oleracea* L.), pea (*Pisum sativum* L.), radish (*Raphanus sativus* L.), and carrot (*Daucus carota* L., cv. *sativa)*
**Category of species (Grass, Herb, Shrub, Tree):** Herb
**Geographic location of study:** Pots containing soil from the Ap horizon of Hazelwood silt loam from Lower Fraser Valley of British Columbia, Canada
**Exposure duration:** 35 to 130 days, depending on species maturity
**Soil extraction and analytical method:** Known quantity added
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH, % oxidizable organic matter, CEC, and base saturation
**Plant extraction and analytical method:** Nitric-perchloric acid mixture AA spectroscopy
**Plant part analyzed:** broccoli/cauliflower leaf; oat stalk, leaf, and husk; lettuce, leaf; spinach, leaf; pea, vine; radish, top; and carrot, top
**Purpose of study:** To investigate Cd uptake by various parts of food crops.
**Study conclusions:** In edible plant parts, the highest Cd accumulation was in lettuce and spinach leaves, followed by uptake in brassica tops, radish and carrot tubers, pea seeds, and oat grains. Yields of some parts were reduced by Cd phytotoxicity.

**Reference:** Khan and Frankland 1983
**Analytes considered:** Cd, Pb, and Zn
**Species:** Radish (*Raphanus sativa* L. cv Cherry Belle)
**Category of species (Grass, Herb, Shrub, Tree):** Herb
**Geographic location of study:** Columns of brown earth soils from Dytchleys Field Station near Brentwood and from Weald Country Park, Essex, UK
**Exposure duration:** 42 days
**Soil extraction and analytical method:** Hot $HNO_3$ followed by aqua regia ($HCl/HNO_3$), EDTA extractions also available; and AA spectrophotometry
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH and soil horizon
**Plant extraction and analytical method:** 2M $H_2$SO4 followed by 6M HCl, followed by conc. Hcl; AA spectrophotometry

**Plant part analyzed:** Roots and shoots
**Purpose of study:** To determine the toxic effects of cadmium and lead on radish plants and their movement through the soil profile and uptake by the plant.
**Study conclusions:** Lead was less mobile than Cd. Cd was accumulated more by the plant shoot and Pb by the plant root. When Cd or Pb caused phytotoxicity, Zn levels in the plant were close to deficient values. Cd toxicity caused chlorosis, while Pb toxicity caused reduced growth.

**Reference:** Lagerwerff 1971
**Analytes considered:** Cd, Pb, Zn
**Species:** Radish
**Category of species (Grass, Herb, Shrub, Tree):** Herb
**Geographic location of study:** Pots containing soil sampled from three locations near roads, probably in Maryland
**Exposure duration:** Maturity
**Soil extraction and analytical method:** 1 N HCl (provide correction factor for estimating total concentrations of cadmium and lead), and AA spectroscopy
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH (altered)
**Plant extraction and analytical method:** Acid digestion and AA spectroscopy
**Plant part analyzed:** Tops and roots
**Purpose of study:** To investigate the uptake of the three metals by radish and the yield in the presence of metals. Treatments included exposure to light aerial contamination (200 m from a road) and indoor separation from air pollution.
**Study conclusions:** In general, yield increased with metal addition to the soil, perhaps because of zinc deficiency. "The content of each metal in the plants increased by only a fraction of the increase in the soil metal content." Increasing the pH from 5.9 to 7.2 led to a decrease in metal content and yield of radish. The accumulation of metals by the plants grown outside (in air contamination) was significantly higher than that of plants grown inside. The authors estimate contributions of air contamination to accumulation.

**Reference:** Lamersdorf et al. 1991
**Analytes considered:** Pb and Hg
**Species:** Norway spruce (*Picea abies*)
**Category of species (Grass, Herb, Shrub, Tree):** Tree
**Geographic location of study:** Northwest Germany
**Exposure duration:** Indefinite
**Soil extraction and analytical method:** $HNO_3$ and AA spectroscopy
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** CEC and pH
**Plant extraction and analytical method:** $HNO_3$ and AA spectroscopy
**Plant part analyzed:** Needle
**Purpose of study:** To calculate a mass balance of metals at a forest site. Uptake was measured in needles, branches (bark/cortex), stem (bark/cortex/wood), fine roots (vital/subvital), and roots (cortex/wood). Only needles were used to calculate the uptake factor for this report.
**Study conclusions:** The concentration of cadmium in needles was similar to that in the humus layer. Lead in needles was significantly lower.

**Reference:** MacPhee et al. 1960
**Analytes considered:** As, DDT, BHC, chlordane, and parathion
**Species:** Carrot, bean, and pea

**Category of species (Grass, Herb, Shrub, Tree):** Herb and root crop
**Geographic location of study:** Experimental plots, Kentville, Nova Scotia
**Exposure duration:** < 1 year
**Soil extraction and analytical method:** Stated in Chisolm et al. 1955, Can. J. Agr. Sci. 35:433-439
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** None
**Plant extraction and analytical method:** Stated in Chisolm et al. 1955, Can. J. Agr. Sci. 35:433-439
**Plant part analyzed:** Seeds, pods, vines, and leaves
**Purpose of study:** To study the persistence and effects of pesticides in soil.
**Study conclusions:** Uptake of arsenic increased with concentration in soil.

**Reference:** Miles and Parker 1979.
**Analytes considered:** Cd, Pb, Zn, and Cu
**Species:** Little bluestem (*Andropogon scoparius*) and black-eyed Susan (*Rudbeckia hirta*)
**Category of species (Grass, Herb, Shrub, Tree):** Herb
**Geographic ;ocation of study:** Ggreenhouse experiment using soils from rural and urban locations, probably in or near Indiana
**Exposure duration:** 12 weeks
**Soil extraction and analytical method:** Nitric acid digestion (also DTPA) and AA spectroscopy
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH, organic matter, CEC, N, K, and P
**Plant extraction and analytical method:** Nitric acid digestion (also DTPA) and AA spectroscopy
**Plant part analyzed:** Top and root
**Purpose of study:** To study toxicity (germination and growth) and uptake of heavy metals in two plants.
**Study conclusions:** Increases in soil concentrations led to increases in plant concentrations (tops and roots). Uptake was usually greater for black-eyed Susans than for little bluestems. Accumulation was usually higher when rural soils were used than when urban soils were used. Cadmium was readily translocated from root to shoot in black-eyed Susans.

**Reference:** Miller et al. 1976
**Analytes considered:** Cd
**Species:** Soybean (*Glycine max* L. Merr. var. Amsoy)
**Category of species (Grass, Herb, Shrub, Tree):** Herb
**Geographic location of study:** Pots containing the surface horizon of nine agricultural soils from Illinois
**Exposure duration:** 4 weeks
**Soil extraction and analytical method:** Known addition of Cd
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH, CEC, and P
**Plant extraction and analytical method:** Ashed, boiling 3N Hcl, and AA spectroscopy
**Plant part analyzed:** Shoots
**Purpose of study:** To investigate the uptake of Cd and the effects of the metal on yields of soybean. Soils with a range of cation exchange capacities, pHs, and available soil P were used.
**Study conclusions:** Cd uptake and growth inhibition was highest in low-pH soils. The concentration of Cd in the shoots was significantly correlated with soil CEC, Bray $P_1$ test for available soil P, and the interaction of CEC X pH, the interaction of the $P_1$ test X pH, the soil Cd concentration, and the dry weight of the shoots. No correlation was observed between soil pH and accumulation.

**Reference:** Miller et al. 1977
**Analytes considered:** Cd and Pb
**Species:** Corn (*Zea mays* L., Wf9 x M14)

**Category of species (Grass, Herb, Shrub, Tree):** Herb
**Geographic location of study:** Pots containing soil that was probably from Illinois
**Exposure duration:** 10, 17, 24, and 31 days
**Soil extraction and analytical method:** Known chemical addition
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:**
**Plant extraction and analytical method:** Ashed, 3N Hcl and AA
**Plant part analyzed:** Shoots
**Purpose of study:** To investigate the uptake of Pb and Cd in corn and the interactive effect of the two chemicals.
**Study conclusions:** Accumulation of Cd was increased by the addition of Pb. Cadium in soil reduced the uptake of Pb.

**Reference:** Otte et al. 1990
**Analytes considered:** As
**Species:** Common reed (*Phragmites australis* (Cav.) Trin. ex. Steud.) and stinging nettle
**Category of species (Grass, Herb, Shrub, Tree):** Grass and herb
**Geographic location of study:** Flood plains of Dordtsche Biesbosch, Netherlands
**Exposure duration:** Unknown, maybe life of plant
**Soil extraction and analytical method:** 6M HCl or aqua regia ($HNO_3$/HCl)
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** P only
**Plant extraction and analytical method:** $HNO_3$/$HClO_4$ and AAS and MHS hydride system
**Plant part analyzed:** Roots and shoots
**Purpose of study:** To study the uptake of arsenic in the field and under experimental conditions with varying concentrations of phosphate.
**Study conclusions:** Plants took up increasing levels of As with increasing concentrations in the soil. Reeds accumulated more As in the roots, and nettles accumulated more in the shoots. Arsenic concentrations in the roots of the nettle were positively correlated with P but negatively correlated with As in the soil. Concentrations of As in the roots of the reed were not correlated with the concentrations of As and P in the soil.

**Reference:** Sadana and Singh 1987
**Analytes considered:** Cd, Pb, and Zn
**Species:** Wheat (*Triticum aestivum* L. var. WL 711)
**Category of species (Grass, Herb, Shrub, Tree):** Grass
**Geographic location of study:** Pots containing loamy soil from Punjab Agricultural University farm at Ludhiana, India
**Exposure duration:** Maturity
**Soil extraction and analytical method:** Known amount added and background metals extracted with 1 N HCl
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH, organic carbon content electrical conductance, and calcium carbonate
**Plant extraction and analytical method:** $HNO_3$:$HClO_4$:H2$SO_4$ = 9:3:1 and AA spectrometry
**Plant part analyzed:** Straw and grain
**Purpose of study:** To investigate the uptake and yield reduction of wheat in metal-polluted soil.
**Study conclusions:** The Cd and Pb accumulation in wheat straw was much higher than in grain; however, the uptake of Zn in grain was higher than in straw.

**Reference:** Sadiq 1985
**Analytes considered** Cd, Pb, Ni, Mn, Cu, Zn, and Fe
**Species:** Corn
**Category of species (Grass, Herb, Shrub, Tree):** Herb
**Geographic location of study:** Saudi Arabia
**Exposure duration:** 1 month
**Soil extraction and analytical method:** Nitric-perchloric acid (also DTPA extraction)
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH
**Plant extraction and analytical method:** Nitric-perchloric acid
**Plant part analyzed:** Whole plant
**Purpose of study:** To study the uptake of 3 metals by corn in 16 calcareous soils.
**Study conclusions:** Cd was accumulated to higher levels than Pb or Ni. Concentrations of Cd, Mn, Cu, and Zn in corn (but not Ni or Pb) were significantly correlated to the DTPA-extractable metal in soil.

**Reference:** Sadiq 1986
**Analytes considered:** As
**Species:** Corn
**Category of species (Grass, Herb, Shrub, Tree):** Herb
**Geographic location of study:** Saudi Arabia
**Exposure duration:** 25 days
**Soil extraction and analytical method:** Known quantity of As added to soil (also DTPA extraction)
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** Electrical conductivity, calcium carbonate equiv., chloride, and bicarbonate-extractable P
**Plant extraction and analytical method:** Nitric-perchloric acid
**Plant part analyzed:** Whole plant
**Purpose of study:** To study the uptake of As by corn in 19 soils.
**Study conclusions:** Concentrations of As in corn plants were significantly correlated to water-extractable As and P in the soil but not to DTPA-extractable or total As.

**Reference:** Severson et al. 1992
**Analytes considered:** As, Ba, Cd, Ce, Co, Cr, Cu, Hg, La, Li, Mn, Ni, Pb, Se, Sr, V, Y, and Zn
**Species:** Dune grass (*Ammophilia arenaria*), dune willow (*Salix repens*), and feather moss (*Hylocomium splendens*)
**Category of species (Grass, Herb, Shrub, Tree):** Grass and shrub
**Geographic location of study:** Frisian Islands, Germany
**Exposure duration:** Indefinite, lifetime of plant
**Soil extraction and analytical method:** Extraction method not stated. ICP-AES used for all elements except for As and Se, determined using hydridegeneration AA spectroscopy and Hg, determined using AA spectroscopy.
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) pPresented:** pH, %C, Al, and Fe
**Plant extraction and analytical method:** Extraction method not stated. ICP-AES used for all elements except for As and Se, determined using hydride generation AA spectroscopy and Hg, determined using AA spectroscopy.
**Plant part analyzed:** Stems and leaves at 10 cm above surface (dune grass) and leaves from willow shrubs
**Purpose of study:** To measure element concentrations in soil and vegetation of the Frisian Islands.
**Study conclusions:** Concentrations permit the calculation of uptake factors. Most element concentrations (except possibly Hg and Pb in soil) do not suggest anthropogenic sources of contamination.

**Reference:** Wallace et al. 1977
**Analytes considered:** Cd, Mn, Fe, Cu, and Zn
**Species:** Bush bean (*Phaseolus vulgaris* L. var. “Improved Tendergreen”) and corn (*Zea mays* L. var, “Golden Bantam”)
**Category of species (Grass, Herb, Shrub, Tree):** Herb
**Geographic location of study:** Pots of Yolo loam soil, probably from California
**Exposure duration:** 30 days (beans), and 24 days (corn)
**Soil extraction and analytical method:** Known addition of Cd
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:**
**Plant extraction and analytical method:** 1/10 N HCl and emission spectrography
**Plant part analyzed:** Leaves and stems or shoots
**Purpose of study:** To investigate Cd uptake in the presence of other metals and chelating agents was investigated. Studies were done in soil or soil solution.
**Study cnclusions:** In solution, Cd always decreased the concentration of Mn in leaves, stems, and roots. In soil, added Cd decreased concentrations of Mn and Cu in foliage. Without the added Cd, chelating agents increased concentrations of Mn, Cu, and Fe in plants. Decreased yields are also discussed.

**Reference:** Xian 1989
**Analytes considered:** Cd, Zn, and Pb
**Species:** Cabbage
**Category of species (Grass, Herb, Shrub, Tree):** Herb
**Geographic location of study:** Greenhouse, Tokyo
**Exposure duration:** 90 days
**Soil extraction and analytical method:** $HNO_3$-$HClO_4$ (total), and other fractions, including exchangeable, carbonate, Fe-Mn oxide, organic, and residual
**Soil characteristics (pH, CEC, % OM, % Clay, etc.) presented:** pH, CEC, organic C, inorganic C, Fe, Mn, and texture
**Plant extraction and analytical method:** $HNO_3$-$HClO_4$ digestion, flame AA spectrophotometer
**Plant part analyzed:** Roots and shoots
**Purpose of study:** To determine uptake of the metals from different soil fractions.
**Study conclusions:** The uptake was related to soil concentration. Metals in exchangeable and organic fractions of soil determined accumulation more than total concentrations of the metals in soil. Uptake factors were higher for Cd than for Zn or Pb, which is notably the order of the solubility of the metals.