What we know

1. Solubility of heavy metals is directly related to sorption capacity of residuals and soil. Soil pH and Fe oxides are very important factors controlling metal solubility in these systems.

Many scientific studies have generated a large body of scientific information on benefits and environmental impacts associated with land application of biosolids and other residuals (Basta, 2000; NRC, 1996; Power and Dick, 2000). Results from these studies have shown that heavy metal solubility and availability in land-applied residuals is governed by fundamental chemical reactions between metal constituents and soil and residual components. Sorption is an important chemical process that regulates partitioning of heavy metals between solution and solid phases in soils. Iron, aluminum, and manganese oxide soil minerals are important sinks for heavy metals in soil and residual-amended soils. Heavy metal cations sorb to soil organic matter (SOM) and other forms of humified natural organic matter (NOM). The type of sorption by NOM affects the environmental fate of heavy metal. Heavy metal cations form sparingly soluble phosphate, carbonates, sulfides, and hydroxides. Sorption and many metal precipitation processes are highly pH dependent with increased sorption with pH. The pH of the soil-residual system is often the most important chemical property governing sorption and precipitation of heavy metals.

2. Key concepts governing phytoavailability of heavy metals in residual-treated soil are (i) the plateau effect, (ii) the salt effect, and (iii) the soil-plant barrier.

Application of residuals to soil affects phytoavailability by introducing heavy metal into the soil and/or redistributing heavy metals into different chemical pools that vary in phytoavailability (Alloway and Jackson, 1991). Soil extraction methods are available to access changes in heavy metal availability in soils treated with residuals. Application of biosolids increases heavy metal solubility and availability in soil. Increases in availability are a function of metal type and metal loading. Plant bioassays show that biosolids increase extractability and plant uptake. Transmission of heavy metals through the food chain is affected by the soil-plant barrier (Chaney and Giordano, 1977). The barrier limits transmission of metal through the food chain either by soil chemical processes that limit solubility (e.g., soil barrier) or by plant senescence from phytotoxicity (e.g., plant barrier). The soil-plant barrier limits transmission of many heavy metals through the soil-crop-animal food chain, except Cd, Zn, Mo, and Se. Cadmium, which has lower affinity for metal-sorbing phases (e.g., oxides, NOM), has the greatest potential for transmission through the food chain in levels that present risk to consumers (Chaney and Ryan, 1994; Chaney et al., 1999). Corey et al. (1987) hypothesis that metal bioavailability in residual-treated soils would show a “plateau” that high residual loadings correspond to the heavy metal sorption capacity of the residual was field tested and confirmed by Jing and Logan (1992). Metal bioavailability studies should be based on residual addition to soil and not based on spiking studies where heavy metal salts are added to soils. The “salt-effect” in soils spiked with metal salts overestimates heavy metal bioavailability.

3. Oxide mineral surfaces are important to determine the long-term environmental fate and bioavailability of heavy metals in residual treated soils.

Heavy metals do not degrade in soil and many are considered persistent bioaccumulative toxins (PBTs). The risk to human and ecosystem health from land-application of PBTs in residuals depends on solubility and bioavailability of these contaminants in the residual-treated soil. Uncertainties exist in the effect of decomposition of soil organic matter complexes that bind metal and uncertainties of the effect of slower long-term reactions between metals adsorbed to inorganic oxide surfaces in soil on metal solubility and bioavailability. Recent research findings show heavy metal is sorbed to oxide phases of biosolids (Hettiarachchi et al., 2002). Heavy metals sequestered to oxide surfaces will likely remain sequestered longer than metal complexed by biosolids NOM. However, the stability of metal sequestered by oxide depends on the metal and the mineral oxide surface. Long-term mineral crystallization reactions may “eject” metals from the solid phase into solution. The long-term stability of sequestered metal bonded to metal oxide surfaces remains uncertain.
What we don’t know (e.g., research needs)

1. We do not have guidelines that set heavy metal loading limits for land application of many nonbiosolid residuals. It is likely that heavy metal loading limits developed for biosolids is not transferable to other residuals. Research is needed to develop land application guidelines with metal loading limits for nonbiosolid residuals.

Increased land application of municipal, industrial, and agricultural wastes will continue to grow because of economic and societal benefits. Research on many residuals is limited or nonexistent and may prevent development of guidelines that allow land application of these materials. Research and guidelines used for biosolids will not be transferable to many residuals with very different chemical properties and behavior.

2. The effect of new information on Part 503 since promulgation of Part 503 is unknown. Limits should be determined for new metals (Tl, Be, W, V) in biosolids not considered by Part 503.

There is a large body of data on heavy metal behavior in biosolids treated soil since the promulgation of Part 503. We do not know what effect consideration of the new data will have on limits for metals considered in Part 503. Since the promulgation of Part 503, data has become available regarding land application of new heavy metals (e.g., Tl, Be, W, V) in biosolids. Limits for the new metals associated with land application of biosolids should be determined using the original Part 503 risk assessment methods.

3. We know very little regarding the effect of residuals on ecological receptors in soil ecosystems or the ability of residuals to reduce or eliminate ecotoxicity in heavy metal contaminated soils.

The effect of residual application on organism health and important biological processes (organic residue recycling, nitrogen fixation, respiration) is a growing concern. Ecological risk assessment will be used to establish guidelines for land application of residuals. Risk-based ecotoxicological research on the effect of soils treated with residuals is needed to develop land application guidelines.

4. A great deal of uncertainty of the long-term environmental fate of heavy metals in land-applied residuals remains. Advanced spectroscopic methods should be used to resolve some of this uncertainty.

A great deal of progress has been made in advancing our understanding of the long-term fate of heavy metals in residual-treated soil in the last two decades. However, there remains a great deal of uncertainty in the environmental fate of heavy metals, and several important issues remain “indeterminate.” Environmental chemistry has seen great advances in analytical instrumentation that allows molecular-based spectroscopic studies. Application of advanced spectroscopic methods has the potential to derive fundamental information on the molecular environment of the heavy metal in residual and residual-treated soils. Information is needed on the molecular level regarding heavy metal sequestration to answer many long-term environmental fate questions.

5. A “holistic” interregional study of “recommended best management practices” to evaluate benefits and potential hazards from long-term application of biosolids is needed.

During the last two decades, more than 2,200 technical papers have been published regarding land application of biosolids. Research findings from these studies have provided the technical basis to plan and design beneficial biosolids land application systems. However, almost all of these studies have been focused on a concern (e.g., heavy metals, nutrients, pathogens, etc.) and do not have a “holistic” approach focusing simultaneously on multiple factors. Few studies are field studies and even fewer are long-term (>5 yr) field studies (Basta, 2000). Many studies focus on “worse-case” scenarios and not “recommended best management practices.” Few studies are interregional addressing different cropping/soil systems across various climatic regimes. Although there are 2,200 technical papers on biosolids, a “holistic” interregional
study of “recommended best management practices” to evaluate benefits and potential hazards from long-term application of biosolids has not been conducted and is needed.

References


