

Soil Toxicity in Cropland Due to Trace Elements Found in Sewage Sludge

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Abstract

Application of sewage sludge to cropland could result in soil contamination, phytotoxicity, and accumulation of trace elements in the food supply. The magnitude of the problem depends on the interrelationships of a number of factors, such as the composition of sludge, the rate and frequency of applications, soil characteristics, and plant species. Sludge type and sludge-soil interactions influence the chemical forms of a metal which determine its availability for plant uptake. Soil is a hostile environment to most bacterial and viral pathogens. Lack of historical evidence of disease outbreaks from application of secondary activated, anaerobically digested, or chemically treated sewage waste indicates that these organisms neither retain virulence nor maintain infective numbers within the soil environment. Wastes should not be applied to root crops during the current growing season or to above-ground crops for 1 month before harvest; and animals should not be allowed to graze an area for 2 to 3 weeks after waste application.

Keywords: Soil; toxicity; cropland; trace element; sewage; sludge.

1. Introduction

Trace elements have been defined as the elements that occur in natural systems in small amounts and that, when present in excessive concentrations, are toxic to living organisms [1]. The plantsoil system has three protective mechanisms that can limit these potentially toxic trace elements in the aerial portions of a plant, and so minimize health problems to animals or humans. The "Soil-Plant Barrier," as it is called,

includes: 1) elements that are insoluble in soil and do not accumulate in the plant (Pb, Hg, Cr, F, Ag, Au, Ti, Sn, Si, and Zr); 2) elements that are absorbed into the root but are insoluble in the root or have limited translocation to the shoot (Fe, Al, and occasionally Hg and Pb); and 3) elements which when applied in excess cause phytotoxicity, so plants are not consumed by man or domestic animals (Zn, Cu, Ni, Co, Mn, As, and B). Not all trace elements present in municipal sewage sludges fall into one of these three categories. Important exceptions are Cd, Se, and Mo which can cause toxicities in animals and humans. Molybdenum and Se are present in sewage sludges in low concentrations, thus these elements normally do not limit the rate of sludge application to soil. The Council for Agricultural Science and Technology [2] classified Cd, Cu, Mo, Ni, and Zn as potential hazards in land application of municipal sewage sludge. However, additional plant and soil factors further modify the uptake and the concentration of elements in crops. These metals tend to accumulate in plants and cause either reduced yields or health problems to animals or humans that ingest the plants.

A number of investigations have been conducted in the greenhouse and in the field to assess the phytotoxicity and availability of potentially toxic elements to plants grown under three different soil conditions: soils treated with sludge, soils treated with sludges supplemented with metal salts, or soils treated with metal salts alone. The concentrations of Cd, Cu, Mn, Ni, Pb, and Zn in the edible parts of lettuce tops (*Lactuca sativa* L.) and onion bulbs (*Allium cepa*) were generally much higher when the plants were grown on sludge-amended soils in the greenhouse rather than when the plants were grown in the field [3]. Moreover, reduced yields and higher Cr, Cu, and Zn concentrations were observed in plants grown in soils treated with additions of inorganic salts than were observed in plants grown in soils treated with equivalent amounts of these metals from sludge additions [4-6]. Therefore, plant data from studies in the greenhouse or from additions of inorganic metal salts should not be used as the only indicator of the potential adverse effects of applying municipal sewage sludge under field conditions. Additional field research is needed to substantiate the findings of these experiments.

2. Sludge Composition

Trace element concentrations in sludges exhibit wide variations from one city to another, from one treatment plant to another within the same city, and from season to season within a single treatment plant [7-14]. The extent and nature of the industrialization in the sanitary district and the pretreatment requirements largely determine the metals that will be present in municipal sewage sludge. Low levels of trace elements in domestic sewage sludge are present from food and human wastes, from plumbing and wastewater transport systems, and from surface runoff [15]. Metals exist in different forms in municipal sewage sludges. Their form depends on the chemical properties of the sludge and on the chemistry of the metal [16]. Using a sequential extraction procedure to fractionate metals, Stover *et al.* [1976] ranked the relative quantities of different forms of Cu, Zn, Pb, Cd, and Ni present in municipal

sewage sludge as follows: Cu: sulfides > carbonates > organic bound = adsorbed > exchangeable; Zn: organic bound > carbonates > sulfides > adsorbed > exchangeable; Pb: carbonates > organic bound > sulfides > adsorbed > exchangeable; Ni: carbonates > organic bound > exchangeable > adsorbed > sulfides; Cd: carbonates > sulfides > organic bound > adsorbed = exchangeable. Less than 17 percent of the total amount of Cu, Zn, Pb, and Cd in sludges and approximately 22 percent of Ni are in the sorbed and exchangeable fractions, that is, the forms readily available to plants. The remainder of the metals is present in forms which require conversion to water-soluble, exchangeable, or sorbed forms before uptake by plants. Different chemical forms of a metal may predominate in different sewage sludges. Thus, the behavior of a metal after incorporation into the soil may not be similar for different sludge [13-16].

3. Sludge-Soil Interaction

Limited information is available on the reactions of metals in municipal sewage sludge with soils, so reactions between metals in sludges and soils are not completely understood. Many researchers have reported that after municipal sewage sludge is incorporated into soil, portions of the metals revert to non-extractable, less available chemical forms [12, 15-16]. After addition to the soil, some metals change only slightly in chemical character. Chromium, which is present as a colloidal precipitate in municipal sewage sludge, changed little in its chemical form. It remained mostly insoluble after incorporation of sludge in soil [17]. The chemical and physical properties of soils that receive sludge influence metal conversions. Soil properties, such as CEC, pH, organic matter content, sesquioxide content, redox potential, texture, and presence of other elements affect plant uptake, solubility, and mobility of these metals [5-8, 11-13]. Not all metals react similarly to changes in these soil properties. For instance, soil pH levels which decrease the availability of metal cations to plants increase the availability of Mo. After incubating the sludge-soil samples for one growing-degree year, the researchers grew barley (*Hordeum vulgare* L.) to measure the quantities of plant-available potentiality toxic metals. Incubation, sludge application rate, and soil pH affected metal accumulation within the roots and tops of barley seedlings. As sludge application rates increased, an increase in the removal of Cr, Ni, Zn, and Pb occurred when barley was grown on the acid soil. However, there was no change in the uptake of these metals when barley was grown on the high pH soil. Thus, with different levels of soil pH, metals released by the decomposition of sewage sludge either increased or decreased in availability for plant uptake. The formation or the strengthening of metal complexes with higher soil pH levels and incubation affects their availability. The presence and the concentrations of other metals can have a pronounced effect on the uptake of the metal in question [17-19]. Cadmium concentration increased in plant tissue as soil Cu levels increased [4]; the levels of Cr, Ni, and Zn also affected the magnitude of the increase. These interactions are extremely complex and are not well understood.

4. Plant Factors

Comparisons between crop species show wide variations in their ability to absorb potentially toxic trace elements from the sludge-soil system. Cereals and legumes accumulated less Cd in shoots than did leafy vegetables, like curlycress (*Lepidium sativum* L.), lettuce (*Lactuca sativa* L.), and spinach (*Spinacia oleracea* L.). Sensitivity of plants to metal toxicity can be associated with the tendency to accumulate the metal in shoots. Some plant species can tolerate high levels of metals in tissue or can confine accumulated metals to the roots and provide resistance to toxicity. Potentially toxic metal concentrations are not the same in all portions of the plant. The specific amount of a trace element taken up by a plant species is directly proportional to the amount of sludge-borne metals added and the growth stage of the crop [11-17].

5. Pathogens

Although no incidence of disease from land application of treated wastes has been reported, bacteria, viruses, and parasites associated with municipal sewage sludges present a potential problem. The concern lies in the transfer of pathogens to humans or grazing animals that ingest plants with sludge-contaminated surfaces. However, "One must be chary of the type of microbiological thinking that equates the mere presence of microbes with illness or the potential for illness. The fact is that illness is an unusually complex phenomenon that does not have a 1:1 relationship to microbes". Sludge-borne bacteria and viruses from land application systems are not a serious threat to health because these pathogens are poor competitors outside the host. The survival of these organisms in the soil depends on a number of environmental factors. Temperature, sunlight, moisture, the availability of organic matter, soil pH, soil particles, and the presence of toxic substances and competitive organisms influence bacteria and virus survival in soils and sewage sludge. Bacteria and viruses are very susceptible to desiccation; therefore, soil moisture is important to the survival of these organisms. Soil is a hostile environment to most bacterial and viral pathogens. Lack of historical evidence of disease outbreaks from application of secondary activated, anaerobically digested, or chemically treated sewage waste indicates that these organisms neither retain virulence nor maintain infective numbers within the soil environment. Although numerous parasitic species are present in municipal sewage sludge, only certain of the parasites are considered potential problems. The potential for parasitic disease transmission by land disposal of sewage sludge is magnified because these forms are extremely resistant and can persist and remain infective for long periods in the soil.

6. Conclusions

The unique composition of sludge and many factors in the soil-plant system that influence the chemical composition and plant uptake of these metals add complexity to solving the problem. The accumulation of trace elements within plants grown on sludge-amended soils is easily measured. However, the quantity of metals, originally present in sewage sludge and eventually absorbed by the plant root, is difficult to

assess. A method which accurately estimates metal availability within the soil needs to be developed and tested under field conditions with a number of different soils and sludge types. Any changes (chemical, physical, or biological) in the chemical forms of sludge-borne metals, which might alter their availability, must be characterized. The reactions with trace elements, which occur after sludge is incorporated into soil and after an extended time has passed, require further investigation. Information about these subjects would increase our knowledge and permit the development of an accurate estimate of the potential health risk from sludge-borne metals. Existing data indicate that pathogenic organisms (bacteria, viruses, or parasites) occur in sludges and, for varying time periods, in sludge amended soils. Transfer of bacteria or viruses to mammals in controlled land application systems is unlikely, because these organisms are unable to survive outside the host for lengthy periods. Certain nematodes and cestodes have the greatest potential for long-term survival outside the host in a resistant egg or cyst stage. Although these pathogenic organisms may be present in sewage sludge, their presence does not assure pathogen transfer to a mammal. Research is needed to determine the virulence of these organisms or to determine the potential for a disease outbreak from controlled land application of treated municipal sewage sludges which contain these organisms.

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