



Soil Amendments for Site Restoration

An Online Continuing Education Course for Engineers

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1.0 INTRODUCTION

Hundreds of thousands of acres of disturbed and contaminated land scar this country's landscape. Some of these lands are in remote locations making cleanup very difficult. Others have minimal funds for cleanup or are so large that cleanup becomes economically impractical. There is a need for cost-effective, low energy technologies that can be applied at these sites. This course provides information on the use of soil amendments, a cost effective *in situ* process for remediation, revitalization, and reuse of many types of disturbed and contaminated landscapes.

This course focuses on amendments that are generally residuals from other processes and have beneficial properties when added to soil. Commonly used amendments include municipal biosolids, animal manures and litters, sugar beet lime, wood ash, coal combustion products such as fly ash, log yard waste, neutralizing lime products, composted biosolids, and a variety of composted agricultural byproducts, as well as traditional agricultural fertilizers. Applied properly, soil amendments reduce exposure by limiting many of the exposure pathways and immobilizing contaminants to limit their bioavailability. The addition of amendments restores soil quality by balancing pH, adding organic matter, increasing water holding capacity, re-establishing microbial communities, and alleviating compaction. As such, the use of soil amendments enables site remediation, re-vegetation and revitalization, and reuse.

Superfund sites, large and small mining sites, landfills, and industrial sites such as refineries, smelters, foundries, milling and plating facilities, and other sites with contaminated or disturbed soils exhibit a variety of problems that often can be addressed effectively and directly through the use of soil amendments. These problems include:

- The toxicity of various soil contaminants, principally metals, can be harmful to plants, soil animals, and soil microbial populations.
- A higher- or lower-than-normal soil pH range can cause soil infertility and cause soil metals (low pH) and oxyanions (e.g., arsenate at high pH) to go into solution.
- Excess sodium (Na) can cause toxicity to plants, a breakdown of soil physical structure, and dispersion, which limits root growth, aeration, and water infiltration through the soil.
- Excess salts (e.g., sulfates and chlorides) limit plant rooting and water and nutrient uptake.
- Changes in soil physical properties, such as density, aggregation, and texture, can reduce water infiltration and the moisture-holding capacity of the soil and stifle efforts to revegetate a site.
- Deficiencies in essential micronutrients like Zn and Mn can lower soil fertility; however, the same elements can be toxic at higher concentrations. In some cases, soil treatments to reduce phytotoxicity of one contaminant may reduce the phytoavailability of another essential element. Adding that nutrient as a companion fertilizer can prevent the deficiency due to the soil treatment.

Although soil amendments and associated enhancements in microbial activity can be used to address volatile and semivolatile contaminants that have left sites barren of vegetation, this course focuses on the use of amendments on sites dominated by inorganic contaminants.

1.1 Background

The bioavailability of contaminants poses a health risk to animals and humans who may be exposed to contaminated sites. Possible exposure pathways include ingestion of contaminated soil or water from the site, direct contact with contaminated soil, inhalation of contaminants adhered to dust in the air, and ingestion of food items (i.e., plants or animals) that have accumulated contaminants from exposure to contaminated soil or water. Managing the risks posed by contaminants at a site involves understanding the possible pathways and applying appropriate remedial measures to mitigate, treat, or remove sources (Ref: 46).

Figure 1 illustrates how soil amendments can help mitigate exposure to contaminants. With the addition of appropriate soil amendments, metals in the amended area are chemically precipitated and/or sequestered by complexation and sorption mechanisms within the contaminated substrate. Metal availability to plants is minimized, and metal leaching into groundwater can be reduced. In certain cases, metal availability below the treated area is also reduced.

Plants stabilize the landscape from erosion, greatly reducing surface water runoff and sediment loss to receiving streams. Plants also reduce erosion caused by wind.

Active plant growth is an integral part of the soil amendment process; vegetation relocates water in the root zone and can transpire several hundred thousand gallons of water per acre during the

growing season. This relocation has a significant impact on the volumes of water and metals that are able to move toward the groundwater. The selection of plant species for amended soil is based on the availability of seed or seedlings, their ability to establish and grow in the newly created root zone, the species' inability to trans-locate (move) metals from roots into the above-ground biomass of the plant, and land use and management considerations.

Because soil amendments have a wide range of uses, the knowledge presented in this course may be applied to various situations ranging from time-critical contaminant removal actions to ecological revitalization projects. Practitioners can use soil amendments to “jump-start” ecological revitalization at significant cost savings compared to traditional alternatives. In addition to eliminating exposure pathways and/or immobilizing metals and other contaminants, recycling these residual organic byproducts, instead of disposing of them, results in significant ecological benefits for the hydrosphere and atmosphere.

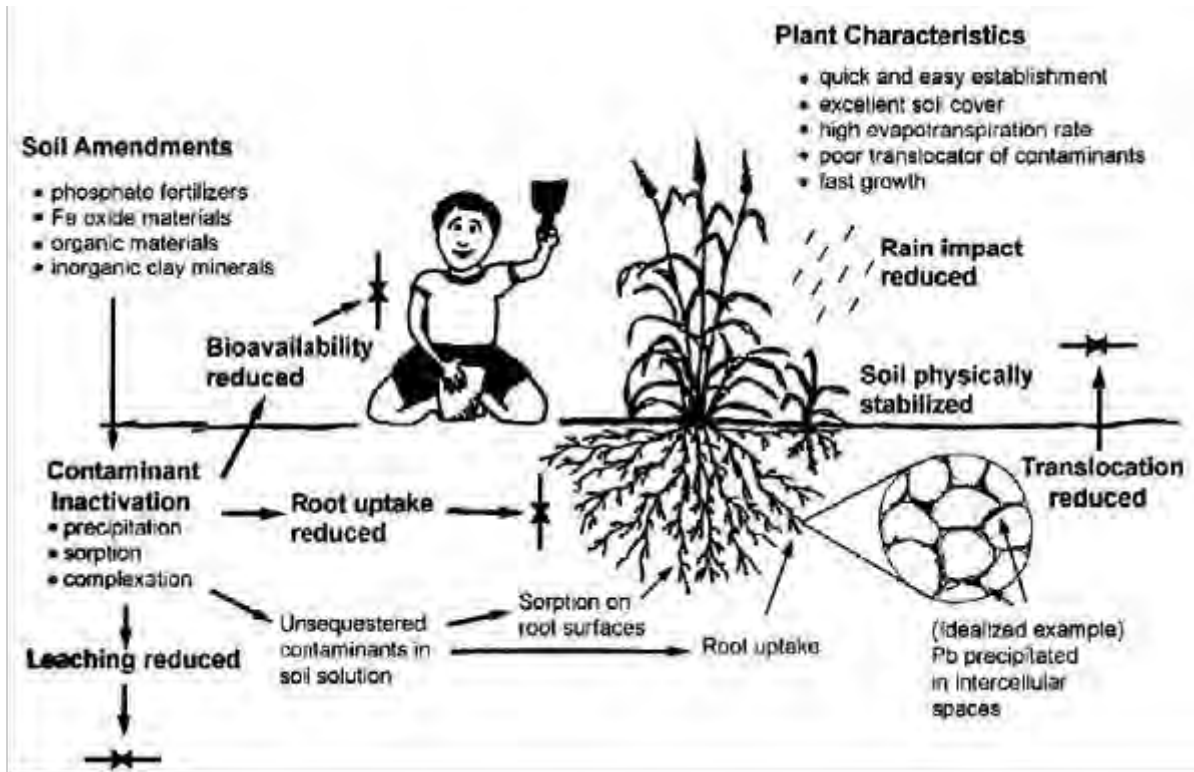


Figure 1. The Role of Soil Amendments and Plants in the Amendment of Metal-Contaminated Soil (Ref. 3)

2.0 TYPES OF PROBLEMS ADDRESSED BY SOIL AMENDMENTS

Soil amendments can be used to address two primary categories of problems at contaminated sites: (1) contaminant bioavailability/phytoavailability and (2) poor soil health and ecosystem function. Solutions to the specific types of problems within these categories depend on the nature of specific contaminants, known exposure pathways and adverse effects, and specific interactions involved with the various recommended soil amendments and other contaminants (see Table 1).

Table 1: Types of Problems Addressed by Soil Amendments

	Exposure Pathways and Adverse Effects	Interactions	Solutions
<i>Contaminant Bioavailability/Phytoavailability Problems</i>			
Toxicity (inorganic)			
Aluminum (Al)	Phytotoxicity Runoff Leaching	Low pH ² = more toxic; Low P = more toxic; High calcium (Ca) = less toxic	Raise pH greater than 6.0, add OM and P; add gypsum or other high soluble Ca source
Arsenic (As)	Soil Ingestion Runoff Leaching	High pH ² = more toxic; High P = more soluble	Add organic matter (OM) and adjust pH to between 5.5-6.5
Borate (BO ₃ ³⁻)	Phytotoxicity	Low and High pH ² = more toxic	Add iron oxide and acidify (pH between 6.0-7.0)
Cadmium-to-Zinc Ratio (Cd:Zn) ¹	Food chain	High ratio = greater bioavailability (risk) of Cd	Add Zn to reduce the Cd:Zn ratio
Chromate (CrO ₄ ²⁻)	Phytotoxicity Runoff Leaching	High pH ² = more toxic	Add reductants, e.g., OM, biosolids; also acidify to less than 6.5
Copper (Cu)	Phytotoxicity Runoff Leaching Aquatic receptors	Low pH ² = more toxic; low OM = more toxic	Raise pH (6.0-7.0), add P, OM, and sorbents
Lead (Pb)	Soil ingestion	Low phosphorus (P) = more toxic	With no As present, raise pH to 6.0 or greater; with As present, raise pH to 5.5-6.5; add P, and iron oxide
Manganese (Mn)	Phytotoxicity Runoff Leaching	Low pH ² = more toxic	Raise pH greater than 7.0
Molybdenum (Mo)	Food chain Cu:Mo ratio	High pH ² = more toxic; Low Cu = more toxic	Acidify (pH between 5.5- 6.5) and add Cu
Nickel (Ni)	Phytotoxicity	Low pH ² = more toxic; low P = more toxic	Raise pH (7.0-8.0), add P, OM, and sorbents
Selenium (Se)	Food chain Runoff Leaching	High pH ² = more toxic	Acidify (pH between 5.5-6.5)
Sulfate (SO ₄ ²⁻)	Phytotoxicity to salt effects	NA	Irrigate soil
Zinc (Zn)	Phytotoxicity	Low pH ² = more toxic; low P = more toxic	Raise pH (7.0-8.0), OM, and sorbents ³ , e.g., iron and manganese oxides, WTR ⁴
Toxicity (organic)			
Polycyclic Aromatic Hydrocarbon (PAH)	Soil Ingestion	Low OM ⁵ = more bioavailable	Add OM and tillage
Polychlorinated Biphenyl (PCB)	Soil Ingestion	Low OM ⁵ = more bioavailable	Add OM and tillage

	Exposure Pathways and Adverse Effects	Interactions	Solutions
Nutrient Deficiencies and Low Fertility			
High Calcium-to-Magnesium Ratio (Ca:Mg) ¹	Induced Mg deficiency in plants; Can reduce growth or kill plants	Very strong acidity causes loss of exchangeable cations (Ca, K, Mg), which makes Mg deficiency more likely; Addition of only calcitic limestone	Add Mg
High C:N ¹ ratio			High N or high-N soil amendments, e.g., manures, solids
High N			High cellulose carbon, e.g., sawdust, rice hulls, or wood chips
High P			Add Al or Fe to acid soils or alkaline soils to bind P; WTR (Water Treatment Residuals) may be an effective source of Al for this purpose
Low Carbon-to-Nitrogen Ratio (C:N) ¹			High cellulose C e.g., sawdust, rice hulls, or wood chips
Low Nitrogen (N)		High C:N ¹ ratio = low N availability	Add N and/or high-nitrogen OM
Low P	Limits growth	Increases metal availability ⁸	Add P or high-P organic soil amendments
Manganese (Mn) deficiency	Limits growth	NA	Add Mn or lower pH to less than 6.0

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- 1 Ratios:
 - C:N ratio = 15-40:1
 - Ca:Mg ratio = no greater than 20:1
 - Cd:Zn = <0.015 on weight basis
 - Cu:Mo = >2:1 for cattle and >5:1 for sheep. Recommended Cu levels in feed/forages are 8 to 11 mg/kg. This amount should provide adequate copper if the diet does not exceed 0.25 percent sulfur and 2 mg Mo/kg diet. In a Cu-deficient diet, Mo can be toxic. Sulfur status of feed and forage also is a co-factor (Ref. 30, 26). Cu deficiency in cattle and sheep is easy to correct with mineral salt licks or supplements.
- 2 Low pH = <5.5; High pH = >8
- 3 WTR = water treatment residuals
- 4 Target OM% for soil = >2.5%; target OM% for contaminated soil = >5%