REMEDIAION OF CONTAMINATED SOILS WITH GREEN PLANTS: AN OVERVIEW

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SUMMARY

Billions of dollars each year are spent on the remediation of contaminated soils in the United States alone. Contaminated soils represent an economic liability as well as a technical challenge. New technologies are needed to address numerous contaminants, especially those that are neither volatile nor mobile in soil solutions. One emerging technology, "phytoremediation", employs green plants in the remediation process. The technique is relatively new, with few field demonstrations; however, it represents an ever-growing area of research built on a sound technical basis. This technology draws heavily from a wide range of agronomic, biological, and engineering disciplines. Exploiting all plant-influenced biological, microbial, chemical, and physical processes to remediate contaminated sites is the goal of much research in this area. In certain situations, sites remediated with a plant-based technology are expected to have significant economic, aesthetic, and technical advantages over traditional engineering solutions. This paper provides an overview of the phytoremediation area with an emphasis on providing background information and research avenues to plant biologists.

Key words: hydrocarbons; heavy metals; pollution; metabolism; detoxification.

INTRODUCTION

The remediation of contaminated soils in the United States is a multibillion dollar a year industry. Most often sites are remediated through a wide variety of engineering-based technologies that have evolved over the last 3 decades. These technologies can be grouped into two broad categories: a) isolation and containment techniques, and b) decontamination techniques. Isolation and containment techniques exploit physical, chemical, and hydraulic barriers to isolate the pollutant and prevent its escape. This remediation strategy offers no actual reduction in the quantity of pollutant on a particular site, but the risk of the pollutant causing further environmental damage is reduced. Examples of containment techniques include vaults, caps, and hydraulic isolation curtains, as well as physical absorption or entrapment of the pollutant into a stable matrix (e.g., cement). In contrast, decontamination techniques reduce the total quantity of the contaminant at the site. Site decontamination permits increased flexibility in future land use decisions. Examples of decontamination techniques include soil washing, vapor extraction, and microbial bioremediation. One common site decontamination technique is the excavation of the hazardous material and disposal to a secure landfill. This strategy, despite its unsophistication and relatively high cost is often favored by the remediation engineer for smaller sites. It is dependable, leaves a clean site, and has definitive starting and end points. On the downside, it represents a transfer of the pollutant to a second location, and questions of residual liability linger. In addition, the siting of new secured and hazardous waste landfill operations is becoming increasingly more difficult.

The development of a site remediation strategy involves balancing legal, physical, chemical, biological, and economic considerations. Sites are often complex, with numerous environmental concerns. Philosophically, many site managers would prefer that the treatment process leave their site in as pristine a condition as possible. This is not always technically feasible. The chemical and physical properties of certain hazardous wastes sometimes preclude all current site decontamination techniques except for excavation and subsequent reburial. Seeming plausible solutions on closer examination result in transferring the pollutant from one medium to another with resulting increases in volume and complexity of the material to be treated.

There is often a legal, economic, and aesthetic advantage to remediating a site with minimal surface disruption. With certain contaminants and site conditions (e.g., underground storage tanks for gasoline) this "in situ" remediation is common. Soils with relatively immobile contaminants and tight soil structure, however, pose a technical challenge to all in situ techniques. Engineering technologies are being explored (e.g., electroosmosis, soil fracturing, thermal decomposition, and surfactant washing), but in many cases will be cumbersome and costly. Plant-based systems seem to be an interesting, cost-effective alternative that poses an exciting technical challenge to the research community.

Phytoremediation is defined as the use of green plants to remove, contain, or render harmless environmental contaminants. This definition applies to all plant-influenced biological, chemical, and physical processes that aid in remediation of contaminated substrates. The concept itself is not new. The use of plants in waste water treatment schemes is over 300 yr old (16). Plant-based remediation

is also evolving in the control of both indoor air pollution (25), and urban smog (34). This paper, however, will confine itself to the latest media to be targeted by plant-based remediation methods: contaminated soils, sludges, and sediments.

These authors have explored the vegetation on dozens of sites where soil has been degraded by manufacturing, mining, and disposal activities. The ability of plants to survive in soils declared legally "hazardous" has proven to be impressive. Many people unfamiliar with hazardous waste sites imagine such sites to be barren. In truth, when they are devoid of vegetation, most have active "vegetation management" strategies (herbicide applications, stone mulch, etc.) to control vegetation. Many soils legally classified as "hazardous" revegetate rapidly when removed from these vegetation management schemes. Not all sites, however, revegetate as rapidly. Certain sites have pH, texture, ionic, and nutrient limitations that need to be altered before the establishment of a vegetative cover. In most cases, common agronomic practices can be utilized.

**PLANTS AS ENGINEERING STRUCTURES**

Most site remediation personnel view vegetation as "debris", both in a legal and technical sense. Many industrial site managers have engineering backgrounds and are unfamiliar with the physics and chemistry of plants. We have found that redefining green plants in engineering parlance has been useful in describing the potential use of plants in remediation to this audience. A green plant is a "solar-driven, pumping, and filtering system that has measurable loading, degradative, and fouling capacity" (11). Roots are "exploratory, liquid-phase extractors that can find, alter and/or translocate elements and compounds against large chemical gradients". The internal and external surface of many plant parts are also home to microbial communities that can be exploited. Root surfaces maintain active microbial biofilms. These and a root's mycorrhizal extensions into the soil significantly augment soil-surface contact and increase the plants own somewhat meager metabolic capacities. The exploitation of these rhizosphere communities to remediate soil contaminants is an active area of research at numerous laboratories. Parallels between the rhizosphere and current engineering practices are numerous and the concept is familiar to many in the field. Degradation rates of certain xenobiotics can often be increased by the addition of exogenous carbon sources and encouraging microbial growth (composting and bioaugmentation). Additionally, many remediation managers are aware of fungal inoculants (e.g., white rot fungi) being marketed for the in situ destruction of relatively immobile, soil-bound organics such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). When plants are redefined in such terms, both the biologist and remediation engineer can contribute to research in the area. Engineering modeling studies have provided research goals in terms of rooting structure, patterns, water use, transpiration, and metabolism. Meeting these goals by the selection, creation, and cultivation of plants and their associated microflora is an exciting technical challenge.

Phytoremediation is a relatively new concept; however, techniques, skills, and theories from well-established fields are easily transferable. The concept requires a new paradigm. Traditionally we think of crops as productive, a source of food, fiber, and fuel. Plants as destructive or absorptive entities requires rethinking their agronomy, toxicology, biochemistry, microbiology, and molecular biology. The process is both an interesting exercise as well as a source of research leads. Certain microbial and plant engineering strategies that have been considered commercial failures in the past due to yield decreases of as little as 5% (e.g., xylem endophytes), may now have renewed promise. A yield decrease of 50% or more may be acceptable if it were to achieve maximum site decontamination.

**PLANTS IN CONTAINMENT STRATEGIES**

The capacity of plants to transpire large quantities of water is significant and has been exploited in the dewatering of sludge (27), prevention of downward water flux through landfill caps (22), and containment of contaminated water downgradient of a problem site (29). Certain sites, although polluted, do not pose an obvious environmental risk unless there is off-site migration into a waterway. Under authority of the Clean Water Act, these sites may then be of regulatory concern by both state and federal agencies. Pollutants slowing leaching from these soils into a shallow aquifer and then subsequently into a small stream have been targeted by this root-intercept strategy.

Plants have been integrated into engineering technologies in erosion control and are used commonly to maintain the integrity of caps, ditches, and berms. In numerous remediations, as the operator moves toward "closure", a site erosion plan often specifies vegetative covers. Particularly hardy grasses are also sold for revegetating the banks of some polluted ditches as an interim "corrective action" measure. On at least one site plants have been used to stabilize the actual contaminated soil matrix after the metal contaminants had been chemically stabilized into the matrix by the addition of soil amendments (24). Plant roots scavenge available metals but there is little movement from root to shoot. The site is visually impressive and the "before" and "after" results are remarkable.

The ability of many wetland plants to alter the pH around their roots, provide oxygen into the anaerobic zone, and prevent stream bed erosion is being explored for the remediation of seeps from old mining and landfill operations (33). These mine and landfill seeps are often extremely acidic and carry significant heavy-metal concentrations. In the wetland environment where the biotic activity increases alkalinity, sulfide ion concentration, and organic residues, the metal ions precipitate out and the water is released to the stream outflows.

**PLANTS IN DECONTAMINATION STRATEGIES**

Plants absorb both organic and inorganic contaminants from soils. Absorption, sequestration, and metabolic transformations of these pollutants are possible and potentially exploitable to clean contaminated soil. Not all pollutants and matrices are possible. Due to the perceived limitations in rooting depth and time requirements, most researchers in the field currently target relatively non-leachable contaminants that pose little eminent risk to health or the environment. These restrictions are not as formidable nor exclusive as they may first sound; however they should be remembered when considering the usefulness of a given demonstration system to field application.

Plants have a long history of use as reed bed (14), wetlands (31), and overland flow (30) for the polishing of waste water. Their use in remediation of soils is more recent; however, reports of pesticide spill clean-up (12), degradation of polycyclic aromatic hydrocarbons (PAHs) (5), chlorinated solvents (1), DDT (23), dioxanes (6),