1 Soil Bioremediation and Phytoremediation – An Overview

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1 Introduction

In the 45-year period of 1930–1975, the global human population has increased by approximately 2 billion, rising to 4 billion. A further population increase of 2 billion occurred in the 25-year interval 1975–2000 and population is expected to reach 8 billion by 2020. Population growth and the resultant development of large high-density urban populations, together with parallel global industrialization, have placed major pressures on our environment, potentially threatening environmental sustainability. This has resulted in the buildup of chemical and biological contaminants throughout the biosphere, but most notably in soils and sediments.

Cases of uncontrolled contamination of soil and other media with these toxic chemicals emerged, drawing attention to the threats caused by these chemicals to our environment and human health. For example, the Love Canal area in Niagara Falls, New York State was the site of an abandoned canal that was used by the Hooker Chemical Company as a location for disposal of 22,000 tons of PCBs, dioxins, pesticides and other chemical wastes during the 1940s and early 1950's. The site was then covered up and acquired by the City of Niagara Falls and subsequently used as a location for a school and housing. By 1978 toxic chemicals had leaked from the soil into the basements of area homes and high rates of miscarriages and birth abnormalities were reported among residents.

There are many other significant historical examples, including the dioxin crisis in Belgium, Italy and Bhopal. In addition, it was observed

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that many of the toxic chemicals have a tendency to eventually transfer from solid media to aqueous media and then to bioaccumulate in high lipid-containing species such as fish (Bernard et al. 1999). A further concern is the growing accumulation of pharmaceuticals in the environment, mostly excreted in urine (Kozak et al. 2001).

The historical foundation for modern environmental biotechnology lies in the composting of organic wastes into soil fertilizers and conditioners. In its broadest sense bioremediation includes biological treatment of wastewater, sewage, food and agricultural wastes, contaminated soils and groundwater. While its definition is the subject of debate, Prince (1998) defines bioremediation as "the process of judiciously exploiting biological processes to minimize an unwanted environmental impact; usually it is the removal of a contaminant from the biosphere". The term "intrinsic bioremediation" essentially involves taking no action but rather monitoring a natural process of contaminant reduction without intervention. Hence, intrinsic bioremediation can hardly be termed as a technology, but it has met with some success as a low cost approach.

Perhaps more than any other event, the Exxon Valdez oil spill, off the coast of Alaska, demonstrated the potential for a large-scale application of biological processes for cleanup of hydrocarbon-contaminated soil (bioremediation; Prince et al. 1998). Since that event, the application of bioremediation as a biotechnological method for soil remediation has gained prominence as an alternative or used in combination with physical or chemical treatment methods.

Soil bioremediation processes may be implemented using a variety of different engineered configurations ranging from in situ subsurface (unexcavated) processes to application of completely mixed soil slurry reactor systems for treatment of excavated soils. The technology is interdisciplinary, involving microbiology, engineering, geology, ecology, chemistry and perhaps other disciplines. The choice of configuration applied can shift the relative emphasis among the disciplines. The common objective in the various processes is to create the necessary environment to facilitate growth and contaminant degradation by the appropriate biological organisms. Bioremediation has now been used successfully to remediate many hydrocarbon-contaminated sites as well as sites containing selected other contaminants (Singh et al. 1999; Van Hamme et al. 2003).

It has been estimated that non-biological processes would cost US$ 750 billion over the next 30 years to remediate all of the known hazardous waste sites in the United States (Pimentel et al. 1997). However, the cost would be reduced to $75 billion with the use of bioremediation over the same period of time. According to another estimate, worldwide

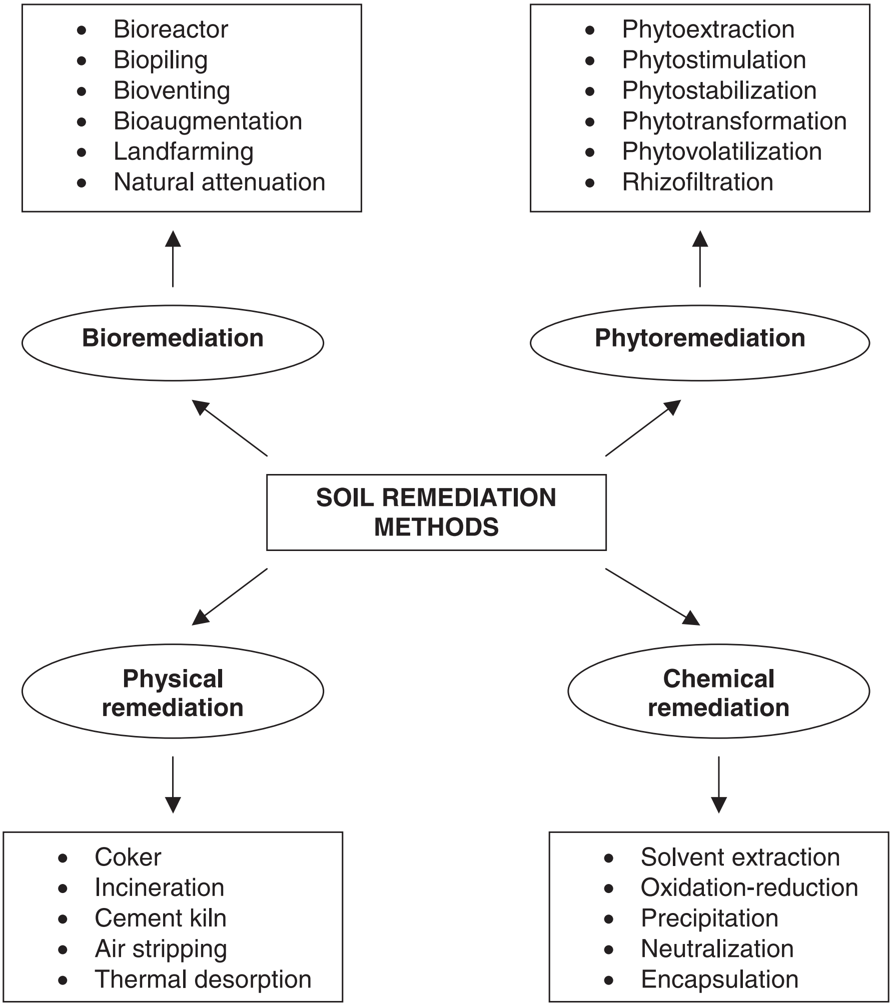

Fig. 1. Soil remediation methods

use of bioremediation would cost $14 billion per year compared to the use of current technologies at $135 billion per year (Hunter-Cevera 1998). Various biological and non-biological methods used in soil remediation are shown in Figure 1.

While there are many aspects of soil-related biodegradation and bioremediation, this volume will primarily focus on remediation of chemical contaminants in soil and will not address the issues of biowaste recycling.

2

Major Environmental Contaminants

There are two major groups of environmental contaminants, namely chemical and biological wastes that can accumulate in or be transmitted via soil as a result of the population expansion and industrial intensification described above. The chemical contaminants can be classified broadly into two groups, organic and inorganic contaminants.

2.1

Chemical Contaminants

The huge expansion of the chemical and petroleum industries in the 20th century has resulted in the production of a vast array of chemical compounds and materials that have transformed our lives. For example, annual volumes of individual bulk chemicals produced in the United States range from 5–20 million metric tons for ethylene, propylene, vinyl chloride, benzene and ethylbenzene and from 1–5 million tons for a large number of other organic chemicals. Approximately 140 million tons per annum of synthetic polymers/plastics are produced globally (Shimao 2001). The global yearly volume of crude oil production is approximately 72 million barrels per day (West 1996), while the total world refining capacity is 74.4 million barrels per day (West 1996). The latter huge numbers (about 25 billion barrels per year) indicate the scale and volumes of refined fuels and other oil-based products produced and used annually. Thus if one assumes that only 1% of these volumes enters the environment through spills, waste disposal or volatilization, this amounts to 266 million barrels per annum.

Industrial activities have also resulted in undesired contamination of soil and other media with heavy metals, so often toxic to human and animal health. Contamination of soil and solid wastes with high activity radionuclides, such as ^{235}U, ^{99}Tc and ^{241}Pu represents an additional environmental hazard, with the potential for these metals to be radiotoxic to all life forms (Lloyd and Macaskie 2000). Mention should also be made here of excessive levels of inorganic fertilizer-related chemicals introduced into soil, such as ammonia, nitrates, phosphates, and phosphonates, which accumulate, or lead to the contamination of our water courses through run-off or of our air through volatilization.

2.2
Biological Wastes and Contaminants

A second category of waste which threatens the environment is biological wastes, including raw and digested sewage (biosolids), raw and digested animal manures, and vegetable wastes. While these biological wastes have traditionally been recycled into soil for agricultural benefit increasing urbanization and the continued expansion of cities requires that these materials be transported over larger and larger distances for application to farm land. Likewise the continuing shift to intensive livestock farming (factory farms), typically located close to areas of high population, means that traditional land disposal practices of animal wastes are often rendered uneconomic because of high transport costs. Waste organic products of vegetable and food processing are also candidates for recycling back into soil, but again high volume intensive factory operations require large areas of land for recycling. Alternative waste reduction and beneficial use outlets or other economical disposal approaches are being sought for these wastes.

An additional problem associated with biological wastes relates to the risks of transmission of infectious diseases when infected materials are applied to soil. This dimension has become more prominent through the recent emergence of high profile infectious diseases, such as the prion, BSE; viruses, such as foot and mouth or West Nile and intestinal bacterial pathogens. Infected soils can facilitate disease spread through direct or indirect contact with watercourses, plants, animals or humans.

The introduction to or disposal of recombinant organisms in soil is a related concern, given the potential for recombinant strain proliferation, modification or recombinant gene transfer processes in the soil. One small outcome arising from this concern is that the potential to use recombinant organisms in bioremediation processes has been constrained. There is surely a need to understand better the nature of soils as host media for retention, survival and propagation of these biological organisms/vectors.

3
Microbial Transformation of Chemical Contaminants

Processes for metabolism of organic contaminants may be differentiated depending on the organism’s ability or otherwise to derive energy or carbon from the transformation for growth. With primary substrates the cell gains energy and metabolites which can be used for cell maintenance, division and growth. In the case of secondary substrates the