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Phytoremediation: A Study of Practical Applications and Current Research

ABSTRACT

Practical applications of phytoremediation are essential for the clean-up of moderately and severely contaminated sites in an economical and environmentally responsible way. The usage of plants to do a job that would otherwise be done by chemicals or energy intensive soil removal is a natural choice on several levels. First, by using plants for clean-up, pollutants are being absorbed by nature and cleansed in the most natural way, all while aiding in restoring the site. Second, and perhaps most importantly, phytoremediation is a low energy and low input process. Usage of fossil fuels and other chemicals are kept to a minimum and, in most cases, phytoremediation yields better results than that alternative. Economically, phytoremediation is also the method of choice in nearly all application scenarios.

KEYWORDS

Phytoremediation; Phytotransformation; Phytoextraction; Heavy Metals; Phytostabilization; Rhizofiltration; Rhizosphere Bioremediation; Bioconcentration Factor; Phytoextraction Efficiency.

INTRODUCTION AND FORMS OF PHYTOREMEDIATION

There exist five forms of Phytoremediation, all of which remediate pollutants from soil and water in different ways:

Phytotransformation

Phytotransformation occurs when a plant is able to uptake a pollutant or chemical into its roots and break it down into an environmentally benign substance. This is primarily done by the plants metabolism. Phytotransformation breaks down organic substances such as fuel oils, pesticides, explosives, solvents, and industrial chemicals. It is not effective in remediating inorganics.
Phytotransformation is known as the “green liver” model because it breaks down chemicals much the same as the liver in a human breaks down chemicals and renders them harmless.

Phytoextraction

Phytoextraction is a form of phytoremediation which is used for the remediation of sites with high levels of inorganic compounds such as metal contaminants from the soil into the plant matter via plant roots. With this method, plants act as filters or traps for metals as they remove them for the contaminated soil. Unlike Phytotransformation, phytoextraction cannot break down compounds like heavy metals into environmentally benign substances. Rather, plants are harvested and incinerated, with waste ash disposed of in a hazardous waste landfill.
Other options include harvesting biomass for metal extraction. With many precious metal prices on the rise, there have become an increased interest in "phytomining." Phytomining is a form of phytoextraction that extracts nickel, cobalt, and other metals, including the platinum and palladium from known contaminated sites. Plants can be harvested, dried, and smelted to recover the metal.

Phytostabilization

Phytostabilization is the process of using plants and their roots to stabilize a contaminant in the soil. This interaction between plants and contaminants retards the rate of contaminants leaching into groundwater. Phytostabilization is achieved through several ways including pH control, reduction or rainfall infiltration through increased evapotranspiration. It is usually more successful in remediating metals with addition of nutrients such as phosphate or lime to the soil. Phytotransformation is primarily used at abandoned mining and smelting sites where levels of metal are too high to expect to phytoextract all or most of it.

Rhizofiltration

Rhizofiltration is a form of phytoremediation that refers to the use of plant roots to absorb, concentrate, and precipitate toxic metals from contaminated groundwater. Suitable plants with stable root systems are supplied with contaminated water to acclimate them to the conditions of the area in need of remediation. The plants are then transferred to the contaminated site to collect the contaminants, and once the roots are saturated, they are harvested.

Rhizosphere Bioremediation

Plants play an indirect role in Rhizosphere Bioremediation. They act as hosts for bacteria and other tiny organisms that perform the actual decontamination. The plants main purpose is to encourage the growth of these small organisms by providing a root structure and a supply of nutrients.

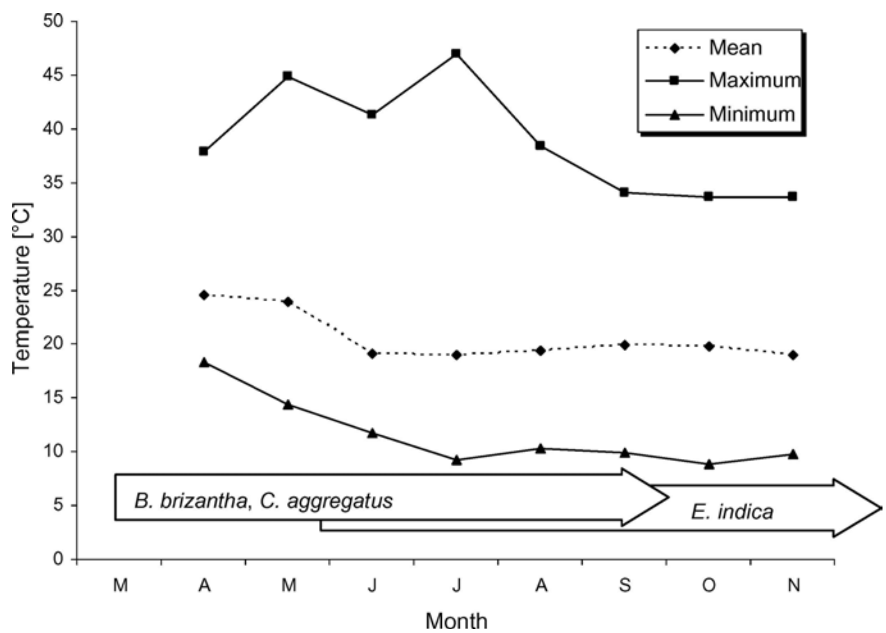
LIMITING AND EXPERIMENTAL FACTORS

Root Depth

Perhaps the most limiting factor to the effectiveness of phytoremediation is the maximum depth to which the roots can reach. While phytoremediation yields a very positive result when the roots of a plant reach down to where the chemical to be remediated is located, they yield no result to any chemical that is below the root depth. Additionally, the plant used at a given site must be able to handle and have a positive effect on the chemical once it has reached the depth where it is located. (Merkl, 2005)

Soil and Temperature Conditions

The conditions that have a tremendous impact on plants used in phytoremediation are soil and temperature. These conditions play a major role in both a plants effectiveness in up taking contaminates from the soil and also its ability to thrive and even survive in a location. While a plant should be robust enough to uptake and remediate a soil of contaminates, factors such as soil pH, soil porosity and moisture content of the given soil will play a significant role in its life expectancy and effectiveness.
Temperature at the site is also of importance and will affect how effective a plant is at remediating the soil as well as how long it will live. Colder temperatures in many locations will render phytoremediation less effective or non-useable as a remediation method. During usage, temperature must be controlled and recorded to every extent possible. (Merkl, 2005)



Temperature in greenhouse during experiment (Merkl, 2005).

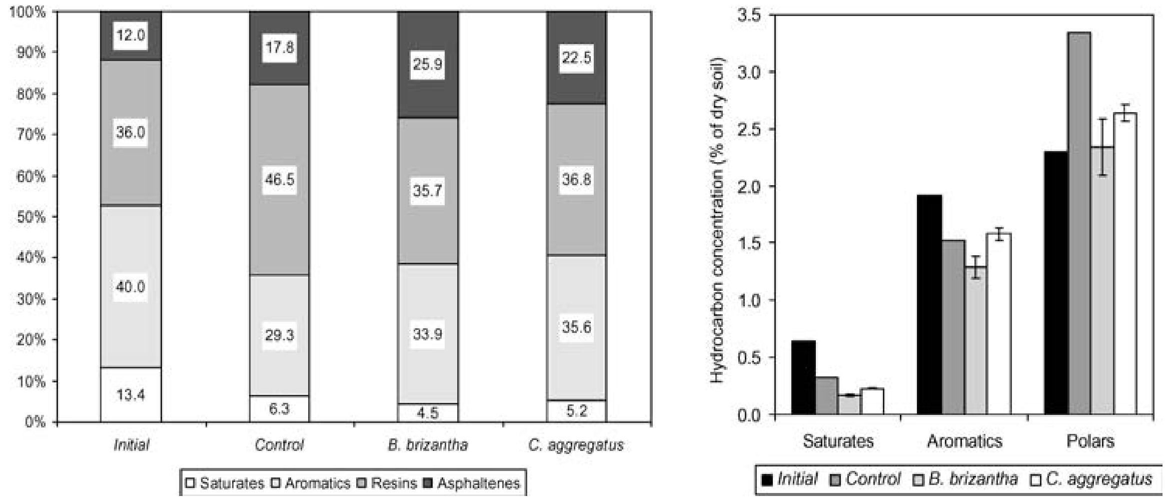
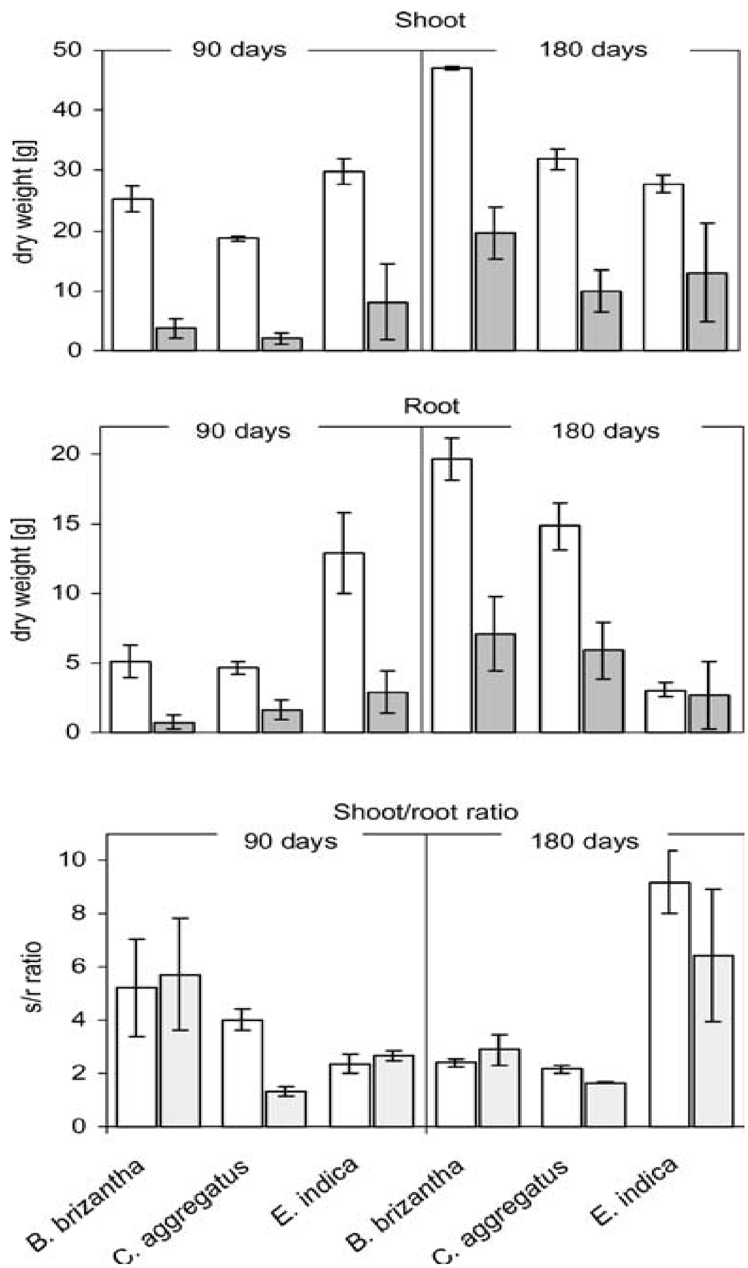


Fig. 2. Fraction analysis (SARA) of TOG in soil. Left: Composition of TOG. Right: Corresponding absolute values. (Merkl, 2005).

Biomass Production and Uptake Effectiveness

A plants ability to grow well and thrive while up taking a significant amount of contaminates from a site is critical. In fact, a plants growth rate is directly tied to its effectiveness during phytoremediation, even it is possesses a slow metabolism. In turn, a plant that grows slowly will in turn not be able to take in as many chemicals as a plant that grows faster.

Fig. 1 Assessment of Tropical Grasses



Biomass production of shoot and root, and shoot/root ratio (Merkl, 2005).

CASE STUDIES AND SUCCESSES OF PHYTOREMEDIATION

Phytoremediation has had significantly positive impact on sites that it has been applied to. Significant examples include:

Superfund Sites

The Oregon Poplar Site and The J-Field Aberdeen Proving Ground are both Superfund sites managed by the U.S. Environmental Protection Agency. They are two of 1,245 Superfund sites currently in United States. Phytoremediation is a viable option at many of these sites and is currently being incorporated at over 200 sites.
The Oregon Poplar Site has long history of being contaminated with Volatile Organic Compounds (VOCs). Most of the contaminates are the outcome of illegal dumping on the site. Over the first 2 years of the site remediation using poplars planted on four acres, the trees showed both normal growth and substantial VOC uptake from the soil with no tree deaths. (EPA)
The J-Field at Abredeen Proving Grounds site was used as a disposal site for chemical warfare agents, munitions and industrial chemicals from 1940 through the 1970s. The site was planted with 183 poplar trees on one acre. These poplars are estimated to remove 85% of existing pollutants on the site over a 30 year time period. (Gascon 2006)

Chernobyl

After the Chernobyl nuclear meltdown disaster hit the Ukraine in 1986, vast amounts of radioactive materials were spread in both soil and groundwater near the site. Using the Rhizofiltration method, sunflowers achieved a 90% reduction in Caesium in a two week period. (Department of Energy, Energy Citations Database)

TRADITIONAL METHODS OF REMEDIATION

While phytoremediation is a promising form of environmental clean-up, it is not yet as widely used as other more traditional forms. Examples include Soil Washing which includes the excavation of soil from a site, chemical treatment of soil offsite to “wash” toxins out, and eventual landfilling of most of soil at hazardous waste landfill. Another conventional technique is Soil Capping, which simply includes paving over a contaminated area. A final widely used yet controversial technique is the “Pump-and-Treat” method. This is used for groundwater contamination and includes pumping contaminated water to the surface for treatment. Since it has first been used on a large scale in the early 1980s, its results have been found to vary at best. (EPA)

ECONOMICS OF PHYTOREMEDIATION

When applied to a site that has the proper conditions for effective phytoremediation to occur, it is usually the cheapest cleanup option to use. Examples include the estimated 30-year cost of remediating a 12-acre lead contaminated site being $12 million for excavation and disposal, $6.3 million for soil washing and $200,000 for phytoextraction (Cunningham, 1996). The cost of remediating a 1-acre sandy loam site is estimated at a minimum of $400,000 for excavation and storage, and $60,000-$100,000 for phytoextraction (Salt et al. 1995). In terms of water remediation, the estimated cost for a 20-foot deep aquifer on a 1-acre site to be treated is $660,000 for Pump-and-Treat, while phytoremediation would cost $250,000.

DOWNSIDES OF PHYTOREMEDIATION

It has been shown that phytoremediation is a viable option for a variety of environmental cleanup and remediation scenarios. However, its primary drawback is a main reason why it is not used in more cleanup efforts. The time that is takes plants to grow is significant, and an additional expense that many landowners, developers, and agencies cannot afford. While phytoremediation has been shown to be economically cheaper than other conventional methods, these methods are often chosen because of time issues. In addition to the time it takes plants to grow, usage of phytoremediation on industrial and other heavily contaminated sites needs more research into critical areas. Temperature, soil condition, and effectiveness over certain periods of time are all areas that need to be improved upon for phytoremediation to become more widely used.

CONCLUSIONS

There exist many contaminated sites in need of differing forms of remediation to restore them to conditions which are suitable for new development or natural preservation. Phytoremediation has a tremendous potential to remediate these sites in a ways that is economical and environmentally benign. It does, however, have many challenges to overcome. Temperature, uptake effectiveness, soil conditions and contamination levels, and time are all issues that affect phytoremediation being used over less effective and more expensive forms of remediation. Overall, phytoremediation is and remains an exciting and useful method of environmental restoration and will only become more effective with time and research.

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