Perspectives of phytoremediation for soil contaminated with pesticides

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Introduction

Soil pollution is a serious environmental problem, not only in the highly industrialised western countries, but also in developing countries. Contaminated sites may cause a severe risk for humans and ecosystems. The extent and the character of polluted sites vary strongly. A substantial part of the polluted sites consists of large areas of which the upper layer is more or less diffusely polluted with pesticides. These pesticides are in general highly stable organic pollutants and are not easily biodegradable in nature.

Remediation of this type of polluted sites by means of excavation, followed by chemical, thermal, biological, physical treatment, or a combination of these methods, is technically possible. However, financially such a method is absolutely not feasible. For this area only in-situ treatment options can be considered. If the intention is to remove or destruct the pollutants, than in-situ treatment methods based on physical or chemical processes are less suitable for these areas. Most promising are the biological methods, notwithstanding the persistent character of the pollutants. Regarding these biological methods two types of treatment processes can be considered: microbiological degradation and phytoremediation. The first process makes use of natural microbial degradation processes, which are often enhanced by supplementing the micro-organisms with nutrients, water, carbon sources and electron donors or by changing the temperature. Often also adding enriched cultures of micro-organisms with specific degradation characteristics may be helpful. Phytoremediation is based on the use of plant growth in polluted soils to enhance bioremediation. It can be considered as a relatively innovative technology, which shows great promise to enhance bioremediation processes. It is rapidly gaining interest because it is basically simple and inexpensive. During the last 5 to 10 years an increasing effort has been made to develop this technique for practical application (15, 17). Most attention has been paid to the accumulation of heavy metals in plants and the immobilisation of heavy metals in the soil by root activity (2, 21, 29, 31, 32, 35). However, recently more and more attention is given to the phytoremediation of sites polluted with organic pollutants.

The aim of this paper is to discuss briefly the principles of phytoremediation, the practical experience already obtained in general with phytoremediation, and the perspectives phytoremediation can offer for the remediation of large soil area, diffusely polluted with pesticides. Also the scientific and technological aspects, which have to be considered in order to bring the practical application of phytoremediation more nearby, are discussed.

Principles of phytoremediaton

Phytoremediation by means of plants may occur by sequestering, absorption, translocation, or immobilisation of pollutants. Regarding these plant mechanisms, several phytoremediation approaches and processes are possible for organic pollutants:

- *Stimulation of soil micro-organisms by plant root activity*. It is known that the rhizosphere environment is high in microbial abundance and rich in microbial activity. In the rhizosphere of some plants, released plants exudates and enzymes can stimulate the biodegradation of contaminants. Roots also improve soil aeration, stimulating aerobic biodegradation processes.
- *Phytotransformation*. This process involves the transformation of organic pollutants into less toxic or less mobile components. This process includes phytodegradation, which is the metabolic conversion of the organic pollutant in the plant structure. It also includes possible conversion of organic pollutants in the plant into more volatile organic pollutants, which can release to the atmosphere by volatilisation via the plant leaves. This process is called phytovolatilisation.
- *Accumulation of pollutants in the plant*. This phytoremediation approach is especially of importance in case of heavy metals polluted sites.
- *Phytostabilisation*. This process reduces the mobility of pollutants in the soil by root activity. Also this process is of special interest for soils polluted with heavy metals.

There is a lot of literature dealing with the fundamental aspects of phytoremediation processes (18, 25). In the context of this paper these aspects will not be discussed here. Reference is made to the general literature about plants and the interaction between plants and environmental pollutants such as pesticides and heavy metals.

Practical experience

During the last five to ten years a lot of experience has been obtained regarding the application of phytoremediation for treatment of soils and sediments polluted with organic pollutants or heavy metals. This experience varies strongly from labscale research to large- scale field trials in practice. Most experience has been obtained with soils and sediments polluted with heavy metals. Experience with organic pollutants is also substantial but varies strongly due to the strong variation in types of organic pollutants involved but also due to the various types of soils that have been investigated.

A very brief summary of the most important organic pollutants, which have been investigated regarding their phytoremediation potential, is given in the following list:

CT (carbon tetrachloride)
- Plants: poplar trees
- References: 33.

TCE (trichloroethylene)
- Plants: cottonwood trees, poplar tree
- References: 12, 13, 24, 28

PAHs (polyaromatic hydrocarbons)
- Plants: clover, lucerne, rye grass, corn plants, turfgrass, poplar trees, fescue, willows
- References: 14, 27

PCBs (polychlorinated biphenyls)
- Plants: plant cells, plant enzymes
- References: 6, 26

TNT (2,4,6 trinitrotoluene)
- Plants: Catharantus roseus, Medicago sativa, Cirex buchannanii, Miscanthus sinensis
- References: 3, 4, 34

PHC (petroleum hydrocarbons)
- Plants: clover, lucerne, rye grass, corn plants, willows
- References: 5, 9, 20, 30

PCP (pentachlorophenol), TCP (2, 4, 5 trichlorophenol)
- Plants: rye grass
- References: 11, 22

VOCs (volatile organic compounds such as trichloroethylene and tetrachloroethane)
- Plants: poplar trees
- References: 8

HCH (hexachlorocyclohexane)
- Plants: mycorrhizal fungi
- References: 23

Aldrin, dieldrin
- Plants: spikerush
- References: 36

Atrazine, metolachlor, trifluran, arochlor
- Plants: Kochia, poplar tree
- References: 1, 7

Organophosphates (malathion, dementon-s-methyl, ruelene)
- Plants: plant tissue cultures, enzyme extracts
- References: 16

From the abovementioned literature dealing with phytoremediation of polluted soils and soil/groundwater systems, especially systems polluted with organic pollutants, the following general conclusions may be drawn:

- Results regarding the total remediation effect vary strongly,
- It is often not clear what type of removal mechanisms is dominant and responsible for the overall removal efficiency,
- Literature dealing with fundamental aspects is rather scarce,
- Often the phytoremediation process is enhanced by adding compost or by the simultaneous use of specific fungi in the root zone,
- Research and development regarding the remediation of large sites, diffusely polluted with pesticides, is scarce,
- Part of the literature on phytoremediation involves the use of plant tissues in aquatic systems,
- Modelling of phytoremediation processes has hardly been investigated,
- Large-scale practical experience is scarce.

Although the literature dealing with phytoremediation of polluted soils strongly varies, the results obtained so far are very promising and deliver a sound basis for further development of phytoremediation as a real alternative for large soil area, diffusely polluted with pesticides.

Perspectives

Phytoremediation is an innovative and very promising technology with a high potential for practical application. Several different types of phytoremediation are being used already commercially. However from the results of the research and development efforts until now, but also from the practical experiences obtained so far with this technique, it is evident that for further improvement of the techniques and for achievements of new breakthroughs more insight is necessary in the process. This especially holds for the relevant transport and conversion processes in both the plant and the root zone. Many parameters affect these processes. Only in that case the practical applicability of phytoremediation to treat large areas, which are diffusely polluted with pesticides, comes nearby. The scientific aspects that have to be considered in that respect are, among others:

- The lowest final concentration of pollutants that can be achieved practically. A concentration below the standard concentration for clean soil is in fact necessary,
- The treatment time necessary for achieving the required low concentration of the pollutant,
- The necessity to add chemicals, nutrients, water, etc. to the soil in order to enhance the bioremediation process,
- The necessity to cultivate the soil regularly.

To make phytoremediation economically feasible it is not only important to have benefits from the cleaned area, for example, for agricultural production purposes, for industrial activities, for housing, for nature development, for recreation etc., but also to have benefits from the plants which are growing on the site during the remediation process (19). It can be expected that phytoremediation requires a vegetation growth during several to many years. In that respect, the following issues need attention:

- The type of plants and the intrinsic economical value of the plant. Plants can be produced for the production of biomass for energy production in electrical power plants. Plants can also be used as a source for other types of energy, such as motor fuel, alcohol, etc. Also the production of specific chemicals can be an option. It will be clear that plants which have grown during the remediation process are not suitable for the production of food or feed products,
- The harvesting of the plants and the subsequent treatment of the plants focused on energy production or production of chemicals,
- Protection of the remediation area against possible uptake of plants or plant products by birds or terrestic animals. This means that the polluted area have to be isolated from the surroundings in a proper way. Costs of remediation, isolation of the polluted area, harvesting, and treatment of plants have to be compared with the revenues of a clean area and the benefits of the plants or plants products in order to get in indication of the net costs of the remediation process.

It will be clear that such an integral approach requires the cooperation of soil and plant scientists, environmental and process technologists, and governmental and societal bodies responsible for solving the problem of a polluted area and the destination of the area, if cleaned-up.

Conclusion

During the last five years the interest for phytoremediation as an alternative soil treatment system has strongly increased. Literature results show that phytoremediation has a very high potential. In that respect it offers a very interesting perspective for remediation of large soil area diffusely polluted at the top layer. This perspective is also very promising because in fact no other alternatives for such sites are available. Strengthening of the research input is a prerequisite for the development of practical methods.

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