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Phytoremediation and Bioremediation of Land Contaminated by Hydrocarbons: Modeling and Field Applications

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요 약 문

Phytoremediation which uses plants to enhance the bioremediation through stimulation of microbial activity and root uptake, has been a topic of increasing interest. Mathematical model were developed that can be applied to various bioremediation methods in the unsaturated zone, especially phytoremediation, for simulating the fate and transport of contaminants under field conditions. A 2-year field study was conducted using 72 (1.5 m long and 0.1 m diameter) column lysimeters with four treatments: Johnsongrass; wild rye grass; a rotation of Johnsongrass and wild rye grass; and unplanted fallow conditions. The developed model represented the fate and transport of contaminant both in vegetated and unplanted soils satisfactorily for field applications. Parameters related to the contaminant concentration in the water phase were the main parameters determining the contaminant fate in the vadose zone and indicated that the bioavailability can be the most important factor in the success of phytoremediation as well as bioremediation applications.

Key word : phytoremediation, bioremediation, model, bioavailability, field experiments

1.Introduction

Phytoremediation can provide an alternative remediation technique and can reduce the runoff and leaching from the contaminated sites (Erickson et al., 1994; Schnoor et al., 1998; Sung et al., 2002a). Mathematical models can provide fundamental understanding of contaminant fate at phytoremediation sites and provide valuable information before field implementation is undertaken, thus saving time and money (Corapcioglu et al., 1999). Phytoremediation models can be used as predictive tools to assess the potential effectiveness of various plant species in a phytoremediation operation. At actual remediation sites, quantitative models can provide managers with guidance on monitoring and operation. Mathematical models was developed that can be applied to various bioremediation methods, especially phytoremediation, for simulating fate and transport of a recalcitrant contaminant. Field study was conducted for two years and the model was applied to field data obtained in lysimeters containing freshly contaminated soil.

2.Model Development

Flow in the unsaturated zone can be represented using a two-phase flow approach. The mass conservation equation for water phase in the vegetated unsaturated zone soil by neglecting water compressibility can be expressed as (Sung et al., 2002b)

$$\frac{\partial\theta_w}{\partial t} = -\frac{\partial}{\partial z}[q_T f_w(\theta) + Kk_{rw}(1-f_w(\theta)) - Kk_{rw}\frac{dh_c}{d\theta_w}\frac{\partial\theta_w}{\partial z}(1-f_w(\theta)) + Kk_{rw}\frac{\rho_g}{\rho_w}(1-f_w(\theta))] - (U_w + E); \qquad f_w(\theta_w) = \frac{k_{rw}/\mu_w}{k_{rw}/\mu_w + k_{ra}/\mu_g} \tag{1}$$

The mass balance equation for a contaminant in the water phase in the rhizoshpere soil region can be expressed as

$$\frac{\partial\theta_{rhw}C_{rhw}}{\partial t} = -\frac{\partial}{\partial z}\left(q_w C_{rhw} - D_{Hw}\frac{\partial\theta_{rhw}C_{rhw}}{\partial z}\right) - a_s\rho_b\left(K_1 C_{rhw} - C_{rhs}\right) - \frac{\partial}{\partial t}\left(K_{bs}C_{rhw}C_{rhm}\right) - \frac{\mu_{m,(T)}}{Y_{x/s}}C_{rhm}\left(\frac{C_{rhw}}{K_{rhw} + C_{rhw} + K_i C_{rhw}^{2}}\right)\left(\frac{C_{rhp}}{K_{rhp} + C_{rhp}}\right) - K_{rgw}\theta_{rhg}\left(K_H C_{rhw} - C_{rhg}\right) - \sigma_r K_{rrw}\left(K_{rw}C_{rhw} - C_r\right) - U_w T_{scf} C_{rhw} + K_{wbr}\theta_w\left(C_{bw} - C_{rhw}\right) \tag{2}$$

3.Materials and Methods

A 2-year field study was conducted using 72 (1.5 m long and 0.1 m diameter) column lysimeters with four treatments: Johnsongrass; wild rye grass; a rotation of Johnsongrass and wild rye grass; and unplanted fallow conditions (Figure 1a). Contaminants were mixed into the soil to a concentration of 10 mg/kg soil each and then packed in the lysimeters to a bulk density of 1.4 g/cm^3 (Figure 1b). Soil moisture in the lysimeters was maintained near field capacity gravimetrically. Columns were destructively sampled each time period. Samples of vegetation, roots, and soil were collected and measured for contaminant concentrations.

Figure 1 Photograph of (a) the column lysimter facilities and (b) soil contamination using a cement truck.

To determine the influence of roots on bioremediation, the columns were divided into 6 sections (0-10, 10-30, 30-60, 60-90, 90-120, 120-150 cm). Analysis of the TNT were conducted using an immunoassay procedure (Strategic Diagnostic Inc.) as validated by U.S. EPA Office of Solid Waste (U.S. EPA, 1995).

4.Results

Numerical experiments were conducted with actual weather, soil, and irrigation data to investigate model behavior under field conditions to determine the main factors influencing phytoremediation implementation. The results showed that parameters related to the contaminant concentration in the water phase such as i.e., aqueous solubility, octanol-water partition coefficient, and organic carbon content were the main parameters determining the contaminant fate in the vadose zone.

Experimental results showed that the concentrations of TNT in soil extracts markedly declined with time, reaching the limit of detection (0.25 mg/kg) by or before day 110 (92 days after germination). Vegetation dramatically reduces soil moisture content in the root zone which tends to immobilize contaminates in the root zone and reduce the potential for surface runoff.

The proposed model was applied to a field experiment for a period of one year. Figure 2 compared simulated values with experimental data of TNT for Johnsongrass planted column. Results showed good correlation between simulated and experimental data. This result is consistent with the hypothesis that bioavailability is an important factor in determining contaminant degradation by plants as well as microorganisms.

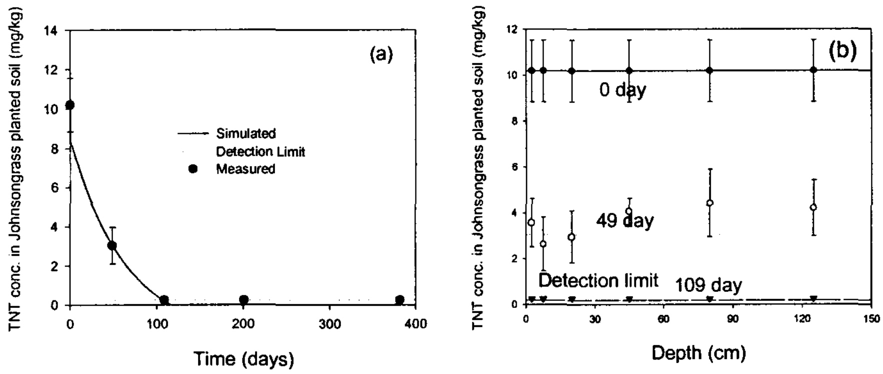

Figure 2 Comparison of simulated values with experimental data of TNT (a) Temporal variation at 20 cm below the surface and (b) Spatial variation of TNT concentration.

5.Conclusions and Discussion

In this study, mathematical models were developed that can be applied to various bioremediation methods in the unsaturated zone, especially phytoremediation. Laboratory and field experiments were conducted to determine soil properties, soil hydraulic functions, and root properties as well as contaminant dissipation under field conditions. If the water phase concentration is low and degradation is limited by mass transfer rate rather than by microbial activity, the enhancement of bioremediation by plants become negligible. Contaminant decay as well as aging in the soil may introduce an uncertainty factor for soil remediation especially in freshly contaminated soils. For field application, the proposed model gave an acceptable representation of the fate and transport of contaminant both in vegetated and unplanted soils. This study suggested that other natural purification mechanisms such as aging, volatilization, and natural bioremediation should be taken in to consideration to maximize the plant effect and minimize the cost in phytoremediation applications. Nitrogen levels in the soil should be maintained for optimum vegetation growth and to support microbial populations in the soil. Microbial activities and plant contamination are closely related and it suggests that plant and microorganisms can have complementary roles in well managed phytoremediation system (Sung et al., 2001).

6.References

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