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A simple approach to modeling microbial biomass in the rhizosphere

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Abstract

Microorganisms make an important contribution to the degradation of contaminants in bioremediation as well as in phytoremediation. An accurate estimation of microbial concentrations in the soil would be valuable in predicting contaminant dissipation during various bioremediation processes. A simple modeling approach to quantify the microbial biomass in the rhizosphere was developed in this study. Experiments were conducted using field column lysimeters planted with Eastern gamagrass. The microbial biomass concentrations from the rhizosphere soil, bulk soil, and unplanted soil were monitored for six months using an incubation–fumigation method. The proposed model was applied to the field microbial biomass data and good correlation between simulated and experimental data was achieved. The results indicate that plants increase microbial concentrations in the soil by providing root exudates as growth substrates for microorganisms. Since plant roots are initially small and do not produce large quantities of exudates when first seeded, the addition of exogenous substrates may be needed to increase initial microbial concentrations at the start of phytoremediation projects.

Keywords: Microbial biomass; Exogenous substrates; Indigenous substrates; Mathematical model; Eastern gamagrass; Root exudates

1. Introduction

Microorganisms make an important contribution in the breakdown of contaminants in bioremediation and phytoremediation projects (Reynolds et al., 1999). Even if microorganisms do not consume a contaminant as a primary substrate, they can degrade recalcitrant

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contaminants by cometabolism (Boopathy et al., 1994; Schwab et al., 1995; Fletcher et al., 1995). Enhanced biodegradation may take place in contaminated soil when additional substrates increase the number of microorganisms. Roots can greatly affect microbial biomass concentration and distribution in the soil as microbial growth is stimulated by the input of readily assimilable organic substrates from the roots such as, exudates, mucilage, and dead root cells (Newman and Watson, 1977; Anderson et al., 1993). The rhizosphere is defined as the zone of interaction between plant roots and soil microorganisms (Lynch, 1990). Therefore, during phytoremediation, microorganisms can have a complementary role with plants for contaminant dissipation (Sung et al., 2001a).

An accurate estimation of microbial concentrations in the soil would be extremely valuable in predicting contaminant dissipation during various bioremediation processes. Several models have been developed to access the effects of roots on microbial populations in vegetated soil. Newman and Watson (1977) developed a model to simulate microbial growth in the rhizosphere. Darrah (1991) simulated microbial biomass changes in the rhizosphere considering both soluble and insoluble carbon. Narayanan et al. (1995) included the concentration of root exudates as growth substrates in a Monod type model for vegetated soil. Chang and Corapcioglu (1998) applied a biofilm approach to explain enhanced biodegradation in the rhizosphere. Blagodatsky and Richter (1998) proposed a model that can consider carbon and nitrogen turnover for microbial growth in soil. Choi et al. (1999) developed a model describing the main kinetics activated during the degradation processes of organic matter in soil. However, currently there is not a simple model that considers the effects of substrate addition from an exogenous supply or substrate addition from indigenous conversion.

In the present study, a simple approach to a mathematical model for simulating microbial biomass changes in response to substrate concentration changes is presented. The model was developed for the phytoremediation of contaminants in soils and can be applied to various bioremediation methods like bioaugmentation. The model can access temperature stress on microorganism growth, substrate provision from roots, exogenous substrate addition, and indigenous substrate conversion. This model was validated using the field data obtained from lysimeter phytoremediation experiments with freshly contaminated soil planted with Eastern gamagrass (Sung et al., 2001b).

2. Model development

When the supply of a primary substrate is considered to be limiting, microbial metabolism and subsequent microbial growth was assumed to follow the Monod equation. In the Monod equation the rate of microbial growth with cell decay and maintenance is described by:

$$\frac{\mathrm{d}C_\mathrm{m}}{\mathrm{d}t} = \left(\mu_{\mathrm{m},(T)}\left(\frac{C_\mathrm{P}}{K_\mathrm{P}+C_\mathrm{P}}\right)\left(\frac{C_\mathrm{O}}{K_\mathrm{O}+C_\mathrm{O}}\right) - K_\mathrm{d}\right) C_\mathrm{m} \tag{1}$$

where C_m the is microbial concentration in the soil ($\mathrm{g\,cm^{-3}}$), C_P and C_O aqueous phase concentrations of dissolved primary substrates and electron acceptors in the soil ($\mathrm{g\,cm^{-3}}$), respectively, K_P and K_O the half-saturation constants for primary substrate based on the soil-water phase and electron acceptors for microbial growth ($\mathrm{g\,cm^{-3}}$), respectively, K_d the first-order endogeneous decay coefficient that includes cell maintenance and death ($\mathrm{h^{-1}}$), and $\mu_{\mathrm{m},(T)}$ is the apparent maximum microbial growth rate that is dependent on temperature ($\mathrm{h^{-1}}$).

Generally, microorganisms have an optimum temperature range for growth with threshold values for both low and high temperatures (Paul and Clark, 1989). Although there are differences in the detailed response for individual species, the general response of microbial activity to temperature changes can be expressed using the stress index as follows:

$$S_\mathrm{fTm} = \begin{cases} 0, & T \le T_\mathrm{min} \text{ or } T \ge T_\mathrm{max} \\ A_1 \dfrac{T - T_\mathrm{min}}{T_\mathrm{alt} - T_\mathrm{min}}, & T_\mathrm{min} \le T \le T_\mathrm{alt} \\ (1 - A_1)\dfrac{T - T_\mathrm{alt}}{T_\mathrm{lt} - T_\mathrm{alt}} + A_1, & T_\mathrm{alt} \le T \le T_\mathrm{lt} \\ 1, & T_\mathrm{lt} \le T \le T_\mathrm{ut} \\ \dfrac{T_\mathrm{max} - T}{T_\mathrm{max} - T_\mathrm{ut}}, & T_\mathrm{ut} \le T \le T_\mathrm{max} \end{cases} \tag{2}$$

where S_fTm is the stress index for temperature. The subscript alt is the point of inflection or slope change of the temperature stress index. The subscripts max and min denote the limiting maximum and minimum temperature. The subscripts lt and ut denote lower and