Available online at www.sciencedirect.com
SCIENCE DIRECT®
Science of the Total Environment 367 (2006) 979–987
Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Humankind
www.elsevier.com/locate/scitotenv

Aerobic and anaerobic biodegradation of phenol derivatives in various paddy soils

Atsushi Shibata [a], Yasushi Inoue [a], Arata Katayama [a,b,*]

[a] *Department of Geotechnical and Environmental Engineering, Nagoya University, Chikusa, Nagoya 464-8603, Japan*
[b] *EcoTopia Science Institute, Nagoya University, Chikusa, Nagoya 464-8603, Japan*

Received 10 November 2005; received in revised form 30 January 2006; accepted 31 January 2006
Available online 13 March 2006

Abstract

Microbiological degradation of phenol and some of its alkyl-derivatives (*p*-cresol, 4-*n*-propylphenol, 4-*i*-propylphenol, 4-*n*-butylphenol, 4-*sec*-butylphenol, 4-*t*-butylphenol, and 4-*t*-octylphenol) was examined under both aerobic and anaerobic conditions in seven Japanese paddy soils. Aerobic biodegradation of phenol derivatives was detected in all the paddy soils examined. The half-lives ranged from 2 to 19 days. The aerobic degradation rate of 4-*t*-octylphenol was correlated inversely with the total carbon contents of paddy soils, and there were significant inverse correlations between the aerobic degradation rate and the size of alkyl groups of alkylphenols. Anaerobic biodegradation of phenol and *p*-cresol was detected in three soils with the half-lives ranging from 24 to 260 days for phenol and from 11 to 740 days for *p*-cresol, respectively. The three soils were characterized by low contents of nitrate and iron oxides. Other soil properties did not show any significant correlations with the anaerobic degradation rates. In one soil, we found for the first time anaerobic biodegradation of 4-*n*-propylphenol. However, the other five compounds (4-*i*-propylphenol, 4-*n*-butylphenol, 4-*sec*-butylphenol, 4-*t*-butylphenol and 4-*t*-octylphenol) were not degraded over 224 days of incubation. These results suggest that phenol and all the alkylphenols were degraded within several days when paddy soil is not flooded and so under aerobic conditions. Under flooded and anaerobic conditions, 4-*n*-propylphenol would be degraded as well as phenol and *p*-cresol while alkylphenols with long and branched alkyl chains were hardly degraded at all.

Keywords: Alkylphenol; Aerobic biodegradation; Anaerobic biodegradation; Paddy soil

1. Introduction

Phenol and alkylphenols are known environmental pollutants. In particular, octylphenol and nonylphenol, which are known to have estrogenic activity (Soto et al., 1991; Jobling and Sumpter, 1993; Renner, 1997), are intermediates of the degradation of alkylphenol ethoxylate surfactants (APEOs), used in domestic detergents and in formulations of pesticides and industrial products (Ahel et al., 1994a,b, 1996). Many studies have reported the environmental fates of APEOs and their metabolism in seawaters, river sediment, and sewage treatment effluents (Ekelund et al., 1993; Ying et al., 2002; Yuan et al., 2004). In contrast, there are few studies of the biodegradation of alkylphenols and APEOs in agricultural soils (Topp and Starratt, 2000; Mortensen and Kure, 2003). Bacteria capable of biodegrading APEOs were shown to exist in rice paddy soil (Nishio et al., 2002). Our recent work described and characterized in

* Corresponding author. EcoTopia Science Institute Nagoya University, Furo-cho, Chikusa, Nagoya 464-8603, Japan. Tel.: +81 52 789 5856; fax: +81 52 789 5857.
E-mail address: a-katayama@esi.nagoya-u.ac.jp (A. Katayama).

0048-9697/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.scitotenv.2006.01.031

Table 1
Properties of soils used in this study

	Kuridashi	Yatomi	Kamajima	Nagakute B-10	Nagakute C-16	Togo	Anjo
Soil groups (FAO/UNESCO)	Eutric Fluvisols	Eutric Fluvisols	Eutric Gleysols	Eutric Gleysols	Umbric Andosol	Eutric Gleysols	Eutric Gleysols
Soil texture	SiL	SiL	SiL	Lic	Lic	LiC	LiC
pH (H_2O)	6.7	6.3	6.6	4.9	5.6	5.0	5.5
Total C (%)	0.99	1.30	2.05	1.05	3.59	1.15	1.34
Total N (%)	0.03	0.03	0.10	0.04	0.14	0.04	0.04
Cl^- (mg/kg)	38.6	125.8	423.8	27.9	107.4	26.3	31.5
SO_4^{2-} (mg/kg)	96.5	163.0	191.9	137.0	278.0	278.5	425.0
NO_3^- (mg/kg)	0.8	2.3	1.7	1.9	3.8	4.2	4.1
Iron oxides (mg/kg)	6.9	14.0	2.3	2.1	26.2	24.2	23.6
Moisture content % (pF 1.8)	30.7	31.4	26.1	19.5	35.2	16.2	25.6

detail one possible mechanism of biodegradation using a bacterium that was isolated from rice paddy soil (Sato et al., 2001, 2003). However, the fates of alkylphenols in rice paddy soil and in anaerobic soil environments remain to be elucidated. Anaerobic sites are distributed widely in soil environments. Since rice paddy soils are

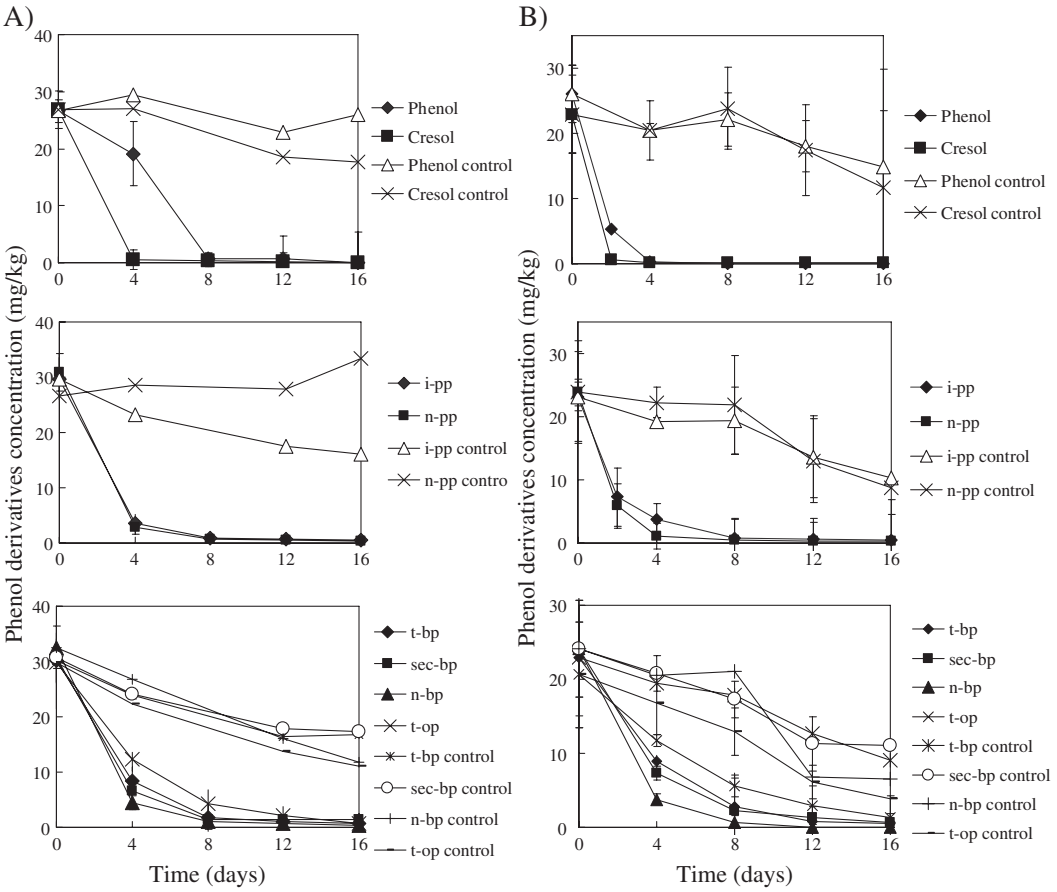

Fig. 1. Aerobic degradation of phenol derivatives (A) in Nagakute B-10 soil and (B) in Kamajima soil. Abbreviations: 4-*i*-propylphenol (*i*-pp), 4-*n*-propylphenol (*n*-pp), 4-*t*-butylphenol (*t*-bp), 4-*sec*-butylphenol (*sec*-bp), 4-*n*-butylphenol (*n*-bp), and 4-*t*-octylphenol (*t*-op). "Control" means a sterile soil used as a control.