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Solid phase bioremediation of pendimethalin in contaminated soil and evaluation of leaching potential

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Abstract

Substrate leaching experiments were performed to study the relative leaching potential of pendimethalin in various types of soil matrices. Pendimethalin leaching showed up to a depth of 30 cm in all the studied soil matrices, irrespective of pH conditions used. The leaching potential of pendimethalin was assessed at various pH conditions. Comparatively higher leaching potential was observed in basic conditions compared to the neutral and acid conditions of soil. Soil phase bioremediation of pendimethalin was also performed on all the soil matrices. Among the studied variations, bioremediation experiments performed in presence of sunlight showed higher efficiency. Bioaugmentation along with sunlight showed higher remediation efficiency in all the studied soil matrices. Biostimulation did not respond positively on the progress of bioremediation.

Keywords: Pendimethalin; Leaching; Solid phase bioremediation; Sunlight; Bioaugmentation; pH

1. Introduction

The extensive use of pesticides in agriculture is compromising of soil and water quality and major concern was to protect water resources (Younes and Galal-Gorchev, 2000). Pendimethalin is a pre-emergence herbicide, which is used to destroy or prevent the growth of weeds. It is normally used on crops and residential lawns and ornamental plants. Widespread use of pendimethalin led to its detection as a contaminant in soil, ground water, surface water and air (Barbash and Resek, 1996; Capel et al., 1998; Larson et al., 1999). Pendimethalin was also detected in soil and ground water beneath herbicide manufacturing units, loading and mixing facilities (Barbash and Resek, 1996). It adsorbs strongly to organic matter and clay minerals and is thus not mobile in soil. It is moderately persistent with a field half-life of approximately 90 days and does not undergo rapid microbial degradation (Wauchope et al., 1992). Pendimethalin was normally degraded through photo-degradation, volatilization or by biodegradation (WHO, 1993; Moza et al., 1992; Smith et al., 1979; Zhang et al., 2000; Miller et al., 1996).

Biodegradation was a fundamental attenuation process for pesticides in soil (Guo et al., 2000; Venkata Mohan et al., 2006; Rama Krishna et al., 2006; Shailaja et al., 2006), which is catalyzed by soil microbes and is governed by both abiotic and biotic factors. Biodegradation process was affected by a variety of interactions among microorganisms, various soil constituents, and the specific pesticide involved. Sorption was the key in controlling pesticide transport, transformation and bioaccumulation processes (Calvet, 1989; Linn et al., 1993; Rudel et al., 1993). Field experiments were conducted on atrazine, metolachlor and diuron to study the consequences of the penetration depth and properties of pesticides on the risk of subsequent leaching (Delphin and Chapot, 2006). The sorption and leaching of ethametsulfuron-methyl by acidic soil after organic amendment with humic acid was studied in batch and soil column experiments (Youbin et al., 2006). However, no report is available regarding leaching studies of pendimethalin in soil.

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This communication reports the results of the investigations carried out on the leaching potential and biodegradation of pendimethalin in different soils under various experimental conditions.

2. Methods

2.1. Pendimethalin

Pendimethalin (*N*-(1-ethylpropyl)-3,4-dimethyl-2, 6-dinitro benzenamine) with 98% purity was (M/S Shogan organics Limited, Mumbai) used in the bioremediation studies. Pendimethalin is very stable when stored between 5 and 130 °C to acids and alkalis. It slowly decomposes when exposed to light and DT_{50} in soil in 90 days. It has a melting point in the range of 54–58 °C; solubility in water is 0.3 mg/l at 20 °C (Walker and Bond, 1977).

2.2. Soils

The soil matrices used in the investigation were procured from the garden of Indian Institute of Chemical Technology (IICT), Hyderabad and Agricultural University, Rajendra Nagar, Hyderabad. The soil (S1) at IICT was being used for horticultural activities and soils S2–S6 were used for experiments in agricultural research. Soil samples were taken at 0–0.05 m and 0.10–0.15 m depths, between crop rows (0.70 m). The properties of the soils were estimated and depicted in Table 1.

2.3. Augmented inoculum and characteristics

Mixed microflora available in the outlet of the ETP facility of the institute which is a mixture of domestic and laboratory wastewater was used as augmenting inoculum. The inoculum was collected from the outlet of the oxidation pond. The microflora was exposed to a wide variety of solvents and chemicals originating from the laboratory. The pH of the ETP outlet used as inoculum for augmentation was 7.2 ± 0.3 with COD ranging from 175 to 190 mg/l. The CFU in the ETP outlet was 2.4×10^7 CFU/ml.

Table 1
Properties of soil matrices used in the experiments

Properties	Soil					
	S1	S2	S3	S4	S5	S6
pH	7.2	8.12	7.5	8.6	8.74	7.82
Bulk density (g/cm^3)	1.17	0.562	0.575	0.583	0.606	0.729
Specific gravity	1.1	1.264	1.258	1.144	1.225	1.539
Soil texture[a]						
1. Sand	40.1	34.2	24.1	32.8	65.9	17.4
2. Silt	42.3	43.52	20.2	37.1	22.0	35.5
3. Clay	17.6	22.28	55.7	30.1	12.1	47.1
Soil moisture[b]						
1. Field	19.5	18.67	17.61	10.1	16.8	11.2
2. Air dry	1.5	1.16	2.1	1.4	2.6	1.28
Organic matter (%)	0.8	1.2	2.2	0.6	1.4	0.92
Particle size (μm)	710	710	710	710	710	710
CFU [c]	39	120	75	57	68	110

S1 – Loam; S2 – Silty loam; S3 – Clay; S4 – Clay loam; S5 – Sandy loam; S6 – Silty clay.
[a] Soil texture in %.
[b] Soil moisture in %.
[c] Per gram of soil ($\times 10^4$).

2.4. Soil leaching experiments

Leaching experiments were carried out using columns made up of glass 60 cm (l) and 3.1 cm (dia). Nylon mesh with an effective pore diameter of 60 μm was placed on the base of the column to minimize the dead-end volume. Six types of soils (500 g) were added to each column and filled up to a height of 50 cm. The upper part of the column was uniformly covered with glass wool to minimize the surface disturbance. Initially the soil columns were saturated with de-ionized water to remove the entrapped air. Ten grams of each soil was treated with 100 μg of pendimethalin, which was then dissolved in acetone. The soil was air-dried for 24 h at room temperature (25 ± 2 °C) and layered on the top of the column (up to 5 cm height). The columns were eluted with 1 l of de-ionized water with three different pH conditions (2.5, 6.8 and 9.0) for six different soils studied. The leachate was collected in different conical flasks (200 ml each portion) for the estimation of pendimethalin. At the end of the elution the columns were sectioned into 10 cm deep portion, were dried at room temperature and homogenized (manually). Sub-samples of the soil (5 g) were extracted in conical flasks, placed in a shaker for 24 h with 25 ml of HPLC grade acetonitrile. Subsequently filtered (0.2 μm cartridge) and concentration of pendimethalin was estimated by HPLC.

2.5. Solid phase (in situ) bioremediation experiment

Six different soils were air-dried and sieved to 2 mm. The experiments were carried out on petri plates (18 cm diameter) by taking 650 g of soil. Water and ETP microflora were added to the soil samples to maintain the moisture content in and around 3%. Pendimethalin dissolved in acetone was sprayed on to the soil aggregate surface by means of micro-syringe. Pendimethalin loading of 5.5 mg/g was used throughout the remediation experiments with five variable conditions viz. absence of sunlight and nutrients (acts as control) (SP1), presence of sunlight (SP2), addition of nutrients (biostimulation) (SP3), bioaugmented with ETP microflora in absence of sun light (SP4) and bioaugmented with ETP microflora under sunlight (SP5) (Table 2). The soil was exposed to sunlight for 8 h/day for all the experiments. The pH of the soil (1:10) was maintained between 6.9 and 7.1. The degradation efficiency was assessed by determining the amount of pendimethalin residue remaining in the soil over a period of 45 days. Sampling was done once in every 5 days by taking 5 g of soil. The soil was extracted in a conical flask, placed in a shaker