JOURNAL OF ENVIRONMENTAL SCIENCES 44 (2016) 131–140

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/jes

JES JOURNAL OF ENVIRONMENTAL SCIENCES

www.jesc.ac.cn

Lead toxicity thresholds in 17 Chinese soils based on substrate-induced nitrification assay

Ji Li[1,2], *Yizong Huang*[1,*], *Ying Hu*[2], *Shulan Jin*[3], *Qiongli Bao*[1], *Fei Wang*[2], *Meng Xiang*[2], *Huiting Xie*[2]

1. *Agro-Environmental Protection Institute, Ministry of Agriculture, Tianjin 300191, China*
2. *Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China*
3. *Shangrao Normal University, Shangrao 334000, China*

ARTICLE INFO

Article history:
Received 5 June 2015
Revised 25 August 2015
Accepted 1 September 2015
Available online 29 January 2016

Keywords:
Pb toxicity
Leaching
Nitrification assay
Risk assessment

ABSTRACT

The influence of soil properties on toxicity threshold values for Pb toward soil microbial processes is poorly recognized. The impact of leaching on the Pb threshold has not been assessed systematically. Lead toxicity was screened in 17 Chinese soils using a substrate-induced nitrification (SIN) assay under both leached and unleached conditions. The effective concentration of added Pb causing 50% inhibition (EC50) ranged from 185 to >2515 mg/kg soil for leached soil and 130 to >2490 mg/kg soil for unleached soil. These results represented >13- and >19-fold variations among leached and unleached soils, respectively. Leaching significantly reduced Pb toxicity for 70% of both alkaline and acidic soils tested, with an average leaching factor of 3.0. Soil pH and CEC were the two most useful predictors of Pb toxicity in soils, explaining over 90% of variance in the unleached EC50 value. The relationships established in the present study predicted Pb toxicity within a factor of two of measured values. These relationships between Pb toxicity and soil properties could be used to establish site-specific guidance on Pb toxicity thresholds.

Introduction

Lead (Pb), a nonessential element, is frequently implicated in soil pollution. The potential environmental risk of Pb has received increasing attention because of the presence of Pb worldwide and the potential exposure of terrestrial organisms, wildlife and human beings (Watanabe, 1997). China is now the world's largest producer of lead ore and refined lead, and also the largest refined lead consumer in the world. The problem of soil lead pollution arose and became serious with the rapid development of the mining and smelting industry. For the past few years, efforts have been made to investigate Pb toxicity thresholds in European and Australian soils with various toxicity assays, such as plant growth (Cheyns et al., 2012) and microbial assays (Rusk et al., 2004). However, few such studies have been reported for Pb toxicity in Chinese soils.

It is well recognized that soil physicochemical properties are important factors in predicting the toxicity and bioavailability of metals, such as copper (Cu), zinc (Zn), nickel (Ni) and lead (Pb), in soils (He et al., 2015; Broos et al., 2007; Oorts et al., 2006b; Rooney et al., 2006). Bradham et al. (2006) concluded that soil pH was the most important factor related to Pb bioavailability and toxicity to earthworms. Although it is widely recognized that soil properties play a crucial role in affecting toxicity (Cremazy et al., 2013; Li et al., 2011; Li et al., 2009, 2010; Oorts et al., 2006b, 2007; Rooney et al., 2006, 2007), few countries have incorporated

* *Corresponding author*. E-mail: hyz@rcees.ac.cn (Yizong Huang).

http://dx.doi.org/10.1016/j.jes.2015.09.019
1001-0742

soil physicochemical properties in their soil quality guidelines. With scientific data like that provided by the present studies, the ecologically relevant Chinese soil guidelines could improve more quickly.

Laboratory toxicological assays based on fresh spiking of metals into soils are not able to predict the chronic toxicity of metals in the field (Schwertfeger, 2011; Oorts et al., 2006a; Giller et al., 1998). Spiking soils with soluble metal salts not only increases the metal content of a soil but also increases the ionic strength of the soil solution and decreases the soil pH by replacement of protons from the exchange complex with metal cations. These changes in soil properties are artifacts of spiking with soluble metal salts and affect the metal bioavailability and soil microbial response (Speir et al., 1999). Aging processes and loss of excess salts by leaching may contribute much to this discrepancy (Oorts et al., 2006a). Therefore, leaching after metal addition has been proposed as an agreed approach to reduce the chemical artifacts of the spiking procedure (*e.g.*, salt effect, increased metal solubility) that can decrease the ecological relevance of soil toxicity assays (Schwertfeger, 2011; Smolders et al., 2009; Oorts et al., 2006a, 2007; Bongers et al., 2004; Stevens et al., 2003). The effects of leaching on Pb ECx values in soils require further study on a larger scale before leaching is used as a standard protocol in soil toxicity assays.

Soil microbial processes were selected because of their high sensitivity to metal addition, and these processes are considered to predict soil function in terrestrial risk assessments. Based on this rationale, substrate-induced nitrification (SIN) was selected as the end point to assess the potential risks of Pb in soil. The aims of this study were: (1) to determine the effect of leaching on Pb toxicity as it affects the SIN assay in a range of Chinese soils, and (2) to develop quantitative relationships between soil physicochemical properties and the toxicity thresholds.

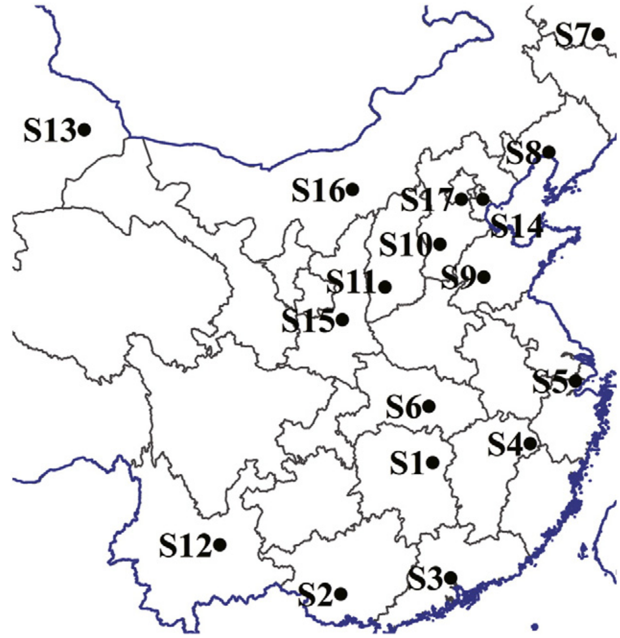

Fig. 1 – Location of soil sampling sites.

1. Materials and methods

1.1. Soils

Seventeen uncontaminated topsoils were collected throughout China (see Fig.1 and Table 1 for detailed information). The soils represent the major soil types and cover a wide range of soil pH and organic matter content of arable soils, which are expected to affect the toxicity and bioavailability of Pb in soils. Five surface soil samples (0–10 cm) were collected at each site. Soil samples were sealed in polyethylene bags and stored at 4 prior to analysis.

The soils were air-dried and sieved through 2 mm mesh, and soil physicochemical properties were determined. Soil pH was measured in 0.01 mol/L $CaCl_2$ (soil:water ratio, 1:5) after shaking for 1 hr and allowing to settle for 30 min. Cation exchange capacity (CEC) was measured with 1 mol/L ammonium chloride at pH 7. Organic carbon was calculated as the difference between total and inorganic carbon content. Total carbon and nitrogen were determined by ignition with a Variomax CNS elemental analyzer (Vario EL III, Germany). The clay content of soils was determined through particle size analysis after destruction of organic matter with H_2O_2, removal of carbonate and soluble salts with HCl, and dispersion with sodium hexametaphosphate (Gee and Bauder, 1986).

Total Pb concentrations were determined by inductively coupled plasma-optical emission spectrometry (ICP-OES; Optima 8300 DV, PerkinElmer, USA) or inductively coupled plasma-mass spectrometry (ICP-MS; Agilent, USA) after boiling aqua regia (HNO_3:HCl = 1:3) extraction. All soil properties are expressed on an oven-dried (105) weight basis (Table 1).

1.2. Soil treatments

Sieved, air-dried soil was spiked with Pb (as $Pb(NO)_3$ in deionized water, 50 ml/kg) at 25, 50, 100, 200, 400, 800 and 1000 mg Pb/kg dry soil for soils with pH < 5; 50, 100, 200, 400, 800, 1200 and 1600 mg Pb/kg dry soil for soils with pH from 5 to 7; and 100, 200, 400, 800, 1200, 1600 and 2400 mg Pb/kg dry soil for soils with pH > 7. The spiked soils were incubated for 1 day at 100% maximum water holding capacity (MWHC), then air-dried at 25°C, and sieved through 2-mm mesh.

The freshly spiked soils were leached with artificial rainwater ($CaCl_2$ 5×10^{-4} mol/L, $Ca(NO_3)_2$ 5×10^{-4} mol/L, $MgCl_2$ 5×10^{-4} mol/L, Na_2SO_4 10^{-4} mol/L, and KCl 10^{-4} mol/L, pH 5.9). The leached soil treatments were also air-dried at 25°C and sieved through 2-mm mesh. All leached and unleached soils were stored at room temperature before starting the SIN assay.

1.3. Substrate-induced nitrification assay

All leached and unleached soils were used to establish a standard SIN assay (Li et al., 2009, 2010; Oorts et al., 2006b). Three replicates of 7 g amended soil for each Pb treatment were preincubated under dark aerobic conditions at 20 ± 2°C in 50-mL centrifuge tubes. Additional deionized water was added to adjust to 50 ± 5% MWHC, taking into account the volume of