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Investigation on the eco-toxicity of lake sediments with the addition of drinking water treatment residuals

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ABSTRACT

Drinking water treatment residuals (WTRs) have a potential to realize eutrophication control objectives by reducing the internal phosphorus (P) load of lake sediments. Information regarding the ecological risk of dewatered WTR reuse in aquatic environments is generally lacking, however. In this study, we analyzed the eco-toxicity of leachates from sediments with or without dewatered WTRs toward algae *Chlorella vulgaris* via algal growth inhibition testing with algal cell density, chlorophyll content, malondialdehyde content, antioxidant enzyme superoxide dismutase activity, and subcellular structure indices. The results suggested that leachates from sediments unanimously inhibited algal growth, with or without the addition of different WTR doses (10% or 50% of the sediment in dry weight) at different pH values (8–9), as well as from sediments treated for different durations (10 or 180 days). The inhibition was primarily the result of P deficiency in the leachates owing to WTR P adsorption, however, our results suggest that the dewatered WTRs were considered as a favorable potential material for internal P loading control in lake restoration projects, as it shows acceptably low risk toward aquatic plants.

Introduction

Water management faces a global call for control of eutrophication due to phosphorous (P) loading (Carpenter, 2008). Internal P loading from sediments, specifically, has been identified as one of the major causes of excessive P in lakes (Egemose et al., 2010). At present, chemical immobilization is considered as an effective method of minimizing internal P loading (Paller and Knox, 2010); this technique involves adding chemicals to the lake to reduce P mobility in sediments. Low-cost and environmentally friendly chemicals with high P adsorption capability are essential for future advancements in chemical immobilization techniques (Wang et al., 2012).

Drinking water treatment residuals (WTRs) are ubiquitous by-products generated during potable water production primarily comprised of aluminum (Al) and iron (Fe) hydroxides owing to their effective coagulant utilization (Babatunde and Zhao, 2007). WTRs have demonstrated high adsorption capability toward many contaminants, such as arsenic (As) (Nagar et al., 2013), chromium (Cr) (Zhou and Haynes, 2011), copper (Cu) (Castaldi et al., 2015), lead (Pb) (Zhou and Haynes, 2011), mercury (Hg) (Hovsepyan and Bonzongo, 2009), nickel (Ni) (Mahdy et al., 2012), organic pesticide (Zhao et al., 2013, 2015), P (Razalia et al., 2007), perchloric acid (Makris et al., 2006), selenium (Se) (Ippolito et al., 2009), sulfide (S) (Wang and Pei, 2012), and tetracyclines (Punamiya et al., 2015). Many researchers have explored

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P-adsorbing WTR recycling as-applied to environmental pollution control measures (Bai et al., 2014). WTRs can be used as amendments to reduce the loss of P from P-rich soils (Agyin-Birikorang et al., 2009), and as main substrates for constructed wetlands to remove excessive P from wastewater (Zhao et al., 2011).

Recently, WTRs have shown considerable potential to ameliorate internal P loading in lakes for eutrophication control purposes (Wang et al., 2015a). Specifically, WTRs can reduce internal P loading from sediments under different dissolved oxygen levels (Wang et al., 2013b). The immobilization capability of WTRs is quite stable, for example, it is hardly affected by pH (5–9), illumination intensity, resuspension, ionic concentration, organic matter in sediments, or microbial activity (Wang et al., 2013a, 2013c). The potential toxicity to aquatic organisms caused by sediments with the addition of WTRs must be thoroughly tested before the materials can be reasonably applied in practice, however.

Therefore, we examined the potential eco-toxicity of lake sediments with addition of WTRs following growth of green algae *Chlorella vulgaris* under different doses, incubation times, and pH values to assess the risk of reusing WTRs in aquatic environments. The indices used for measurement were algal cell density, chlorophyll (Chl) content, malondialdehyde (MDA) content, antioxidant enzyme superoxide dismutase (SOD) activity, and subcellular structure. We expect that the results presented here will facilitate future use (and reuse) of WTRs to reduce internal P loading in lakes for eutrophication control purposes.

1. Materials and methods

1.1. Sample collection and preparation

Dewatered WTRs were collected from the dewatering workshop of the Ninth Water Supply Plant of Beijing, wherein both poly aluminum chloride and ferric chloride are used as coagulants. The fresh dewatered WTRs were air-dried, ground, and sieved to a diameter of <1 mm. Lake sediment was obtained from Jiaozhuang Village in Lake Baiyangdian (38°53′N, 115°59′E). The upper 10 cm of the sediment was collected and filtered through a 1.8 mm screen to remove impurities, then homogenized mechanically. The sediment was stored at 4°C until use (within 48 hr).

WTRs were mixed with sediments at doses accounting for 0% (control), 10%, and 50% of the sediment in dry weight. The mixtures were then incubated for 10 days and 180 days, respectively. After incubation, the mixtures were freeze-dried, ground, and sieved to a diameter of <1 mm. Six samples in total were investigated: raw sediments incubated for 10 days (RS-10 d) and 180 days (RS-180 d), sediments with the addition of 10% WTRs incubated for 10 days (WAS-10 p-10 d) and 180 days (WAS-10 p-180 d), and sediments with the addition of 50% WTRs incubated for 10 days (WAS-50 p-10 d) and 180 days (WAS-50 p-180 d). The WTR doses and incubation times were selected based on values defined in a study by Wang et al. (2012), who indicated that inorganic P can be successfully immobilized by WTRs within 10 days at a 10% dose ratio of WTRs to sediment in dry weight. Because the applied WTRs cannot be recovered from lake sediment in practice, the exposure duration of WTRs may be longer than 10 days during real-world application. Accordingly, incubation times of 10 days and 180 days were selected to investigate the short- and long-term effects, respectively, of WTR addition on sediment toxicity to algae. In addition, doses of P inactivating agents for lake restoration in practice would likely be greater than the calculated theoretical doses due to various factors affecting natural environments (Meis et al., 2013), so doses of 10% and 50% were selected to determine the effect of WTR addition dosage-wise.

1.2. Leachate preparation

Leachates were prepared according to methods outlined by Mamindy-Pajany et al. (2010) with slight modifications. A 1:10 (*m*/V:g/mL) sample and extractant ratio was used. Algal cell culture medium, which was sterilized at 121°C at 1.05 kg·cm^2 for 30 min, was used as extractant. The mixtures were filtrated with a 0.22 μm sterile acetate nitrate filter after being shaken at 60 r/min for 24 hr at (20 ± 2)°C. The filtrates (leachates) were then stored at 4°C in a dark environment prior to eco-toxicological and chemical analyses (within 24 hr). The sterilized medium was adjusted to pH of 6.0, 7.0, 8.0, or 9.0 with 1 mol/L NaOH or HCl solutions to form leachate extractant samples of varying pH values. During leaching, the pH was manually adjusted every 2 hr during the first 12 hr then every 4 hr during the last 12 hr.

1.3. Algal growth inhibition assays

C. vulgaris algae were obtained from the Institute of Hydrobiology, Chinese Academy of Sciences. Algal growth assay was conducted by following Guideline 201 (Freshwater Alga and Cyanobacteria, Growth Inhibition Test) of the Organization for Economic Cooperation and Development (OECD). The algae was grown in the OECD recommended algal cell culture medium (NH_4Cl 15 mg/L, $MgCl_2{\cdot}6H_2O$ 12 mg/L, $CaCl_2{\cdot}2H_2O$ 18 mg/L, $MgSO_4{\cdot}7H_2O$ 15 mg/L, KH_2PO_4 1.6 mg/L, $FeCl_3{\cdot}6H_2O$ 80 μg/L, $Na_2EDTA{\cdot}2H_2O$ 100 μg/L, H_3BO_3 185 μg/L, $MnCl_2{\cdot}4H_2O$ 415 μg/L, $ZnCl_2$ 3 μg/L, $CoCl_2{\cdot}6H_2O$ 1.5 μg/L, $CuCl_2{\cdot}2H_2O$ 0.01 μg/L, $Na_2MoO_4{\cdot}2H_2O$ 7 μg/L, and $NaHCO_3$ 50 mg/L), and algal cells were cultured in 100 mL OECD medium (control) or sediment leachates in 250 mL Erlenmeyer flasks. The initial cell densities were approximately 1 × 10^5 cells/mL. The flasks were stored in an incubator at (25 ± 0.5)°C with illumination by white incandescent lights (100 ± 5 μE/(m^2·sec), light:dark cycle 14 hr:10 hr) and shaken by hand three times daily.

As mentioned above, we also conducted algal growth inhibition assays under different pH levels. To achieve and maintain the desired pH of treatment and control groups during the experiments over 120 hr, buffer solutions were added to a final concentration of 3.6 mmol/L and pH was adjusted with 1 mol/L NaOH or HCl solutions. Ethane sulfonic acid buffer 2-(N-morpholino) was used to maintain a pH value of 6.0, pH 7.0 was stabilized with 3-(N-morpholino) propane sulfonic acid buffer, pH 8.0 was stabilized with 4-(2-hydroxyethyl)-1-piperazinepropanesulfonic acid buffer, and pH 9.0 was stabilized with 2-(cyclohexylamino) ethane sulfonic acid buffer (Van Hoecke et al., 2011). Prior to the assays, the algae were