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Cadmium removal capability and growth characteristics of *Iris sibirica* in subsurface vertical flow constructed wetlands

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ABSTRACT

Due to the increasingly serious river pollution of heavy metals, especially cadmium (Cd), the Cd pollution issues have aroused more and more political and academic attentions. In this study, microcosmic subsurface vertical flow constructed wetlands (MVFCWs) were planted with *Iris sibirica* to treat simulated polluted river water with different concentrations of Cd. The objective of this study was to investigate the Cd removal capacity of *I. sibirica*, plant growth characteristics and plant uptake, in order to fill the blank in the research of *I. sibirica* purification mechanism of Cd polluted water and meet the needs of the actual constructed wetland project. The plants grew well under any Cd treatments over the study period. The maximum Cd content in belowground parts was 1669.4 mg/kg and in aboveground parts 12.8 mg/kg on a dry weight basis when exposed to 6 mg/L Cd for 50 days. The maximum bioconcentration factor (BCF) values for root and shoot tissues were 323.2 and 3.8 respectively, obtained for 3 mg/L Cd, which indicated that the plants can play an important role for removal of Cd through phytoextraction. The test results showed that the average removing rate of Cd from the wastewater could reach 91.8%. High removal efficiency in the study proved that wastewater polluted by Cd could be treated effectively using MVFCWs with *I. sibirica* plant.

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1. Introduction

Heavy metal contamination in water environment is a serious problem that threatens not only the aquatic ecosystems but also human health. Unlike organic pollutants, which can be degraded into harmless chemical species, heavy metals are not degraded through biological processes (Arroyo et al., 2010). Of the many heavy metals that are present in water bodies, cadmium (Cd) is considered to be highly toxic to most organisms and can contaminate the food chain (He et al., 2005). High concentrations of Cd are toxic to plants for a variety of reasons, including inhibition of germination, root elongation and death, leaf chlorosis and withering, and reduction of plant biomass (Wang et al., 2008).

Conventional physical and chemical processes for the treatment of heavy metal contaminated wastewater are not only expensive but also insufficiently effective. Therefore, there is a considerable interest in the development of low-cost, effective, affordable and environmentally friendly solution for the treatment of sites contaminated by heavy metals. Constructed wetlands (CWs) are considered as be a reliable water treatment technology (Vymazal, 2011) and have the potential to remove metals and metalloids. Vertical subsurface flow constructed wetlands (VFCWs), which are of the low energy requirements, low cost, eco-friendly way and convenient operation and maintenance, can be potentially applied in developing countries with serious water pollution problems (Baptista et al., 2008). Compared with the horizontal flow system, VFCWs have smaller area demand, higher oxygen transfer capability, and simple hydraulics, although pore clogging can be a problem (Cooper, 2005; Zhao et al., 2011). But in present work microcosmic subsurface vertical flow constructed wetlands (MVFCWs) filled with composite fillings used as substrate media, which have good porosity to prevent clogging. However, few studies have investigated the application of VFCWs to treat Cd contaminated river water.

Macrophytes are assumed to be the primary biological component of wetlands. In general, the roles of wetland plants are to: (1) take up nutrients, heavy metals and toxic substances from wastewater; (2) transfer oxygen to rhizosphere for the growth, reproduction, and decomposition of microorganisms; and (3) enhance and stabilize the hydraulic transportation of media (Zhang et al., 2010). The choice of plants is an important issue in CWs, as they must survive the potentially toxic effects of the effluent and its variability (Maine et al., 2009). In some cases, the vegetation has either failed completely or proved difficult to establish in

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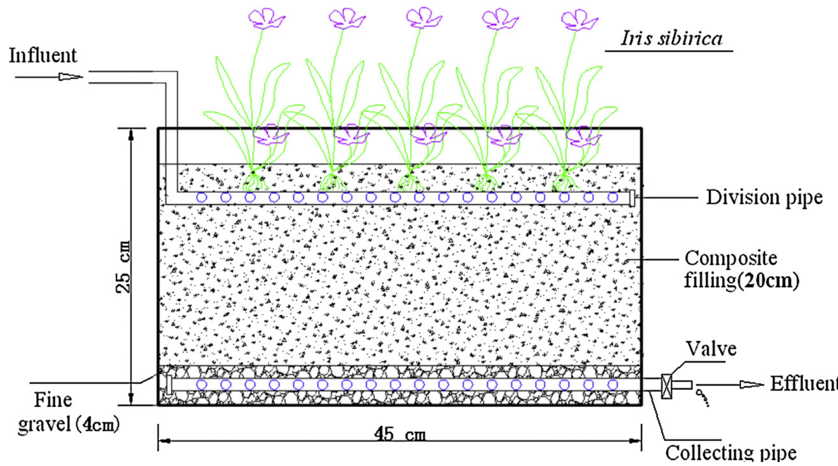

Fig. 1. Schematic diagram of the MVFCWs.

CWs. As improvements in the design of CWs are starting to reach a plateau, species selection may be the best way to maximize pollutant removal (Brisson and Chazarenc, 2009). Works on *duckweed* (Zayed et al., 1998), *water hyacinth* (Zhu et al., 1999), *water dropwort*, *calamus* (Wang et al., 2002), *Thlaspi caerulescens* (Wócik et al., 2005), *Myriophyllum heterophyllum* and *Potamogeton crispus* (Sivaci et al., 2008) and *Rorippa globosa* and *Rorippa islandica* (Sun et al., 2011) were reported for Cd uptake. However, the information about the Cd accumulation of *Iris sibirica* and its influence on plant growth characteristics has not been reported in literature. The *I. sibirica* is a flowering plant species in the family Iridaceae. It is native to Northeast Turkey, Russia, and Eastern and Central Europe. *I. sibirica* is a rhizomatous herbaceous perennial that can grow from 50 to 120 cm (20 in to 47 in) tall (Gao et al., 2014). It has also a good root system (Wang et al., 2012). The plant is ideal for the present study because of its rapid growth rate and extensive root system. Besides, it is an overwintering plant and can survive even when the temperature is extremely low.

Therefore, the objectives of the present investigation were to (1) evaluate the growth characteristics and the Cd accumulation ability of the *I. sibirica*; (2) assess the performances of systems planted with *I. sibirica* and the unplanted systems; (3) provide beneficial reference for plant selection in CWs and meet the needs of the actual constructed wetland project.

2. Materials and methods

2.1. Plant material and growth conditions

I. sibirica plants (Fig. 2b) with virtually similar biomass were transplanted from two-stage baffled surface-flow CWs in Jialu River, Zhengzhou City, Northern China, on March, 2014. Each *I. sibirica* plant was thoroughly cleaned under running tap water to remove sediment and other particles. For experimental studies, plants of *I. sibirica* were further acclimatized in 10% modified Hoagland solution (Hoagland and Arnon, 1950) for one week under laboratory conditions. Then the seedlings of *I. sibirica* were transplanted in wetland units filled with simulated Cd polluted river water.

2.2. Experimental design

2.2.1. Design of constructed wetland

The experimental site was established at transparent rain shelter at the Institute of Environmental Sciences of Zhengzhou University, Northern China (112°42′–114°14′ E, 34°16′–34°58′ N). The microcosmic wetland systems were designed in a subsurface vertical flow style. MVFCWs were divided into five units, which were utilized to study the treatment effects of water quality at different influent concentrations (U0: Blank treatment; U1: low Cd; U2: medium Cd; U2 control: medium Cd; U3: high Cd). U0, U1, U2 and U3 were planted with plants and one U2 control remained unplanted as a control. The schematic diagram of MVFCW unit is illustrated in Fig. 1. The treatment units made of plastic containers with dimension of 45 × 35 × 25 cm were built in three replicates. Fig. 2a and b showed the treatment unit and *I. sibirica* plants. The MVFCW units were filled with support media consisted of gravel (D_{10} = 15 mm) at a depth of 4 cm to prevent the clogging of PVC tubes at the bottom. The units were then filled with composite filling as the substrate at a depth of 20 cm. The composite fillings consisted of round ceramsite, blast furnace-granulated slag, soil, and sawdust at a proportion of 3:3:2:1. Round ceramsite has an effective size (D_{10}) of 8–15 mm, uniformity coefficient of 1.21, and porosity of 31.1%. The parameters of the blast furnace-granulated slag were 1.5–37 mm effective size, 6.44 uniformity coefficient, and 48.2% porosity. Some of the factors considered during construction included the substrate which must have good porosity to prevent clogging and must possess special capabilities to filtrate and absorb heavy metals. The influent entered the unit through a PVC tube (D_{10} = 18 mm) with a perpendicular drip dispersion tube with aligned holes to produce a laminar flow. Multi-hole PVC tubes were embedded into fore-upper and back-bottom gravel in every unit as inlet and outlet, respectively.

2.2.2. Operation conditions of wetland

In order to minimize variability in the experiment, the experiment was undertaken with synthetic metal containing (Cd) inflow water which was utilized to simulate the characteristics of polluted river water based on Chinese environmental quality standards for different grades of surface water (MEPC, 2002). All MVFCW units were irrigated with simulated polluted river water with the desired Cd concentrations at a constant flow rate of 8 L per day to maintain water level up to the substrate surface. The theoretical hydraulic retention time was approximately 28 h. The Cd inflow concentration of U0, U1, U2, U2 control, U3 were 0, 1, 3, 3, 6 mg/L respectively. The pH value was set as 7.0–7.5. The water temperature was 17 ± 2 °C, while COD, TN, TP and NH_4^+-N concentrations were 50.00 ± 5.89, 5.00 ± 1.34, 1.00 ± 0.33 and 3.75 ± 0.09 mg/L respectively. Table 1 showed the characteristics of influents from the wetland microcosm units.

The experiments were carried out on March 15, 2014 over a period of 55 days. After a week of acclimation, the plants were allowed to be fully established and the system achieved a steady state. The units were intermittently fed with the test solution from a

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