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Willow bed fertigated with domestic wastewater to recover nutrients in subarctic climates

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ABSTRACT

Conventional methods for wastewater treatment emphasise protecting human health, receiving waters and the environment. Consequently, they are generally designed to reduce pollutant levels and are not well-suited for creating resources. This paper describes a new, more sustainable and energy-efficient approach to wastewater treatment that satisfies health and environmental standards while also facilitating resource recovery. A full-scale compact willow bed was intensively fertigated with domestic wastewater in a cold climate to examine biomass production, the recovery of nutrients in willow biomass, and wastewater treatment. The performance of the willow bed was assessed for two years, covering three growing seasons. The studied frost-tolerant willow clones produced good biomass yields per unit area (6–7 ton dry matter/ha and year) under intensive fertigation with dense planting and continuous harvesting. The biomass yield of willow species exhibiting vertical growth seemed to be greater than that for lateral growth species in the dense stands studied. In contrast to biomass production, nutrient recovery was facilitated by intensive fertigation, continuous harvesting and less dense planting with a horizontally growing willow clone. The estimated nitrogen accumulation in above-ground biomass was 210 kg/ha and that of phosphorus was 30 kg/ha. 90% of the accumulated nutrients in the above-ground biomass were removed from the site during the experimental period. However, the quantity of nutrients accumulated in the willow biomass represented only a small fraction of the loaded or removed amount. The willow bed was shown to be an efficient prefilter for reducing the abundance of particulate and organic matter, leaving the bulk of the remaining nutrients in forms that could be recovered in subsequent treatment steps.

1. Introduction

The purpose of recycling is to conserve resources so that they become available for reuse. Current methods for wastewater treatment focus on to reduce pollutant levels, and thus, do not conserve phosphorus (P) and nitrogen (N) resources in municipal/domestic wastewater. Phosphorus is removed from sewage by reaction with either iron or aluminium, reducing its availability to plants (Kirkham, 1982; Kyle and McClintock, 1995), while nitrogen levels in sewage are reduced by dispersal into the atmosphere. These lost nutrients need to be replaced by applying artificial fertilisers. However, fertiliser production consumes finite global reserves, i.e. phosphate rock (Cordell et al., 2009) and fossil fuels (Smil, 2001), requires large amounts of energy (Wood and Cowie, 2004), and generates considerable amounts of pollution (Hettige et al., 1994) and greenhouse gases (Wood and Cowie, 2004). While systems for recovering P from wastewater have been studied in detail (Ashley et al., 2009; Balmér et al., 2002; Valsami-Jones, 2004) and have found practical applications (Cordell et al., 2011), the recovery of N from wastewater has received less attention. It is possible to recover P and N simultaneously in wastewater treatment plants by means of struvite formation, but this can only recover a minor fraction of the N found in sewage because the P:N ratio in struvite is 1:1 (Li and Zhao, 2003). Efficient recycling of P and N can be achieved by source separating systems (Larsen et al., 2009). However, this approach would require costly reconstructions of existing sewage systems. Source separation systems aside, solutions for recovering wastewater P tend to be capital- and energy-intensive (Balmér et al., 2002), and are thus sub-optimal in terms of sustainability. Natural treatment systems such as constructed wetlands might be a more attractive solution in this respect because in addition to being low-cost and low-tech, they provide services by simultaneously reducing and recycling nutrients from wastewater into biomass. In addition to improving the quality of the receiving waters, the constructed wetlands produce plant biomass, which can be used as a source of biofuel or as a soil enhancer and thus adds value

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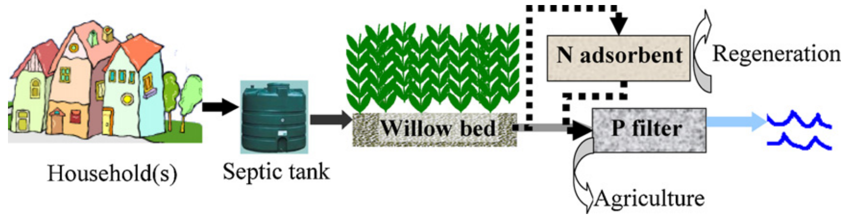

Fig. 1. A concept of small scale treatment system designed for nutrient recovery. After saturation, N adsorbent is regenerated and the released N could be used in agriculture, while P filter material is replaced with fresh P sorbent and the spent P sorbent can be used in agriculture.

to the treatment process (Polprasert, 2007). Willows (*Salix* spp.) are widely used as energy crops because of their high biomass production, efficient nutrient uptake, high rates of evapotranspiration, and flood tolerance. It has been suggested that in cold regions, the high frost tolerance of reed canary grass (Landström et al., 1996) could make it a more suitable crop than willow grown in short rotation coppices (Perttu, 1983). However, willow has some significant advantages over reed canary grass, e.g. lower ash content (Paulrud et al., 2010) and lower harvest losses (Larsson et al., 2006). In addition, the ratio of the energy input (i.e. the energy expended on planting, fertilising, harvesting and transport) to the energy content of the crop is lower for willows than for reed canary grass for any given biomass production level (Börjesson, 2007). A variety of systems based on constructed wetlands planted with willows (Börjesson and Berndes, 2006; Gregersen and Brix, 2001; Larsson et al., 2003; Obarska-Pempkowiak and Gajewska, 2005; Wu et al., 2011) have been created and used to treat municipal and domestic wastewater. However, these systems take up large areas of land and much of the N in the feed is lost into the atmosphere via nitrification–denitrification. Similarly, much of the P in the feed is dispersed into the soil (Dimitriou and Aronsson, 2011; Kadlec and Wallace, 2008; Larsson et al., 2003); the amount accumulated in the plants represents only a minor fraction of the total quantity removed from the wastewater (Dimitriou and Aronsson, 2011; Larsson et al., 2003). In the rural areas of the Nordic countries, many homes are dependent on onsite systems. As such, there is a need for a robust and compact onsite treatment system that remains functional in a cold climate while efficiently removing and recovering nutrients. A suitable system is illustrated in Fig. 1, in which the wastewater passes through a highly loaded willow bed and then through N and P filters; the willow bed primarily serves to pretreat the sewage while also producing biomass, with the bulk of nutrients being retained by (ad)sorption in the subsequent filters. The N-saturated adsorbent can be regenerated, but the saturated P sorbent has to be replaced with fresh material; in both cases, the recovered nutrients are available for agricultural use. The aim of the study described herein was to assess the performance of the compact willow bed with respect to biomass production, nutrient recovery from municipal wastewater and wastewater treatment, in a cold climate over a two-year period covering three growing seasons.

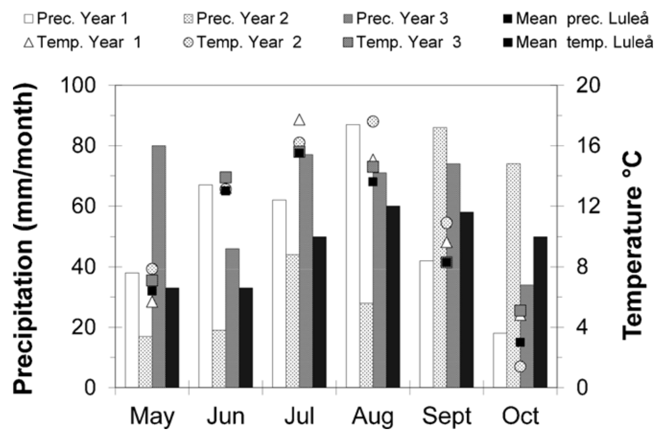

Fig. 2. Monthly average temperatures at a weather station, 19 km south of the site, during the growing periods, along with long-term mean temperatures for Luleå, measured about 19 km south from the experimental site.
From SMHI (1991, 2011).

2. Materials and methods

An experimental plant was constructed in Luleå (65°41′N; 22°20′E), approximately 100 km below the Arctic Circle in Sweden and evaluated over three growing seasons, during 2005–2007; 2005 is referred to as Year 1, 2006 as Year 2, and 2007 as Year 3. Monthly averages temperatures and precipitation at a weather station, 19 km south of the studied site, are presented in Fig. 2 during the growing seasons along with the long-term means.

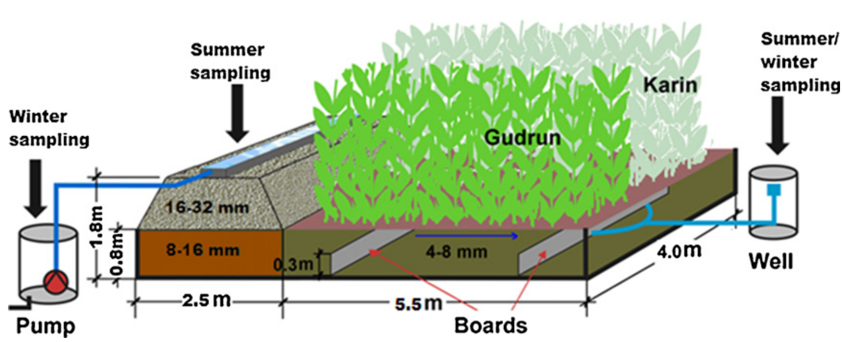

Fig. 3. Layout of the experimental plant with the dimensions of the bed and the bed material grain sizes. The sampling points are indicated with the arrows.