Ecological Engineering 98 (2017) 82–90

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Application of primary treated wastewater to short rotation coppice of willow and poplar in Mongolia: Influence of plants on treatment performance

G. Khurelbaatar[a,b,*], C.M. Sullivan[a], M. van Afferden[a], K.Z. Rahman[a], C. Fühner[a], O. Gerel[c], J. Londong[b], R.A. Müller[a]

[a] Environmental- and Biotechnology Centre (UBZ), Helmholtz Centre for Environmental Research - UFZ, Permoserstraße 15, 04318 Leipzig, Germany
[b] Urban Water Management and Sanitation, Bauhaus Universität Weimar, Coudraystraße 7, 99421 Weimar, Germany
[c] Mongolian University of Science and Technology Darkhan, Tsagaan Chuluut St. 5, 15th Bag, Darkhan, Mongolia

ARTICLE INFO

Article history:
Received 24 September 2015
Received in revised form 13 July 2016
Accepted 5 October 2016

Keywords:
Wastewater treatment
Short rotation coppice
Treatment performance
Cold climate
Land application
Mass removal
Mongolia

ABSTRACT

The influence of short rotation willow coppice on wastewater treatment performance under Mongolian climatic conditions is still poorly understood. For this purpose, one bed planted with willow (*Salix* spec.) and Poplar (*Populus* spec.) trees and one unplanted bed (as control) were operated over two years with pre-treated domestic wastewater under the same operating condition (with a daily hydraulic load of 5 mm). The results showed better wastewater treatment performance for the planted bed. An average mass removal rate of 241 ± 14 $g\,m^{-2}\,a^{-1}$ (86% removal efficiency), 130 ± 26 $g\,m^{-2}\,a^{-1}$ (93% removal efficiency), 82 ± 11 $g\,m^{-2}\,a^{-1}$ (80% removal efficiency) and 7.1 ± 1.2 $g\,m^{-2}\,a^{-1}$ (85% removal efficiency) was observed for COD, BOD_5, TN and TP respectively in planted bed over two study years. On the contrary in the unplanted bed, the average mass removal rate was found to be as 135 ± 1 $g\,m^{-2}\,a^{-1}$ (59% removal efficiency), 121 ± 28 $g\,m^{-2}\,a^{-1}$ (89% removal efficiency), 43 ± 1 $g\,m^{-2}\,a^{-1}$ (43% removal efficiency) and 3.7 ± 0.2 $g\,m^{-2}\,a^{-1}$ (46% removal efficiency) for COD, BOD_5, TN and TP, respectively, over two study years. Additionally, the planted bed irrigated with pre-treated wastewater showed greater tree growth (height, biomass yield) as compared to the plants that were grown within the control area without any additional irrigation (i.e. natural growth). The results demonstrate that the presence of willow and poplar trees positively influences wastewater treatment performance and indicate that short rotation coppice irrigated with pre-treated wastewater can be an economically viable alternative for wastewater treatment and producing biomass for energy production in Mongolia.

1. Introduction

Application of wastewater onto land is one of the oldest and most common forms of wastewater treatment and is well accepted in North America and parts of Europe. Crites and Tchobanoglous (1998) described land treatment as the controlled application of wastewater onto land surface to achieve a designed degree of treatment through natural, physical, chemical, and biological processes within the plant-soil-water matrix. While trees are often not the preferred crop used for land application systems, there are a variety of examples of their successful application (Pedrero and Alarcón, 2009; Tzanakakis et al., 2009). The approach is adapted into willow based short-term coppice and has been applied in Scandinavia and other parts of Europe (Aronsson et al., 2002; Börjesson and Berndes, 2006). Perttu (1993) identified that the nutrient ratios associated with wastewater (N = 100, P = 14 and K = 64) were similar to that required for short rotation willow coppice (N = 100, P = 14 and K = 72). Laboratory trials by Perttu and Kowalik (1997) identified that willows irrigated with wastewater provided a biomass yield of 2–3 times, compared with the case when no fertilizer was applied. As a result, the concept of applying partially treated wastewater onto willow stands grew in popularity as it offered two main benefits:

1. the increased removal of nutrients and other pollutants from wastewater; combined with
2. the increased yield of biomass.

---

* Corresponding author at: Environmental- and Biotechnology Centre (UBZ), Helmholtz Centre for Environmental Research - UFZ, Permoserstraße 15, 04318 Leipzig, Germany.
E-mail address: ganbaatar.khurelbaatar@ufz.de (G. Khurelbaatar).

http://dx.doi.org/10.1016/j.ecoleng.2016.10.010
0925-8574/

There have been several numbers of applications of this system in Scandinavia and North America for secondary treated wastewater and China for primary treated wastewater (Börjesson and Berndes, 2006; Ou et al., 1997; Rosenqvist and Ness, 2004). However, to our knowledge, such systems have not yet been investigated concerning treatment performance under Mongolian climatic conditions.

A combination of environmental, social and demographic conditions including rapid population growth and urbanization together with aging infrastructure have made the effective treatment of wastewater extremely difficult in Mongolia. Historically, a variety of different wastewater treatment technologies (e.g. activated sludge, trickling filter, and simple sedimentation with consecutive chlorination and infiltration basins) have been used to service sewerage infrastructure from industrial and residential areas with the treated water being diverted to water bodies or infiltrated into the ground. Due to extremely cold winter temperatures, the existing sewerage infrastructure is buried to a depth of 3.5 m to 4.5 m in order to avoid freezing. Moreover, the biological treatment step, which is common to many conventional wastewater treatment plants, requires heating or additional housing during winter months when mean monthly temperature ranges between −20 °C to −25 °C (MoMo, 2009).

While a number of approaches have been applied, there is a pressing need for simple and cost-effective treatment alternatives that can function under such extremely challenging conditions in Mongolia.

In this study, a pilot-scale experiment was carried out in order to investigate the suitability of short rotation coppice for wastewater treatment under Mongolian conditions. The objectives of this paper are to investigate: i) the effect of trees on the wastewater treatment performance and ii) the influence of irrigation with pre-treated wastewater on biomass or wood production.

2. Materials and methods

2.1. Site description

Within the framework of the MoMo II project (Integrated Water Resource Management in Central Asia – Model Region Mongolia), a pilot-scale research facility was established at the Mongolian University of Science and Technology (MUST) in Darkhan city, Mongolia (49°27′31.95″N, 105°58′42.92″E) in Summer 2011. The region is in the transition zone between boreal climate with cold and dry winters and cold, semi-arid steppe climate (MoMo, 2009). During the investigation period of study year 1 (from June 2012 to May 2013) and Study year 2 (from June 2013 to May 2014), the daily mean air temperature and accumulative precipitation data were collected from the local climate station in Darkhan city, which is located 11 km from the pilot-scale research facility. The daily mean air temperature and accumulated mean precipitation data during those two study years are presented in Fig. 1. The mean daily minimum and maximum temperatures range from −33 °C to −15C° in January and from 10 °C to 32 °C in July, respectively. In this region main rainfall events occur in summer. When compared to the long term mean precipitation of 265 mm (MoMo, 2009), both years 2012 and 2013 experienced a higher amount of rainfall of 364 mm and 492 mm, respectively.

2.2. The pilot plant

The pilot plant consisted of a sewerage interception and diversion system, a primary settling tank, four treatment beds, a planted control area, and a sampling manhole (Fig. 2).

2.2.1. The primary settling tank

The settling tank was constructed 6 m below the ground level and divided into three chambers with a total internal volume of approximately 5 m^3. The volume of the initial settling compartment of the tank was 2.5 m^3, while the remaining two compartments were 1.25 m^3 each. The final portion of the tank contained three submersible pumps (20 L m^{-1}, 290 W, HOMA C), which provided primary treated wastewater to the treatment beds. The pumps were controlled by electronic timers, regulating the daily irrigation time. At the outlet of the irrigation pipes, water counters were installed in summer (not in winter in order to avoid freezing) to measure the volume of the water distributed into the treatment beds. The feeding pumps were calibrated four times a year to maintain a consistent loading rate. The hydraulic retention time in the settling tank was about 7 to 8 days in summer and nearly 10 days in winter.

2.2.2. Treatment beds, winter storage and control area

In order to investigate different treatment approaches, four identical beds (Bed A, B, C and D) were constructed. The cross-section of a typical bed with plants is presented in Fig. 3. The surface area of each bed was approximately 16 m^2 (3.55 m × 4.50 m) and was excavated to a depth of 2.25 m below the ground level. The grading of all of the excavated walls was about 30%. In order to collect the drainage water and to prevent the beds from water leakage, a 1 mm PVC liner was installed between two layers of geotextile (300 g m^{-2}) at the bottom and also on the surrounding walls of each bed. The drainage pipes (PVC, 100 mm diameter and perforated with 10 mm holes in every 30 mm) were installed at a spacing of 1 m at the bottom of each bed in order to serve as a collection network. This network was connected to a 100 mm drainage pipe (non-perforated) that exits the bed at the outlet. The pipe network within the beds was then covered with a drainage layer (height: 15 cm) of locally available and washed gravel (size: 8 – 16 mm; Source: local river area). The bottom drainage layer was then covered by an intermittent or transition layer (height: 5 cm) of washed and cleaned gravel (size: 2–8 mm; Source: local river area). The local endemic soil (gravel: 8.3%, silt: 14.1%, sand: 77.3%), which was excavated from the site during the construction phase, was placed back into the bed to a height of 0.90 m below the ground level as the main layer (Fig. 3). The beds were left for two weeks to allow the soil to settle before additional soil was added in order to obtain the required depth of main soil layer. A remaining 'spare' capacity of 15.6 m^3 was left in the system to allow for water and ice accumulation on top of the beds during winter months.

The primary treated wastewater was fed to the beds via a 25 mm pipe. The irrigation pipe penetrated the liner and associated geotextile close to the penetration of the collection pipe in each bed. The pipe was directed to the center of the bed and raised vertically in the middle (Fig. 3). This installation was required to enable a "back-flush" for avoiding freezing of water in the pipe during winter time. Additionally, the pipe was surrounded by a rubber-plastic composite with an external aluminum foil. The outlet of the pipe was extended to a height of the ground level.

Three out of four beds were planted with locally available willow and poplar trees (10 of each species). The trees were two years of age at the time of planting in October 2011. Bed A remained unplanted in order to compare the results in terms of effects of plants on treatment performance. Due to the difference in the treatment surface (16 m^2 at 0.90 m below the ground level) and surface area at the ground level (around 20 m^2), the precipitation values are multiplied by a factor of 1.25 in water balance calculation.

In addition to the four treatment beds, an area of 16 m^2 was established as control area. The control area was also planted with