Journal of Water Process Engineering 7 (2015) 153–160

Contents lists available at ScienceDirect

Journal of Water Process Engineering

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

Sustainable greywater management with *Axonopus compressus* (broadleaf carpet grass) planted in sub surface flow constructed wetlands

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ARTICLE INFO

Article history:
Received 27 December 2014
Received in revised form 5 June 2015
Accepted 9 June 2015
Available online 23 June 2015

Keywords:
Water reuse
Greywater treatment
Phytoremediation
Constructed wetlands
Wastewater treatment
Rhizosphere treatment

ABSTRACT

The scarcity of freshwater has emerged as one of the most pressing problems of the 21st century. This problem could be addressed partially by collection, treatment and reuse of greywater. In this context, constructed wetlands (CWs) become attractive due to their simple mode of operation, effectiveness in treatment and applicability at small/single household levels as well as in community levels. Hence the present study investigates the treatment of greywater in a laboratory scale horizontal sub-surface flow constructed wetland planted with *Axonopus compressus* (Sw.) P. Beauv. – a common landscape plant. The experiment was conducted for a period of 50 days with change in wastewater every 10 days (1 run). During each run the wastewater was circulated using a peristaltic pump at an HRT of 7.8 h. The results show that CWs planted with *A. compressus* performed well in the treatment of greywater than the unplanted control with an average removal of 93% turbidity, 95% COD, 98% NO_3^-–N, 67% PO_4^{3-}–P, and 95% of anionic surfactants. The plant also survived well with increase in biomass and number during the experiment and proved to be an efficient bioagent suitable for the treatment of greywater in CWs. The study further suggests that the use of commercially valuable ornamental plants in the CWs as bioagents will improve the aesthetic beauty, public acceptance and help to generate revenue apart from the major benefit of wastewater treatment.

1. Introduction

The scarcity of freshwater is one of the major concerns in developing as well as in developed countries. With rapidly growing population and improving living standards the pressure on freshwater resources is increasing, leading to the reduction in the daily per capita availability of freshwater. For example the per capita surface water availability in India during the years 1991 and 2001 were 2300 m^3 and 1980 m^3, respectively, and estimated projections indicate further reduction to the levels of 1401 m^3 by the year 2025 and 1191 m^3 by the year 2050 [1]. Adding to this problem, in most of the developing countries centralized sewer systems and wastewater treatment plants exist only in larger cities, whereas the small and medium-sized towns generally discharge their wastewater untreated into the environment [2]. In this context, it is high time to think about cost effective, easy to operate, safe and sustainable solutions to the present day's water crisis.

One approach which has gained popularity in recent years is the separation of greywater from general sewage, for the purpose of onsite treatment and reuse [3]. Greywater which is defined as urban wastewater without any input from toilets, generally includes water from sources such as baths, showers, hand wash basins, washing machines, dishwashers and kitchen sinks [4,5]. It contains low concentration of organic matter, nutrients and pathogens as compared to black water [6] and comprises upto 75% of the wastewater produced in households [7]. Hence separate collection, treatment and reuse of greywater will help to reduce the pressure on freshwater resources and wastewater treatment plants [3]. It will also help to meet the projected water demand of the future in a sustainable way [8].

Motivated by the facts cited, several treatment technologies (physical, chemical and biological) were developed in the past and tested with varying degrees of magnitude and success. However many of the high technology wastewater treatment systems are not suitable for developing countries since they require high initial investment, consistent power supply and skilled labor for operation and maintenance [9]. On the other hand, constructed wetlands, which depend on natural processes for pollutant removal

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http://dx.doi.org/10.1016/j.jwpe.2015.06.004

have been considered as a promising environment friendly option and cost effective technology for greywater treatment and reuse [10]. The treatment efficiency of constructed wetlands is supposed to be higher in tropical countries due to the warm temperature and associated higher rate of microbial activities and plant growth. Moreover the versatility of constructed wetlands usable at small/single household levels as well as in community levels makes it a preferred option for the treatment of greywater.

Constructed wetlands (CWs) are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating wastewater [11]. They are considered as a complex bioreactor with a number of physical, chemical and biological processes involving substratum, microbial communities and plants [12]. CWs are generally classified as surface flow (SF) and subsurface flow (SSF) systems. Surface flow (SF) CWs are densely vegetated systems with open water surfaces and typically have water depths of less than 0.4 m. In subsurface flow (SSF) CWs, the water flows underneath and through the plant rooting media and water level is maintained below the surface of the substratum. SSF–CWs are further subdivided into horizontal flow (HF) and vertical flow (VF) systems depending on the direction of water flow through the porous medium (sand or gravel) [13,14]. The SSF–CWs are reported to cause fewer problems arising from odors, insects or public exposure than SF–CWs [15] and hence are suitable for the onsite treatment and reuse of greywater. Studies showed that SSF–CWs are effective in removing pollutants such as suspended solids, organic matter and nutrients from wastewater. This is achieved as a result of microbiological degradation, plant up-take and by physical–chemical processes such as filtration, sedimentation and adsorption. Anaerobic and aerobic processes were reported to take place within the pores of the filter media [14]. Most performance data available for CW systems are from temperate climates, but the treatment performance is expected to be significantly higher in tropical areas because of the high temperature and the associated higher microbial activity [2].

The literature is rich with reports suggesting that plants have a positive role in the removal of pollutants in constructed wetlands. Most of the plants used in constructed wetlands are either weeds or aquatic plants, which have the characteristic of higher growth rate – an important criteria needed in phytoremediation. A few examples of plants used in constructed wetlands are *Colocasia esculenta* [16,17], *Typha latifolia* [17–19], *Phragmites australis* [20] etc. However for the onsite application of constructed wetlands ornamental and landscape plants are preferred much due to their aesthetic appeal. Konnerup et al. [9] studied the performance of two ornamental plants *Canna* (*Canna* × *generalis* L. Bailey cv. Red King Humbert) and *Heliconia* (*Heliconia psittacorum* L.f. × *H. spathocircinata* Aristeguieta cv. Golden Torch) in a pilot-scale subsurface flow constructed wetland treating domestic wastewater. They reported efficient removal of COD, whereas the removal of total nitrogen (TN) and total phosphorus (TP) was low. They further reported plant uptake as a significant removal process for nutrients in lightly loaded systems. In another study Ling et al. [21] compared the performance of two ornamental plants *Syzygium campanulatum* and *Ficus microcarpa* in a constructed wetland. Considering the large amount of data available on weeds and aquatic plants, very few are available on the performance of terrestrial ornamental or landscape plants, perhaps none on greywater treatment. Hence the present study examines the treatment of greywater in a horizontal subsurface flow constructed wetland system planted with a common landscape plant *Axonopus compressus*. The primary aim is to evaluate the feasibility of using *A. compressus* to purify greywater in a laboratory scale CW system. A comparison was also made on the performance of vegetated CWs (planted with *A. compressus*) and the control CWs (having no plants). *A. compressus* is a shade tolerant plant commonly used for landscaping in this region. The findings of the study would be useful in developing simple, compact, cost effective and aesthetically pleasing constructed wetland systems for greywater treatment.

Table 1
Composition of the synthetic greywater.

Constituents	Concentration
Lactic acid	100 mg/l
Cellulose	100 mg/l
Sodium dodecyl sulphate	50 mg/l
Glycerol	200 mg/l
Sodium hydrogen carbonate	70 mg/l
Sodium sulphate	50 mg/l
Potassium nitrate	36.08 mg/l
Potassium di hydrogen phosphate	21.95 mg/l

Source: Modified from Hourlier et al. [22]

2. Materials and methods

2.1. Source and preparation of Axonopus compressus

A. compressus (Sw.) P. Beauv., commonly known as broadleaf carpet grass or blanket grass was used as bio agent in the present study. The plant belongs to the family Poaceae. The plants were collected from the campus of Mahatma Gandhi University, Kottayam, India. Special attention was given to collect plants of uniform size and to avoid root damage during collection. The plants were transferred to the laboratory immediately after collection and were washed carefully in running tap water and then with distilled water to remove sand/clay particles. Each planted CW was provided with 25 healthy plants (92.6 plants per m^2) of more or less equal size and weight having equal number of leaves.

2.2. Greywater

Synthetic greywater was prepared in the laboratory by modifying the procedure given by Hourlier et al. [22] and the same was used in the experiments. The composition of the synthetic greywater is shown in Table 1.

2.3. Analytical methods

The wastewater samples were analysed periodically starting from zero hour for different physico-chemical parameters. The pH was measured using digital pH meter (Systronics, India), Turbidity by TN-100 Turbidimeter (Eutech, Singapore), Electrical Conductivity and Total Dissolved Solids were measured using digital conductivity meter (Mettler-Toledo, Switzerland), COD, NO_3^- –N, PO_4^{3-} –P and Anionic surfactants were analyzed according to standard procedures [23]. All analyses were completed within 24 h of sampling.

2.4. Experimental design

Three constructed wetlands (CWs) were fabricated using plastic crates with 60 cm × 45 cm × 48.5 cm (L × W × D) dimensions. Rock chips of charnockite (gravel) having 6–10 mm diameter and with a porosity of 0.43 was used as sole bed material. The gravel was washed thoroughly with tap water and sun dried before filling the crates. The crates were filled with gravel up to 35 cm depth. All constructed wetlands were arranged with a gentle slope, so that the greywater flows slowly from the upstream end to the downstream end through the gravel bed. A PVC pipe having 43 cm length perforated at uniform intervals (8 cm) was fitted horizontally in the upstream end of each CW just above the gravel bed in order to serve