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Application of hydroponic systems for the treatment of source-separated human urine

Linyan Yang [a,b,c], Apostolos Giannis [b], Victor W.-C. Chang [b,c,*], Bianxia Liu [b], Jiefeng Zhang [c], Jing-Yuan Wang [b,c]

[a] Interdisciplinary Graduate School, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore
[b] Residues and Resource Reclamation Centre (R3C), Nanyang Environment and Water Research Institute, Nanyang Technological University, 1 Cleantech Loop, CleanTech One, Singapore 637141, Singapore
[c] Division of Environmental and Water Resources, School of Civil and Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore

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ABSTRACT

Hydroponic systems are widely used for the treatment of nutrient rich wastewaters. In this study, a hydroponic system was applied as the final treatment stage of source-separated human urine after urea hydrolysis, induced-struvite precipitation and ammonia stripping in tropical conditions (Singapore). The results showed that water spinach grew efficiently in the pretreated urine with 1:50 dilution ratio at the growth rate 0.68 cm/d, leaf number 2.27 pieces/d, shoot dry mass 0.33 g, water content 93.86%, and nitrogen and potassium conversion rate 0.46 and 0.51 mg/mg, respectively. This hydroponic system removed 58–66% chemical oxygen demand (COD), 41–49% total nitrogen (TN) and up to 47% total suspended solid (TSS), indicating sufficient urine stream polishing. Nitrification was observed when COD reduced by 60%, possibly because of oxygen competition between nitrobacteria for nitrification and microbes for COD degradation. The kinetic study revealed that zero-order model provided best fitting for COD and ammonia-nitrogen (NH_4^+-N) removal, while second-order model was more suitable for TN removal.

1. Introduction

Domestic wastewater is a misplaced resource rather than the waste to be discarded. Human urine is characterized as the main contributor of nutrients to domestic wastewater with 85% of nitrogen, 50% of phosphorus, and 55% of potassium but only 1% of the total volume (Larsen and Gujer, 1996). The installation of source-separated toilet diverts urine from feces making it more effective to recover and reuse nutrients (Larsen et al., 2001). Urine is an inexpensive source that may contribute to plant nutrition or enhance soil fertility (Salminen et al., 2001). However, the untreated urine may pose many environmental problems as well as odor issues.

Researchers have applied several phytoremediation technologies to treat human urine. A step-by-step procedure of green algae, zooplankton and plants cultivation was applied for nutrient recycling from human urine (Adamsson, 2000). Kirchmann and Pettersson (1995) have demonstrated the feasibility of using human urine in agriculture. Urine occupies equal fertility value with industrial fertilizers (Pradhan et al., 2007). Constructed wetlands with upflow macrophyte were successfully applied to remove ammonia in the diluted urine system (Farahbakhshazad and Morrison, 1997). New concept of forward osmosis treatment technology demonstrated good rejection of 50–80% for ammonium in hydrolyzed urine and >90% for phosphate and potassium in both fresh and hydrolyzed urine (Zhang et al., 2014). In addition, systematic investigations on urine management regarding urea hydrolysis, induced-struvite precipitation and ammonia stripping were conducted in our previous studies in order to recover

Abbreviations: COD, chemical oxygen demand; TN, total nitrogen; TP, total phosphorus; TSS, total suspended solid; NH_4^+-N, ammonia-nitrogen; NO_3^--N, nitrate-nitrogen; NO_2^--N, nitrite-nitrogen; PO_4^{3-}-P, phosphate-phosphorus; DO, dissolved oxygen; EC, electrical conductivity; DI, de-ionized; ICP–OES, inductively coupled plasma-optical emission spectroscopy; ICP–MS, inductively coupled plasma–mass spectroscopy; ANOVA, analysis of variance; LSD, least significant difference; PGR, plant growth rate; PLN, plant leaf number; PDM, plant dry mass; PWC, plant water content; RDM, root dry mass; SDM, shoot dry mass; DRs, dilution ratios; FAO, Food and Agricultural Organization; NEA, National Environmental Agency.

* Corresponding author at: School of Civil and Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore. Tel.: +65 67904773; fax: +65 67921650.
E-mail address: wcchang@ntu.edu.sg (V.W. -C. Chang).

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phosphorus and nitrogen from human urine (Liu et al., 2014, 2013; Zhang et al., 2013). However, very limited studies reported further urine polishing to reach the sewer discharge standard.

The hydroponic system is a new technique of cultivating plants in a soilless environment to avoid nuisances of weeds, soil-borne diseases and land limitations. Domestic wastewater and anaerobic digestion effluent of food and vegetable wastes have been used as feeding nutrient solutions in hydroponic systems (Krishnasamy et al., 2012; Vaillant et al., 2003). Silverbeet, tomato, radish, lettuce and water spinach were commonly employed as targeted hydroponic plants (Endut et al., 2010; Krishnasamy et al., 2012; Lorena, 2012). In a source-separated sanitation concept, the rich nutrients in urine can be used for plant growth, and plants serve as biofilters for urine polishing (Endut et al., 2010).

To our knowledge, there is limited research on using urine as a medium for hydroponic cultivation. Direct use of hydrolyzed urine is phytotoxic due to its high ammonia concentration. Ammonium ion tends to convert into ammonia gas when the pH value surpasses 7.5 (Demuynck et al., 1984). Dissolved ammonia is more toxic to plants than ammonium ion (Hageman, 1984). The objective of this study was to engage the hydroponic system to polish urine after partial nutrient recovery, to meet sewer discharge standard. Optimum urine dilution ratio for maximum plant growth and pollutant removal with microbial relevant mechanisms were both under consideration. Bench-scale experiments were conducted under tropical conditions and commercial nutrient solution was applied for comparison.

2. Materials and methods

2.1. Urine collection

Fresh urine was collected from 30 voluntary adults and mixed in a sterile plastic bottle. Urease enzyme (~1 mg) was added to 15 L urine to enhance urine hydrolysis giving final pH value 9.3 (Zhang et al., 2013). Afterwards, 0.2 L seawater per liter urine was added to recover phosphorus by induced-struvite precipitation, while the remaining phosphorus (~16 mg/L) was used for plant cultivation (Liu et al., 2013). Air striping process was implemented until ~800 mg/L ammonia remained in the urine (Liu et al., 2014). Table 1 shows the differences between the pretreated urine (which was the feed solution for the hydroponic system), concentrated nutrient solution (which was commercially used for plant cultivation after dilution), and the FAO wastewater standards for crop cultivation (FAO, 1992).

2.2. Plant selection

The cultivation of indigenous plant species in hydroponic systems is favorable since these plants require less management and acclimatize quickly in native climate conditions. Vital criteria for plant selections in hydroponic systems are specified: (a) adaptability to hydroponic systems; (b) availability in local context; (c) relatively short life circle. Preliminary experiments were carried out to evaluate several kinds of plants such as leaf lettuce (*Lactuca sativa*), water spinach (*Ipomoea aquatica*), lawn (*Hydrocotyle sibthorpioides*), and golden pothos (*Epipremnum aureum*). However, only water spinach grew sufficiently in the hydroponic system and thus it was selected as the cultivation plant. Water spinach was nourished from seeds to plantlets in a farm in Singapore for two weeks until it reached to an approximate length of 8 cm.

2.3. Experimental design

Bench-scale hydroponic experiments were conducted in a transparent PVC tank with 6 mm thickness and 800 mm × 600 mm × 100 mm (length × width × height) dimension (Fig. 1). The tank was divided into three troughs. Three covers with 5 holes (D = 120 mm) covered each trough in order to reduce odor. The holes were packed with plastic pots which were filled with light-expanded clay aggregates as an environmental friendly material

Table 1
Characteristics of undiluted urine after pretreatment, concentrated commercial nutrient solution, and FAO wastewater quality standards for crop production.

Parameters[a]	Pretreated urine (before dilution)[b]	Concentrated nutrient solution[c]	FAO standards
pH	8.45	5.89	6.5-8
EC(μs/cm)	31350	337200	700[d]
DO	2.15	8.47	N.A.
COD	4120	3400	N.A.
TSS	3150	2000	N.A.
TN	1210	33320	N.A.
NH_4^+-N	881	4300	N.A.
NO_3^--N	9.04	27600	5[d]
NO_2^--N	0.33	0.8	N.A.
PO_4^{3-}-P	16	8780	N.A.
K	1667	44525	N.A.
Ca	17.8	14020	N.A.
Na	4207	673	207[e]
Mg	32.65	10595	N.A.
Zn	0.77	8.71	2.0[f]
Fe	0.419	519.8	5.0[f]
B	2.435	372	0.7[d]
Mo	0.074	0.076	0.01[f]
Mn	0.003	192	0.20[f]
Cu	0.6125	6.3	0.20[f]
SO_4^{2-}	5170	100900	N.A.
Cl−	7955	N.D.	365[e]

Note: N.D. means not detectable; N.A. means data are not available.
[a] The unit is mg/L unless specified.
[b] Urine parameters before dilution (dilute ratio 1:10, 1:20, 1:30 and 1:50 for practical usage).
[c] Concentrated nutrient solution parameters (dilute ratio 1:200 for practical usage).
[d] Guideline of no restriction on use for irrigation.
[e] Guideline of less than moderate restriction on use for irrigation.
[f] Threshold levels of trace elements for crop production.