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Treatment and utilization of septic tank effluent using vertical-flow constructed wetlands and vegetable hydroponics

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Abstract: Vertical flow constructed wetlands is a typical ecological sanitation system for sewage treatment. The removal rates for COD, BOD_5, SS, TN, and TP were 60%, 80%, 74%, 49% and 79%, respectively, when septic tank effluent was treated by vertical flow filter. So the concentration of COD and BOD_5 in the treated effluent could meet the quality standard for irrigation water. After that the treated effluent was used for hydroponic cultivation of water spinach and romaine lettuce, the removal efficiencies of the whole system for COD, BOD_5, SS, TN and TP were 71.4%, 97.5%, 96.9%, 86.3%, and 87.4%, respectively. And it could meet the integrated wastewater discharge standard for secondary biological treatment plant. It was found that using treated effluent for hydroponic cultivation of vegetables could reduce the nitrate content in vegetables. The removal rates for total bacteria and coliform index by using vertical flow bed system with cinder substrate were 80%—90% and 85%—96%, respectively.

Keywords: septic tank effluent; vertical-flow; constructed wetlands; vegetable hydroponic

Introduction

In traditional Chinese agriculture, human faeces and urine were used separately by households to the soil as organic fertilizer in order to provide nutrients for crop growth and to reduce soil deterioration. This system could supply human being with organic foods such as creals and vegetables. This recycling form was similar to the modern concept of "organic agriculture". However, in urbanization areas, human faeces and urine of city dwellers could not be returned to the soil due to the larger amount of human excreta output and the pressure of communication and transportation between cities and rural areas. Although it should be the best organic fertilizer for agricultural use since it contains high nitrogen and phosphorus in human urine and excreta, it is becoming into very important pollution source of eutrophication in water body, and should be drawn into the secondary biological treatment plant for reducing nitrogen and phosphorus. This procedure not only needs capital investment but also wastes energy and nutrient resources.

Sewage aquaculture is a more direct method for utilization of human urine and excreta. In both India and China, sewage is used to irrigate vegetables and other short-term crops and to support fish culture (Jana, 1998; Yan, 1998). Even in a Nordic climate, stendund wastewater aquaculture has been conducted in a greenhouse mesocosm in Sweden (Gusterstam, 1996; 1998), and the potential use of human urine by greenhouse culturing of microalage, zooplankton and tomatoes was also tested in Sweden (Adamsson, 2000). Guterstam (Guterstam, 1991) has also shown that it is possible to culture tomato plants in hydroponic system based on domestic wastewater. Although there is an economic benefit on the side of fertilizer value of nutrients in the wastewater, there is a high risk of easy transmission of water borne diseases when raw sewage is used (Krishman, 1987). Therefore, sewage should be treated prior to reuse (Kivaisi, 2001).

Being low-cost and low-technology system, constructed wetlands (CWs) are used for treating various types of wastewater e.g. domestic wastewater, acid mine drainage, agricultural wastewater, landfill leachate, and urban storm-water (Kivaisi, 2000). A septic tank followed by a soil filter composed of *Juncus* was tested in Brazil. Further experimentation on the combination of a septic tank and CWs with

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Typha and *Eleocharis spp* was recently proposed for treatment of domestic wastewater (Valentim, 1998). Moreover, the feasibility of using a designed integrated aquaculture-wetland ecosystem for experimental food production and inorganic nitrogen removal from tertiary-treated wastewater was also tested in Los Angeles County, CA (Costa-pierce, 1998). And domestic wastewater treatment with means of soilless cultivated plants was also conducted in China (Li, 1997).

The objectives of this study were: (1) to use the combination system of septic tank and CWs for domestic wastewater treatment and to make the treated effluent for detoxification, disinfection, oxygenation, and sanitation; (2) to use nutrients in treated effluent from the combined treatment system for hydroponic cultivation of vegetable and to purify wastewater further by plant root system; (3) to cultivate ornamental plants and other commercial flowers in vertical-flow constructed wetlands (VFCW) surface for enhancing its economic benefit and esthetic value; and (4) to build up a pilot-scale plant for decentralized ecological wastewater treatment and utilization in urbanized areas.

1 Materials and methods

1.1 Flow system

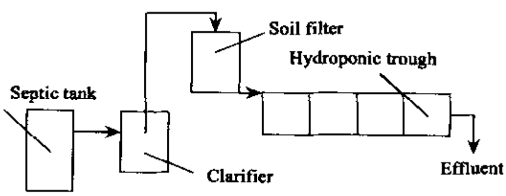

Fig.1 Diagram of filter and hydroponic system

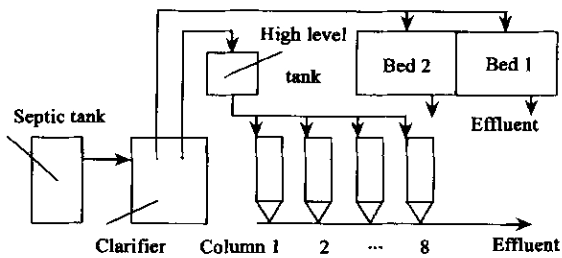

Fig.2 Schematic of vertical flow system

1.2 System parameter

Artificial soil filter, with 1 m^2 of surface area and 1.3m high (Fig.1), was filled with 20 cm gravel in the bottom and followed 90 cm artificial soil, made of sand, soil, and turf etc. Multi-hole pipe was used for wastewater surface spraying irrigation.

Hydroponic cultivation of vegetable, with 4 m^2 of surface area and 0.4m high, divided to 4 parts (Fig.1), was designed for two serials. Each serial contains two parts. Serial 1 was water spinach (in fall) and tomato (in spring), serial 2 was romaine lettuce (in fall) and cherry tomato (in spring). Control, designed for hydroponic and soil cultivation of water spinach and romaine lettuce in both greenhouse and field, were set.

Vertical flow constructed wetlands (VFCW), with two beds (each bed: 1.86 m × 1.68m × 1.2m; L × W × D), were filled with 10 cm high gravel in the bottom and followed with 100 cm mixed substrate (Fig. 2). Bed 1 was filled with artificial soil and planted with *Canna generalis*. Bed 2 was filled with the mixture of sand and topsoil and planted with ornamental plants like pink, lily, rose, and gladiolus etc.

Vertical flow constructed wetlands (8 columns), with 1.3m high, were constructed with 20 cm diameter PVC tubes (Fig.2). The columns were filled with substrates on the following order: A funnel was placed on the bottom of the column, followed by 10 cm of washed gravel, and then filled with the mixture of cinder, soil and turf. Of these eight columns, column 2, 4, 6, 8 were planted with *Cyperus alternifolius*, and column 1, 3, 5, 7 were left unplanted.

1.3 Wastewater used for experiment

Wastewater used for experiment was pumped from septic tank effluent of W.C. in Building 5, South China Agricultural University (SCAU). The quality of this septic tank effluent was monitored during experimental period, and the monitoring results showed that this septic tank effluent concentration of organic matter is similar to municipal wastewater. COD ranged from 120 to 400 mg/L and BOD_5 from 60 to 150 mg/L. TN averaged from 10 to 50 mg/L and TP from 1.5 to 12 mg/L.

1.4 Operation and maintenance

System 1: The combination of artificial soil filter and vegetables hydroponic, was operated from Sept. 1998 to June next year. It was continuously flooded 2 hours every 3 days followed by dry period for 70 hours. The treatment capacity and hydraulic loading rate(HLR) were 0.6 m^3 and 20 cm/d, respectively. The treated effluent was used to fill hydroponic trough to cultivate vegetables. The hydraulic retention time was 5.4d.

System 2: Vertical flow constructed wetlands included two beds and eight columns. The former has been operating since October 1, 2000. It was flooded two times each day with 1 hour for each time. The latter has been operating since March 8, 2001. The watering of regime for column 1 to 4 was 8 hours wet period and followed by 40 hours dry period, the time ratio of wet to dry is 1:5. Whilst it was 12 hours wet period and followed 36 hours dry period for column 5 to 8, and the time ratio of wet to dry is 1:3.

1.5 Analysis methods

The influent and effluent of each treatment unit were measured once a week. Water sampling analysis methods for water quality are as follows: dichromate method for COD; dilution and inoculation method for BOD_5; gravimetric method for SS; potassium-persulfate decomposition and ultraviolet spectrophotometric method for TN; potassium-persulfate decomposition and colorimetric method with molybdenum blue for TP; dilution and smearing method for total bacterial and coliform.

Analysis methods for plant quality are as follows: spectrophotometric method with phenol disulfonic acid for nitrate; 2,6-dichlorophenolindophenol method for vitamin C; Kjeldahl method for coarse protein; Shaffer-somogyi's method for soluble sugar.

2 Results and discussions

2.1 The removal effect of COD and BOD_5 by the artificial soil filter and hydroponic system

The effluent concentration of COD in septic tank, artificial soil filter and hydroponic basin was monitored during the experimental period. The result is shown in Table 1. The concentration of COD in septic tank effluent ranged from 120 to 180 mg/L, and reduced to 60 to 80 mg/L after artificial soil filter treatment. The average removal rate of COD in artificial soil filter was less than 60%. It is because of its long drying period, fast infiltration rate, low hydraulic loading rate and low pollutant loading rate. Although the concentration of COD in the treated effluent after hydroponic cultivation of vegetable was lower than 45 mg/L and could meet the integrated wastewater discharge standard (60 mg/L) for secondary biological treatment plant, the removal rate of COD for the whole system was 71.4%. It was most likely due to the low temperature and slow growth of vegetable in the late autumn.

The effluent concentration of BOD_5 in septic tank, artificial soil filter and hydroponic basin was also monitored during the experiment period, the results are shown in Table 2.

Data showed that the concentration of BOD_5 in raw sewage was about 60 mg/L, and averaged 10 mg/L after being treated by artificial soil filter. It not only meets the integrated wastewater discharge standard (20 mg/L) for secondary biological treatment plant but also is superior to the quality standards for irrigation water. The concentration of BOD_5 in the treated effluent dropped to 2 mg/L after being treated by hydroponic cultivation of water spinach and romaine lettuce, and could reach the first level of the environmental quality standard (2 mg/L) for surface water. The removal rate of BOD_5 by the system 1 was high up to 97.5%.

Table 1 The concentration of COD in treated effluent after different treatment units (mg/L)

Treatment unit	Growth stages of vegetable hydroponic			Harvest
	Fixation	Former growth	Later growth	
Septic tank effluent	149.1	153.3	163.8	125.3
Artificial soil filter	70.9	67.7	69.2	62.1
Water spinach	50.7	48.5	50.1	46.4
Romaine lettuce	44.6	43.9	41.7	38.9
Removal efficiencies, %	70.1	71.4	74.5	69.0

Table 2 The concentration of BOD_5 in treated effluent after different treatment units (mg/L)

Treatment unit	Growth stages of vegetable hydroponic			Harvest
	Fixation	Former growth	Later growth	
Septic tank effluent	54.5	61.4	64.9	56.5
Artificial soil filter	10.4	11.1	11.7	9.61
Water spinach	5.34	6.55	5.79	5.50
Romaine lettuce	1.48	1.40	1.36	1.70
Removal rates, %	97.3	97.7	97.9	97.0

2.2 The removal effect of SS by the artificial soil filter and hydroponic system

The concentration of SS in the septic tank effluent was high, averaged 250 mg/L (Table 3). This high SS content effluent was directly pumped to the artificial filter without any primary treatment so that the SS concentration in the treated effluent was still higher than 60 mg/L, and its removal rate averaged 73.6%. The reason is that the infiltrate rate of artificial soil filter was so fast that the SS concentration in the treated effluent was high, but the SS concentration in the final treated effluent was less than 10 mg/L after being treated by hydroponic cultivation of water spinach and romaine lettuce. The water quality was superior to the integrated wastewater discharge standard(20 mg/L) for secondary biological treatment plant. The removal rate of SS by the system 1 was high up to 96.9%.

Table 3 The concentration of SS in treated effluent after different treatment units (mg/L)

Treatment unit	Growth stages of vegetable hydroponic			Harvest
	Fixation	Former growth	Later growth	
Septic tank effluent	209	281	263	247
Artificial soil filter	74.6	73.3	62.4	53.8
Water spinach	26.5	20.2	18.4	16.7
Romaine lettuce	9.44	8.80	7.13	5.69
Removal rates, %	95.5	96.9	97.3	97.7

2.3 The removal effect of TN and TP by the artificial soil filter and hydroponic system

The effluent concentration of TN in the septic tank effluent averaged only 10 mg/L (Table 4), but the TN concentration in the soil filter effluent varied slightly with a range of 3.73—6.04 mg/L. Although the average removal rate of TN was only 49% by artificial soil filter, it could supply sufficient nitrogen for hydroponic cultivation of vegetables followed. Both ammonia nitrogen and nitrate nitrogen were assimilated and transmitted to organic nitrogen in plant body by vegetables culture. The concentration of TN in the treated effluent was lower than 1.5 mg/L after being treated by hydroponic cultivation of water spinach and romaine lettuce, and could reach the fourth level of the environmental quality standard(2.0 mg/L) for surface water. The removal rate of TN by the system 1 was 86.3%, and almost reached the tertiary treatment level.

Table 4 The concentration of TN in treated effluent after different treatment units(mg/L)

Treatment unit	Growth stages of vegetable hydroponic			Harvest
	Fixation	Former growth	Later growth	
Septic tank effluent	10.51	10.47	9.65	9.56
Artificial soil filter	5.35	6.04	5.74	3.73
Water spinach	1.77	1.81	1.39	1.57
Romaine lettuce	1.65	1.34	1.20	1.24
Removal rates, %	84.3	86.2	87.6	87.0

The concentration of TP in septic tank effluent ranged from 1.5 to 2.0 mg/L(Table 5) during experimental period. The average removal rate of TP by artificial soil filter was 78.7%, and the effluent concentration of TP ranged from 0.3 to 0.42 mg/L. It fitted to the integrated wastewater discharge standard (0.5 mg/L) for secondary biological treatment plant. After taking up by hydroponic cultivation of vegetables, the concentration of TP in the final treated effluent was slightly high than 0.20 mg/L, and almost reached the fourth level of the environmental quality standard(0.20 mg/L) for surface water. The average removal efficiency of TP for septic tank effluent by the system 1 was 87.4%.

Table 5 The concentration of TP in treated effluent after different treatment units(mg/L)

Treatment unit	Growth stages of vegetable hydroponic			Harvest
	Fixation	Former growth	Later growth	
Septic tank effluent	1.91	1.97	1.47	1.60
Artificial soil filter	0.40	0.35	0.30	0.42
Water spinach	0.29	0.28	0.24	0.32
Romaine lettuce	0.21	0.27	0.18	0.22
Removal rates, %	89.0	86.3	87.8	86.3

2.4 Effect on the quality of hydroponic vegetable cultivated by using treated effluent

Both hydroponic cultivation of romaine lettuce using nutrient solution in greenhouse and soil cultivation of romaine lettuce in field were also conducted as control when the experiment of hydroponic cultivation of romaine lettuce using treated effluent was studied. The quality analysis for romaine lettuce was made, and the result is shown in Table 6. Coarse protein was accounted on percentage of dry matter. Since the nitrate contain in vegetable is one of the important index for vegetable quality, therefore, how to reduce the nitrate contain in hydroponic cultivation of vegetables using nutrient solution is very important for harmless production of vegetable. Table 6 shows that the nitrate content in romaine lettuce hydroponicly cultivated by using treated effluent was the lowest, without adding any fertilizer. The content of vitamin C, coarse protein, and soluble sugar in romaine lettuce under three kinds of cultivation was no significant difference. Considering the output of vegetable, the nutrient solution hydroponic cultivation was higher than that of treated effluent hydroponic cultivation, and the latter was high than that of field soil cultivation. Although coliform index in raw sewage can be removed by the VFCWs system at the range of 76.9%—99.9%(Table 7), there is a risk of easy transmission of water-borne disease by vegetable root system, stem, and leaves. Therefore, these vegetables hydroponic cultivated by the treated effluent could not be eaten raw.

Table 6 The result of analysis for romaine lettuce quality under three kinds of experiment

Item	Weight of fresh stem, g/each stem	Nitrate, g/kg	Vitamin C, g/kg	Coarse protein, % in dry matter	Soluble sugar, %
EHC	88.59	237.6	133.4	22.5	0.35
NSHC(CK1)	119.42	378.6	138.5	22.1	0.38
SC(CK2)	81.57	301.0	135.2	23.6	0.40

Notes: EHC is the effluent hydroponic cultivation; NSHC is the nutrient solution hydroponic cultivation; SC is the soil cultivation

2.5 The removal effect of total bacteria and coliform index by the VFCW treatment system

The vertical flow constructed wetland systems, which including two beds and eight columns, have being operated for nine months and three months, respectively. The total bacteria and coliform index in the treated effluent were measured recently (Table 7).

Table 7 The removal efficiencies (*RE*) of total bacterial and coliform index by VFCW treatment system

Columns	Substrates	Plants	Total bacterial (number × 10^4/ml)			Coliform (number/ml)		
			Raw sewage	Effluent	*RE*, %	Raw sewage	Effluent	*RE*, %
Bed 1	Artificial soil	*Canna glauca*	2190	748	65.9	4300	890	79.3
Bed 2	Sand + soil	*Dianthus chinensis*	2190	640	70.8	4300	994	76.9
Column 1	Cinder + soil	Unplanted	2770	241	91.3	5200	200	96.2
Column 2	Cinder + soil	*Cyperus alter*.	2770	443	84.0	5200	466	91.0
Column 3	Cinder + soil	Unplanted	2770	258	90.7	5200	176	96.6
Column 4	Cinder + soil	*Cyperus alter*.	2770	305	89.0	5200	306	94.1
Column 5	Cinder + soil	Unplanted	2770	285	89.7	5200	188	96.4
Column 6	Cinder + soil	*Cyperus alter*.	2770	596	78.5	5200	782	85.0
Coulmn 7	Cinder + soil	Unplanted	2770	665	76.0	5200	752	85.5
Column 8	Cinder + soil	*Cyperus alter*.	2770	177	93.6	5200	4	99.9

Table 7 shows that the removal rates of total bacteria and coliform index for VFCW (bed) system of mixture, which used sand as main substrate, were 70% and 80%, respectively. And lower than that of mixture used cinder slag as main substrate. The removal rates of above two indexes by the mixture of cinder substrate were 80%—90% and 85%—96%, respectively. Especially in low hydraulic loading rate, the removal rates of above two indexes by the mixture of cinder substrate were 93.6% and 99.9%, respectively. The effluent quality was well fit to both environmental quality standard for surface water (10000 individuals/L) and water quality standard for scenery and recreation area(10000 individuals/L). Therefore, VFCW system is really ecological sanitation system for sewage treatment.

2.6 The removal effect for septic tank effluent by VFCW (beds) treatment system

Bed 1 and bed 2 of VFCW system were operated from October 1, 2000 to June 18, 2001. It has been operated for 200 days. The treatment capacities of bed 1 and bed 2 were recorded by water meter, and showed that the total treatment capacities were 134.8 m^3 and 124.8 m^3, respectively. So the hydraulic loading rates of bed 1 and bed 2 were 21.6 cm/d and 20.0 cm/d, respectively. And the effluent quality from bed 1 and bed 2 was monitored and showed in Table 8. Table 8 shows that the removal rates of BOD_5 and NH_4^+-N were going up with prolonged operation time. But this phenomenon was not showed for COD and TP. The removal rates of COD and TP most likely have relationship with inflow concentration of COD and TP. The higher inflow concentration of COD was treated, the higher removal rate of COD could get. Nevertheless, the higher inflow concentration of TP was treated, the lower removal rate of TP gained. In addition, compared bed 1 with bed 2 for removal rates, the removal rates of COD, NH_4^+-N, and TP for bed 1 were better than that of bed 2. This may attribute to the turf added in bed 1. However, the removal rate of BOD_5 for bed 2 was better than that of bed 1. This means that removal rate of BOD_5 has no relationship with turf added.

Table 8 The removal efficiencies(*RE*) for septic tank effluent by VFCW (beds) treatment system

Items	Date	Raw sewage, mg/L	VFCW bed 1		VFCW bed 2	
			Effluent, mg/L	*RE*, %	Effluent, mg/L	*RE*, %
COD	19/10,00'	142.4	53.6	62.4	70.35	60.6
	21/3, 01'	310.4	87.6	71.8	109.9	64.6
	18/6, 01'	182.2	55.0	69.8	108.3	40.5
BOD_5	19/10, 00'	65.7	22.5	65.8	21.6	67.1
	21/3, 01'	127.5	28.8	77.4	26.2	79.5
	18/6, 01'	79.7	6.89	91.4	6.43	91.9
NH_4^+-N	19/10, 00'	76.3	33.7	55.8	45.9	39.8
	21/3, 01'	158.1	62.4	60.5	86.6	45.2
	18/6, 01'	115.5	32.9	71.5	54.7	52.7
TP	19/10, 00'	6.05	2.05	66.1	4.05	33.1
	21/3, 01'	11.6	8.09	30.5	8.80	24.4
	18/6, 01'	8.97	3.45	61.5	2.98	66.7

3 Conclusions

The concentration of COD and BOD_5 in treated effluent for septic tank effluent after treating by artificial soil filter or VFCW system could meet the standards for irrigation water quality. The removal rates for total bacteria and coliform index were 80%—90% and 85%—96%, respectively. And could increase dissolved oxygen content in the treated effluent from null to 4—5 mg/L. Therefore, it can provide the possibility for hydroponic cultivation of vegetable by using the treated effluent.

Hydroponic cultivation of water spinach and romaine lettuce was successfully conducted by using treated effluent as liquid nutrient without any fertilizer adding and no oxygenation. The content of nitrate in vegetables growing in treated effluent by hydroponic cultivation was the lowest, field soil cultivation was in the second, and nutrient solution hydroponic cultivation was the highest.

Using treated effluent for hydroponic cultivation of vegetables not only further promoted the removal rates of COD, BOD_5, SS, TN, and TP in the treated effluent, and made the treated effluent quality reach the tertiary level, but also developed hydroponic cultivation of vegetable by using water resource and nutrients in the treated effluent.

It was found that vertical-flow constructed wetlands surface could plant with ornamental plant, or even fresh cutting flowers other than plants like reed and cattail. It not only enhanced removal efficiencies of total nitrogen and phosphorus, but also improved aesthetic value and gained some income as well.

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