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Treatment of Piggery Wastewater by Three Grass Species Growing in a Constructed Wetland

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Abstract

The study aimed to investigate the efficiency of piggery wastewater treatment by the surface flow constructed wetland with three different grass species; bulrush (*Scirpus* spp.), cattail (*Typha angustifolia* L.), and vetiver grass (*Vetiveria zizanioides* L.). All pilot units were used for wastewater treatment by the flowing surface water system, giving a system carrying capacity of several 0.18 m^3 d^{-1} of HLR with a 5 day hydraulic retention time (HRT). The results showed that the cattail pilot showed improvement in several wastewater quality indicators: biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total kjeldahl nitrogen (TKN) with efficiencies of 80.59, 84.11 and 88.08 %, respectively. The vetiver grass was most efficient of the three grasses in treating total phosphorus (TP). The efficiency of constructed wetland treatment using bulrush and cattail for TP was not significantly different. The piggery wastewater treatment with a 5 day HRT was able to reduce the dirtiness in wastewater but ultimately was unable to meet the wastewater quality standard. Thus, the periods for hydraulic retention time should be increased to establish the optimal retention time for effective wastewater treatment.

Keywords: *Scirpus* spp.; *Typha angustifolia* L.; *Vetiveria zizanioides* L.; Constructed wetland; Removal efficiency

Introduction

Treatment of organic waste is a global problem. Livestock is one of the most important point sources of polluting wastewater, and is the cause of major declines in the quality of river water. Wastewater from swine farms can overburden the environment with organic pollutants and heavy metals. Wastewater from swine farms therefore requires treatment to meet the standard of the Department of Pollution Control before it can be released into the environment.

Constructed wetland with plants is known as an effective, low cost, and environmentally friendly system for wastewater treatment. Recently, constructed wetlands have been used to treat wastewater from various agricultural activities including swine farms [1]. The use of plants is becoming increasingly popular for treatment of both industrial and domestic effluents, offering a simple, robust and cost-effective means of wastewater treatment. A large number of plant species have the ability to remediate contaminated sites whether in soil or sediment. Non-edible plants such as grasses, ferns and weed species are of special interest.

Cattail (*Typha angustifolia* L.) is an aquatic perennial, found in a wide variety of wetland habitats, including polluted water bodies. It has the ability to absorb large amounts of nutrients and can produce large quantities of biomass [2]. Cattails grow well in acid environments from pH 4-7, and can also resist salinity up to 15-30 ppt. They are able to thrive in water depths of 10-75 cm. The roots are highly effective in absorbing nitrogen and phosphorus in wastewater [3].

Bulrush (*Scirpus* spp.) has been used to treat domestic effluents in rural communities, where the relatively small volumes of effluent means conventional systems are not cost-effective [4]. Bulrush is mostly found in wetlands, growing well in water at pH 5-7.5, and tolerant to Salinity up to 0.5 ppt. They thrive in depth not exceeding 50 cm. Bulrush has an extended root system, and grows over a period of 3-4 months [5].

Vetiver grass (*Vetiveria zizanioides* L.) is a versatile plant, with proven uses in soil and water conversation, land rehabilitation, pollution control, water quality improvement, and other environmental protection applications. Vetiver grass roots help to filter sediments and plant debris, sewage flows into them from various sources and can also absorb nutrients and heavy metals from wastewater [6]. Vetiver grass is internationally recognized for its effectiveness in wastewater treatment in terms of reducing nitrogen (N), phosphorus (P), and absorbing substantial amounts of cadmium (Cd), mercury (Hg), and lead (Pb) [4, 7].

Due to high costs of installation and maintenance, the majority of small and medium sized swine farms have no appropriate wastewater treatment methods and raw wastewater is typically released directly into the river. However, alternatives low cost systems have been developed with different levels of efficacy. Plant treatment is one such approach that has been tested in Uttaradit province to treat wastewater from small swine farms; its key advantages are low cost and simple maintenance. The grasses are hardy and locally available in abundance. However, choice of grass species is an important consideration, with implications for efficiency of wastewater treatment. Also, the suitable period of each grass species usage is different (90 d for Cattails, 45 d for Bulrush and Indonesian vetiver grass) [8]. This research aims to investigate the efficiency of these three species for wastewater treatment in small-sized swine farms.

Materials and method

1) Constructed wetland unit preparation

Four constructed wetland units were built with a concrete plot size 1 m width, 3 m in length and 1 m deep. Each pilot unit was filled with soil to a depth of 60 cm and 1 % slope [9]. All pilot units were used for wastewater treatment by a flowing surface water system. The unplanted pilot unit served as the control plot, while the remaining three pilots were planted with bulrush (*Scirpus* spp.), cattail (*Typha angustifolia* L.) and vetiver grass (*Vetiveria zizanioides* L.)

2) Grass preparation

Each plant species was selected and planted separately in each experimental units, with 25 cm spacing between rows and columns. Eleven plants were planted in each of the 3 rows, making a total of 33 plants per unit. [9] The plants were allowed to grow in the water for two weeks in order to adapt then, the water was drained and replaced with wastewater from the swine farm. The control pilot units were set up as in the experimental unit but without the plants.

When the plants reached a height of 30 cm the wastewater was released into the plots by letting the wastewater flow over the soil surface until the water reached a depth of 30 cm. The system thus had a capacity of 0.9 m^3 of wastewater. The water flow rate was adjusted to 0.18 m^3 d^{-1} of HLR with 5 day hydraulic retention time [10]. The total period of treatment water inspection was 8 weeks.

3) Water quality analysis

The water samples of influent and effluent from each pilot unit were collected and analyzed when the wastewater was drained into the plot after 2 weeks. When the water flew steadily, the treatment process started and the study period continued for 8 weeks. Wastewater samples from the influent and effluent were collected every week throughout the operation period. The sampling was conducted at the same time in the mornings. The samplers were analyzed for water quality indicators (COD, BOD, TKN, TP, DO, pH, EC and temperature). The temperature, DO, pH and EC were measured on-site using a DO meter, pH meter and EC meter, respectively. Other parameters (COD, BOD, TKN and TP) were performed immediately after the samples were transported to the laboratory by using the Standard Methods for the Examination of Water and Wastewater Treatment [11]. Details are presented in Table 1.

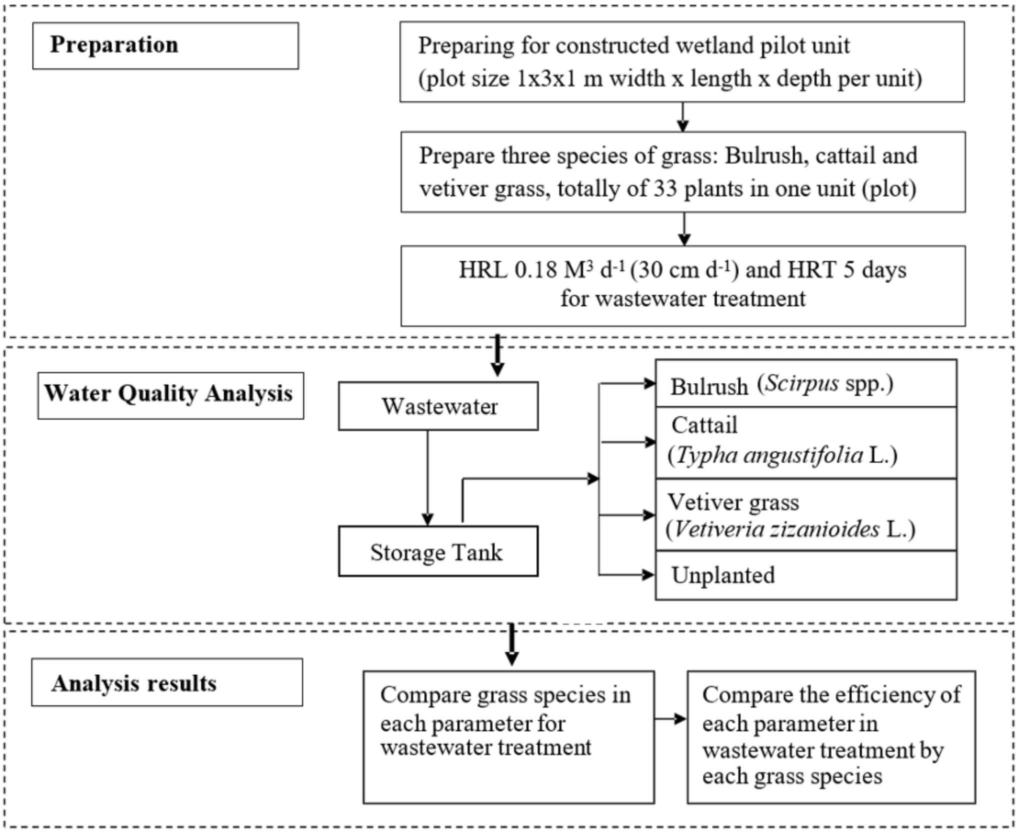

Figure 1 Schematic diagram of the wastewater treatment and the CW pilot plant.

Table 1 Quality index for inspected water and analysis method

Indicators	Unit	Method
Temperature	°C	Thermometer
pH	-	Electrometric method (pH meter)
EC	mS	Conductivity meter
DO	mg L^{-1}	Membrane electrode meter (DO meter)
BOD	mg L^{-1}	Azide modification
COD	mg L^{-1}	Closed reflux method
TKN	mg L^{-1}	Digestion, distillation and titration
TP	mg L^{-1}	Sulfuric acid-nitric acid digestion

4) Efficiency of wastewater treatment

In the analysis of water quality, the treatment efficiency for each parameter can be calculated using the following Eq.1.

$$\text{Efficiency (\%)} = (A-B)\times 100/A \qquad \text{(Eq.1)}$$

When A = quality of water entering the system and B = quality of water exiting the system.

The efficiency of the treatment system was analyzed by comparing the percentage removal and concentration for each indicator. Duncan's Multiple Range Test (DMRT) was used to compute the statistical differences among the three treatment groups. All statistical analyses were performed at the 0.05 significance levels.

Results and discussion

1) Wastewater characteristics

Thailand swine wastewater quality standard type C, which is produced on farms with 50-500 pigs, indicates that COD, BOD and TKN value should not exceed 400,100 and 200 mg L^{-1}, respectively. Wastewater characteristics from the primary wastewater sediment tank are presented in Table 2. The temperature varied with the environment. While the pH was within standard requirements, levels of BOD and COD in the wastewater samples exceeded the national permissible standard. Average TKN was within the national standard requirement.

2) Water quality and effectiveness of treatment

In the three different treatments, all indicators except EC had demonstrated significant improvement in wastewater quality; however, there were no significant differences among the treatments. The wastewater after treatment had lower pH and it was within the national standard for swine farm wastewater (pH = 5.5-9.0). The EC of polluted water was reduced to a low value, as was found in a study of phytoremediation of waste using vetiver in retting area of India [12]. The average DO in the pilot units increased after treatment. The effluent from the cattail pilot has the highest DO (4.93 mg L^{-1}) and lowest pH because the cattails are able to reduce the pH of the wastewater, partially remove its dark color as well as reduce the toxic load. Moreover, it was found that cattails are highly tolerant to salinity. A study of the plant's internal structure reveals its ability to absorb water and nutrients in its spongy cells. The plant's root systems (rhizomes) extend horizontally beneath the soil surface and start new upright growth [13]. In addition, the intervention resulted in increased levels of DO, and also suggests an inverse relationship with coliform level, and higher BOD and COD removal efficiency [14]. Its affinity indicated that the grass could be used to develop an environmentally friendly remediation method for polluted wastewater.

Table 2 Swine farm wastewater characteristics

Indicators	Unit	Range	Average ± SD	Effluent standard for pig farm*
Temperature	°C	27.0 - 29.7	28.48±1.35	-
pH	-	6.82 - 7.68	7.28±0.05	5.5 - 9.0
EC	μs cm^{-1}	1,999.10 - 4,890.00	2,247.44±1,366.99	-
DO	mg L^{-1}	0.00 - 2.45	0.389±0.05	-
BOD	mg L^{-1}	469.62 - 1,390.00	767.90±39.45	100
COD	mg L^{-1}	541.87 - 2,952.00	1,330.25±194.49	400
TKN	mg L^{-1}	58.10 - 212.80	158.67±106.00	200
TP	mg L^{-1}	32.96 - 134.21	69.90±13.30	-

Note: * = Standard for effluent of swine farms with 50-500 pigs

- = Not enforced

3) Organic Substance Treatment

Wastewater treatment using plants relies on a number of factors including the microorganisms living in the plants' roots, which are important in absorbing oxygen necessary for wastewater degradation. The wastewater treatment is able to reduce BOD and COD to carbon dioxide. The plant roots are the primary locus for oxidation of organic substances roots [15]. Although the effectiveness of wastewater treatment in the pilot units using plants was greater than the control units for every parameter, the BOD and COD in effluent wastewater were still higher than the national standard requirement for swine farm wastewater. Compared with standard water quality, it was found that effluent with 5 d HRT exceeded the standard value in which BOD and COD were 100 mg L^{-1} and 400 mg L^{-1}, respectively. BOD and COD effluent from all plants treatment were significantly different from the control effluent at $p \leq 0.05$. The average BOD in bulrush, cattail, and vetiver grass were 76.42, 80.59, and 74.90 %, respectively. Moreover, the average COD were 80.49, 84.11, and 70.03 %, respectively. Removal efficiency for organic substances was higher in the Cattail treatment, as represented by BOD and COD values. With application of constructed wetland, wastewater was degraded through a complex process involving sedimentation, absorption through filtration, decomposition and transformation by microorganisms. In addition, the plants play a role in oxidizing both organic and non-organic compounds. The mechanism of BOD treatment referred to microbial decomposition and sedimentation [16]. For the highest efficiency in the decomposition and transformation of pollutants, microorganisms are essential. Furthermore, the underwater plant structures also promote the decomposition and transformation of pollutants. Soil and plant roots provide habitats for microorganisms and plant roots release nutrients. Plants emerging over water had a larger structure and extended roots [15].

Factors affecting COD removal effectiveness were plant species and hydraulic retention time (HRT). The effectiveness of COD treatment was reduced with shorter HRT since the organic substances in COD form could not be decomposed in time [5]. Plant species was found to have no influence over BOD removal effectiveness [17]. To enhance the effectiveness of COD treatment, the HRT must be increased. Several prior studies have reported that transformation of microbial nutrients was the main treatment mechanism in wetland systems. [18] Moreover, the result of domestic wastewater treatment by SFCW with bulrush within five days under the same conditions of tropical countries showed that the effectiveness of BOD treatment was between 32.4 to 91.0 %, with the average of 51 %.

4) Nutrient treatment

Aquatic plants help absorb nutrients and elements such as nitrogen and phosphorus, which then accumulate in many parts of the plants, reducing the nutrient burden in the water [15]. Nitrogen (N) was removed primarily through nitrification and denitrification. Nitrification occurs under aerobic conditions in water and soil. Other mechanisms for nitrogen removal include evaporation of nitrogen in the form of ammonia at high pH and temperature. Phosphate (P) is primarily absorbed by plant roots in contact with soil [19]. Plant nitrogen uptake differs according to the system configuration, loading ranges, wastewater type and environmental conditions [20]. The TKN and TP effluent concentration in this experiment was reduced, and the TKN met the national standard requirement of swine farm wastewater categories A and B (not over 120 and 200 m L^{-1}). The concentration of TKN in the effluent in the experimental pilot unit was statistically different from the control pilot.

Average TKN treatment efficiency of bulrush, cattail and vetiver grass pilot unit were 85.25, 88.08 and 87.71 %, respectively (Table 4), with cattail presenting the highest efficiency to treat TKN. The reduction of TKN might be due to sedimentation or particulate organic matter. At the optimal temperature and pH, plants photosynthesize and lead to crystallization of some compounds such as NH_4CaPO_4 [21]. Moreover, $NH^+{}_4$-N helps increase soil absorption because the soil was able to absorb cations from solution and from soil microorganisms. Nitrogen in NO_3^--N form is labile and was able to enter soil and ground water [22]. TP treatment in the constructed wetland with bulrush, cattail and vetiver grass was effective, resulting in TP levels of 65.42, 65.20, and 82.98 %, respectively. The vetiver grass plot was most effective in TP treatment, whilst no significant differences in removal efficiency were found between bulrush and cattail. P treatment was dependent on physical mechanisms such as sedimentation, precipitation, and adsorption on soil or other catalytic agents [23-24]. The phosphorus uptake capacity of macrophytes is reported to be lower than the nitrogen uptake capacity [25].

The beneficial role of plants in constructed wetland is not always evident, and appears to depend on several parameters such as the duration of operation, vegetation type and characteristics of the wastewater. Wetland plants absorb nutrients from soil through their roots, helping to reduce the levels and thus toxicity of dissolved nutrients and pollutants, especially nitrogen and phosphorus [15] though mechanisms such as nitrification, denitrification, and plant assimilation [26]. The community wastewater treatment by vetiver grass can remove nutrients especially P from the wastewater [27]. Moreover, microbial nutrients transformation was reported as the main removal mechanism in wetland treatment systems [14]. This study demonstrated the effectiveness of vetiver grass, particularly for N and P removal, as was found in China [7, 28].

Among the factors influencing effectiveness of TKN and TP removal in wetland wastewater treatment systems, hydraulic retention time (HRT) was the dominant factor affecting removal efficiency. Efficiency of pollutant removal increased with HTR. A retention time of 6 d was the most effective in phosphorus removal (around 14 %) [29]. With the same retention time, bulrush plots had better phosphorus removal than cattails; the more rapid growth of bulrush results in higher nutrient demand. The mechanisms of phosphorus removal were assimilation through soil layers, sedimentation, and plant assimilation. A study on nitrogen removal from piggery wastewater showed that cattails had better efficiency than *Cyperus malaccensis* Lamk., in collecting nitrogen in their leaves, trunks and roots, respectively [30].

Table 3 Influent and effluent characteristics of wastewater treatment by three grass species

Indicators	Wastewater	Wastewater effluent in each treatment unit			
	Influent	Control	Bulrush	Cattail	Vetiver
pH	7.28±0.20	7.87±0.43	7.36±0.60	6.99±0.40	7.87±0.21
	(6.82-7.45)	(7.88-8.93)	(6.79-7.94)	(6.59-7.90)	7.65-8.22
EC	3591.94±814.80	753.47±543.91	632.04±361.50	558.39±376.10	775.168±436.23
(µs cm^{-1})	(1999.1-3760.0)	(237.3-1799.0)	(299.5-1602.2)	(222.33-1534.3)	(260.92-1568.3)
DO	0.73±0.09	2.46±1.63	3.61±0.53	4.93±1.07	4.86±2.01
(mg L^{-1})	(0.01-2.45)	(0.01-4.92)	(2.86-4.46)	(3.65-6.58)	(1.28-7.50)
BOD	854.77±365.41	282.87±182.02	213.95±191.40	182.81±160.35	191.98±183.61
(mg L^{-1})	(469.6-1390.0)	(73.89-653.5)	(37.50-650.1)	(38.75-512.1)	(38.75-615.0)
COD	1690.44±696.05	439.72±337.87	355.22±262.87	319.34±307.69	530.70±321.61
(mg L^{-1})	(1103.5-2952.0)	(166.66-1080.0)	(133.33-900.0)	(66.66-900.0)	(211.20-1080.0)
TKN	104.38±37.82	13.23±3.15	11.10±8.25	8.77±7.13	10.96±4.27
(mg L^{-1})	(58.10-168.58)	(1.72-37.10)	(2.25-22.96)	(1.54-19.60)	(7.47-20.53)
TP	67.19±39.49	26.26±22.04	23.68±18.40	23.54±18.32	19.14±2.88
(mg L^{-1})	(38.56-134.21)	(6.88-71.33)	(5.51-60.00)	(3.97-58.64)	(4.10-13.30)

Note: Mean±SD are shown for species treatment. Numbers in brackets mean efficiency values (minimum to maximum).

Table 4 Removal Efficiency of surface flow constructed wetland

Indicators	Removal efficiencies (%) of each treatment unit			
	Control	Bulrush	Cattail	Vetiver
BOD	68.45±16.40a	76.42±16.36b	80.59±12.10bc	74.09±16.97b
	(44.15-85.54)	(53.23-92.02)	(63.16-92.77)	(46.67-96.23)
COD	75.16±8.25ab	80.49±6.94b	84.11±9.43bc	70.03±9.53a
	(63.41-86.51)	(69.51-89.21)	(69.51-94.60)	(43.34-93.78)
TKN	79.15±22.19a	85.25±14.13b	88.08±12.24b	87.71±8.12b
	(44.60-90.26)	(57.35-98.66)	(66.27-99.08)	(69.13-95.33)
TP	61.26±19.07a	65.42±15.08ab	65.20±16.84ab	82.98±9.01c
	(25.23-62.72)	(39.89-87.33)	(40.87-90.87)	(70.99-96.22)

Note: Means values within each row followed by the same letter are not significantly different at $p \geq 0.05$. Mean±SD are shown for species treatment. Numbers in brackets mean efficiency values (minimum to maximum).

Conclusion

Contaminants and nutrient levels in piggery wastewater were minimized using bulrush, cattail and vetiver grass. The surface flow constructed wetland with cattail pilot showed improvement in wastewater quality indicators: BOD, COD, TKN with efficiencies of 80.59, 84.11 and 88.08 %, respectively. The vetiver grass was found to be the most efficient in removing total phosphorus (TP), while the efficiency of constructed wetland treatment using bulrush and cattail for TP was not significantly different. The piggery wastewater treatment through a period of 5 days hydraulic retention time (HRT) was able to reduce the dirtiness in wastewater but unable to meet the national wastewater quality standard. Further study is needed to establish the optimal hydraulic retention time for effective wastewater treatment.

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