NITROGEN REMOVAL FROM PIGGERY WASTEWATER
BY A VERTICAL CONSTRUCTED WETLAND
AND HORIZONTAL FLOW SAND BED

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Abstract
Piggery wastewater creates various problems in many areas throughout Thailand. Constructed wetland systems are an appropriate, low cost treatment option for tropical countries such as Thailand. In this study, a combined system: a vertical flow constructed wetland planted with Cyperus flabelliformis over a horizontal flow sand bed without plants was used to treat settled piggery wastewater. This system is suitable for using in farms where land is limited.
The average COD and nitrogen loading rate of the vegetated vertical flow bed were 1050 kg/ha.d and 110 kg/ha.d respectively. The wastewater was fed intermittently at intervals of 4 hours with a hydraulic loading rate of 3.7 cm/d. The recirculation of the effluent increased total nitrogen (TN) removal efficiency from 71% to 85%. The chemical oxygen demand (COD) and total kjeldahl nitrogen (TKN) removal efficiencies were 95% and 98%. Nitrification was significant in vertical flow Cyperus bed, and the concentration of nitrate increased by a factor of 140. The horizontal flow sand bed enhanced COD removal, denitrification was satisfactory and nitrate reduction was 60%. Plant uptake of nitrogen was 11.2 kg N/ha.d or dry biomass production was 27.9 ton/ha over 100 days. Suspended solids and fecal coliform bacteria removal were over 98% and 99% respectively.

Keywords combined system, Cyperus flabelliformis, nitrogen, plant uptake, recirculation, pig farm wastewater
INTRODUCTION

Livestock farming has recently undergone rapidly development in Thailand. The growth of large scale pig farms has created a need for suitable technology for waste disposal. The majority of these farms do not manage their wastes appropriately and their wastewater discharges have an adverse impact on receiving water. Many producers are considering the use of economic technologies to treat their wastes and control odor emission. Treatment technologies, including anaerobic digestion, lagoons and composting have been used for several years but the effluent quality is still unsatisfactory. Constructed wetland systems have recently been introduced to treat pig farm effluent following anaerobic digestion but due to insufficient knowledge and experience, these systems have not yet been effective. The high concentration of ammonia in the wastewater could be a major cause of their failure.

Constructed wetlands have the potential to remove nitrogen from piggery wastewater (Szogi, et al., 1999). According to Cooper and de Maeseneer (1996), the system with a vertical flow follow by horizontal flow bed can be smaller and can remove significant amounts of nitrate in horizontal flow stage. A vertical flow bed showed 80-95% nitrification and a combined horizontal flow bed 75-80% denitrification rate in a study by Platzer (1996). Platzer (1999) also found that a recirculation rate up to 200% can be used without hydraulic problem for vertical flow beds. More research is needed to evaluate the suitable operating conditions for piggery wastewater treatment.

METHODS

The experiment was conducted in a tank constructed of iron plate, 1.2m.x1.2m.x 1.2m.(WxLxH). The tank was separated into two sections by a plastic sheet: the upper section was 80 cm. deep and the lower section was 30 cm. deep. The upper section was filled with gravel (1-2 cm.) to a depth of 10 cm., followed by 70 cm. depth of course sand (1-2 mm.). Four 2 cm. diameter influent PVC pipes with 0.5 cm. holes and separated by 5 cm. were laid on the surface of the upper section. The wastewater was fed intermittently (4 hours on and 4 hours off) at the surface of the media and flowed vertically to the bottom of the upper section. A drainage pipe of the same diameter collected water from the bottom of
the upper section (vertical flow) and passed to the top of lower section which was filled with course sand. The water flowed horizontally and across to the bottom of the lower section (figure 1). In the second run, 50% of the effluent was recycled to the upper vertical flow section.

The upper section was planted with *Cyperus flabelliformis*. The height of the plants was measured at weekly intervals. Nitrogen concentration in the plants were also analyzed both before and after operation of each run.

Piggery wastewater from the faculty of Agriculture, Chiang Mai University, was used in the experiment. It was flushed from the pig pens into the settling tank with a retention time of about 5 days. Only clear supernatant was used in the experiment.

The average temperature of the raw wastewater and mixing wastewater were around 24.9 °C and 25.7 °C. The temperature of the vertical flow and horizontal flow bed effluent were 25.8 and 26.1 °C, respectively.

![Fig. 1. Experimental design](image-url)
The influent and effluent from vertical (effluent1) and horizontal flow sections (effluent2) were collected and analyzed for COD, TKN, NH3-N, NO3-N, SS, Alkalinity, Coliform bacteria, pH and temperature according to the method for the examination for water and wastewater (APHA,1995).

Fig. 2. The experimental set up

RESULTS AND DISCUSSION

Run 1: without recirculation of the effluent

The analysis commenced when the plants were 2 weeks old and were acclimatized to the wastewater used in the experiment. The raw wastewater was fed intermittently with hydraulic loading rate of 3.7 cm./d. The average of COD concentration in the raw wastewater was 2800 mg/l during the steady state or 1050 kg COD/ha.d. The COD in the raw wastewater varied from 1725 to 3210 mg/l. The experiment was conducted for 60 days from June to August 1999 and the average temperature of the raw wastewater was 25 °C. COD removal efficiency reached 97% after passing through the vertical flow section and at the end of horizontal flow part, the removal efficiency further increased to 98%. The average COD in the effluent was 43 mg/l (figure 2).
Nitrification and denitrification were measured and nitrification was satisfactory. The average concentration of TKN in the raw wastewater was 240 mg/l or 90 kgTKN/ha.d.

The reduction in vertical flow section was 97% and the TKN in the effluent was reduced to 6.6 mg/l. The reduction was increased to 98% in the horizontal flow section resulting in 3.9 mg/l TKN effluent concentration. The same pattern was observed for NH3-N with a concentration of 168 mg/l in the raw wastewater, which was reduced in the final effluent to 3.1 and 1.9 mg/l, respectively (figure 3). There was minimal loss of ammonia due to volatilization as the pH of the wastewater in both sections was neutral. The nitrate concentration was increased significantly in the final effluent. There was only a trace amount of nitrate in the raw wastewater (0.27 mg/l) but after passing vertically through the upper section, nitrification resulted in an increase in the concentration of nitrate to 72.8 mg/l followed by a reduction to 63.2 mg/l in the horizontal flow section due to denitrification.

![Fig. 3. Total COD profile without recirculation of the effluent](image)

The reduction of alkalinity after passing through the vertical flow section (93.8%) was due to nitrification. The concentration of alkalinity increased again from 53.4 mg/l to 79.4 in the horizontal flow section due to the denitrification reaction. Denitrification was not significant though the removal efficiency in term of total nitrogen reached 70.8%. The following experiment aimed to increase denitrification in the horizontal flow section by the recycling of 50% of the effluent to the raw wastewater.
The influent concentration of suspended solids was fluctuated between 380 to 760 mg/l. After steady state, the vertical flow bed reduced SS to 12-39 mg/l or 25 mg/l in average. The reduction was increased only a little more in the horizontal flow part to 22 mg/l in the final effluent.

The reduction of coliform bacteria was also measured. In the raw wastewater, total coliform (TC) and fecal coliform (FC) bacteria were $25 \times 10^{11}$ and $21 \times 10^{11}$ MPN/100 ml respectively. The reduction was very high and the effluent from the vertical flow bed showed TC and FC concentration of approximately $16 \times 10^4$ and $20 \times 10^4$ MPN/100 ml., the reduction increased in the horizontal flow bed and $15 \times 10^2$ TC and $12 \times 10^2$ FC MPN/100 ml were recorded in the final effluent.

**Run 2 : Recirculation of 50% of the effluent**

The experiment was carried out with the same procedure but 50% of the effluent was recycled and mixed with raw wastewater. The hydraulic loading was then changed to 5.6 cm./d.

![Fig. 4. NH₃-N profile without recirculation of the effluent](image)

The experiment was conducted for 100 days from August to December 1999. The COD concentration in the raw wastewater was higher than in the previous experiment and the average concentration was 3342 mg/l during the steady state but after mixing with the
recycled effluent, the concentration was reduced to 1809 mg/l. The removal efficiency was around 96% in the upper section increasing to 97% after passing through the lower horizontal flow section. Average COD concentration in the final effluent was around 83 mg/l. The recycling of the effluent did not significantly enhance the COD removal efficiency.

Recycling of the effluent enhanced the nitrogen removal efficiency. The TKN and NH₃-N concentration in the raw wastewater were also higher than the previous run. The average concentration of TKN and NH₃-N were 406 and 302 mg/l, respectively. After mixing with 50% effluent, the concentrations of TKN and NH₃-N were diluted to 230 and 170 mg/l (figure 5). Both TKN and NH₃-N were reduced by 99%. The average nitrate concentration in raw wastewater was 1.1 mg/l and after mixing with the recycled effluent, the concentration increased to 32 mg/l. The increase of nitrate to 140 mg/l in the vertical flow bed was significant (figure 6). The reduction of TKN and NH₃-N was caused by nitrification, and the denitrification occurred in the horizontal flow section reducing nitrate to 57 mg/l or approximately 60%.

The total nitrogen removal efficiency was higher when 50% of the effluent was recycled. In the first run, without recycling, the TN removal was around 70% but in the second run the TN removal reached 85%. Laber et al.(1996) also found that a recirculation rate of 50-60% and intermittent feeding could increase the nitrification/denitrification and total nitrogen removal was 53 % in a combined constructed wetland system.

The pH of raw influent was around 7.3 in average and 7.1 in the mixing wastewater. After passing a vertical flow bed, pH reduced to 6.0 due to nitrification reaction and the absorption of NH₃ by plants. The pH was increased again to 6.7 in horizontal flow bed by the reduction of nitrate.

Evaporation in a vertical flow section was observed since the experimental unit was located outdoor and exposed to sun light. The water lost was approximately 63%.
The growth and nitrogen accumulation in the plants were measured and analysed at the end of each run. The dry biomass of *Cyperus* at the end of the first and the second runs were 15.5 and 27.9 ton/ha. Respectively and the growth rate was reduced with time. The nitrogen content was maximum in the stems then leaves and roots as shown in table 1. The total nitrogen accumulation were 0.81 g/m².d and 1.1 g/m².d at the end of each run, respectively.
Kootatep and Polprasert (1997) reported N uptake by cattails in the tropic using domestic wastewater was 3 kg/ha.d and the increment of dry biomass was 16.1 ton/ha in 90 days in comparison to 8.13 kg/ha.d and 15.5 ton/ha in 60 days and 11.2 kg/ha.d and 27.9 ton/ha in 100 days of Cyperus in this study.

The experiment is continuing in order to determine the optimum recycling ratio for nitrogen removal.

Table 1. Nitrogen accumulation in plants with recirculation of the effluent

<table>
<thead>
<tr>
<th>constituent</th>
<th>initial period</th>
<th>after 100 days</th>
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<tbody>
<tr>
<td></td>
<td>leave</td>
<td>stem</td>
</tr>
<tr>
<td>N content, gN/g</td>
<td>0.0074</td>
<td>0.0083</td>
</tr>
<tr>
<td>N plant uptake, gN/m².d</td>
<td>0.414</td>
<td>0.491</td>
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Raw wastewater suspended solids concentration was in the range of 644-2,288 mg/l or 1,400 mg/l in average. The reduction was almost completed in the vertical flow part (97.6% removal efficiency) and was increased to 98% in the final effluent.

The reduction of coliform bacteria was observed. Recycling of 50% of the effluent showed a similar reduction in the bacteria as in the first run. The TC and FC in the raw wastewater were 26x10¹¹ and 13x10¹¹ MPN/100 ml. and after passing through the vertical flow section, the number of TC and FC were 16x10⁴ and 11x10⁴ MPN/100 ml and reduced to 14x10² and 10x10² MPN/100 ml. in the final effluent, respectively.

CONCLUSIONS

The use of a combined system with a vegetated vertical flow bed constructed wetland over horizontal flow sand bed is an alternative method for wastewater treatment where land area is limited. The efficiency of the system, especially for COD and nitrogen removal was satisfactory. Recirculation of 50% of the nitrified effluent increased nitrogen removal efficiency and TN removal could reached 85%. According to Laber et.al.(1996), TN
removal was 53% with 50% recirculation but the concentrations of nitrogen and COD in the influent in this study were higher. Nitrification with intermittent feeding was very successful. After recirculation of the effluent, the denitrification increased from 13 to 60%. A 98% and 99% reduction of suspended solids and coliform bacteria were achieved and the recirculation did not further improve the removal efficiency significantly, as for COD.

Biomass production of *Cyperus* and nitrogen uptake were similar with and without effluent recirculation and nitrogen uptake was highest in the stems, followed by leaves and roots.

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**REFERENCES**


