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Nitrogen Transformation within Constructed Wetlands Purifying Secondary Treated Sewage

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Abstract: - Most of domestic wastewater is either untreated or only primarily settled by septic tanks in Taiwan. Manure produced by concentrated swine operations is also one of the primary pollution sources of watercourses. Recently, constructed wetlands have received tremendous interests as one of the contemporary alternatives employing to enhance the water quality regarding nitrogen nutrients due to the deterioration of groundwater quality. Wetlands can be employed to enhance water quality, with saving in infrastructure construction costs as well as providing economic, environmental, and social benefits. The main objectives of this study were to investigate the nitrogen nutrients removal mechanisms and efficiency within the field scale natural purification systems. The systems included an oxidation pond, two serial surface flow wetlands with a cascade in between, and a subsurface flow system. These water purification systems received secondary treated sewage as their inflow. The macrophytes within the study system were submergent plants including cattails and reeds. The average BOD and COD percent removal efficiency was approximately 86 and 42%, respectively. The ratio of BOD to COD decreased from 0.63 in the initial aerobic compartment to 0.16 in anoxic parts of the systems, indicating most biological degradable materials were decomposed in the aerobic oxidation pond and surface flow wetlands. Total Kjeldahl nitrogen (TKN) and ammonium decreased from 7.58 to 2.45 and 5.46 to 1.86 mg/L, respectively, while nitrate nitrogen increased from 1.86 to 5.68 mg/L within the aerobic oxidation pond and surface flow wetlands. This result demonstrated nitrification occurring within aerobic units. The nitrate nitrogen continued to decrease from 5.56 to 1.21 mg/L within the anoxic subsurface wetlands through denitrification transformation. Total nitrogen removal was from 10.62 to 3.78 mg/L, with the percentage removal of total nitrogen around 64.3%. The primary nitrogen removal and transformation mechanisms within the studied wetland systems were nitrification within aerobic followed by denitrificaiton within anaerobic systems. pH of the systems ranged from 6.5 to 7.8 which indicate the ammonia volatilization is negligible. The submergent macrophytes enhance aeration through oxygen transferring that attributing the higher organic matter removal and nitrification rate. The wetland systems are prominent options of nitrogen nutrients removal in tropical countries, while tertiary wastewater systems are too costly or unable to operate. Results of this study will be useful for applying similar treatment train natural purification systems to purify secondary treated sewage in tropical regions.

Key-Words: - Constructed wetlands, nitrogen removal, nitrification, denitrification

1 Introduction

In Taiwan, the sewerage connection rate is fairly low. Most of domestic wastewater is either untreated or primarily settled by septic tanks. Constructed wetlands might be one of the contemporary options to enhance the water quality and have been primarily employed for rural or sewage treatment in tropical regions. Though, different biological and physicochemical treatment processes have been applied to remove nitrogen nutrients from secondary treated sewage and each has its own technical and economical limitations. Conventional advanced wastewater treatment requires significant capital investments and consumes large amounts of energy. The wetland system possesses the merits of low-cost and less labor intensive while it is capable of removing various pollutants including heavy metals, organic matters, pathogenic indicators, and nutrients. Constructed wetlands are growing popularity as a natural and economical alternative for purifying contaminated water. Numerous studies have been conducted to research on the removal efficiency of

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pollutants including organic matters and nutrients within wetlands [1].

In Taiwan, manure produced by concentrated swine operations is one of the primary pollution sources of watercourses. The wastewater generated is either untreated or poorly treated by anaerobic followed by aerobic pollutant removal processes. The effluent is then sprayed on fields or discharged in the surrounding waterways. If nutrients in the effluent are applied in excess of plant uptake rates, the nutrients may contaminate the surface or groundwater due to runoff and leaching. The recent monitoring data showed that elevated ammonium and nitrate levels were detected in groundwater. One option for nutrient removal might employ constructed wetlands prior to land application or waterway discharge [2].

Excess amounts of nutrients nitrogen discharge into rivers and streams, leading to eutrophiction and aquatic ecosystem impact due to low dissolved oxygen. Nitrification-denitrification, microbial assimilation, plant uptake, ammonia volatilization, adsorption, organic accumulation and sedimentation are the possible nitrogen removal mechanisms within constructed wetlands [3]. Nitrification-denitrification is the favorable mechanism for nitrogen removal by converting ammonia to nitrogen gases emitting to the atmosphere. Nitrate nitrogen reduction in wetland is through two processes including denitrification and nitrogen uptake by macrophytes. The latter process is important only if the plant is harvested [4]. Constructed wetlands are water purification systems that mimic the functions of natural wetlands by enhancing processes involving vegetation uptake, soil and associated microbial degradation. The role of vegetation also includes creating aerobic degradation environments around root zones via atmospheric diffusion [5].

Besides the organic pollutants removal, wetland systems can be also employed as the nitrogen removal alternative that occurs through a sequence of ammonification, nitrification, and denitrification. Effluent from the wetland can be percolated slowly to supply the underlying aquifer while the wetlands employed as the nitrogen removal of groundwater quality enhancement in Taiwan. The aim of this research intended to study the reduction rates of various pollutants including organic matters and nutrients treated within the treatment wetlands. The research was carried out to demonstrate the constructed wetlands were the viable options for further enhancing the quality of secondary sewage by reducing nitrogen nutrient and organic pollutants.

2 Materials and Methods

The field-scale natural purification systems included a pretreatment oxidation pond, two serial surface flow wetlands with a cascade aeration part in between, followed by a subsurface wetland. The hydraulic retention time, total areas, and inflow rate of the studied natural purification systems were 12 days, 800 m^2, and 140 CMD, respectively. The inflow water was sewage from campus treated by secondary biological processes. Two surface flow wetlands were planted to submergent macrophytes including cattails (*Typha latifolia*) and reeds (*Phragmites austrials*). Nitrogen removal investigations into the efficiency and fate of nitrogen were carried out by sampling and analyzing from the marked points within the system (Fig. 1). The concentrations of TKN, ammonium, nitrite, and nitrate were determined. Organic matters and water quality parameters such as pH, temperature, and dissolved oxygen were also monitored. All water samples were analyzed in accordance with the Standard Methods for Examination of Water and Wastewater.

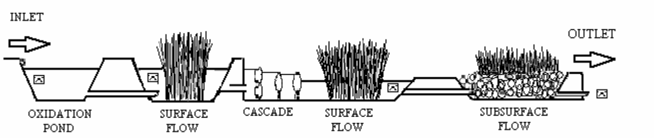

Fig. 1. Layout of filed scale purification systems

3 Results and Discussions

The monitored results of water quality parameters including temperature, pH, and dissolved oxygen are shown in Fig. 1, 2, and 3. Nutrient removal in constructed wetlands has been shown to be temperature dependent. Southern Taiwan is located in the tropical areas, the average monitored temperature ranged from 18 to 29^oC, which is higher than the temperatures in North America and European countries. The higher temperature is believed to enhance the microbial degradation and transformation rates. The removal and transformation rate of pollutants within the wetland systems might be more significant in the tropical regions. The pH values varied from 6.5 to 7.8 which were reported as the feasible ranges for nitrogen microbial transformations and least ammonia volatilization. Dissolved oxygen concentrations were below saturation in these studied wetland systems. Increasing levels of dissolved oxygen concentrations in surface flow wetlands indicated transferring oxygen through submergent vegetation from atmosphere and also attributed to cascade system increasing aeration.

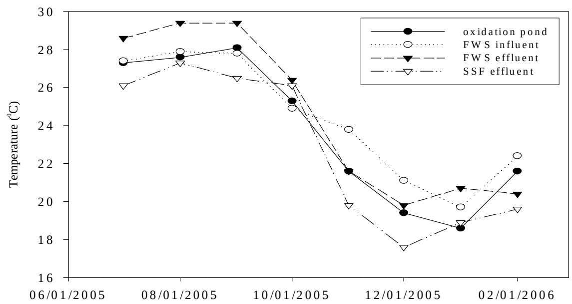

Fig. 2. Monthly average temperature variations

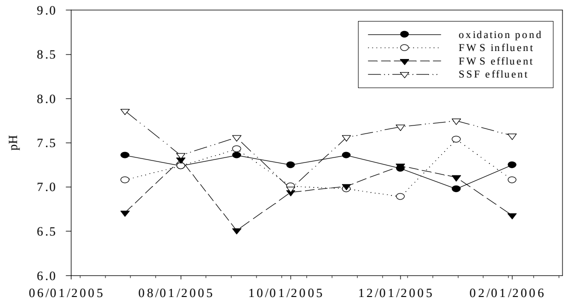

Fig. 3. Monthly average pH variations

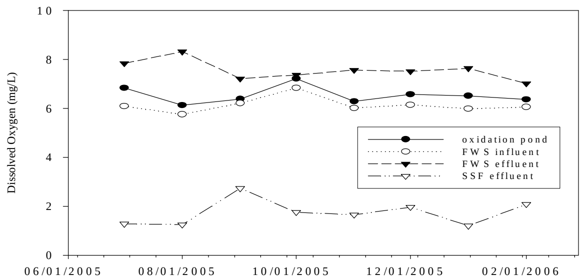

Fig.4. Monthly average DO variations

The influent BOD and COD were 9.7 and 15.5 mg/L, respectively, while effluent BOD and COD were 1.4 and 9.0 mg/L, respectively (Table 1). The average BOD and COD percent removal efficiency in this study was approximately 86 and 42%, respectively. The BOD and COD removal efficiency were consistent with reported in other literatures [6, 7]. In Fig. 5, the ratio of BOD to COD decreased from 0.63 in the initial aerobic compartment to 0.16 in anoxic parts of the systems, indicating most biological degradable materials were decomposed in the aerobic oxidation pond and surface flow wetlands. Poor removal of organic matters might attribute to limiting oxygen availability within the anoxic subsurface flow system. Though, sedimentation and adsorption are also considered to be mechanisms for organic matter removal. In wetland systems, BOD and COD are principally removed by microbiological activity. The high BOD removal efficiency shown in the surface flow wetlands planted cattail and reeds suggested that vegetation can enhance transporting extra oxygen for substrate attenuation. The performance of vegetated systems might be further enhanced if above ground biomass is harvested rather that allowed to decay within the wetlands. The effect of submergent vegetation in surface flow wetlands on shading algae and inhibiting algal activity might be the likely influence of organic matter removal. Oxidation pond and surface flow wetlands also provided quiescent conditions for settling suspended solids and particulate BOD. This might be attributed to the higher organic matter removal in the aerobic components of the studied systems.

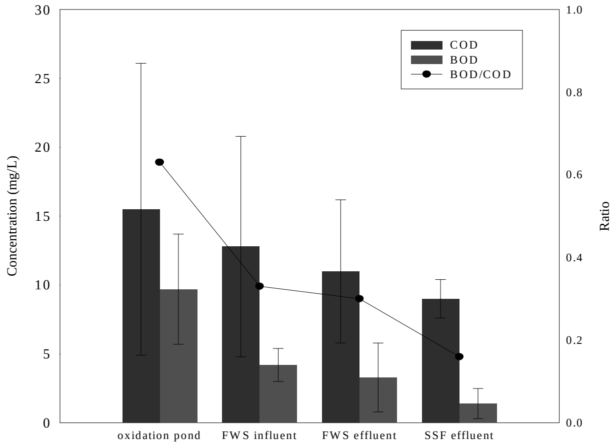

Fig. 5. Concentrations of BOD and COD(BOD/COD ratio)

Table 2 is a summary of nitrogen transformation data. Ammonium in the inflow water averaged 65 to 75% of TKN. The inflow water of the studied wetlands systems were ammonium dominated rather than organic nitrogen or nitrate. Ammonium inflow ranged from 5.01-6.73 mg/L (mean=5.46) while TKN ranged from 6.18-8.63 mg/L (mean=7.58). The outflow of ammonium and TKN ranged from 0.78-1.34 mg/L (mean=1.06) and 1.05-1.74 (mean=1.38), respectively. The wetland removed or stored approximately 82% of inflow TKN. The monitored data demonstrated seasonal oscillation with higher TKN and ammonium removal during summer months. This phenomenon might be due to increased photosynthetic activity which produced dissolved oxygen facilitating nitrification. Another explanation for this seasonal variation was likely the increasing macrophyte uptake of ammonium during the growing season. Further investigations of plant uptake will be carried out. In Fig. 6, TKN and ammonium decreased from 7.58 to 2.45 and 5.46 to 1.86 mg/L, respectively, while nitrate nitrogen increased from 1.86 to 5.68 mg/L within the aerobic oxidation pond and surface flow wetlands. The results demonstrated nitrification occurring within aerobic units. The nitrate nitrogen continued to decrease from 5.56 to 1.21 mg/L within the anoxic subsurface wetlands through denitrification transformation. Total nitrogen removal was from 10.62 to 3.78 mg/L. The percentage removal of total nitrogen concentration was around 64.3%, demonstrating that constructed wetlands in tropical areas might be a promising option to purify secondary treated sewage regarding nitrogen nutrient removal. The predominant decrease of total nitrogen was within the subsurface wetland compartment where denitrification occurred.

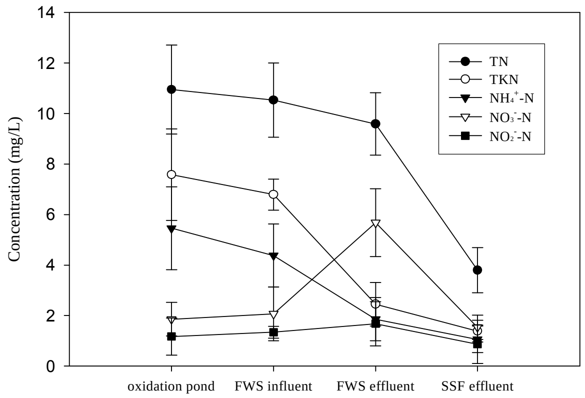

Fig. 6. Nitrogen species profiles within purification system

Nitrogen transformation in wetlands occurs by biological processes including ammonification, nitrification, denitrification, nitrogen fixation, and nitrogen assimilation. For secondary treated sewage, the predominant forms of nitrogen might be ammonium and nitrate depending on aeration levels in secondary treatment processes. Nitrification and denitrification are generally indicated as the principal processes for nitrogen reduction [8]. Nitrification is a rate-limiting mechanism in both aerobic and anaerobic environments. The transformation of ammonium to nitrate, the nitrification process, within the aerobic systems was significant in the study. Plant uptake of ammonium is also a removal mechanism while all plants parts are reservoirs for nitrogen storage. Ammonium might be also trapped in sediments [9]. Plant uptake and possible ammonium settling might also attribute to the total nitrogen decreasing in the surface flow wetlands in this study. The extents of these two mechanisms will be further tested.

Carbon availability might be the limiting factor for denitrification in the subsurface flow systems. However, the decomposition of macrophyte plants in the proceeding surface flow wetlands might yield sufficient carbon sources in the studied systems. Nitrification should be enhanced because it will increase the nitrate available or denitrification. The studied surface flow wetland systems are feasible for nitrification enhancement due to the permissive oxygen conditions with the assistance of submergent macrophyte and a cascade unit.

Nitrification- denitrification was considered as the predominately nitrogen removal mechanism in this study. Ammonia volatilization might be negligible since pH of tested water samples were below 9.3. Nevertheless, ammonia volatilization was correlated with the ammonia nitrogen concentrations and background water parameters. Nitrification and treated water dilution were both reducing ammonia volatilization.

Influent organic concentration, temperature, dissolved oxygen were found to be factors of influence in this study regarding nitrogen nutrient removal. The performance of surface flow followed by subsurface flow wetland systems for removing nitrogen nutrients was demonstrated in this study to be a prominent option to polish secondary treated sewage.

4 Conclusions

The predominant forms of nitrogen are ammonium in the influent, nitrification and denitrification were the principal processes for nitrogen reduction. Considerable potential by employing the treatment train natural purification systems for removing both organic matters and nitrogen nutrients was demonstrated in this study. Studies of other nitrogen removal mechanisms in the systems such as plant uptake and sediments trapping will be further investigated.

In conclusion, constructed wetland systems are one of the viable options serving as environmentally sustainable, socially accepted and cost-effective nutrient purification processes. Constructed wetlands have emerged as alternatives for assisting to solve a wide range of environmental and water quality problems while the sewerage connection is fairly low in Taiwan. Wetland systems are particularly attractive alternatives for enhancing the secondary treated wastewater and groundwater quality enhancement due to their incorporating into the landscape plan and its operational simplicity and cost efficiency.

This research has showed that constructed wetlands can be designed to provide nitrogen nutrient removal by incorporating oxidation ponds, surface flow wetlands and subsurface flow wetlands into a treatment train. Results of this study will be useful for applying similar natural purification systems to purify secondary treated sewage in tropical regions.

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Table 1. Concentrations and removal rates of organic pollutants in purification systems

Analytical parameters		Oxidation pond	FWS influent	FWS effluent	SSF effluent	Total removal rate (%)
BOD	concentration (mg/L)	9.7±4.0	4.2±1.2	3.3±2.5	1.4±1.1	85.57%
	Removal rate (%)		56.70%	9.28%	19.59%	
COD	concentration (mg/L)	15.5±10.6	12.8±8.5	11±5.2	9.0±1.4	41.93%
	Removal rate (%)		17.42%	11.61%	12.90%	
BOD/COD	ratio	0.63	0.33	0.3	0.16	

Table 2. Nitrogen species concentrations and removal rates

Analytical parameter		Oxidation pond	FWS influent	FWS effluent	SSF effluent	Total removal rate (%)
TN	concentration (mg/L)	10.62±1.76	10.2±1.47	9.8±1.23	3.78±0.89	64.30%
	Removal rate (%)	-	3.90%	3.70%	56.70%	
TKN	concentration (mg/L)	7.58±1.81	6.79±0.61	2.45±0.86	1.38±0.43	81.80%
	Removal rate (%)	-	10.50%	57.30%	14.10%	
NH_4^+-N	Concentration(mg/L)	5.46±1.64	4.38±1.25	1.86±0.86	1.06±0.53	80.60%
	Removal rate (%)	-	19.80%	46.20%	14.60%	
NO_3^--N	concentration (mg/L)	1.86±0.67	2.07±1.06	5.68±1.34	1.54±0.48	-
NO_2^--N	concentration (mg/L)	1.17±0.73	1.34±0.24	1.68±0.87	0.87±0.76	