Nitrogen removal from concentrated latex wastewater by land treatment

Vikanda Thongnuekhang¹ and Udomphon Puetpaiboon²

Abstract

Thongnuekhang, V. and Puetpaiboon, U. 
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Most of the concentrated latex factories in the South of Thailand discharge treated wastewater that contains high level of nitrogen to a nearby river or canals leading to a water pollution problem. A study of land treatment system was conducted to treat and utilize nitrogen in treated wastewater from the concentrated latex factory. The experimental pilot-scale land treatment system was constructed at the Faculty of Engineering, Prince of Songkla University, Hat Yai Campus. It consisted of water convolvulus (Ipomea aquatica, I. Reptans), tropical carpet grass (Axonopus compressus (Swartz) Beav.) and control unit (no plantation). The treated wastewater from the stabilization pond system of the selected concentrated latex factory in Songkhla was used to irrigate each experimental unit. Influent and effluent from the experimental units were analyzed for TKN, NH₃-N, Org-N, NO₃⁻-N, NO₂⁻-N, BOD₅, sulfate, pH and EC. The land treatment system resulted a high removal efficiency for nitrogen. Tropical carpet grass provided higher removal efficiency than other units for all parameters. The removal efficiency of water convolvulus and control unit were not significantly different. The average removal efficiency of TKN, NH₃-N, Org-N, BOD, and sulfate for tropical carpet grass unit were 92, 97, 61, 88 and 52%, for water convolvulus unit were 75, 80, 43, 41 and 52% respectively.

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Land treatment for wastewater has been investigated and practised at several locations in the world for a long time. The advantage of land treatment is the combination of wastewater treatment and recycling in the same process. Wastewater will be applied to the land surface to achieve a specified degree of treatment through the natural physical, chemical, and biological process within the soil-plant-water matrix. This system provides high efficiency for nutrients removal. Boyden and Rababah (1996) studied wastewater reuse to irrigate lettuce. They reported that more than 80% of nitrogen and 77% of phosphorous were removed from the settled primary sewage by applying it to the roots of lettuce. It is possible to irrigate vegetables with wastewater where a large quantity of nutrients is efficiently removed by vegetable. High nutritive value in wastewater reduces fertilizer application rates and increases productivity of poor fertility soils (Al-Lahham et al., 2003). Kouraa et al. (2002) reported that the crop production has a remarkable im-
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In Thailand, Chaimongkol et al. (2002) presented that the effluent of sewage treatment plant of Chiang Mai Municipality was suitable for agriculture with the expected yield similar to the one using natural water.

In the South of Thailand, there are many concentrated latex factories. Usually, wastewater from the concentrated latex industry contains high amount of nitrogen originating from natural rubber and ammonia compounds added into the production processes. Most of these factories discharge treated wastewater still containing a high level of nitrogen to the natural river or canals leading to water pollution problems such as algae bloom, dissolved oxygen depletion, etc. Therefore, study of land treatment system was considered and conducted to treat and utilize nitrogen in treated wastewater from the concentrated latex factory.

Regarding the latex production process, zinc oxide (ZnO) and sulfuric acid (H₂SO₄) are other two chemicals added into the process. ZnO is added to preserve rubber whereas H₂SO₄ is used in skim rubber production. Therefore, contamination of zinc and sulfate in the concentrated latex wastewater was considered for land treatment system operation.

The main objectives of this study are; 1) to study nitrogen removal efficiency of land treatment system, 2) to study possibility of using the treated wastewater from concentrated latex factory for irrigation and 3) to study mass balance of nitrogen-transformation in land treatment system.

Materials and Methods

Experimental set-up

Pilot-scale experimental land treatment unit was conducted in this research. It consisted of two land treatment units and one control unit (no plantation). The dimension of each unit was 1×2 m (W×L) and 0.2 m soil thickness with 2% slope. Plastic sheet lining was installed at the bottom to prevent infiltration. Each experimental unit was added with sandy clay loam soil. Water convolvulus and tropical carpet grass were planted into each land treatment unit. Treated wastewater from stabilization pond system of the selected concentrated latex industry in Songkhla was used to irrigate plants and control units with water application rate at 4 cm/week by distribution over each unit twice a day. Each land treatment unit was operated at a different period according to the growing period. The water convolvulus unit was operated for 36 days. Tropical carpet grass and control units were operated for 50 days.

Wastewater analysis

During operation period, influent and effluent were analyzed every 3 days for water convolvulus unit and every 5 days for tropical carpet grass and control unit to determine pH, electrical conductivity (EC), biochemical oxygen demand (BOD₅), nitrite nitrogen (NO₂⁻-N), nitrate nitrogen (NO₃⁻-N), ammonia nitrogen (NH₃-N), organic nitrogen, total kjeldahl nitrogen (TKN) and sulfate. Analysis of parameters was done according to the Standard Methods for the Examination of Water and Wastewater (APHA, AWWA and WEF, 1995).

Plant and Soil analysis

Plant and soil samples were analyzed before and after the experimental run. Plants were dried at 65°C and sent to the Central Analytical Center, Faculty of Natural Resources, Prince of Songkla University, to determine TKN and zinc content. Zinc contents in plants after harvest should less than the maximum safety level of zinc in food (15 mg/100 g wet weight (APFAN, 1994)). Zinc accumulation in plant can be harmful to health. Soil samples were taken from pilot-scale experimental units and sent to the Central Equipment Division, Faculty of Science, Prince of Songkla University, to determine NO₃⁻-N, NO₂⁻-N and TKN.

Results and Discussion

Wastewater analysis

Characteristics of wastewater for irrigating experimental land treatment unit are shown in
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Table 1. It demonstrated that pH, sodium adsorption ratio (SAR) and zinc in wastewater were suitable for irrigation. Electrical conductivity (EC) may affect the ability of plants to uptake water but it was at a slight level. Therefore, it was possible to use treated wastewater from the concentrated latex factory for irrigation.

Influent and effluent of land treatment experimental system were analyzed for pH, EC, BOD₅, NO₂⁻-N, NO₃⁻-N, NH₃-N, Org-N, TKN and sulfate. The average analysis results are shown in Table 2. The major form of nitrogen in influent was ammonia nitrogen. Plants are able to use this form of nitrogen for growth and it can be accumulated in the soil (Brady and Weil, 1996). Hence, all experimental units provided low level of nitrogen in effluent. In contrast NO₃⁻-N in effluent of all experimental units were higher than influent. This could occur because of conversion of the NH₃-N to be NO₂⁻-N and NO₃⁻-N by nitrifying bacteria under aerobic condition (nitrification process). However, nitrate in the effluent still met the Drinking Water Quality Standard by EPA (US EPA, 1996)

Table 3 shows the average removal efficiencies of TKN, NH₃-N, Org-N, BOD₅ and sulfate for each experimental land treatment unit. It can be clearly observed that tropical carpet grass unit provided the best results. This could occur because of higher density of tropical carpet grass in the land treatment unit. TKN, NH₃-N, Org-N, BOD₅ and sulfate removal efficiencies for water convolvulus and control unit were not significantly different. The results indicated that all experi-

Table 1. Characteristics of treated wastewater from selected concentrated latex factory.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Wastewater from selected concentrated latex factory</th>
<th>Degree of restriction on use*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pH 8.4</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>EC (dS/m) 1.82</td>
<td>Slight to moderate</td>
</tr>
<tr>
<td></td>
<td>SAR 1.47</td>
<td>Severe</td>
</tr>
<tr>
<td></td>
<td>Zn (mg/l) 0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* FAO (1985)

Table 2. Mean characteristics of influent and effluent of land treatment system.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Water convolvulus</th>
<th>Carpet grass/Control</th>
<th>Control</th>
<th>Water convolvulus</th>
<th>Carpet grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>TKN (mg/l)</td>
<td>41.00±14.06</td>
<td>33.05±13.79</td>
<td>10.03±4.72</td>
<td>2.47±0.50</td>
<td>8.49±4.16</td>
</tr>
<tr>
<td>NH₃-N (mg/l)</td>
<td>35.79±14.15</td>
<td>28.05±13.17</td>
<td>7.16±4.04</td>
<td>0.75±0.65</td>
<td>5.54±3.10</td>
</tr>
<tr>
<td>Org -N (mg/l)</td>
<td>5.22±2.23</td>
<td>5.00±2.60</td>
<td>2.88±1.14</td>
<td>1.72±0.67</td>
<td>2.94±1.69</td>
</tr>
<tr>
<td>NO₂⁻-N(mg/l)</td>
<td>0.30±0.12</td>
<td>0.34±0.15</td>
<td>0.64±0.29</td>
<td>0.68±0.39</td>
<td>0.95±0.57</td>
</tr>
<tr>
<td>NO₃⁻-N (mg/l)</td>
<td>0.61±0.28</td>
<td>0.67±0.28</td>
<td>0.26±0.12</td>
<td>0.05±0.06</td>
<td>0.29±0.17</td>
</tr>
<tr>
<td>BOD₅ (mg/l)</td>
<td>62±11</td>
<td>65±8</td>
<td>37±7</td>
<td>8±4</td>
<td>45±8</td>
</tr>
<tr>
<td>Sulfate (mg/l)</td>
<td>482±243</td>
<td>471±194</td>
<td>308±71</td>
<td>222±62</td>
<td>323±69</td>
</tr>
<tr>
<td>pH</td>
<td>8.50±0.52</td>
<td>8.40±0.53</td>
<td>7.90±0.48</td>
<td>7.19±1.38</td>
<td>8.12±0.36</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>1.88±0.15</td>
<td>1.82±0.15</td>
<td>1.51±0.17</td>
<td>1.10±0.38</td>
<td>1.49±0.28</td>
</tr>
</tbody>
</table>

Note: X ± SD
mental units provided high removal efficiency of TKN and NH$_3$-N. The average removal efficiency for tropical carpet grass, water convolvulus and control unit was found to be 92, 75 and 74% for TKN, and 97, 80 and 80% for NH$_3$-N, respectively.

Plants analysis

After operation for 36 days, water convolvulus was harvested and analyzed for nitrogen and zinc contents. The results are shown in Table 4, showing that zinc accumulation in water convolvulus was 0.033 g/kg dry weight (0.83 mg/100 g wet weight) which was less than the maximum safety level of zinc in food (15 mg/100 g wet weight). Total nitrogen uptake of water convolvulus was 8.96 grams per experimental unit (4.48 g/m$^2$). The water convolvulus did not achieve mature growth as compared with the natural water convolvulus plant, possibly due to an inadequate trace elements.

Carpet grass was weighed and analyzed for nitrogen and zinc content before and after operation. The results are shown in Table 5, indicating total nitrogen uptake of tropical carpet grass was 10.15 grams per experimental unit (5.10 g/m$^2$).

Soil analysis

Analysis results of soil before and after experimental run are shown in Table 6. Total nitrogen in initial soil was 272.83 mg/kg dry weight. At the end of experimental run, total nitrogen in soil for tropical carpet grass, water convolvulus and control unit increased to 299.74, 293.26 and 336.95 mg/kg dry weight, respectively. The amount of TKN in soil for water convolvulus and tropical carpet grass units after operation decreased from initial values. This could occur because NH$_3$-N was absorbed by the plant and converted to NO$^+_3$-N by nitrification process that can be observed from the increase in NO$^+_3$-N in final soil of all experimental units.

Nitrogen mass balance

In this research, mass balance was deter-
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Table 6. Analysis results of soil before and after experimental run.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Initial</th>
<th>Final</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Water convolvulus</td>
<td>Tropical carpet grass</td>
<td>Control</td>
</tr>
<tr>
<td>TKN (mg/kg)</td>
<td>271.59</td>
<td>245.15</td>
<td>265.38</td>
<td>284.01</td>
</tr>
<tr>
<td>NO₃⁻-N (mg/kg)</td>
<td>1.13</td>
<td>47.49</td>
<td>33.45</td>
<td>52.55</td>
</tr>
<tr>
<td>NO₂⁻-N (mg/kg)</td>
<td>0.11</td>
<td>0.62</td>
<td>0.91</td>
<td>0.40</td>
</tr>
<tr>
<td>TN (mg/kg)</td>
<td>272.83</td>
<td>293.26</td>
<td>299.74</td>
<td>336.95</td>
</tr>
</tbody>
</table>

Table 7. Accumulation of nitrogen in land treatment components.

<table>
<thead>
<tr>
<th>Units</th>
<th>Components</th>
<th>Influent (g)¹</th>
<th>Effluent (g)²</th>
<th>Soil (g)</th>
<th>Plant (g)</th>
<th>Volatilized (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water convolvulus</td>
<td></td>
<td>17.20</td>
<td>1.97</td>
<td>4.96</td>
<td>8.96</td>
<td>1.30</td>
</tr>
<tr>
<td>Carpet grass</td>
<td></td>
<td>19.41</td>
<td>0.82</td>
<td>6.54</td>
<td>10.16</td>
<td>1.89</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>19.41</td>
<td>2.92</td>
<td>15.58</td>
<td>-</td>
<td>0.91</td>
</tr>
</tbody>
</table>

¹ = (Mean concentration of N in influent) × (Flow rate of Inf.) × (Operation period)
² = (Mean concentration of N in effluent) × (Flow rate of Eff.) × (Operation period)

Determinations in terms of total nitrogen over operation period to investigate nitrogen transformation and indicate the major removal mechanisms. Total nitrogen accumulation in any components of land treatment system is shown in Table 7.

Mass balances of nitrogen transformations in each experimental unit are presented in Figures 1, 2 and 3. On the mass balance basis, the accumulation of nitrogen in soil for water convolvulus, tropical carpet grass and control units were 28.8%, 33.69% and 80.28% of the total inflow, respectively. Nitrogen accumulation in soil for water convolvulus and tropical carpet grass were less than the control unit due to most of nitrogen being taken up by the plants. Nitrogen uptake of water convolvulus and tropical carpet grass were 52.09% and 52.34% of total inflow, respectively. Ammonium (NH₄⁺) and nitrate (NO₃⁻) are two forms of nitrogen that plants are able to use for growth.

The mass balance of nitrogen indicates that a part of the nitrogen was lost from land treatment. This might occur by ammonia volatilization and denitrification. Due to pH in land treatment experimental units did not favor ammonia volatilization process which occurs at pH 9.2 (Weiner, 2000). Therefore, denitrification was the major mechanism enhancing nitrogen loss in experimental units. Denitrification is the conversion of NO₃⁻-N to nitrous oxide and nitrogen gas under low oxygen condition. Denitrification occurs when NO₃⁻-N is present in a soil. Namely, NH₄⁺-N was converted to NO₃⁻-N under aerobic condition by nitrification process and then NO₃⁻-N was converted to N₂O and N₂ by denitrification process under low oxygen condition. From the mass balance analysis, nitrogen lost from water convolvulus, tropical carpet grass and control units were 7.59, 9.74 and 4.68% of the total inflow, respectively. Denitrification rate in plant units was higher than in the control unit; this could be possible because of soil moisture of the plant units was higher than of the control unit. High soil moisture content will reduce oxygen level in soil enhancing denitrification rate. Chenfang et al. (2000) reported that soil moisture was the influential factor governing nitrogen loss via the process of denitrification.
Annette and Ralf (1998) reported that N$_2$O and N$_2$ release by denitrification increased with increasing soil moisture content.

**Conclusion**

Land treatment system provided a high nitrogen removal efficiency. In the control unit, the major nitrogen removal mechanism was soil accumulation. Nitrogen accumulation in soil for water convolvulus and tropical carpet grass were less than in the control unit due to most accumulated nitrogen in soil being taken up by plants. Plant uptake was the major nitrogen removal mechanism for the water convolvulus and tropical carpet grass units. Tropical carpet grass provided the highest nitrogen removal efficiency. It indicates that the higher density of plants in the land treatment system enhances nitrogen removal efficiency.

Water convolvulus did not achieve mature growth as compared with the natural water convolvulus plant, possibly due to inadequate trace elements. However, it is possible to irrigate vegetables with the treated wastewater with the addition of chemical fertilizer or manure to yield a commercial crop.

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