Denitrification of Soilless Tomato Crops Run-off Water by Horizontal Subsurface Constructed Wetlands

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Abstract
Soilless tomato crops runoff contains high nutrient concentrations, particularly nitrates, with concentrations ranging from 150 to 500 mg NO₃-N.L⁻¹. Biological denitrification with horizontal subsurface flow wetlands planted with common reed (Phragmites australis) and bulrush (Scirpus lacustris) has been evaluated to treat soilless crops effluent. Because of the high level of NO₃-N, a carbon source was required to support denitrification with a good activity of denitrifying bacteria. Vinery sewages have been chosen because they are easily and freely available in France. The trials were carried out in 20 small horizontal flow wetlands (1.8 m x 0.6 m x 0.67 m water depth). The first results show that the level of nitrate nitrogen can be lowered by 70 to 100% when carbon source supply is sufficient (COD/N = 2 to 4) and with Hydraulic Residence Times of 5 to 10 days depending on the season.

INTRODUCTION
In France, as in northern Europe, greenhouse tomato crops are widely grown in hydroponics systems. Plants are fed with water and nutrients according to their water demand. The volume of nutrient solution delivered is approximately 20-30% more than the crop needs to account for variability of irrigation equipment and crop uptake from the substrate and to keep fertilizer salt levels from increasing in the growing media. The excess volume leaches contains high nutrient concentrations, particularly nitrate nitrogen, ranging from 150 to 500 mg.L⁻¹. This drainage, if not collected and recycled is a potential groundwater pollutant by being discharged in the same area year after year.

Recycling of the drainage is the best solution to reduce nutrient leaching in the environment because it allows the grower to save water and fertilizers (30-40%). However, this technique presents high initial and running costs for small farms. Moreover, total recycling is quite impossible due to water quality (Sédilot et al., 2002). Thus, there is a need for alternative or complementary processes.

Subsurface horizontal-flow constructed wetlands, planted with common reed (Phragmites australis) or common bulrush (Scirpus lacustris), have been tested to treat wastewater such as sewage and dairy effluents. Nitrate and phosphate removal from irrigation run off was tested in Australia in a commercial nursery (Headley et al., 2001). Good results were obtained but with a very low nitrate level in comparison with tomato run off. The horizontal flow in a saturated medium is adapted to nitrate treatment because anoxic conditions are favourable to the development of denitrifying bacteria (Kadlec and Knight, 1996) which reduce nitrate to nitrogen gas. The presence of common reeds gives a better infiltration of water around the rhizomes with a reduction in the risk of clogging the filter and a release of limited quantities of oxygen.

The purpose of the study was to evaluate the performance of subsurface horizontal-flow reed beds to remove high level of nitrogen. This paper presents the results obtained after 4 years of trials.

METHODS
Experimental Approach
The main objective of this work is to evaluate the nitrate removal performance of the reed beds with Hydraulic Residence Times (HRT) ranging from 5 to 10 days, adding
different amounts of carbon to obtain chemical oxygen demand / nitrate nitrogen ratios (COD/NO₃-N) from 1 to 3. Inlet and outlet samples were collected weekly. NO₃-N, PO₄-P, COD, conductivity (EC) and pH were measured from May 2002 to September 2003 according to standard methods for the examination of water and wastewater (APHA, 1995).

Composition of Drainage
Run off tested in this study came from 3 different tomato crops and was collected and stocked in a 500 m single basin. Main characteristics of the drainage are given in table 1.

Bed Description
Twenty small scale subsurface horizontal-flow beds planted with rhizome cuttings of *Phragmites australis* were set up in 2000 in a plastic tunnel at Balandran, Crifl Research Station in Bellegarde (South France, 43.75°N, 4.5°E). The beds 1.8 m long, 0.6 m wide, were filled with 8-16 mm of washed and rolled gravel to give a water depth of 0.67 m. The outlet system allows the water level to be maintained at up to 4-5 cm above the bed surface.

Inflow (31 L per bed) was introduced for 10 hours daily, using a drip irrigation system, and the outflow was collected to record the volume.

Carbon Source
Carbon was added at the inlet of the beds to improve bacterial activity and denitrification process. For this study, different vinery effluents - distillery vinasse then downgraded wine (12°) from Bellegarde winery, with a COD of about 200 g.L⁻¹ - were chosen because of their abundance in the South of France. As only small volumes were needed, downgraded wine was diluted in water. Diluted wine and drainage water were introduced at the same time but separately.

RESULTS AND DISCUSSION
In 2000, results showed that without any source of carbon, nitrate removal is very low. The reduction in nitrate concentration was less than 30%. It was also observed that common reeds presented strong chlorosis while the common bulrush, developed well.

In 2001, the use of distillery vinasse renewed reed growth. However, very frequent clogging of the vinasse distribution tube, due to the small size of the experimental device, leaded to irregular supply of carbon and variation of COD/N ratio.

In 2002 and 2003, good results were obtained with downgraded wine. Table 2 presents load NO₃-N removal with 3 different COD/N ratios. Greater than 76% load removal was achieved with the 3 carbon supplies. Load removal was more important with the highest supply of carbon. However, the difference was insignificant.

Figure 1 illustrates the average weekly inlet and outlet NO₃-N concentrations with COD/N ratio of 3 from April to September. Outlet NO₃-N concentration varied from 0 to 150 mg.L⁻¹. This was probably due to variation of COD/N ratio due to irregular NO₃-N inlet concentration and carbon source supply. This suggests that a higher COD/N ratio is needed to obtain a better denitrification. It is also necessary to adapt weekly carbon supply to take into account NO₃-N load high variations.

Nitrogen uptake by common reeds can reach 250 to 500 kg.ha⁻¹ (Mesleard and Perennou, 1996). On this basis, plant uptake represents in our trial only 2.5 % of nitrogen load removal, a small part compared with the result of bacterial activity.

In these trials, a reduction (60 to 90%) of PO₄-P was also observed. Plant uptake and gravel fixation can explain this phenomenon. However, several years are needed to evaluate long-term removal.

In 2004, an experiment was carried out in a larger constructed wetland of 90 m² planted with *Scirpus lacustris*. At HRT of 10 days and with a COD/N ratio of 3.5, high load removal (more than 90%) was achieved (Fig. 2). Outlet NO₃-N concentrations were
lower than 30 mg.L⁻¹. In this trial, the carbon source is mixed, before entering the bed, with a proportional liquid dispenser.

**CONCLUSION**

These first trials with small pilot-scale horizontal constructed wetlands indicate that high efficiency for NO₃-N removal is possible with Hydraulic Residence Times of 5 to 10 days and with an adapted carbon source supply (COD/N ratio between 3 and 4).

In the south of France, this technique could work with filtrated winery effluent to avoid clogging of the beds. Horizontal subsurface constructed wetlands could allow tomato growers and winery to treat 2 effluents at the same time. This could help to reduce nitrate and phosphate leaching from small soilless crops units or leakage that sometimes occurs in partially closed systems.

**Literature Cited**


**Tables**

Table 1. Main characteristics of tomato crop runoff tested in the beds.

<table>
<thead>
<tr>
<th></th>
<th>EC (mS.cm⁻¹)</th>
<th>pH</th>
<th>COD (mg.L⁻¹)</th>
<th>TSS* (mg.L⁻¹)</th>
<th>NO₃-N (mg.L⁻¹)</th>
<th>NH₄-N (mg.L⁻¹)</th>
<th>PO₄-P (mg.L⁻¹)</th>
<th>SO₄-S (mg.L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>1.7</td>
<td>6.0</td>
<td>&lt;30</td>
<td>6</td>
<td>196</td>
<td>0</td>
<td>0</td>
<td>57.8</td>
</tr>
<tr>
<td>Maximum</td>
<td>3.7</td>
<td>8.5</td>
<td>44</td>
<td>&lt;10</td>
<td>370</td>
<td>0.3</td>
<td>25.7</td>
<td>119</td>
</tr>
</tbody>
</table>

* Total suspended solids

Table 2. NO₃-N inlet and outlet load and percentage load reduction for 3 different COD/N ratios (from May to September 2003).

<table>
<thead>
<tr>
<th>COD/N</th>
<th>Inlet NO₃-N load (g)</th>
<th>Outlet NO₃-N load (g)</th>
<th>NO₃-N Load removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2167</td>
<td>513</td>
<td>76.3</td>
</tr>
<tr>
<td>2</td>
<td>2058</td>
<td>348</td>
<td>83.1</td>
</tr>
<tr>
<td>3</td>
<td>1933</td>
<td>255</td>
<td>86.8</td>
</tr>
</tbody>
</table>
Figures

Fig. 1. Inlet and outlet NO$_3$-N concentrations in a small bed (1 m$^2$) with a COD/N of 3.

Fig. 2. Inlet and outlet NO$_3$-N concentrations in a large bed (90 m$^2$) with a COD/N of 3.5.