Constructed wetlands are suitable to treat wastewater from Italian cheese productions

P. Mantovi*, S. Piccinini*, M. Marmiroli** and N. Marmiroli**

*Research Centre on Animal Production (CRPA), Corso Garibaldi, 42 – 42121 Reggio Emilia, Italy. E-mail: p.mantovi@crpa.it; s.piccinini@crpa.it
**Division Genetics Environmental Biotechnology, Environmental Sciences Department, University of Parma, Viale Usberti, 33A – 43100 Parma, Italy E-mail: marta.marmiroli@unipr.it; nelson.marmiroli@unipr.it

Abstract

Two horizontal sub-surface flow constructed wetlands (h-SSF CW) were set-up and controlled to determine their efficiency in reducing the polluting load of wastewater from Parmigiano-Reggiano and Grana Padano cheese production. Besides, comparisons were made of biomass production and nutrient uptake of cattail (Typha latifolia) reaped at different stages. The average concentrations of the influent waters were about 250-320 mg/l TSS, 940-1060 mgO₂/l COD, 600-700 mgO₂/l BOD₅, 35 mg/l TKN, 8-13 mg/l total P, 60-170 mg/l animal and vegetable fats and oils. The removal of COD, BOD₅ and animal/vegetable fats and oils were above 95%, while resulted 60-65% for nitrogen and very different for phosphorus, varying from 75% in one CW to 20% in the other. Results demonstrated that h-SSF CW could help to solve the problem of the cost-effective disposal of cheese dairy wastewater, being a suitable treatment for reducing pollutants to values in conformance with Italian standards for discharge to a watercourse. Typha latifolia showed considerable biomass yield, though the N and P uptake was quite low if compared with nutrients inputs in CW (about 10%). There is the possibility to maximise biomass yield and nutrient uptake reaping cattail twice a year instead of only one time.

Keywords: bacterial indicators, cattail, copper, horizontal subsurface flow, monitoring, reed bed

INTRODUCTION

In recent years constructed wetlands (CW) have been more and more in use for the clean up of wastewaters from households and agriculture. Sub-surface flow (SSF) constructed wetlands are quite compact in dimensions and offer good purification performances when deployed to amend different types of wastewaters (Schulz et al., 2003; Shepherd et al., 2001; Sun et al., 1998; Vrhovšek et al., 1996).

The aim of this work was to verify the performances and efficacy of SSF-CW applied to cheese factory effluents. Wastewater deriving from cheese production processes has medium-high concentrations of COD, BOD₅, nitrogen and phosphorous, because of the presence of milk’s fats, proteins and carbohydrates (lactose). Pollutants concentrations in wastewater coming from cheese dairies, not subjected to purification treatment, generally exceed the threshold values for discharge into surface waters.

However, it is possible to observe a wide fluctuation in the values of the wastewater flux and the pollutants concentration for different cheese factories. These values depend upon the type of cheese production, its set-up and management, and the effort put by the workers to restrain milk and whey spills and to curtain water consumption. Since cheese factory wastewater bear low levels of Total Suspended Solids and high levels of dissolved organic molecules, they are unsuitable for treatments based on liquid/solid separation. Their characteristics, on the other hand, allow for CW treatment to be applied because there is no need for solid sedimentation pre-treatment procedures.
Besides, our research tried to add knowledge on cattail (*Typha latifolia*) development in CW, to understand how the plant could be managed best. This because *Typha latifolia* is a suitable specie for using in h-SSF systems but it is rarely employed in Italian CW where the general preference is for *Phragmites australis*. This has led to a consequent lack of information on cattail development in Italian CWs.

**MATERIALS AND METHODS**

Two horizontal SSF CW were set-up and controlled over 16 months to determine their efficiency in reducing the polluting load of wastewater from Italian cheese productions factories.

The first CW (figure 1), located 800 metres above sea level in the North Italian Apennines (Montese municipality, Modena province), treated wastewater from Parmigiano-Reggiano production (1,700 tons of milk per year transformed); it had a total surface area of 400 m² and was planted with cattail (*Typha latifolia*).

The second CW (figure 2), located 100 metres above sea level in the Padana plain (Carpaneto municipality, Piacenza province) treated wastewater from Grana Padano production (23,000 tons of milk per year transformed); it had a total surface area of 2700 m² and was planted with reed (*Phragmites australis*). This last factory is quite large in comparison to Italian standards, with a high degree of automation applied in the washing operations; this allows to water saving but increases the concentrations of pollutants in the discharged wastewater (table 1).

Each bed, filled with fine gravel (from 6 to 18 mm diameter), was built upon a sand layer with a 1% slope, and suitably impermeabilised using a synthetic covering protected with geotextile. Near the wastewater inflow and outflow points of each bed a layer of coarse gravel (about 30 mm diameter) was put in place to facilitate the flowing of incoming and outgoing water.

At both sites the pulsed wastewater discharges from the factory were collected in a storage tank that guarantee a regular flow during the whole day towards the wetlands (equalisation). The level of water in the wetlands has been kept at a few centimetres below the gravel surface for the whole monitoring period. After the CW treatment the purified water was discharged into surface waters. Epigeal biomass was harvested each year at the end of the winter.

Influent and effluent wastewater from each bed were collected monthly. The following parameters were analysed, mainly according to APHA (1998) standard methods: pH, Total Suspended Solids (TSS; filtration at 45 μm and drying at 103-105 °C), Chemical Oxygen Demand (COD; titrimetric method), Biological Oxygen Demand (BOD₅; polarization method), Total Kjeldahl Nitrogen (TKN; Kjeldahl digestion), Ammonia nitrogen (NH₄-N; gas-diffusing membrane electrode), Total phosphorus (P; microwave digestion, colorimetry with vanadomolibdophosphoric acid). Organic nitrogen was calculated as TKN minus NH₄-N.

Other pollutants of relevance such as nitrates, chlorides and sulphates (NO₃-N, Cl, SO₄; ionic chromatography), heavy metals (Cd, Cr, Cu, Ni, Pb, Zn; ICP emission spectrometry), anionic and non ionic surfactants (sublation and spectrometry), animal/vegetable fats and oil (gravimetric method) and bacterial indicators like total coliforms and *Escherichia coli* (Petrifilm count plate) and faecal streptococci (membrane filtration) were analysed on a 3-months basis.
For each pollutant under study, removal rates were calculated as:
\[
\frac{\text{inflow} - \text{outflow}}{\text{inflow}} \times 100
\]

In the constructed wetland treating wastewater from Parmigiano-reggiano cheese production comparisons were made of biomass production and nutrient uptake of cattail reaped:

1. in mid June and at the end of the vegetative period (treatment JUN);
2. in mid July and at the end of the vegetative period (JUL);
3. just at the end of vegetative period, in November (NOV).

The cattail was at the 2\textsuperscript{nd} year. Every month, from April till November, plants were sampled from each of the three cutting regimes. Sampling points were located at the top of the CW1 (see figure 1), first hit by the cheese dairy effluent. Epigeal biomass was sampled for dry matter estimation (drying at 103-105 °C); total N (Kjeldahl method) and total P (microwave digestion, colorimetry with vanadomolibdophosphoric acid) were measured as well.

![Scheme of the CW system treating wastewater from Parmigiano-Reggiano production.](image)

**Figure 1** | Scheme of the CW system treating wastewater from Parmigiano-Reggiano production.

- Dimension of each gravel bed: 20 x 10 x 0.9 m
- Total surface constructed wetland: 400 m\(^2\)
- Gravel diameter: about 12 mm in CW1, about 6 mm in CW2
- Plants grown: *Typha latifolia*

A: equalisation tank
B: inspection well

CW1, CW2: first and second constructed wetlands with outflow wells (1, 2).
Dimension of each gravel bed: 45 x 15 x 1 m
Total surface constructed wetland: 2700 m²
Gravel diameter: about 6-12 mm in CW1 and CW2, about 12-18 mm in CW3 and CW4
Plants grown: *Phragmites australis*

A: degreasing-settling§
B: equalisation tank
C: pressurised wastewater injection line
CW1, CW2, CW3, CW4: the four constructed wetlands with their outflow wells (1, 2, 3, 4)
§The fats deriving from degreasing are accumulated in a storage tank

*Figure 2* | Scheme of the CW system treating wastewater from Grana Padano production.
RESULTS AND DISCUSSION

Treatment efficiency

The average fluxes for the wastewater, as evaluated during the whole monitoring period, were 10.5 m$^3$/day from the Parmigiano-Reggiano cheese factory and 70 m$^3$/day from the Grana Padano cheese factory. The water consumption per ton of transformed milk could therefore be estimated at about 2.25 m$^3$ and 1.11 m$^3$ for the Parmigiano-Reggiano cheese factory and the Grana Padano cheese factory respectively.

The main features of influent and effluent waters are shown in table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Average characteristics of influent and effluent waters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater from Parmigiano-Reggiano cheese production</td>
<td>Wastewater from Grana Padano cheese production</td>
</tr>
<tr>
<td>Un-treated</td>
<td>Treated</td>
</tr>
<tr>
<td>pH</td>
<td>6.1</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>253</td>
</tr>
<tr>
<td>COD (mg O$_2$/l)</td>
<td>938</td>
</tr>
<tr>
<td>BOD$_5$ (mg O$_2$/l)</td>
<td>595</td>
</tr>
<tr>
<td>TKN (mg/l)</td>
<td>33.7</td>
</tr>
<tr>
<td>NH$_3$-N (mg/l)</td>
<td>6.0</td>
</tr>
<tr>
<td>Total P (mg/l)</td>
<td>7.7</td>
</tr>
<tr>
<td>NO$_3$-N (mg/l)</td>
<td>0.16</td>
</tr>
<tr>
<td>Cl (mg/l)</td>
<td>422</td>
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<tr>
<td>SO$_4$ (mg/l)</td>
<td>34.8</td>
</tr>
<tr>
<td>CU (mg/l)</td>
<td>0.531</td>
</tr>
<tr>
<td>MBAS (mg/l)</td>
<td>0.7</td>
</tr>
<tr>
<td>CTAS (mg/l)</td>
<td>0.4</td>
</tr>
<tr>
<td>Animal/vegetable fats and oils (mg/l)</td>
<td>59</td>
</tr>
</tbody>
</table>

$^\dagger$ Table 3, Annex 5 to the third part of Italian legislative decree 152/06 (discharge in surface water).

The removal of COD, BOD$_5$ and animal/vegetable fats and oils were above 95%, while resulted 60-65% for nitrogen and very different for phosphorus: 75% in Parmigiano-Reggiano wastewater treatment, only 20% in Grana Padano wastewater treatment, quite constant during the monitoring period.

These features allowed the processed wastewaters to be in compliance with the legislation limits and thus to be discharged into surface waters. The only exception was the total P, slightly above the limit in few samples from the big scale Grana Padano factory. New types of P-free detergents for tanks washing have been utilised to lower P concentrations in wastewater from this factory. These detergents have resulted in a positive effect in lessening P loads.

Phosphorus removal along the wetland length has always followed a linear decreasing trend, which demonstrates that the main process driving P abatement was due to the retention by the gravel bed substrate of the wetland. Figure 3 shows results coming from the monitoring of the CW treating wastewater from the Parmigiano-Reggiano cheese factory: organic N was transformed into ammonia-N, then the latter further decreased in concentration. These observations pointed out that very likely there was an adequate oxidation process, enhanced by the presence of Typha latifolia. The data on N removal and on biomass production, suggest that the major N removal process could be volatilisation, either as ammonia, or, after denitrification, as N$_2$ and other gases (Ciria et al., 2005; McGechan et al., 2005).
Nitrates, chlorides, sulphates and heavy metals (copper excluded) were only detected in low concentrations. Copper was above legislation limit in the Parmigiano-Reggiano cheese factory, mainly deriving from the washing of the vats where the cheese is cooked. Anionic and non-ionic surface-active agents were above legislation limit in the Grana Padano cheese factory. Their outflow concentrations were in conformity with the legislation limit. The removal of bacterial indicators was determined to within 2-4 orders of magnitude.

As already verified in other h-SSF treatment plants (Tanner and Sukias, 1995), in the beds first hit by the dairy effluent the removal efficiencies were always significantly higher than in the succeeding beds; these latter essentially provided a “polishing” step for effluent.

**Plant development**

In cattail reaped just at the end of the vegetative period the accumulation of nitrogen and phosphorus in the epigeal biomass increased until July (figure 4); values then fell from July onwards, due to the transfer of nutrients to the hypogeal parts and to a general slow down of the plants growth (Garver et al., 1988).

Results on dry matter production and nutrients uptake for the three cutting regimes are shown in table 1. The total production of dry biomass was higher in JUL than in the other two treatments. The plants which underwent renewal of vegetation, obtained through intermediate cutting in the summer months, showed a significant overall higher removal of N and P compared to those subjected to a single harvest at the end of vegetative period. It will be necessary to evaluate the possible effects and trade-offs of the summer cuttings on cattail development in the coming years.
Figure 4 | Nutrients concentration in cattail biomass during growing season (treatment NOV).

Table 2 | Production of DM and removal of N and P from aerial parts of Typha latifolia under three different cutting regimes

<table>
<thead>
<tr>
<th></th>
<th>DM (kg/m²)</th>
<th>TKN (g/m²)</th>
<th>Total P (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st harvest 14 June</td>
<td>1.51</td>
<td>27.4</td>
<td>5.8</td>
</tr>
<tr>
<td>2nd harvest 5 November</td>
<td>1.02</td>
<td>14.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Total (JUN)</td>
<td>2.53</td>
<td>42.3</td>
<td>7.8</td>
</tr>
<tr>
<td>1st harvest 15 July</td>
<td>2.24</td>
<td>32.2</td>
<td>8.2</td>
</tr>
<tr>
<td>2nd harvest 5 November</td>
<td>0.79</td>
<td>12.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Total (JUL)</td>
<td>3.03</td>
<td>44.2</td>
<td>9.9</td>
</tr>
<tr>
<td>Only harvest 5 November (NOV)</td>
<td>2.52</td>
<td>22.7</td>
<td>5.4</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Results demonstrated that h-SSF CW could help to solve the problem of disposing of cheese production wastewater in a cost-effective way. As a matter of fact CW constitute a suitable strategy to reduce pollutants’ concentration in compliance with Italian water quality standards.

The chemical and physical features of the target wastewater determine the size of the constructed wetland. This study has prove that these features should be maintained as constant as possible to optimise the quality of the output effluent from the wetland. In order to achieve a constant flow of influent into the CW system, for wastewater from cheese production a simple storage tank can be utilised as a “pre-treatment” to smooth the pulsed flow from the factory and to prevent brine and whey inputs to CW.

No significant drawback has been encountered during the operation of the wetland plants. The system maintenance has been easily brought about by the cheese factory’s staff members themselves, with no additional load to their work schedule. The main activity has always been the plants reaping at the end of winter time, and the disposal of the plant cuttings. Many authors have suggested that the harvested epigeal biomass can be utilised for bioenergy production (Ciria et al., 2005; Suda et al., 2009; Meerburg et al., 2010).

When the monitoring period ended, the systems’ performance levels were highly satisfactory; there weren’t any signs pointing to a decreasing of functionality. There still is to be verified if the performances of the wetland will proceed at such encouraging rates. In any case, in the last few years some new plants have been built treating wastewaters from livestock and cheese productions in Northern Italy.
Results on vegetation show that different cutting regimes applied to *Typha latifolia* lead to changes in the amounts of nutrients removed and in the biomass production over a period of eight months. The maximum rate of N and P removal detected during the experiment represents about 10% of the total nutrients flowing into the CW each year. The high amount of dry matter produced by growing cattail in the CW (up to 30 DM t/ha year) bears potentialities of exploitation as biomass fuel.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


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