# Chapter 10
# Dairy Wastewater Treatment by a Horizontal Subsurface Flow Constructed Wetland in Southern Italy

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**Abstract** Evidence on the efficiency of horizontal flow constructed wetlands (HF CWs) in treating dairy wastewater in the Mediterranean region is reported, showing results from the 3 year long monitoring of a HF CW treatment plant situated in southern Italy. The HF CW treats a mixture of different wastewaters produced by a dairy farm (dairy, milking, milk cooling, restaurant, and house). Samples of wastewater quality (pH, COD, and N-$NH_4^+$) were collected at the inlet and outlet of HF CWs from February 2012 to May 2015. The effluent COD concentrations from dairy activities alone were also collected during the same period, showing the most relevant contribution of dairy wastewater in terms of organic loads. The start-up phase was influenced by the influent pH being too low, which was fixed by adopting a serum separation. The system showed some stress during a management phase lasting 2 months, requiring then 1 month of recovery period. The overall treatment performance is now very satisfactory, with 94.3 % COD removal efficiency based on average influent and effluent values, while a slight increase in effluent N-$NH_4^+$ was registered, probably due to organic matter ammonification.

**Keywords** Dairy wastewater treatment • Horizontal subsurface flow constructed wetland • Mediterranean climate

## 10.1 Introduction

Dairy wastewater is usually produced by the cleaning and sterilization of the milking equipment and by the wash-down of the manure-spattered walls and floors of the milking parlor (Kadlec and Wallace 2009). These activities lead to a dairy

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wastewater characterized by high organic matter concentrations and a wide range of pH as reviewed by Vymazal (2014). The organics present in the wastewater are mainly carbohydrates, proteins and fats originating from the milk. A wide range of pH (between 3.5 and 11) is encountered in the literature, due to use of both alkaline and acidic cleaners and sanitizers. The seasonality of typical dairy activities and the different products produced (milk, butter, yoghurt, ice cream, and cheese) lead to a wide range of dairy wastewater quality in the literature ($BOD_5$ 1400–50,000 mg $L^{-1}$; COD 2000–90,000 mg $L^{-1}$; N-$NH_4^+$ 20–150 mg $L^{-1}$).

Treatment of dairy wastewater through conventional biological treatment technologies (e.g., activated sludge) is problematic for a number of reasons: (i) the high variability in both hydraulic and organic loads of dairy wastewater can be difficult to manage, since more temporally constant influent loads are needed to ensure appropriate performance; (ii) the high organic loads lead to high sludge production, increasing the management costs; and (iii) the need for specialized operation and management staff is a burdensome extra cost, especially for small- and medium-sized dairies. Hence, more flexible constructed wetland (CW) treatment technologies have been widely adopted to treat dairy wastewater (Kadlec and Wallace 2009; Vymazal 2014). Among the different CW configurations, horizontal subsurface flow (HF CW) has been one of the most widely used solutions for treatment of dairy wastewater, showing satisfactory removal efficiencies of 50–98 % for $BOD_5$ and 40–96 % for TSS (Vymazal 2009, 2014). However, a recent literature review (Vymazal 2014) found a lack of evidence of HF CW capability to treat dairy wastewater in the Mediterranean region. For this reason, a 3-year case study of HF CWs used to treat wastewater from a dairy farm in southern Italy is reported here as a representative case study of HF CW performance in the Mediterranean climate.

## 10.2 Material and Methods

The experimental case study is located at Fattoria della Piana, Candidoni (Italy – 38°N, 15°E), a farm situated in the South of Italy. The farm promotes an eco-sustainable approach, recovering the end-products from the dairy (serum) and stable (manure) to produce biogas, and treating wastewaters with CWs.

Fattoria della Piana wastewater comes from a number of sources: houses and a restaurant (maximum 12 residents and 100 restaurant users); the milk cooling plant (average 20 $m^3d^{-1}$); the dairy (20 tons per day of processed milk, which produces 20 $m^3d^{-1}$ of wastewater); and milking (200 livestock, which produce 20 $m^3d^{-1}$ of wastewater). On average, the daily wastewater quantity is 85 $m^3d^{-1}$.

A CW treatment plant has been built to treat this wastewater. According to Italian law, the Fattoria della Piana wastewater can be classified as domestic, and therefore quality limits are only imposed for COD, TSS, and pathogens concentrations. The scheme of the wastewater treatment plant is reported in Fig. 10.1: an equalization

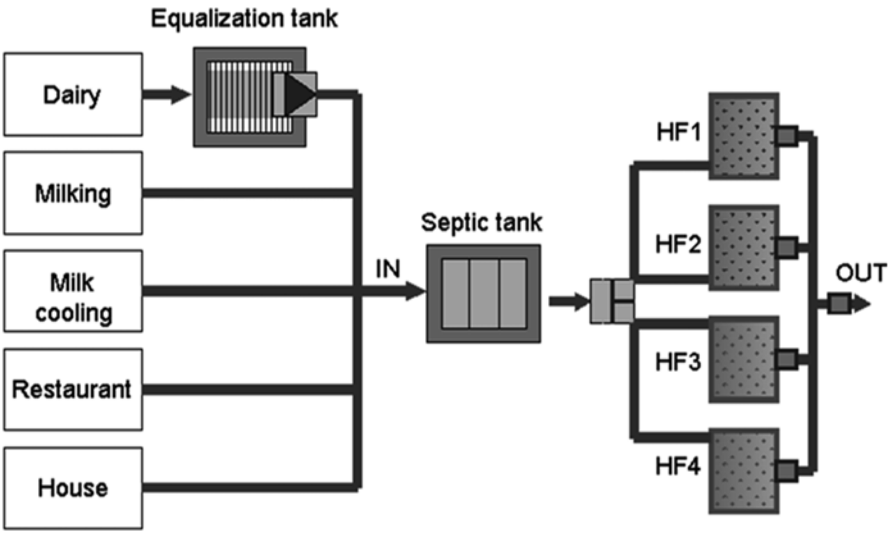


**Fig. 10.1** Scheme of CW wastewater treatment plant

tank is installed for the dairy wastewater; primary treatment for wastewater from all the different sources is performed by a three-chamber septic tank; four horizontal flow constructed wetlands (HF CWs) are installed in parallel as secondary treatment, with a total surface area of 2280 $m^2$ (theoretical hydraulic retention time – HRT – 5.3 days; gravel Ø 8 mm, depth 0.8 m, 15 m W / 38 m L for each of the four HF beds). Each HF CW is also subdivided in 2 hydraulically separated sectors to facilitate management operations, therefore the CW treatment plant is composed of 8 separated sectors. The treated effluent is discharged into a small stream. The treatment plant started operation in February 2012. Since the pH of influent wastewater was too low in the first operational period, the serum from dairy activities (highly acidic) has been separated and sent to an anaerobic digester for biogas production since the middle of May 2012. Management activities were performed between December 2014 and January 2015, during which only 7 of 8 sectors were operational and the water table within the beds was reduced.

Samples of wastewater quality (pH, COD, and N-$NH_4^+$) were collected at the inlet and outlet of the HF CWs from February 29, 2012 to May 11, 2015. Effluent COD concentrations from the dairy equalization tank were also collected during the same period. The wastewater quality dataset is analyzed here to investigate the functioning and efficiency of the HF CW treatment plant for dairy wastewater mixed with other pollutant sources (e.g., milking, domestic). Moreover, we describe in detail the atypical functioning phases of start-up and management, to understand the HF CW response during these critical phases.

## 10.3 Results and Discussion

### 10.3.1 Role of Dairy Wastewater on the Mixed Wastewater Composition

The samples collected at the effluent of the equalization tank can be considered representative of the dairy wastewater composition, while those collected at the influent of the HF CW are representative of the mixed wastewater. The dairy almost always has higher COD concentrations than the mixed wastewater (Fig. 10.2). The average COD concentration in dairy wastewater during the study period was 4079 mg $L^{-1}$ (Table 10.1), which is within the range reported by Vymazal (2014; 2000–90,000 mg $L^{-1}$) and twice the average influent concentration of the mixed wastewater. No relevant changes in pH were observed (Table 10.1). Since only three values of $N\text{-}NH_4^+$ concentration from the equalization tank effluent have been measured, the same analysis has not been done for $N\text{-}NH_4^+$.

The mixing of dairy wastewater with other, less concentrated pollution sources (wastewater from milking, milk cooling, the restaurant, and houses in this specific case) has beneficial effects and should be always performed when possible in farm wastewater treatment. Mixing dairy wastewater with less concentrated wastewater reduces the organic matter concentration in the HF CW influent, limiting the risk of clogging and thus increasing the lifespan of the treatment plant. Furthermore, the domestic blackwater provides nutrients that are often lacking in agricultural effluents.

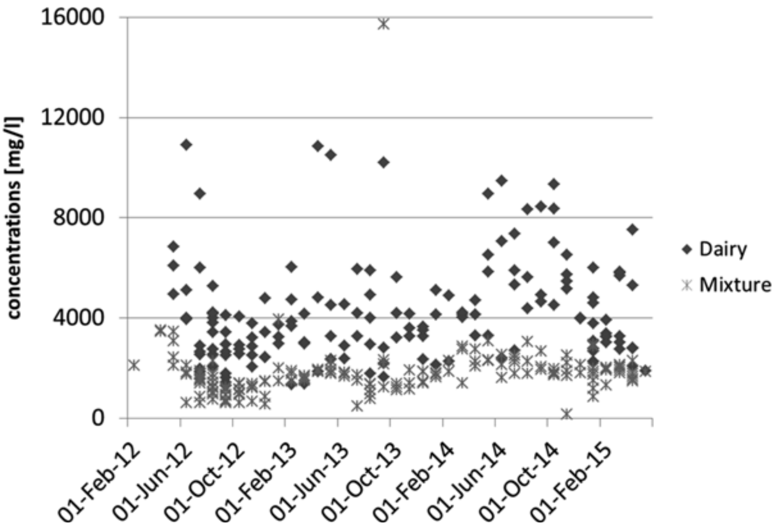


**Fig. 10.2** COD concentrations in effluent from the equalization tank (representative of the dairy wastewater – *diamonds*) and inflow of the HF CW (representative of the mixed wastewater – *stars*) at Fattoria della Piana (Candidoni, Italy) from February 2012 to May 2015

**Table 10.1** Descriptive statistics of pH values and COD concentrations in the effluent from the equalization tank (representative of the dairy wastewater) and in the inflow of the HF CW (representative of the mixed wastewater)

| | pH | | COD (mg L$^{-1}$) | |
|---|---|---|---|---|
| | Dairy | Mixture | Dairy | Mixture |
| Mean | 5.8 | 5.9 | 4079 | 1766 |
| St. dev. | 0.7 | 0.4 | 1982 | 1281 |
| Min | 2.5 | 5.1 | 1284 | 140 |
| Max | 10.0 | 6.8 | 10,843 | 15,730 |
| # of samples | 153 | 154 | 147 | 152 |

Data collected after the starting period, from July 2012 to May 2015

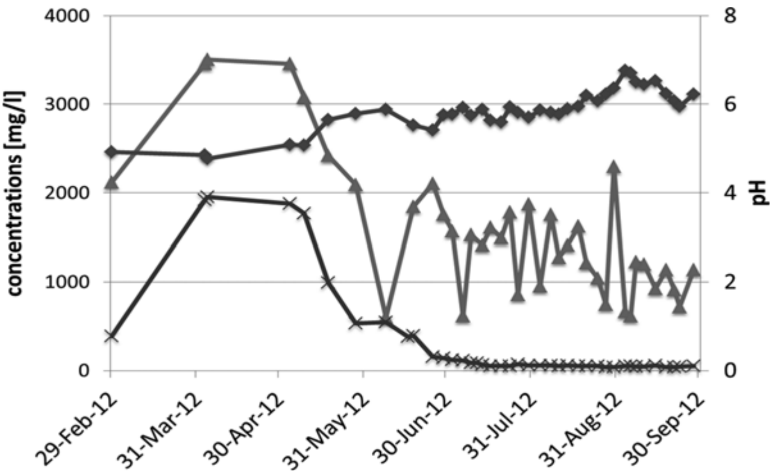


**Fig. 10.3** Correlation between influent (*triangles*) and effluent (*crosses*) COD concentrations from the HF CW and influent pH (*diamonds*) in the starting period (from February to September, 2012)

## *10.3.2 Start-Up Phase*

The first operational period failed in COD removal due to low influent pH (average value of 4.9 from March 2012 to the middle of May 2012). In order to deal with this issue the serum (highly acidic) has been separated at the source and sent to an anaerobic digester for biogas production since the middle of May 2012. This approach promoted an increase in influent pH (around 6), which produced a more suitable environment for the bacterial communities and, consequently, a higher HF CW removal efficiency. This is confirmed by Fig. 10.3, where the improvement in COD treatment performance is clearly correlated with the increased influent pH prompted by serum separation.

Data reported in the literature show a wide range of pH values for dairy wastewater (Vymazal 2014), which can be highly acidic or highly basic (reported pH values ranging from as low as 3.5 to as high as 11). For this reason, a preliminary design to optimize pH is not possible without first analyzing the wastewater to be treated. Hence, it is important to consider some possible ways of managing pH during the design phase (in this case, the possibility of separating the serum) and carefully analyze treatment performance during the start-up phase.

### 10.3.3 Management Phase

After two and a half years of proper functioning, some management activities were performed at the end of 2014, for an early appearance of clogging signals in 1 of the 8 sectors of the CW system, mainly due to some overloads events that took place in the former period. The management, which was done between December 2014 and January 2015, required a limitation on the number of hydraulically separated sectors to treat the wastewater (7 instead of 8, which increased the hydraulic loading rate for each of the remaining 7) and lowering the water table within the beds (reducing the hydraulic retention time). As visible in Fig. 10.4, during the management phase the system showed some stress, maintaining good removal efficiencies but exceeding the limit of 160 mg $L^{-1}$ (Fig. 10.4). After all 8 hydraulically separated sectors and the correct water level were re-established (in February 2015), the HF CW needed a recovery period of almost 1 month to re-establish the removal efficiencies obtained before the management phase.

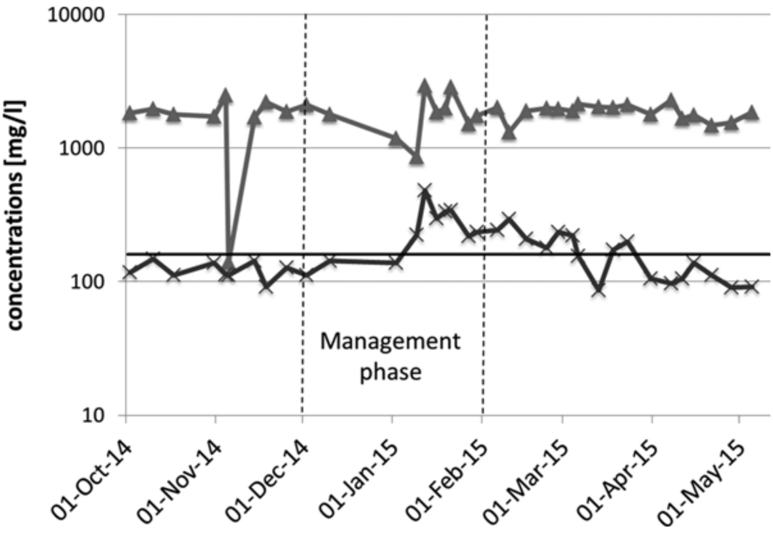


**Fig. 10.4** Influent (*triangles*) and effluent (*crosses*) COD concentration from the HF CW treatment plant at Fattoria della Piana (Candidoni, Italy) before, during, and after the management phase, which lasted from December 2014 to January 2015. *Black continuous line* indicates the Italian limit for discharge into surface water. Vertical axis is in logarithmic scale

These results suggest that HF CWs are able to recover the treatment performance after a management phase in a relevantly short time period and the frequency of such maintenance operations is very low.

### 10.3.4 Overall Treatment Performance

Influent and effluent COD concentrations from the HF CWs for the analyzed period (from February 2012 to May 2015) are shown in Fig. 10.5, highlighting very good performances in COD treatment. Aside from the start-up and management phases, the effluent COD concentration was almost always below the Italian limit of 160 mg $L^{-1}$ for discharge of wastewater in fresh water bodies, except in a few cases.

Table 10.2 summarizes the influent and effluent pH, N-$NH_4^+$, and COD from the HF CWs, using only data after the start-up phase, but including the management phase (i.e., from July 2012 to May 2015). pH was quite stable (low standard deviation) both at the influent and the outlet, with values within the range for optimal bacterial activity (approximately 6–9 – Kadlec and Wallace 2009). COD removal efficiency was very high, with a relatively stable, low effluent concentration (Fig. 10.6). Average COD removal efficiency was 94.3 % based on all 156 samples (Table 10.2), and 93.1 ± 4.9 % (69–97.8 %) when considering only the samples corresponding to a HRT of 4–6 days (52 samples). A slight increase in average N-$NH_4^+$ effluent concentration was observed (Fig. 10.6); this is probably due to ammonifica-

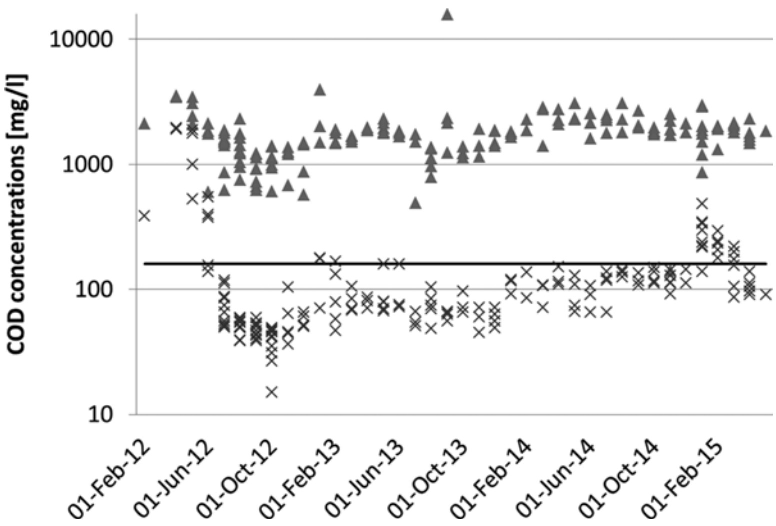


**Fig. 10.5** Influent (*triangles*) and effluent (*crosses*) COD concentration from the HF CW treatment plant at Fattoria della Piana (Candidoni, Italy) from February 2012 to May 2015. *Black continuous line* indicates the Italian limit for discharge into surface water. Vertical axis is in logarithmic scale

**Table 10.2** Descriptive statistics of pH, N-$NH_4^+$, and COD concentrations at the inflow and outflow of the HF CW. Data collected after the starting period, from July 2012 to November 2014

| | pH | | N-$NH_4^+$ (mg $L^{-1}$) | | COD (mg $L^{-1}$) | |
|---|---|---|---|---|---|---|
| | In | Out | Out | In | In | Out |
| Mean | 5.8 | 6.7 | 40.0 | 49.4 | 1766 | 100 |
| St. dev. | 0.4 | 0.2 | 13.2 | 11.7 | 1281 | 67 |
| Min | 5.1 | 6.2 | 3.0 | 25.1 | 140 | 15 |
| Max | 6.8 | 7.3 | 77.6 | 74.9 | 15,730 | 484 |
| # of samples | 154 | 155 | 125 | 131 | 152 | 156 |

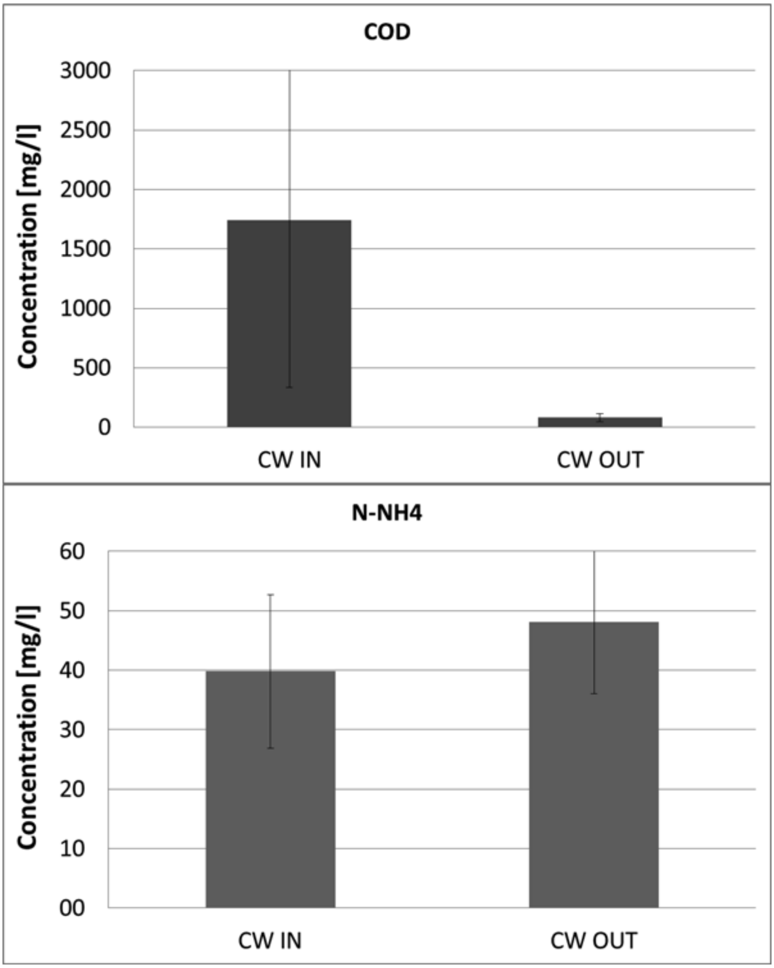


**Fig. 10.6** Average and standard deviation of COD and N-$NH_4^+$ concentrations at HF CW inflow and outflow

tion of the high organic nitrogen content within influent loads (Kadlec and Wallace 2009), determined by high concentrations of proteins in the dairy wastewater (Vymazal 2014). These results suggest that a second, aerobic stage to promote nitrification (e.g., vertical flow constructed wetland – VF CW – Kadlec and Wallace 2009) should be included in cases where there are limits on effluent nitrogen concentrations. A future analysis of influent and effluent total Kjeldhal nitrogen (TKN) is planned to confirm this hypothesis.

## 10.4 Conclusions

The organic load of dairy wastewater from Fattoria della Piana, Candidoni (Italy – 38°N, 15°E), has been successfully reduced by the HF CW treatment plant from 2012 to 2015. The wastewater effluent from the HF CW met the current Italian water quality limits except during the start-up phase and a particular management phase. This study demonstrates the validity of CW technology in treating wastewaters produced by dairies in Mediterranean regions and provides useful insights on how to deal with start-up and management phases for this particular application of the HF CW treatment plant.

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## References

Kadlec, R., & Wallace, S. (2009). *Treatment wetlands*, (2nd ed.) Boca Raton: CRC Press.

Vymazal, J. (2009).The use constructed wetlands with horizontal sub-surface flow for various types of wastewater. *Ecological Engineering*, 35, 1–17.

Vymazal, J. (2014). Constructed wetlands for treatment of industrial wastewaters: A review. *Ecological Engineering*, 73, 724–751.