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Short communication

Nitrogen transformation in horizontal and vertical flow constructed wetlands applied for dairy cattle wastewater treatment in southern Brazil

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ABSTRACT

The aim of this study was to evaluate the nitrogen transformations in horizontal and vertical flow constructed wetlands (HFCW and VFCW), working in parallel and applied for dairy cattle wastewater treatment. Both HFCW (26.50 m^2 of surface area) and VFCW (14.30 m^2 of surface area) were filled up with sand (d_{10} of 0.3 mm and uniformity coefficient of 2.50) as bed media and planted with *Typha domingensis* Pers. HFCW and VFCW worked with an influent flow rate of 3.98 m^3 $week^{-1}$ and 4.50 m^3 $week^{-1}$, respectively. Applying an average loading rate of 151.4 gCOD m^{-2} $week^{-1}$, 10.3 gTKN m^{-2} $week^{-1}$ and 8.2 gNH_4^+-N m^{-2} $week^{-1}$ in HFCW, it was possible to achieve 59% of TN and 58% of NH_4^+-N removals. In VFCW an average loading rate of 317.2 gCOD m^{-2} $week^{-1}$, 21.6 gTKN m^{-2} $week^{1}$ and 13.7 gNH_4^+-N m^{-2} $week^{-1}$ were applied and was obtained 23% of TN and 80% NH_4^+-N removals, where 73% of ammonia removal was due to nitrification process. The macrophytes removed 5.1% and 0.88% of influent N loading rate in HFCW and VFCW, respectively.

1. Introduction

In constructed wetlands, transformations of nitrogen occur in diverse metabolic pathways. According to Saeed and Sun (2012), traditional forms of nitrogen transformation and removal are associated with ammonification, nitrification, denitrification, volatilization, uptake by macrophytes, adsorption by the filtration media, and uptake by microbial biomass.

The various performance levels of constructed wetlands in terms of nitrogen removal is associated with the following conditions: (i) low availability of dissolved oxygen in the medium, thus preventing nitrification due to high concentrations of organic compounds (Platzer, 1999); and (ii) lack of organic carbon available for the denitrification process (Zhai et al., 2013).

Since, the magnitude of nitrogen transformations in constructed wetlands is complex and largely associated with environmental and operational factors, such as influent hydraulic and organic loadings, characteristics of hydraulic flows, time of hydraulic retention and use of macrophytes, there is a need for more in-depth studies to understand the importance of each of the possible nitrogen metabolic pathways in these systems. Given the above, this study aimed to assess the transformations of nitrogen forms in horizontal flow constructed wetlands (HFCW) and vertical flow constructed wetlands (VFCW) being operated simultaneously with the system of dairy wastewater treatment under southern Brazil climate conditions.

2. Material and methods

The wetland systems were implemented in dairy facilities in the city of Frederico Westphalen, southern Brazil (latitude 27°21′33" south and longitude 53°23′40" west, altitude 566 m), producing on average 140 L of milk per day. All wastewater produced in the milking parlor flowed down by gravity into a storage pond (SP) which served as primary treatment. After going through this unit the wastewater flowed into an equalizer tank, from which a fraction was then transported by gravity into the HFCW, and the other portion pumped into the VFCW. The wetlands operated in parallel for the purposes of comparison of performance of both systems. Fig. 1 presents the layout of the studied treatment plant.

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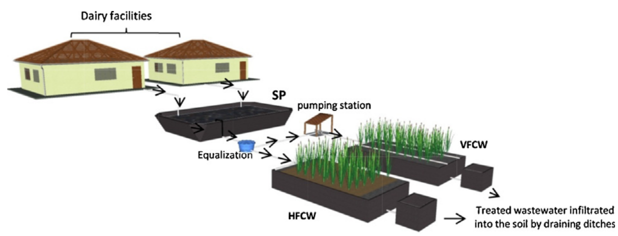

Fig. 1. Schematic layout of the treatment plant.

The HFCW (6.70 × 3.95 × 0.80 m; length x width x usable depth, and a total surface area of 26.50 m^2) operated with an average flow of 3980 L $week^{-1}$, being fed by gravity four times a week, with a daily flow of 995 L during four hours per day at an average hydraulic rate of 37.55 mm d^{-1}. The VFCW (4.40 × 3.25 × 0.80 m; length x width x usable depth, and a total surface area of 14.30 m^2) was fed intermittently assisted by a pumping system, with an average flow of 4500 L $week^{-1}$, which was distributed in 4 pulses of 375 L d^{-1}, 3 days a week, at an average hydraulic rate of 105 mm d^{-1}.

Both HFCW and VFCW were filled up with sand (d_{10} of 0.3 mm and uniformity coefficient of 2.50) as bed media and planted with *Typha domingensis* Pers.

To quantify nitrogen transformations and removals in the wetlands, the contents of nitrogen in the macrophytes' foliar tissue were analyzed as well as the concentrations of the forms of nitrogen in the influent and effluent of each unit.

The quantification of nitrogen concentrations incorporated to the plant tissue of macrophyte *Typha domingensis* Pers. was achieved by pruning the macrophytes to a height of 30 cm above the filter bed and by monitoring the plants growth. The analysis of N concentrations in the foliar tissue was performed as recommended by Tedesco et al. (1995) in different stages of the macrophytes growth.

The wetlands influents and effluents were monitored over one year (November/2011–October/2012) totaling 35 samples (weekly frequency) in three sampling sites, namely, after the equalizer tank, after the HFCW and after the VFCW. Evaluated parameters were pH, Alkalinity, Total Kjeldhal Nitrogen (TKN), Chemical Oxygen Demand (COD), Ammonium Nitrogen (NH_4^+-N) and Nitrate Nitrogen (NO_3^-N), as recommended by Standard Methods (APHA, 2005), except for ammonium nitrogen, which was evaluated according to Vogel (1981). To determine possible differences in the performances of both treatments (HFCW and VFCW), the analysis of variance–ANOVA was applied using software Microsoft™ Excel.

3. Results and discussion

Table 1 describes the means and standard deviation (SD) measured in the wetlands influent (after the equalizer tank) and effluent, as well the average organic and inorganic loadings applied to the HFCW and VFCW.

3.1. Nitrogen removal and transformation in the HFCW

For an average loading of 8.2 gNH_4^+-N m^{-2} $week^{-1}$(Table 1), an average removal of 58% of ammonium nitrogen was achieved. Since nitrification was not apparent in this unit and that ammonia volatilization can be disregarded once the influent pH was close to neutral, it may be inferred that the removal of ammonium nitrogen was basically associated with the following mechanisms: (i) uptake by macrophytes; (ii) uptake by the bacterial biomass; (iii) adsorption to the filter medium.

There was a variation in the ammonium nitrogen removal in the HFCW over the monitoring period (Fig. 2). The highest removal rate occurred when the HFCW operated with the largest loading of ammonium nitrogen (21.6 gNH_4^+-N m^{-2} $week^{-1}$), which coincided with the period following pruning, attaining mean removal efficiencies as high as 74%, compared to 32% of removal before pruning. It should be noted that from the 20th sampling, corresponding to the winter period, there was a decrease of the influent concentration of ammonium nitrogen. During this period, the mean loading dropped to 7.8 gNH_4^+-N m^{-2}, and a mean removal of 85% was achieved. Vymazal (2007) reports that macrophytes can perform a considerable removal of nitrogen when pruning is made regularly.

The mean nitrogen levels in the foliar tissue of macrophyte *Typha domingensis* Pers. were 25.6 g kg^{-1}, considering a growth period of 150 days. Taking into account a total of 850 plants in the HFCW (density of 50 plants m^{-2} of planted filter) and that *Typha domingensis* Pers. incorporates 7.35 g of dry matter per growth meters, removals of nitrogen corresponded to 0.3 kg N of 6 kg N applied, that represents 1.07 g m^{-2} $week^{-1}$. Therefore, the macrophytes are responsible by 5.1% removal of the total nitrogen loading applied to the HFCW.

Low concentrations of nitrate formed may be related to low concentrations of oxygen available in the HFCW, since it was operated in such a way that the filtration medium and the rhizosphere remained saturated with the wastewater undergoing

Table 1
Average values of HFCW and VFCW characteristics and ANOVA statistics.

Parameters	Applied loading rate		Influent	HFCW effluent	VFCW effluent	p-value (HFCW–VFCW)**
	HFCW	VFCW				
T (°C)			18 ± 4	20 ± 4	20 ± 4	
pH			7.2 ± 0.4	6.4 ± 0.2	6.9 ± 0.2	
Alkalinity (mg$CaCO_3$ L^{-1})			670 ± 3	455 ± 300	290 ± 139	
COD (mg L^{-1})*			1,009 ± 298	262 ± 84	323 ± 101	
COD (g m^{-2} $week^{-1}$)	151.4	317.2				
TKN (mg L^{-1})*			69 ± 30	28 ± 15	20 ± 10	0.03201
TKN (g m^{-2} $week^{-1}$)	10.3	21.6				
NH_4^+-N (mg L^{-1})			55 ± 27	23 ± 21	11 ± 10	0.00516
NH_4^+-N (g m^{-2} $week^{-1}$)	8.2	17.3				
NO_3^- -N (mg L^{-1})			5 ± 4	3 ± 1	37 ± 14	2.40×10^{-22}

* 23 Samples.
** Statistical result between concentrations in mg L^{-1} for the constructed wetlands: 5% significance level ($\alpha = 0.05$); p = significance level ($p > \alpha$ accepts H_0; $p < \alpha$ rejects H_0). H_0 = Null hypothesis: there is no difference between the arithmetical means of the groups; H_1 = Alternative hypothesis: there is difference between the arithmetical means of the groups samples.