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# Temperature influence on nitrogen removal in a hybrid constructed wetland system in Northern Italy

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ABSTRACT

The objective of this research was to investigate the efficiency and seasonal performance of a full-scale hybrid constructed wetland system (HCW) in reducing total nitrogen (TN), ammonia nitrogen ($NH_4$-N) and nitrate nitrogen ($NO_3$-N). HCW with a total area of about 130 $m^2$ and hydraulic load of 2 $m^3$/day was composed of three subsurface flow vertical systems (VF), working in parallel and one horizontal (HF) connected in series. The system was loaded daily with synthetic wastewater having an average concentration of TN of 250 mg/L (about 125 mg/L of $NH_4$-N and 125 mg/L of $NO_3$-N). Water samples were collected and analyzed from May to July 2011 and from January 2012 to July 2012. Variations were observed in nutrient removal performance related to temperature.

During the whole monitoring period median reduction efficiency (RE) in the HCW was TN 95%, $NH_4$-N 95% and $NO_3$-N 93%, although three sub-periods characterized by different performances have been observed. During the first period (from May to July 2011) the RE was positive for the three nitrogen forms considered, whereas from January to the end of March 2012 the RE was lower, particularly for TN and $NO_3$-N. From April 2012, when the temperature rose above 14.8 °C, there was an increase in the performance that reached the 2011 values.

Internal production of $NO_3$-N was observed, mainly in the VF systems between January and March 2012. The median removals of mass pollutants per $m^2$ of HCW per day were TN 3.1 g/$m^2$/d, $NH_4$-N 1.5 g/$m^2$/d, $NO_3$-N 1.5 g/$m^2$/d. Segmented regression analysis identified a breakpoint at 14.2 °C for wastewater temperature that caused variations in TN and $NO_3$-N concentration reduction performances. According to this approach the abatement was always positively correlated with temperature, but different regression slopes were obtained below and above the breakpoint. In particular, with lower temperature the abatement of $NO_3$-N and TN increased by 1.7 and 2.0% per °C of temperature increase; with temperature higher than 14.2 °C the increase in abatement due to increased temperature was sharper, especially for $NO_3$-N.



## 1. Introduction

Wetland technology emerged in the 1950s and the use of controlled wetland environments for wastewater treatment has since been developed. The major nitrogen removal mechanism is achieved by biological processes that convert the organic and ammonia nitrogen to nitrate in an aerobic environment (nitrification) and then reduce the nitrate to nitrogen gas in an anoxic environment (denitrification) (Leverenz et al., 2010). Volatilization, absorption and plant uptake play a much less important role in CWs (Kadlec and Wallace, 2009). The use of vertical-subsurface flow constructed wetland (VF) systems became very popular in Europe in the 1990s compared to the horizontal system (HF) due to their enhanced ability to oxidize ammonia nitrogen (Stefanakis and Tsihrintzis, 2012). Single-stage CWs cannot achieve high removal of total nitrogen because of their inability to provide both aerobic and anaerobic conditions at the same time.

The design of hybrid constructed wetland systems (HCW) (combination of vertical and horizontal flow systems) has been proposed to exploit the anoxic areas within the horizontal bed for denitrification (Cooper et al., 1999; Kadlec and Wallace, 2009; Molle et al., 2008). HCW systems have been used to treat domestic or municipal sewage (Brix et al., 2003; Canga et al., 2011), and more recently for many other types of wastewater including

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agro-industrial (Comino et al., 2011), agricultural (Borin et al., 2013; Hunt and Poach, 2001; Kantawanichkul et al., 2003) and landfill leachate (Mæhlum et al., 1999).

As reported in several previous studies (Akratos and Tsihrintzis, 2007; Kadlec and Wallace, 2009; Kotti et al., 2010; Kuschk et al., 2003; Vymazal, 1999) temperature is one of the principal variables that mainly influences biological activity and so the seasonal performances of constructed wetlands. Hill and Payton (1998) reported that the efficiency of treatment in a constructed wetland decreases at low temperature primarily due to reduced biotic activity. Kadlec and Reddy (2001) studied the temperature dependence in surface flow wetlands on removal of contaminants. They concluded that the performance of wetlands in treating wastewater is seasonally cyclic and the biotic reactions are reduced at temperatures lower than the optimal range (20 to 35 °C). Kadlec (2006) pointed out three reasons for the importance of water temperature in treatment wetlands: (1) temperature modifies the rates of several key biological processes, (2) temperature is sometimes a regulated water quality parameter, and (3) water temperature is a prime determinant of evaporative water loss processes. Several biogeochemical processes that regulate the removal of nutrients in wetlands are affected by temperature, thus influencing the overall treatment efficiency (Kadlec and Reddy, 2001).

The goals of this study are (1) to investigate the efficiency of a full-scale hybrid constructed wetland system (HCW) in reducing total nitrogen (TN), ammonia nitrogen ($NH_4$-N) and nitrate nitrogen ($NO_3$-N); (2) study the effects of temperature on nitrogen forms abatement; (3) confirm or identify a wastewater temperature breakpoint that causes variation in nutrient removal performances; (4) study the effects on vertical flow cells performance in relation to different vegetation, medium and operational mode.

## 2. Materials and methods

### 2.1. Hybrid constructed wetland configuration and characteristics

The HCW was located at a private pig farm in Carmignano di Brenta, Padova, in Veneto Region, NE Italy, (E: 11419.58; N: 453745.16; 46 m a.s.l).

It was built in 2008 and designed to provide tertiary treatment of 2 $m^3$/d of pre-treated liquid fraction of pig slurry effluent. The design guidelines provided by APAT were based on municipal wastewater treatment wetlands (APAT, 2005).

The HCW system is composed of three vertical-subsurface flow wetlands (VF1–VF2–VF3) in parallel with a total area of 21 $m^2$, followed by one horizontal-subsurface flow wetland (HF) connected in series (105 $m^2$) (Fig. 1).

The entire system was designed for a hydraulic retention time (HRT) of 7 days as minimum. Each VF unit was built in concrete (length: 10 m; width: 1 m; depth: 0.7 m). Three different plastic sheet liners were placed inside each cell to prevent leakage and contact of wastewater with groundwater. The layers from bottom to top were: nonwoven geotextile sheet with a basic weight of 400–800 g/$m^2$ and thickness 1 mm; interlayer EPDM geo-membrane; nonwoven geotextile sheet with a basic weight of 400–800 g/$m^2$ and thickness 1 mm. The first two cells were filled with washed gravel: grain size 10–20 mm ($d_{10}$ = 8.5 mm; $d_{60}$ = 9.7 mm) with porosity of 40%. The first one (VF1) was vegetated with *Canna indica* L., the second (VF2) with *Phragmites australis* (Cav.) Trin. Ex Steud (common reed). The third (VF3), planted as VF2 cell, was filled with a 0.10 m deep gravel layer (grain size 10–20 mm) overlying a 0.10 m deep coarse sand (grain size 3–5 mm) and zeolite (grain size 5–10 mm) transition layer and a 0.30 m deep gravel drainage layer (10–20 mm in size). The main components of the zeolite were: chabasite 60%, K-feldspar 13%, phillipsite 5%, mica 5% and augite 2%. The synthetic wastewater was distributed evenly over the surface of the VF beds by a pressurized PVC distribution pipe 75 mm in diameter that ran along the VF wetland units. Three filters with interchangeable cartridges were placed in series at the inlet of VF system. The filters were used to remove particles larger than 1 mm from the feeding tank effluent, and were installed to minimize the accumulation of solids in the influent distribution pipe. At the inlet of each VF wetland units a water meter with five digit mechanical counter was attached at the distribution pipe to measure the incoming wastewater quantity delivered to each cell. A drainage pipe (diameter 75 mm and length 10 m) was located on the bottom of each VF cell in order to facilitate effluent collection. The drainage pipe was connected on one side to a 100 mm diameter collection pipe that discharged the effluent from the bed to a manhole that had a water level control structure equipped with a siphon pipe where a timer-controlled pump was placed (Fig. 2).

The siphon maintained water level at 0.30 m from the surface in each VF cell. A 200 watt power submersible pump installed in the same manhole was used to drain the porous media and transport the leachate to separate sumps (OUT VF1, OUT VF2, OUT VF3). The wastewater discharged from each VF sump was collected in a

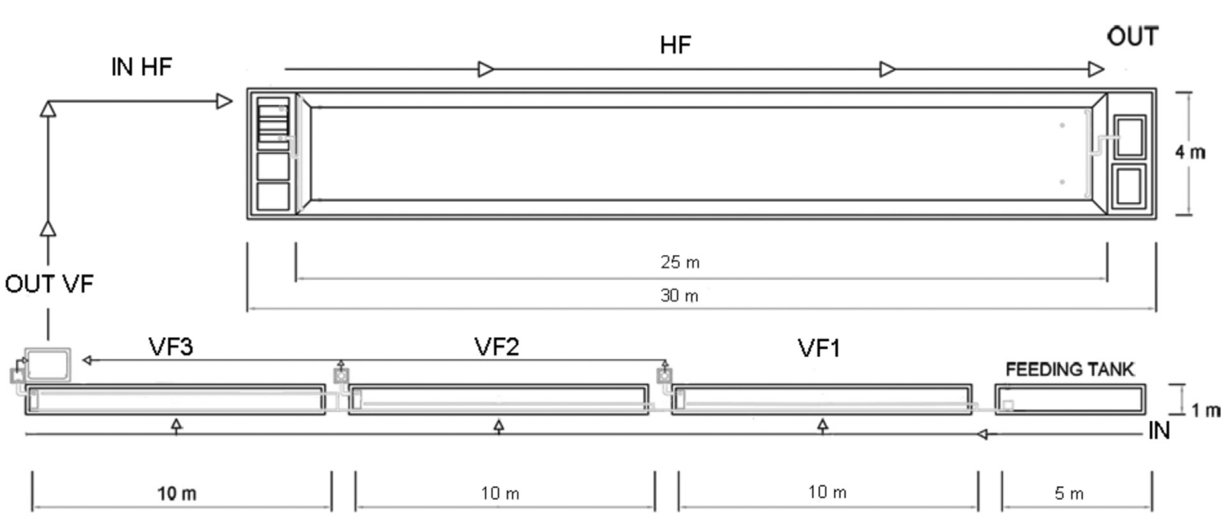


**Fig. 1.** HCW system dimensions in overhead view. Sampling points: (1) influent, (2) VF1 effluent, (3) VF2 effluent, (4) VF3 effluent, (5) influent to HF, (6) HF effluent (final effluent).