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# Newly-established free water-surface constructed wetland to treat agricultural waters in the low-lying Venetian plain: Performance on nitrogen and phosphorus removal

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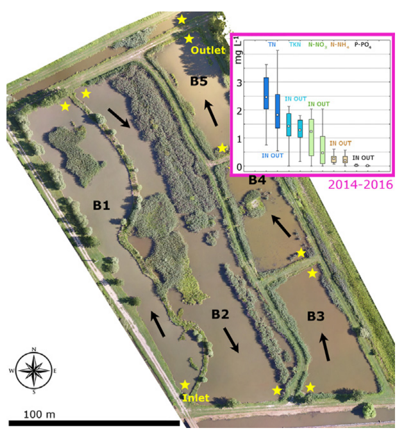
## HIGHLIGHTS

- Agricultural water treatment of FWS CW increased over the 3-year monitoring.
- Total nitrogen mass removal was up to 696 kg ha $y^{-1}$.
- The wetland/catchment ratio of 7% could potentially serve a total of 83 ha.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Constructed wetlands offer promising solutions for controlling nutrient pollution in agricultural systems with relatively low costs and energy inputs. In mainly central and northern Italy, semi-natural and reconstructed Free-Water Surface Constructed Wetlands (FWS CWs) are designed to treat nonpoint-source pollution from agricultural catchments. However, their performance depends on system design and time of establishment. This paper evaluates the efficiency of a recently established FWS CW to remove nonpoint-source nutrient pollution due to agricultural drainage in the low-lying Venetian plain (NE Italy). The system was established in 2014 by creating five consecutive sub-basins vegetated with macrophytes to restore a semi-natural wetland, and later monitored in terms of water quality parameters and nutrients removal over three consecutive agricultural seasons (2014–2016). Total (TN) and nitrate ($N\text{-}NO_3$) nitrogen concentrations showed peaks (16.37 and 15.31 mg $l^{-1}$ for TN and $N\text{-}NO_3$, respectively) in the various sub-basins during spring 2015, associated with fertilisation of surrounding croplands and intense rain events. Performance improved over the three years, with increasing median removals of TN (33.3–49.0%) and $N\text{-}NO_3$ (32.2–80.5%), corresponding to average mass of 1355 kg $y^{-1}$ and 1011 kg $y^{-1}$ for TN and $N\text{-}NO_3$. Concentrations of ammonium ($N\text{-}NH_4$) and orthophosphate ($P\text{-}PO_4$) were generally low (<1 and <0.3 mg $l^{-1}$ for $N\text{-}NH_4$ and $P\text{-}PO_4$, respectively), with average yearly mass removals of 50 kg for $N\text{-}NH_4$ and 9 kg for $P\text{-}PO_4$. According to the overall treatment performance, the FWS CW

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could treat a total area of about 30 ha with a wetland/catchment ratio of 7%. However, we expect that treatment efficiency will increase as a result of bank stabilisation and improvement of the aquatic environment, together with increases in surface vegetation.



## 1. Introduction

Nonpoint-source pollution due to intensive agricultural practices is of considerable concern worldwide, as it affects the functioning of aquatic ecosystems and the provision of safe drinking water (Blankenberg et al., 2015; O'Geen et al., 2010; Ockenden et al., 2014). In Europe, efforts have been made to reduce pressure on aquatic systems by means of the Water Framework Directive (EU, 2000). In addition, the need to improve the natural characteristics of river basins and to curb nitrogen pollution has recently been reported (Grizzetti et al., 2017).

Constructed wetlands (CWs) are naturally based systems, now increasingly used in agriculture because of their ability to act as filters between agricultural areas and bodies of water. Constructed wetlands regulate nutrient fluxes (Borin and Tocchetto, 2007; Mitsch et al., 2001, 2005; Tournebize et al., 2017), especially nitrates, which may represent about 90% of total nitrogen losses (Baker, 1998; Billy et al., 2013; O'Geen et al., 2010), pesticides (Pappalardo et al., 2016) and particulate (Schoumans et al., 2014) with minimal maintenance and energy costs (Davis, 1995; Lee et al., 2009). Of the various CW systems engineered until now, free water-surface constructed wetlands (FWS CW) are the most frequently used in agriculture, since they provide multiple benefits beyond water treatment, e.g., control of flood events and enhancement of biodiversity (Borin and Malagoli, 2015; Semeraro et al., 2015). In addition, compared with other types of CWs, FWS CWs are cost-effective in terms of maintenance and operation (Kadlec and Wallace, 2009; Mitsch et al., 2001; O'Geen et al., 2010; Vymazal, 2010). They are built in sealed basins or a sequence of several sub-basins, in shallow water generally <40 cm deep. Macrophytes, most commonly *Phragmites australis* (Cav.) Trin. ex Steud. and *Typha latifolia* L., play a pivotal role in enhancing filtering and sedimentation, increasing the surface area and sites for microorganism activity and regulating the water/atmosphere gas exchange, which in turn facilitates mineralisation and nitrification/denitrification processes.

Several studies have reported that FWS CWs in agricultural systems can successfully manage varying amounts of pollutants. Vymazal (2017) stated that median removals of nitrogen from agricultural land can range considerably (11–13,026 kg N $ha^{-1}$ $y^{-1}$) because of their dependence on input loads and wetland/catchment ratios (Land et al., 2016), and the primary aims for which they were established (biodiversity, pollution control, amenities, etc.). However, nitrogen water treatment of FWS CWs is often due to climatic- and time-dependent factors which may reduce average denitrification by about 60% (Vymazal, 2007). In particular, this fact was noticed in the short term, in situations in which significant fluctuations in FWS CW performance may occur due to rapid, heterogeneous development of vegetation and the presence of unconsolidated banks (Harter and Mitsch, 2003). Tournebize et al. (2017) highlighted the primary role of both retention and vegetation, which can only provide the organic carbon required by denitrifying microorganisms when it is well-established. Conversely, removal of total phosphorus, estimated close to 50% in FWS CWs, may be hindered in the long term due to saturation in sorption processes and biomass storage. Research on the evaluation of FWS CWs, taking into account local geographic and water quality characteristics, is still required to provide specific guidelines to agronomists and environmental consultants.

The general aim of this study was to evaluate the performance of a newly established 2.4-ha FWS CW, initiated in 2014 and now three years old, which was designed to mitigate nonpoint-source pollution due to nutrients from a low-lying territory under intensive agriculture. The specific aim focused on the evaluation of nitrogen and phosphorus reductions in the water flow and the estimation of their cumulative removal over consecutive years.

## 2. Materials and methods

### 2.1. Study area

The study site is located in the low-lying Venetian plain (NE Italy), in the basin discharging into the Lagoon of Venice. The area is characterised by a dense minor hydrographic network which is used to drain water from areas with shallow water table lying below mean sea level or, alternatively, to provide water for crops. The experiment was conducted in the 'Tenuta Civrana', a private farm, covering 365 ha, in the town of Cona (province of Venice), 45.166° N, 12.066° E. The climate is sub-humid, with mean annual rainfall of 850 mm, usually distributed throughout the year. The mean annual temperature is 14.1 °C, ranging from an average minimum of −1.5 °C in January to an average maximum of 27.2 °C in July. Weather data were collected from a station 4.2 km from the experimental site, belonging to the Environmental Protection Agency of the Veneto Region (ARPAV station at Cavarzere).

A FWS CW covering 2.4 ha was created in early 2014 by restoring a semi-natural wetland. The system is composed of five sub-basins (Fig. 1): B1 and B2 are trapezoidal in shape, have surface areas of 0.5 and 1.0 ha respectively, and a water depth of approximately 0.4–0.6 m. Sub-basins B3, B4 and B5 are shallower (0.3–0.4 m) and smaller surface areas (0.23, 0.2 and 0.2 ha, respectively). The hydraulic system is commonly managed so as to feed the sub-basins by gravity during spring-autumn; the basins remain almost dry in winter. Inlet water comes from a canal (the '*Canale di Cuori*', managed by the local land reclamation consortium) which collects water from the field drainage systems of the farm and surrounding territory. The system is maintained at a fairly constant hydraulic load with a hydraulic detention time of 8–10 days during flooding. Sub-basins B1–B5 are connected in series by means of subsurface pipes (Fig. 1). Secondary subsurface pipes (generally blocked) between sub-basins, which are not in series, were also installed to allow single basins to be isolated for purposes of maintenance.

Wetland vegetation was restored in 2014 with local macrophytes which naturally settle along riparian zones of wetlands, including *Phragmites australis* (Cav.) Trin. ex Steud., *Typha latifolia* L., *Carex* spp., *Juncus* spp., *Phalaris arundinacea* L., *Mentha aquatica* L. and *Iris pseudacorus* L. Four vegetated islands were created in B1 and B2 to slacken the water flow, thus enhancing sedimentation of suspended solids. In sub-basins B3, B4 and B5, *Carex* spp., *P. arundinacea*, *I. pseudacorus* and *M. aquatica* were also planted. During monitoring, this vegetation was still in the process of establishing itself. Sub-basin B2 was the most densely vegetated, especially with *P. australis*, which fully colonised the islands and banks.

### 2.2. Monitoring of water quality

Water quality was evaluated over three consecutive seasons, starting immediately after the establishment of the FSW CW (June 2014) and until June 2016, at six sampling points corresponding to the inlet and outlet of each sub-basin (Fig. 1). As only a subsurface pipe was interposed between sub-basins, it was assumed that the water quality of each sub-basin ('Out') corresponded to that of the inlet ('In')