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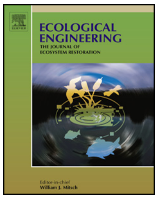

Biomass production and soil organic carbon accumulation in a free water surface constructed wetland treating agricultural wastewater in North Eastern Italy

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ABSTRACT

Free water surface constructed wetlands (FWSs) play an important role in wastewater pollutants removal and, at the same time, vegetated wetlands can act as carbon sinks.

In this study we measured biomass production and soil carbon content variations over five years in a FWS with fluctuating hydroperiod treating agricultural drainage water to evaluate its role in the carbon dioxide cycle.

During the study flooding occurred with a yearly average of 28 days. Annual dry matter production, from 2008 to 2011, ranged between 50 and 60 $\mathrm{Mg\,ha^{-1}}$. The highest C storage was concentrated in the belowground biomass. 83% of total belowground biomass was measured in the 0–20 cm soil layer. During the 2007–2012 period the organic carbon (OC) concentration in the 0–20 cm soil layer slightly increased from 12.3 to 13.1 $\mathrm{g\,kg^{-1}}$ and bulk density from 1.38 to 1.66 $\mathrm{Mg\,m^{-3}}$. In the 20–50 cm soil layer, monitored only in 2009 and 2012, OC concentration was lower and steady (8.8 $\mathrm{g\,kg^{-1}}$). The total soil C accumulation in the five years was 110.73 $\mathrm{Mg\,ha^{-1}}$ of equivalent $CO_{2(eq)}$. Given the positive C balance FWSs can be considered a CO_2 sink.

1. Introduction

Wetlands are complex ecosystems, characterized by waterlogged or standing water conditions during at least part of the year, found in all climatic zones ranging from the tropics to tundra and covering about 5% of the earth's land area (Adhikari et al., 2009). The anoxic wet conditions and high productivity of wetland ecosystems result in an optimum natural environment for sequestering and storing carbon (C) from the atmosphere (Bernal and Mitsch, 2012; Mitsch et al., 2013). Worldwide, these ecosystems have a total C stock amounting to about 20–25% of that in terrestrial soils, so play an important role in global C cycling (Zhang et al., 2008) associated with all aspects of the production and consumption of both carbon dioxide (CO_2) and methane (CH_4) (Brix et al., 2001). Therefore, due to their significant proportion of the terrestrial C pool (Trettin and Jurgensen, 2003; Lal, 2008), being perhaps the largest sinks of C among the soil ecosystems (Choi and Wang, 2004), wetlands are a key element to consider when managing and quantifying the earth's C pool (Bernal and Mitsch, 2008).

Free water surface constructed wetlands (FWSs), capable of removing many contaminants from polluted waters (Maine et al., 2007; O'Geen et al., 2010; Martín et al., 2013), are similar to many natural wetlands where plants are the most conspicuous feature and where the development of complex ecosystems also depends on water conditions during the year. In FWSs, as in natural wetlands, C accumulation is influenced by many factors such as hydrological regime, plant species, climatic conditions (Brix et al., 2001; Davidson and Janssens, 2006), temperature, soil moisture (Adhikari et al., 2009) and water nutrient content. Soil is one of the main elements affecting the processes in FWSs, since its chemical (e.g., organic carbon and total nitrogen) and physical (e.g., bulk density) properties may influence pollutant fate to varying degrees (Passoni et al., 2009). Nitrogen is often the most limiting nutrient in natural or constructed wetlands (Downing et al., 1999), and organic matter dynamics are tightly coupled to the biogeochemical cycle of nitrogen in wetland soils via the processes of decomposition, mineralization and plant uptake (Chen and Twilley, 1999).

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Wetlands are therefore constructed or restored for removing nutrients from surface water and at the same time vegetated wetlands can act as C sinks (de Klein and van der Werf, 2013).

The purpose of this study was to evaluate in a fifteen years old FWS treating agriculture drainage with fluctuating hydroperiod, the plant dry matter (DM) production and soil organic carbon (OC) variations during the last five years of monitoring; the FWS C balance is also discussed.

2. Materials and methods

2.1. Site description

The FWS study began in the summer of 1996 at the Experimental Farm of Padua University at Legnaro, North-East Italy (458 21′ N; 118 58′ E; 6 m a.s.l.) and is ongoing. The climate of the site is subhumid (Köppen climate classification), with a mean annual rainfall of about 850 mm fairly uniformly distributed throughout the year. The temperature increases from January (average minimum value: −1.5 °C) to July (average maximum: 27.2 °C). According to the FAO-UNESCO classification, the soil is a fulvi-calcaric Cambisol, with a loamy texture in the upper 80 cm; the percentage of silt gradually increases with depth, reaching 68–75% at 2–2.4 m. Throughout the study site, there is an upper layer of reduced permeability (saturated hydraulic conductivity around 10^{-5} cm s^{-1}) at 1.5–1.8 m, and an impervious layer (saturated hydraulic conductivity <10^{-6} cm s^{-1}) at about 3 m.

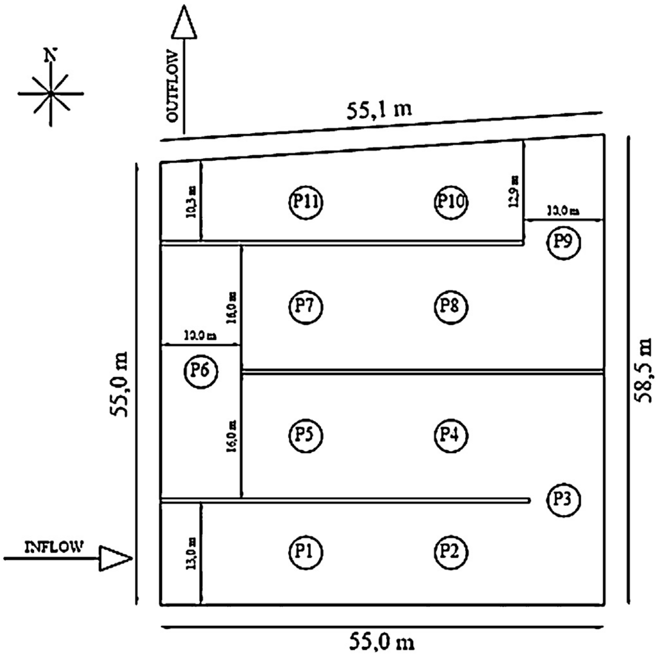
2.2. Wetland description and vegetation management

The FWS was excavated in 1996 as a single treatment cell for agricultural drainage water coming from 5.5 ha of cultivated land. The wetland is almost square in shape, with an area of about 3200 m^2. The bottom is at 0.4 m below the field surface, with a slope of 3‰ from inlet point to outlet as a result of artificial removal of the upper soil profile and its surrounding embankment. The surface and size of the FWS were calculated to guarantee a retention time of at least 7 days, taking into account a 3-days cumulative discharge volume coming from the catchment area with a four-year rain return period. In 2007, before the beginning of the monitoring period referred to in this paper, three banks (0.25 m high and 45 m long each) were erected in the wetland to direct the water flow from inlet to outlet (Fig. 1). At the outlet, an upward curving pipe, placed in a manhole, allows for a pipe of variable height to be inserted to regulate the desired depth of water within the basin. To limit lateral subsurface water flow to and from the FWS, geomembrane waterproofing was installed vertically, to a depth of 1.5 m along the cell perimeter.

The FWS was vegetated with cattail (*Typha latifolia* L.) and common reed (*Phragmites australis* (Cav.) Trin.ex Steud.) in spring 1997. There was no vegetation harvest until 2007, so the biomass produced remained in the wetland. Since January 2007, after FWS rehabilitation, the vegetation has been composed almost exclusively of common reed; irrigation and nitrogen fertilization were applied in summer 2008, 2009 and 2010 (Table 1) to study the biomass production with abundant nitrogen availability. Further specifications are given in Borin et al. (2001), Borin and Tocchetto (2007) and Passoni et al. (2009).

2.3. Monitoring

During the study period (2007–2011) wetland water inflow (fields drainage + rainfall + irrigation) and outflow were monitored. Fields drainage was pumped into the FWS; two mechanical flow meters recorded volumes at the wetland inlet and outlet. Flow meter readings were taken daily. Rainfall was measured at about 500 m distance from the FWS by the experimental farm weather station. Irrigation volume was measured by the functioning time of the system and flow rate. Flooding days were also detected by daily monitoring.



SAMPLING POINTS										
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
18	36	54	72	90	108	126	144	162	180	198
Distance from inlet (m)										

Fig. 1. Layout of the surface flow constructed wetland.

2.4. Vegetation and soil sampling and analysis

Eleven vegetation and soil sampling points were investigated in the wetland at regular distances (18 m) from inflow to outflow. Each 0.25 m^2 area was sampled to a depth of 0.5 m. *P. australis* was harvested at the end of each vegetative season to determine plant biomass production separated in four fractions: (1) aerial; (2) litter; (3) belowground 0–20 cm; (4) belowground 20–50 cm. To measure the dry weight the biomass was dried to constant weight in a forced draught oven at 65 °C. Soil data for 2007 were retrieved from a dataset partially published in Passoni et al. (2009). In 2009 and 2012 soil samples were collected from each sampling point at the end of the vegetative season at two depths (0–20 and 20–50 cm). Bulk density (Grossman and Reinsh, 2002) and OC by dichromate oxidation (Walkley and Black, 1934) were determined in soil cores (5 cm diameter). Total nitrogen content in biomass was determined by Kjeldahl method (Arduino and Barberis, 2000).

Data of vegetation biomass as well as data of soil properties were compared with one-way ANOVA, and the differences between group means were tested using the Student–Newman–Keuls test at 5% significance level.

3. Results and discussion

3.1. Yearly water regime

During the monitoring period annual rainfall ranged from 601 to 1150 mm with an average of 869 mm; the FWS received a yearly