Performance Of A Pilot Hybrid Constructed Wetland As A Post Treatment For Biogas Digestate Liquid Fraction

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ABSTRACT

Animal wastewater management is becoming one of the central topics in the agronomic and environmental systems, especially in the European countries, which are subjected to the hard restrictions of the Nitrate Directive. Livestock farm produce a vast quantity of wastewater, which is not easy to handle. Using anaerobic digestion allows producing alternative energy and reaching discharge standards but the concentrations of nitrogen and phosphorus in the anaerobic digester effluent remain quite high. To reduce them, the use of constructed wetlands (CWs) could be a good perspective. A pilot hybrid CW as a post treatment for biogas digestate liquid fraction was constructed to treat 0.7 m^3/day of digestate fluid fraction in the Northern Italy. In this paper the preliminary performance are described. The first results on the pilot plant performance indicated interesting perspectives for TN e COD removal but more exhaustive information will be reached during the upcoming experiments. A dilution of the fluid fraction of the digester effluent needed to achieve our experimentation, indicating that, in case of a full scale conditions, a pretreatment is necessary before the CW treatment.

Keywords
Vertical Flow Constructed Wetland, Horizontal Flow Constructed Wetland, *Phragmites australis*, *Arundo donax*, COD,

Introduction

Animal wastewater management is one of the central topics in the agronomic and environmental systems, especially in the European country (Martinez et al., 2009) where the Nitrate Directive imposes hard restrictions on its use (EEC, 1991). In the traditional farm the manure was considered an essential and cheap source of fertilizer to preserve but nowadays, with the evolution of stockbreeding, livestock produce a huge quantity of wastewater, difficult to handle. The negative effects of excess spreading on arable land are well-known both for the soil and the water (Smith et al., 2000) so creating new or additional treatments and methods is necessary to observe this European Directive (Henkens and van Keulen, 2001, Harrington and Scholz, 2010).

In this context anaerobic digestion has been proposed as treatment to allocate the waste producing biogas as integrative source of income. However this technology can remove a considerable quantity of carbon but the concentrations of nitrogen and phosphorus of its co-product, the anaerobic digester effluent, remain high (Harrington and Scholz, 2010).

CWs could be a good perspective to reduce this residual pollutant load, due to their removal efficiency and the low cost of installation and maintenance (Sooknah, 2004). However no information are available on their performance in the treatment of the anaerobic digester effluents. To obtain some first information a pilot hybrid constructed wetland (HCW) has been designed and installed in North East Italy and this paper describes its features and reports the preliminary results on its performance.

Materials and Methods

The experimental activity is in progress at Terrassa Padovana, Padova (Eastern Veneto Region, latitude 45°14'42"00 North, longitude 11°54'13"32 East, altitude 4 m a.s.l.). The climate of this site is sub-humid, with a mean annual rainfall of about 800 mm uniformly distributed throughout the year, with a higher variability from September to November. The mean annual average temperature is about 12.5ºC.

The pilot HCW is installed at a Charolais beef cattle farm provided of an anaerobic digestion plant which can produce 1 MW/day electric energy and 576 kW/day thermic energy using slurry (4000 t/year), corn silage (14000 t/year) and residues from agriculture (4000 t/year). This system generates 50 m^3/day of digestate, which is then mechanically separated. The fluid fraction (FD) is stored in three circular section cisterns (25 m in diameter and 3.5 m in height).

The HCW pilot plant (Figure 1) has been designed to treat up to 0.7 m^3/day of FD and to have 3 days of total hydraulic retention time (HTR). The HCW consists into:

a. a concrete catch basin (0.8 x 0.8 x 0.8 m);
b. a sedimentation basin (basin 1) (5 x 2 x 1 m) where the FD is mixed with fresh water for experimental management;
c. an equalisation basin (basin 2) (5 x 1 x 1 m);
d. two sub-surface vertical flow beds (VSSF) (5 x 1 x 1 m, HRT 1 day) one vegetated with *Arundo donax* L. (VF A) and the other with *Phragmites australis* (Cav.) Trin. (VF P);
e. a manhole receiving the waste water to be treated from the equalisation basin and contains two pumps that load the two VSSF beds;
f. a sub-surface horizontal flow bed (HSSF) (5 x 1 x 1 m, HRT 2 days) vegetated with *Ph. australis* (HF);
g. a final catch basin (0.8 x 0.8 x 0.8 m) containing a pump that conveys back the discharged water into the storage tank.

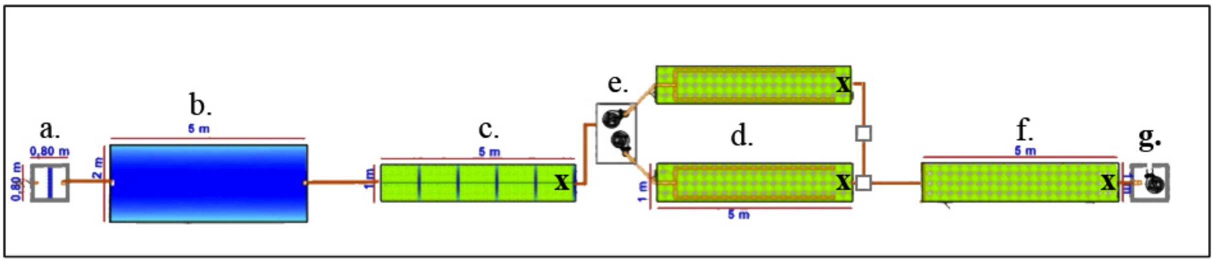


Figure 1. Layout of the HCW pilot plan.

The system has been installed on an artificial embankment and the basins are located at different elevations. The pumps are connected to a central data logger, which allows to programme the functioning time. The VSSF were filled with this stratigraphy from the bottom to the top:

- 15 cm of washed river bed gravel with 5 cm in diameter;
- 50 cm of washed river bed gravel with 1-2 cm in diameter;
- 20 cm of washed river bed sand with 2 mm in diameter;
- 10 cm of washed river bed gravel with 1-2 cm in diameter.

While the HSSF was filled with this stratigraphy from the inlet to the outlet:

- 0.5 m of washed river bed gravel with 5 cm in diameter;
- 4 m of washed river bed gravel with 1-2 cm in diameter;
- 0.5 m of washed river bed gravel with 5 cm in diameter.

The VSSF beds are loaded alternatively every two days. Load is provided during 2 and half hours, with four loading cycles 175 L. The bed is kept completely full of wastewater for 24 hours, afterwards the discharge cycle is activated and the bed is emptied one hour and half. According this management scheme a vertical bed alternates 24 hours of full (anaerobic conditions), 20 hours of empty (aerobic conditions) and 4 hours for load/discharge.
The pilot plant was activated in July 2012 according to the following procedure. Basin 1 is filled with 100 L of FD, pumped from the stock tank, and 600 L of water from the drainage ditch beside the plant. The dilution was necessary due to the extremely high mean values of FD, especially on total nitrogen (TN) (mean value 1678 mg/L) and electrical conductivity (EC) (mean value 22.4 mS/cm). The liquid flows through by gravity to the basin 2 and afterwards is pumped to one of the two VF. After one day in one of the VSSF the solution passes by gravity to HF by a valve and finally comes out to catch basin where a pump takes the liquid to the storage tank.
The monitoring occurred from 21th to 31th August 2012, when the mean values of temperature and precipitation were 25.3°C and 1.4 mm, warmer and more dry than the long term climate condition in this period of the year (22.3°C and 20.1 mm correspondingly).
Samples were obtained by collecting wastewater from each tank as marked with x in the Figure 1, corresponding to inlet in basin 2 (IN), outlet of VF A, outlet of VF P and outlet of HSSF (OUT). After the sampling the wastewater was kept refrigerated at -20 °C and afterwards analyzed in laboratory to quantify TN, ammonium nitrogen (NH_4-N), nitric nitrogen (NO_3-N), total phosphorus (TP), orthophosphate (PO_4-P) and chemical oxygen demand (COD) with the spectrophotometer (Spectrophotometer DR2008 Hach-Lange and specific couvettes test for each parameters) and the turbidity with a turbid meter (Hanna Instruments HI83414). Furthermore *in situ* measurements of pH, Redox potential (E_h), dissolved oxygen (DO) and EC were also taken with the Hach Lange, HQ40d multi parametric probe.
During the monitoring 9 samplings were carried out, almost every day.

Results and Discussion

The median concentration of TN of the diluted FD was quite steady during the monitoring programme, ranging from 350 and 400 mg/L and the median value (378 mg/L) was abated to 289 mg/L at the end of the HCW (Figure 2). Looking at the nitrogen forms concentration, the NO_3-N increased (from 26.4 to 40.2 mg/L), due to the nitrification process in the VSSF bed. The NH_4–N concentration was reduced (from 236 to 141 mg/L): denitrification and volatilization losses possible for the high pH value (median 8.8 pH) (Reddy and Patrick 1984) may be the processes involved. Among the two VSSF beds, the *Phragmites* one had better performance than the *Arundo* in abating TN (VF P 302 mg/L, VF A 384 mg/L) and NO_3-N (39.7 and 54.6 mg/L respectively) while the two species had similar influence on NH_4–N (173 and 179 mg/L for VF P and VF A).

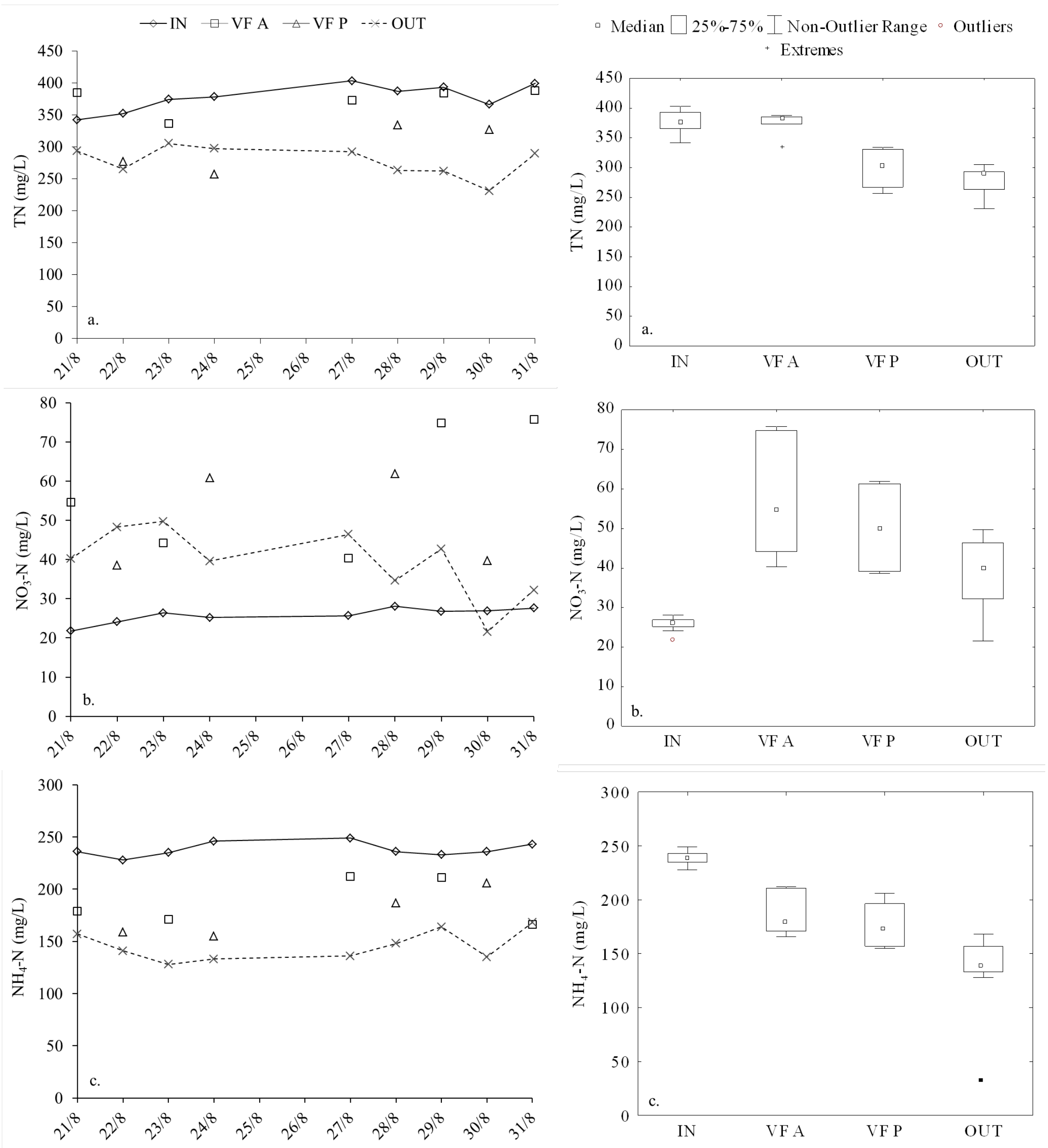


Figure 2. Time patterns and box and whiskers plots of the nitrogen forms during the sampling period: TN(a.); NO_3-N (b.) and NH_4-N (c.).

The median inlet content of TP was 33.5 mg/L while the outlet was 29.2 mg/L. The PO_4-P decreased from 30.7 to 25.6 mg/L. It is well known that PO_4-P is mainly removed by plant uptake and adsorption on the porous media (Kadlec and Knight, 1996) so longer HRT could show better removal. Furthermore reducing conditions, and in this case low DO concentrations (Figure 5), could release dissolved phosphorous by solubilisation of minerals (Kadlec and Knight, 1996). Both VSSF gave similar results.

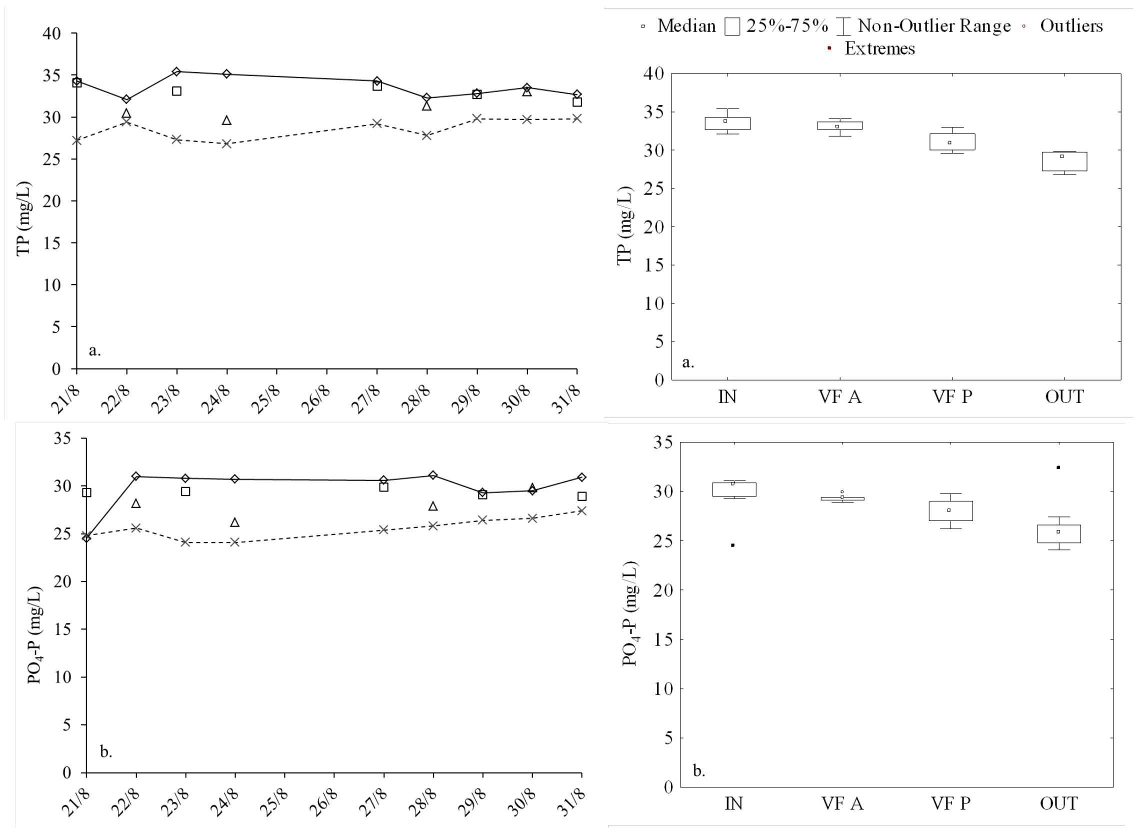
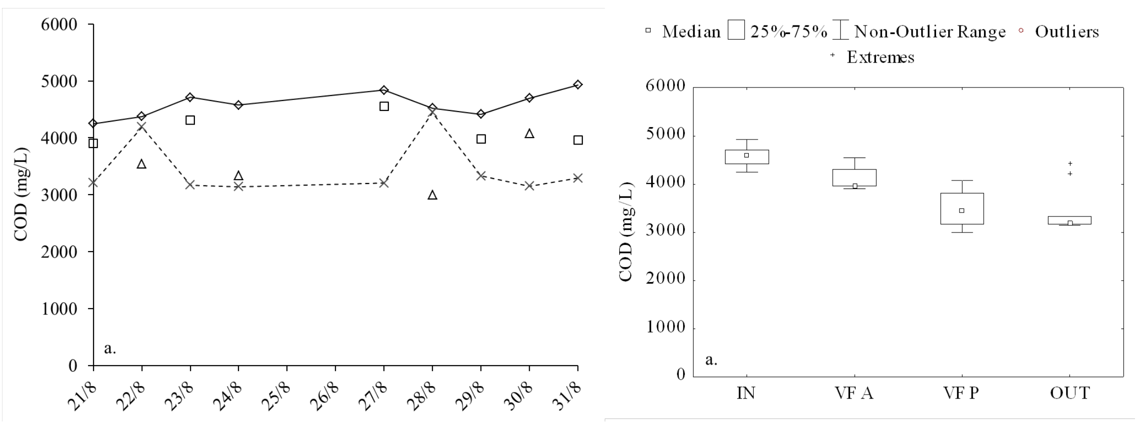


Figure 3. Time patterns and box and whiskers plots of the phosphorous form during the sampling period: TP (a.) and PO_4-P *(b.).*

The median COD concentration (4577 mg/L) of the diluted FD (Figure 4) was progressively reduced along the HCW to a final median concentration of 3212 mg/L.

The initial EC of 5.23 mS/cm increased to 6.17 mS/cm at the end of the pilot plant due to water consumption by evapotranspiration and concentration of the salts. For both parameters VF P had lower values than VF A.



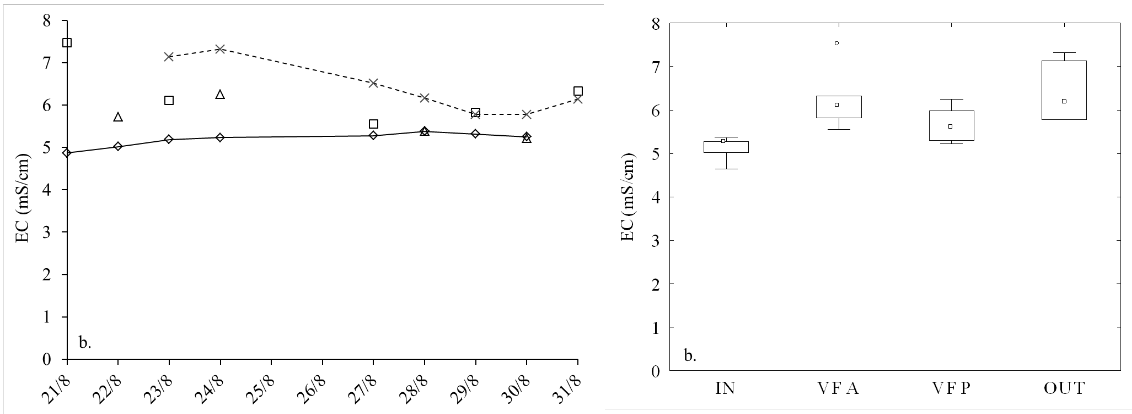


Figure 4. Time patterns and box and whiskers plots of the phosphorous form during the sampling period: COD (a.) and EC (b.).

The diluted FD loading the HCW had E_h values indicating anaerobic conditions (median -324 mV) (Figure 5) but with the transit in VSSF it shifted to anoxic-oxic (median value of 7.8 mV, with a peak at 64.8 mV).

Very low values of DO were present in the diluted FD and the VSSF provided a significant increase (peak of 0.73 mg/L), followed by a reduction in the HSSF (Figure 5). Again VF A and VF P had similar behaviors.

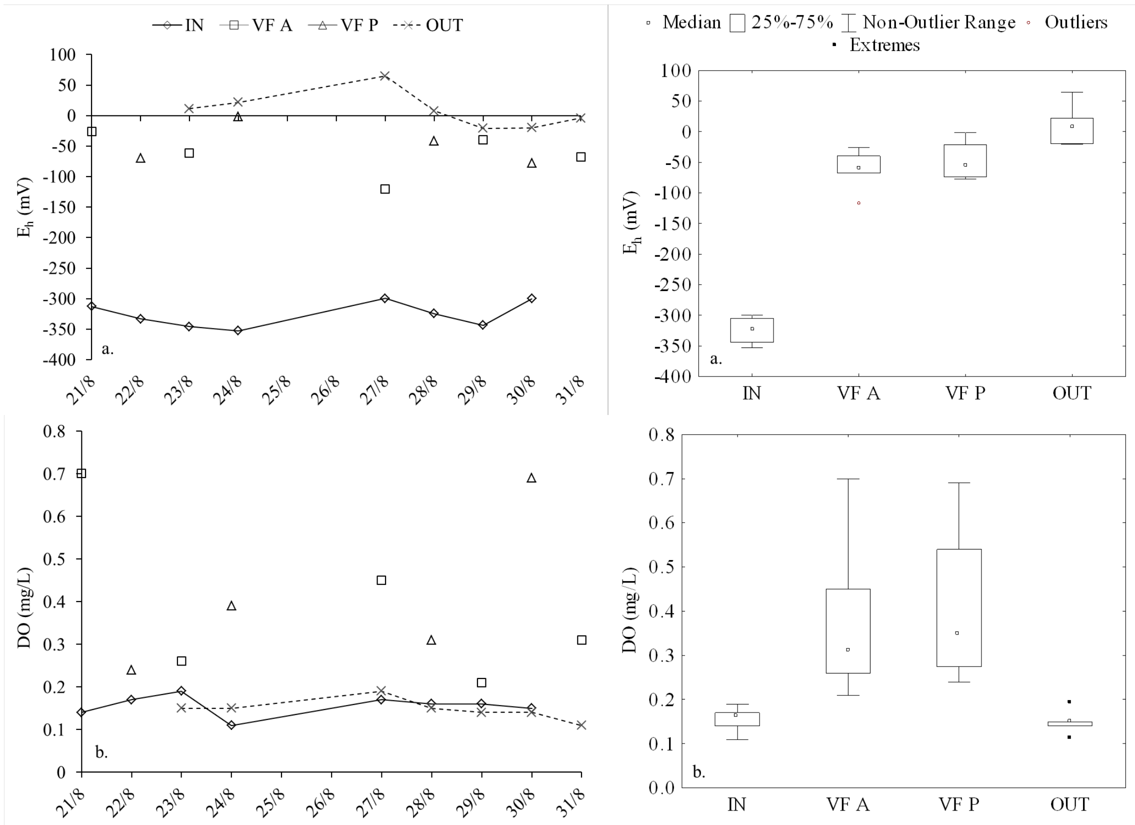


Figure 5 Time patterns and box and whiskers plots of E_h (a.) and DO (b.) during the sampling period.

The removal efficiency calculated on the mass balance of the main parameters is shown in Table 1.

The residence in the HCW determined an average reduction of 35% of the applied volume, mostly due to the high rate of evapotranspiration (He and Mankin, 2002). Furthermore, even

if the HRT is about 3 days, lower than in experimentation of Akratos and Tsihrintzis (2007), the TN removal efficiency was roughly 50% and it could be a good preliminary remark for further experiments. Also the results on COD had good values, comparing with ones by Akratos and Tsihrintzis (2007), despite the short HRT.
During the monitoring the removal efficiency of phosphorous was about 38% for both forms and the turbidity reduced by 41.3%

Parameter	Reduction (%)
Volume	35.0
TN	47.6
NO_3-N	-9.6
NH_4-N	55.7
TP	37.1
PO_4-P	38.7
COD	40.2
Turbidity	41.3

Table 1.The removal efficiency of the pilot plant during the sampling period.

Conclusions
The preliminary results on the pilot plant performance indicate interesting perspectives for TN e COD removal, but more exhaustive information will be produced continuing the experiment. To manage our experiment a dilution of the fluid fraction of the digester effluent has been necessary, indicating that, in full scale conditions, the wetland treatment has to be preceded by an effective pretreatment.

Acknowledgment
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