The Use of Artificial Wetlands to Treat Greenhouse Effluents

V. Lévesque, M. Dorais[a], V. Gravel and C. Ménard
Agriculture and Agri-Food Canada
Horticultural Research Centre
Laval University
Quebec, QC, G1V 0A6
Canada

H. Antoun
Département des sols et de génie agroalimentaire
Centre de Recherche en Horticulture
Université Laval
Québec, QC, G1V 0A6
Canada

P. Rochette
Agriculture and Agri-Food Canada
Ste-Foy, Quebec, QC, G1V 2J3
Canada

S. Roy
Les Serres Nouvelles Cultures
Sagami, Ste-Sophie, QC, J5J 2V3
Canada

Keywords: carbon source, constructed pond, denitrification, greenhouse gas emission, macrophytes, nitrogen and phosphate removal

Abstract

Untreated greenhouse effluents or leak solution constitute a major environmental burden because their nitrate and phosphate concentrations may induce eutrophication. Artificial wetlands may offer a low cost alternative treatment of greenhouse effluents and consequently improve the sustainability of greenhouse growing systems. The objectives of this study were to 1) characterize the efficiency of different types of wetland to reduce ion content of greenhouse tomato effluent, and 2) improve the wetland efficiency by adding carbon of 0-800 mg L^{-1} sucrose. Experiments were conducted at Laval University where 30 pilot scale horizontal subsurface flow artificial wetlands (0.81 m^3) were built. Two types of aquatic macrophytes, *Pragmites australis* and *Typha latifolia,* and a control group without plants were tested. The hydraulic retention time was 10 days. During the study, EC of the greenhouse effluent ranged between 1.5 to 5.5 mS cm^{-1}, while 0 to 800 mg L^{-1} of sucrose was provided to improve the biological activity of the wetland. The macro- and micro-elements, the greenhouse gases (CH_4, CO_2, N_2O) and the population of bacteria were measured for each unit. At commercial scale, two vertical subsurface wetlands (43.2 m^3) were installed at Ste-Sophie Québec, on the production site of Les Serres Nouvelles Cultures (Sagami). According to our results, 50-90% of nitrate (NO_3^-) and 40-100% of phosphate (PO_4^{3-}) were removed from the effluent. At Laval University, artificial wetlands with *Typha latifolia* were more efficient than wetlands with *Phragmites australis* or without plants. Addition of sucrose increased wetlands' microbial population and consequently reduced the mineral content of the wastewater, but increased significantly the emission of greenhouse gases. Results will further be discussed in terms of the best wetland design to treat greenhouse effluents, but also in terms of the environmental impact.

INTRODUCTION

The greenhouse industry in Canada is an expanding agricultural sector generating a sale value of more than 2.4 billions CAN$ for a cultivated area of 2 299 ha (Statistics Canada, 2009). Vegetables production accounted for 50% of the total greenhouse area with a sale value of 929 millions CAN$. Tomato is the most important Canadian greenhouse vegetable (cultivated on 497 ha) followed by sweet pepper (346 ha), cucumber (293 ha) and lettuce (>18 ha) (Statistics Canada, 2009). The expansion of soilless greenhouse culture resulted in higher yields but also in a significant increase of

---

[a] martine.dorais@agr.gc.ca

the fertilizer utilization. To ensure an optimal nutrient uptake and to prevent salt accumulation in the root-zone, plants are generally over irrigated (25 to 45%) with a complete nutrient solution. During the active growing season, around 4 L of nutrient solution is given daily per tomato plant, where up to 2 L can be drained to maintain an appropriate salinity at the root level. This excess part of the nutrient solution is then recycled or lost in the environment if no strict regulation is in place. Growers may be reluctant to recycle their effluents due to the risk associated to pathogens, the cost and maintenance of a disinfection system (UV, heat, ozone) or the difficulty to maintain an optimal nutrient balance (buildup of SO_4, Na, Cl) under specific growing conditions (Dorais et al., 2001; Dorais and Dubé, 2011). Unfortunately, these effluents are rich in nitrate and phosphate, which can have a major impact on the environment (Merlin et al., 2002; Dorais and Dubé, 2011). It is well known that nitrogen and phosphorus contaminate groundwater and promote the proliferation of blue-green algae (*Cyanobacteria*) in lakes and rivers and consequently result in eutrophication. Under Canadian growing conditions, it has been reported that each ha of tomato produces up to 4000-4500 m^3 of wasted nutritive solution containing 7.5 t per year of nutrients such as nitrogen and phosphorus (Omafra, 2008; Dorais and Dubé, 2011). On a daily basis, nutrient pollution may represent a release of 1300 kg NO_3 ha^{-1}, 320 kg P ha^{-1} and 368 kg SO_4 ha^{-1} in the environment.

In order to reduce nutrient emission into the groundwater, the use of a passive, biological and cheap water treatment system such as artificial wetlands (AW) may constitute an economic solution for some growers. This biological system can remove excess of mineral salts present in the effluent while reducing the risk of spreading disease (Kadlec and Knight, 1996; Sleytr et al., 2007). Treatment of wastewater of different origin using AW has been widely studied (Faulwetter et al., 2009; Kadlec and Wallace, 2009; Zhao et al., 2010), and is designed to benefit from physiological, chemical and biological processes in a controlled and predictable manner. Mechanisms such as sedimentation, precipitation, adsorption to soil particles, assimilation by the plant and the conversion by microorganisms are involved (Vymazal, 2008). Artificial wetlands are self-sufficient, requiring little energy and provide a lasting solution to the wastewater treatment (Stottmeister et al., 2003). In addition, AW are tolerant to variable hydrological and contaminant loading rates and have an esthetically natural appearance. However, few studies have been conducted on the use of AW to treat wastewater rich in nutrients such as greenhouse effluents. The objectives of this research project were to characterize the efficiency of different types of wetland to reduce ion content of greenhouse tomato effluent, and to improve the wetland efficiency by adding a source of carbon.

MATERIALS AND METHODS

Experiments were conducted at Laval University, Quebec City, Canada (pilot scale) and at Les Serres Nouvelles Cultures (Sagami), Ste-Sophie, QC, Canada (commercial scale).

Pilot Experimental Scale

Thirty horizontal subsurface flow artificial wetlands filled with gravel (12 mm nominal diameter) were built and localized inside a 150 m^2 greenhouse (split plot design with 5 replicates). The principal plots were a source sucrose (C+) or not (C-) in the wetlands, and the sub-plots were different plants and a control group. AW units were 0.71 m height × 1.32 m length × 0.81 m width. A strip of 10 cm gravel (19 mm nominal diameter) was installed at the affluent entrance of the AW to provide a uniform flow rate and to prevent any preferential paths. Among the 30 AW, 15 AW received a source of carbohydrate during the experiment. Two types of aquatic macrophytes, *Pragmites australis* and *Typha latifolia* and a control group without plants were studied. The hydraulic retention time was 10 days and the flow rate of the wastewater (affluent; greenhouse effluent) was 22.5 L per day. All units received a standard tomato effluent of 1.5 mS cm^{-1} and half of the units received an increasing source of carbohydrate (25, 50, 100, 200 and 400 mg L^{-1} sucrose) at a three-week interval (time interval needed to reach the steady state). When the steady state of 400 mg L^{-1} of sucrose was reached, all AW units received an increasing level of salinity (2.5, 3.5, 4.5 and 5.5 mS cm^{-1} EC) at three-week intervals. For the last three weeks of experiment, a salinity of 5.5 mS cm^{-1} was maintained and 800 mg L^{-1} of sucrose was added (the previous 15 AW had received an increasing source carbohydrate before).

Commercial Experimental Site

Two vertical subsurface flow wetlands (43.2 m^3) were built (2 replicates, each wetland was subdivided into three compartments) under uncontrolled environment (outside) using sand (0.2 mm nominal diameter) as a filling material, and AW were colonized with *Pragmites australis*. The compartment dimension was 1.2 m height × 4.9 m length × 2.45 m width (14.4 m^3 per compartment). Greenhouse effluents were collected in two holding tanks (one for each wetland). Effluents were sequentially pumped to the first compartment of the wetland. Each compartment contained a barrel of 200 L where a pump was installed. As the barrel filled up, the wastewater was pumped to the following barrel and so on until it had reached the last barrel (treated water). A total of eight barrels were installed. Due to seasons and surface of soil frozen during winter, each wetland contained two delivering systems (polyvinyl chloride), one at the surface for the summer and the other one at 0.5 m from the soil surface for winter. An agricultural drain was installed in the bottom of each wetland for the transport of water to the pump located in the barrel from each compartment. The daily volume of treated greenhouse effluent was 300 L (summer) or 150 L (winter) per AW. These volumes represented the quantity of wastewater coming from 200 tomato plants cultivated into a soilless growing system using coir. The hydraulic retention time was approximately 6 days (2 days per compartment).

For the experimental site, water samples (50 ml) were collected every week at the entry and exit of each horizontal subsurface flow wetlands (30 units), while samples were collected every two (summer) or four (winter) weeks in each wetland compartment (6 compartments) at the commercial site. Samples were analyzed for NO_3^-, SO_4^- and Cl^- through high-performance liquid chromatography method using a Dionex ICS 2000 with IonPac®AS18 analytical column in combination with the AG18 guard column. Orthophosphate (ortho-PO_4) was analyzed by the ascorbic acid reduction method developed by Murphy et al. (1962), pH and EC. The water samples were stored at 4°C before being analyzed. The greenhouse gases (methane, CH_4; carbon dioxide, CO_2; nitrous oxide, N_2O) were analyzed by gas chromatography (3800 Varian, Walnut Creek, CA) every second week as described by Rochette et al. (2008). Chamber size was 0.0281 m^3 (1.33 m long × 0.15 m wide × 0.14 m high). One acrylic plastic chamber per experimental unit was located in the middle of the AW and chambers were inserted 10 cm into the gravel bed. Three gas samples (20 ml each) per chamber were collected at different times (0, 12, 24 min). For the experimental trial, effects of wetlands design, sucrose concentration and EC on affluent, effluent and gas concentration were analyzed using the PROC MIXED procedure. The normality of data were evaluated with SAS Univariate procedure (SAS Institute Inc., Cary, NC, USA 9.1, 2002-2003). For the commercial site trials, effects of hybrid wetlands design on affluent and effluents were analyzed using the PROC MIXED procedure. When significant ($P \leq 0.05$) means were compared by the Tukey's tests.

RESULTS AND DISCUSSION

Experimental Site

From 11 April to 10 July, a significant difference in the reduction NO_3^- concentration ($p<0.0001$) of the greenhouse effluent when AW was enriched with sucrose (to average, 48% of NO_3^- reduction) compared to AW free of sucrose (36%) over the sampling period. A similar difference was also observed when EC increased from 1.5 to

5.5 mS cm^{-1} (Fig. 1). For industrial wastewater, Burgoon et al. (1999) also observed a positive effect of carbon enrichment on NO_3-N removal. This higher removal of NO_3-N was associated with a more efficient denitrification process. Adding a source of carbon most likely increased the denitrification reactions of our AW. Consequently, carbon enrichment reduced nitrate concentration of the wastewater but increased significantly ($p<0.002$) the emission of greenhouse gases when sucrose concentration reached 200 mg L^{-1} (Fig. 1). N_2O emissions were usually substantial when affluent wastewater had a low C:N ratio (Kadlec and Wallace, 2009). Baker (1998) suggested that the loading C:N ratio be at least 5:1 so that carbon produced does not become limiting. Similary, Lin et al. (2002) obtained a good reduction of NO_3^- (90%) when loading C:N ratio was 3.5:1. These results are similar in our experience, we obtained a good reduction of NO_3^- when loading C:N ratios were 5:1 and 3.4:1. However, when the loading C:N ratio was below 3.4:1, N_2O emission increased significantly ($p<0.002$) compared with AW without sucrose. Stadmark et al. (2009) observed that an addition of NO_3^- with a source of carbohydrate increase N_2O emissions in AW.

Phosphorus interacts strongly with soil, bed aggregates and biota. In our study, adding sucrose was more efficient in reducing PO_4^{3-} concentration (68%) than NO_3^- (48%) over the sampling period when the EC increased from 1.5 to 5.5 mS cm^{-1} between 10 July and 23 October ($p<0.0001$). Also, while EC increased from 1.5 to 5.5 mS cm^{-1}, we observed a significant difference in the reduction of PO_4^{3-} concentration ($p<0.0001$) of the greenhouse effluent when AW were enriched with sucrose (68%) in comparison to AW free of sucrose (50%). The removal of PO_4^{3-} may be explained by chemical precipitation process with metallic cations such as Ca, Fe, Al or Mg present in the wetlands and increased pH due to denitrification activity (Kadlec and Wallace, 2009). Calcium bound-P is the predominant form of P in alkaline soils while Fe-P and Al-P are predominant forms in acidic soils (Kadlec and Wallace, 2009; Dean, 1949). Merlin et al. (2002) used the wine production residue called “vinasse” as carbon source and the mineral follow-up shows that phosphates can be retained in basins (with substrate). More than 90% of phosphate was adsorbed on the substrate.

NO_3^- and PO_4^{3-} concentrations of the treated wastewater were significantly lower ($p<0.0001$) with plants than without plants but only at 3.5 mS cm^{-1} EC with 400 mg L^{-1} sucrose. Similarly, Tanner et al. (1995) reported that planted wetlands showed a greater overall removal of N and P from dairy farm wastewaters than unplanted wetlands. For a greenhouse tomato effluent, Merlin et al. (2002) observed a significant difference ($p=0.0011$) for the nitrate removal between planted and unplanted subsurface wetlands. Macrophytes are beneficial for the bacterial population because they provide oxygen and carbon needed for metabolic activities such as denitrification (Kadlec and Wallace, 2009). In general plant species (*P. australis* and *T. latifolia*) did not exhibit important differences in their ability to reduce NO_3^- and PO_4^{3-} concentrations in the greenhouse effluents as shown in Figure 1. However, *T. latifolia* was more efficient ($p<0.0001$) than the unplanted control and *P. australis* in removing NO_3^- and PO_4^{3-} from wastewater when 400 mg L^{-1} sucrose was added at EC of 1.5 and 2.5 mS cm^{-1}. When testing eight different plant species (*T. latifolia*, *C. corymbosus*, *E. cordifolius*, *B. mutica*, *D. bicornis*, *V. zizaniodes*, *S. patens*, *L. fusca*) used in artificial wetlands, Klomjek and Nitisoravut (2005) observed that *T. latifolia* had the highest tolerance to salinity.

Commercial Experimental Site

At the Serres Nouvelles Cultures, nitrate concentration in the commercial greenhouse effluent was significantly reduced ($p<0.0001$) by 78, 60 and 86% in summer, fall and winter seasons, respectively after treatment in AW (Fig. 2A and B).

In contrast to NO_3^-, PO_4^{3-} concentration was completely removed (100% of reduction) after the first wetland compartment during the summer and earlier fall seasons, while no PO_4^{3-} was detected in the treated water of the third compartment in the winter and spring. Finer material such as sand has a high surface area enabling a better phosphorus sorption than gravel (Kadlec and Wallace, 2009). For all growing seasons, the

EC of the treated water was significantly reduced within the third wetland compartment ($p<0.0001$). The EC reduction of the wastewater from each compartment has the same profile than the reduction of the NO_3^- concentration (Fig. 2A and D). During summer, fall and earlier winter, the pH (Fig. 2C) of the treated wastewater coming from all compartments was significantly higher than the pH of the greenhouse effluent ($p<0.0001$). This difference was due to the denitrification process, which has an effect on the total alkalinity. In fact, the observed rate of bicarbonate production by the denitrification is about 3.0 g $CaCO_3$ per gram of NO_3-N reduced, which increases the pH of the wetland (Kadlec and Knight, 1996; Kadlec and Wallace, 2009). Also, the three serial compartments in wetland have probably contributed to improve mineral reduction. The combinations of constructed wetland with others wetlands systems (hybrid systems) are necessary to achieve higher treatment efficiency, especially for nitrogen removal as reported by according to Vymazal (2005, 2007). Seo et al. (2008) observed a good removal of nitrogen and phosphorus for treating agricultural wastewater in hybrid constructed wetlands.

In this commercial study, NO_3^- and PO_4^{3-} concentrations fluctuated in time following fertilization management of tomato according to plant vigor and climate conditions. There was a water infiltration in the greenhouse effluent reservoir during late winter and spring explaining the low concentration of NO_3^- and PO_4^{3-} and EC observed in the greenhouse effluent.

CONCLUSION

Adding a carbon source in the wetlands at the experimental site had a positive impact on the removal of mineral elements in the wastewater. Sucrose enrichment was more efficient in reducing PO_4^{3-} concentration than NO_3^- under high EC due to chemical precipitation of PO_4^{3-} with metallic cations. Also, wetlands with plants were more efficient to remove mineral elements than without plants. The presence of vegetation in the wetland was favorable for bacterial population (data not shown). The vegetation contributes the supply of oxygen to the water, and the carbon content of plant litter, which supplied the energy needed for metabolic activities such as denitrification. In general, *P. australis* and *T. latifolia* had comparable capacity to remove mineral elements in the wastewater (data not shown). However, *T. latifolia* was several times more efficient than *P. australis* when the EC of the greenhouse effluent was increased in the wetlands. Furthermore, adding a carbon source and NO_3^- increased the N_2O emission in the wetland.

The high efficiency to remove nutrients (90-100% for PO_4^{3-} and 40-90% for NO_3^-) from the greenhouse effluent at the commercial site via the use of a vertical subsurface flow wetland is promising as a relatively low cost, low maintenance and biological alternative to existing systems. Also, serial compartment wetlands could be used for an optimal performance. However, additional studies are needed to define the best AW design to treat greenhouse effluents with a minimal impact on the emission of greenhouse gases as well as on the reduction of the risk associated to plant pathogens such as *Pythium* spp., *Fusarium* spp. or other plant disease microorganisms.

ACKNOWLEDGEMENTS

Authors are grateful to Stephane Roy and Guy Fortier (Les Serres Nouvelles Cultures, Sagami, Ste-Sophie de Mirabel, QC) for their financial and technical support. Thanks to Normand Bertrand (AAFC) for his technical assistance and, Centre SÈVE and the Horticultural Research Center for financial assistance to participate at the International Symposium on High Technology for Greenhouse System 2009.

Literature Cited

Baker, L.A. 1998. Design consideration and applications for wetland treatment of high-nitrate waters. Water Sci. Technol. 38:389-395.

Burgoon, P.S., Kadlec, R.H. and Henderson, M. 1999. Treatment of potato processing wastewater with engineered natural systems. Wat. Sci. Tech. 40:211-215.

Dean, L.A. 1949. Fixation of soil phosphorus. Adv. Agron. 1:391-411.

Dorais, M., Papadopoulos, A.P. and Gosselin, A. 2001. Influence of electric conductivity management on greenhouse tomato yield and fruit quality. Agronomie 21:367-383.

Dorais, M. and Dubé, Y. 2011. Managing greenhouse organic wastes: a holistic approach. Acta Hort. 893:183-197.

Faulwetter, J.L., Gagnon, V., Sundberg, C., Chazarenc, F., Burr, M.D., Brisson, J., Camper, A.K. and Stein, O.R. 2009. Microbial processes influencing performance of treatment wetlands: a review. Ecolog. Engineer. 35:987-1004.

Kadlec, R.H. and Knight, R.L. 1996. Treatment Wetlands. Lewis Publ., USA. p.893.

Kadlec, R.H. and Wallace, S.D. 2009. Treatment wetlands. Lewis Publ., USA. p.1016.

Klomjek, P. and Nitisoravut, S. 2005. Constructed treatment wetland: a study of eight plant species under saline conditions. Chemosphere 58:585-593.

Lin, Y.-F., Jing, S.-R., Wang, T.-W. and Lee, D.-Y. 2002. Effects of macrophytes and external carbon sources on nitrate removal from groundwater in constructed wetlands. Environ. Poll. 119:413-420.

Merlin, G., Sedilot, C., Herbert, N. and Grasselly, D. 2002. Treatment of tomato greenhouses drainage solutions by experimental constructed wetlands. CTIFL. p.526-533.

Murphy, J. and Riley, J.P. 1962. A modified method for the determination of phosphate in natural water. Anal. Chim. Acta. 27:31-36.

Omafra. 2008. Ministry of agriculture food and rural affairs. http://www.omafra.gov.on.ca/english/environment/hort/grhouse.htm.

Rochette, P. and Bertrand, N. 2008. Soil-Surface gas emissions. p.851-861. In: M. Carter (ed.), Soil Sampling and Methods of Analysis. CRC Press, Boca Raton.

Seo, D.C., Hwang, S.H., Kim, H.J., Cho, J.S., Lee, H.J., DeLaune, R.D., Jugsujinda, A., Lee, S.T., Seo, J.Y. and Heo, J.S. 2008. Evaluation of 2- and 3- stage combinations of vertical and horizontal flow constructed wetlands for treating greenhouse wastewater. Ecol. Eng. 32:121-132.

Sleytr, K., Tietz, A., Langergraber, G. and Haberl, R. 2007. Investigation of bacterial removal during the filtration process in constructed wetlands. Sci. Total Environ. 380:173-180.

Stadmark, J., Seifert, A.-G. and Leonardson, L. 2009. Transforming meadows into free surface water wetlands: impact of increased nitrate and carbon loading on greenhouse gas production. Atmospheric Environment 43:1182-1188.

Statistics Canada. 2009. Les industries des cultures de serre, des gazonnières et des pépinières. Ministre de l’industrie, Ottawa. Catalogue No 22-202-X. 34p.

Stottmeister, U., Wieβner, A., Kuschk, P., Kappelmeyer, U., Kästner, M., Bederski, O., Müller, R.A. and Moormann, H. 2003. Effects of plants and microorganisms in constructed wetlands for wastewater treatment. Biotechnol. Adv. 22:93-117.

Tanner, C.C., Clayton, J.S. and Upsdell, M.P. 1995. Effect of loading rate and planting on treatment of dairy farm wastewaters in constructed wetlands - II. Removal of nitrogen and phosphorus. Water Resour. 29:27-34.

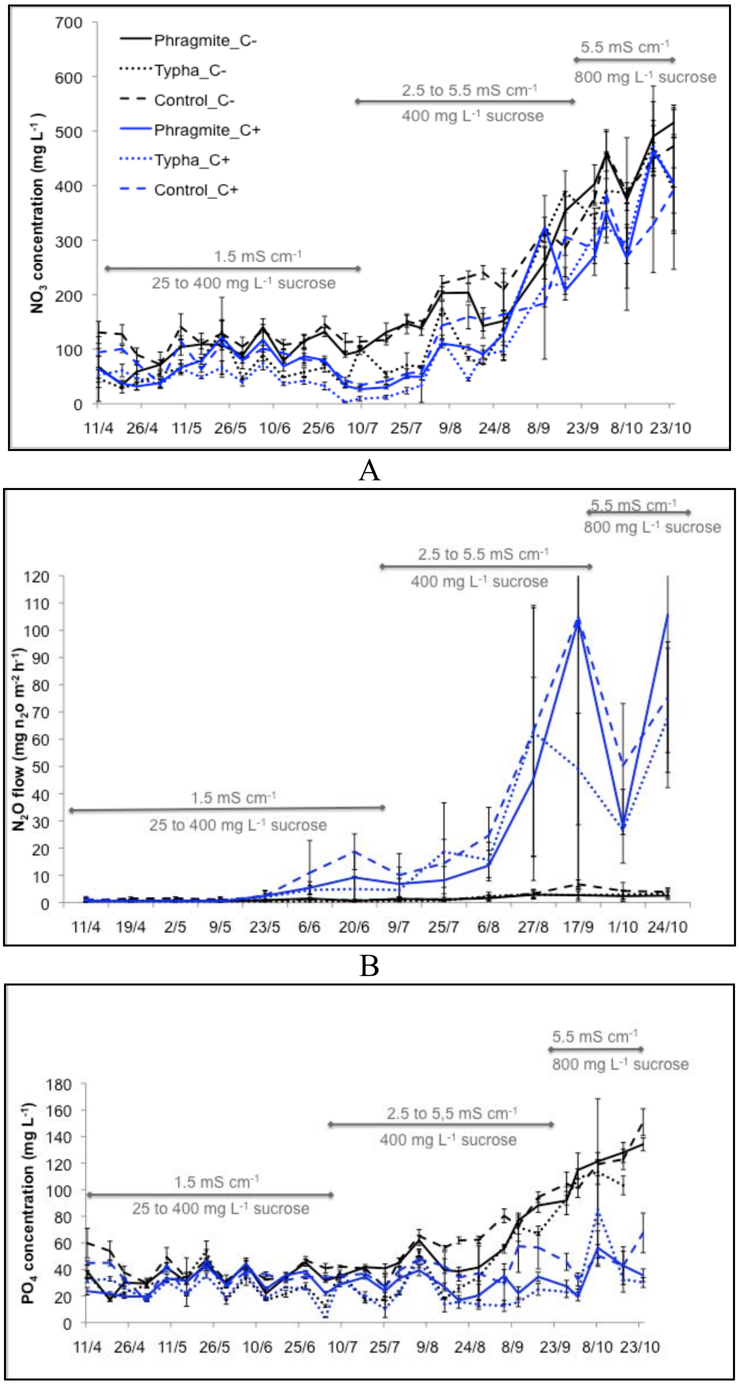
Vymazal, J. 2005. Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment. Ecol. Eng. 25:478-490.

Vymazal, J. 2007. Removal of nutrients in various types of constructed wetlands. Sci. Total Environ. 380:48-65.

Vymazal, J. 2008. Constructed wetlands, Surface flow. Ecol. Eng. p.765-776.

Zhao, Y.J., Liu, B., Zhang, W.G., Ouyang, Y. and An, S.Q. 2010. Performance of pilot-scale vertical-flow constructed wetlands in responding to variation in influent C/N ratios of simulated urban sewage. Biores. Technol. 101:1693-1700.

Figures



A

B

C

Fig. 1. Influence of different plant species, EC and sucrose on the mineral concentration (NO_3^- and PO_4^{3-}) of the treated wastewater and gas emission (N_2O) coming from the experimental AW (C^+ with sucrose, C^- without sucrose) (n=5).

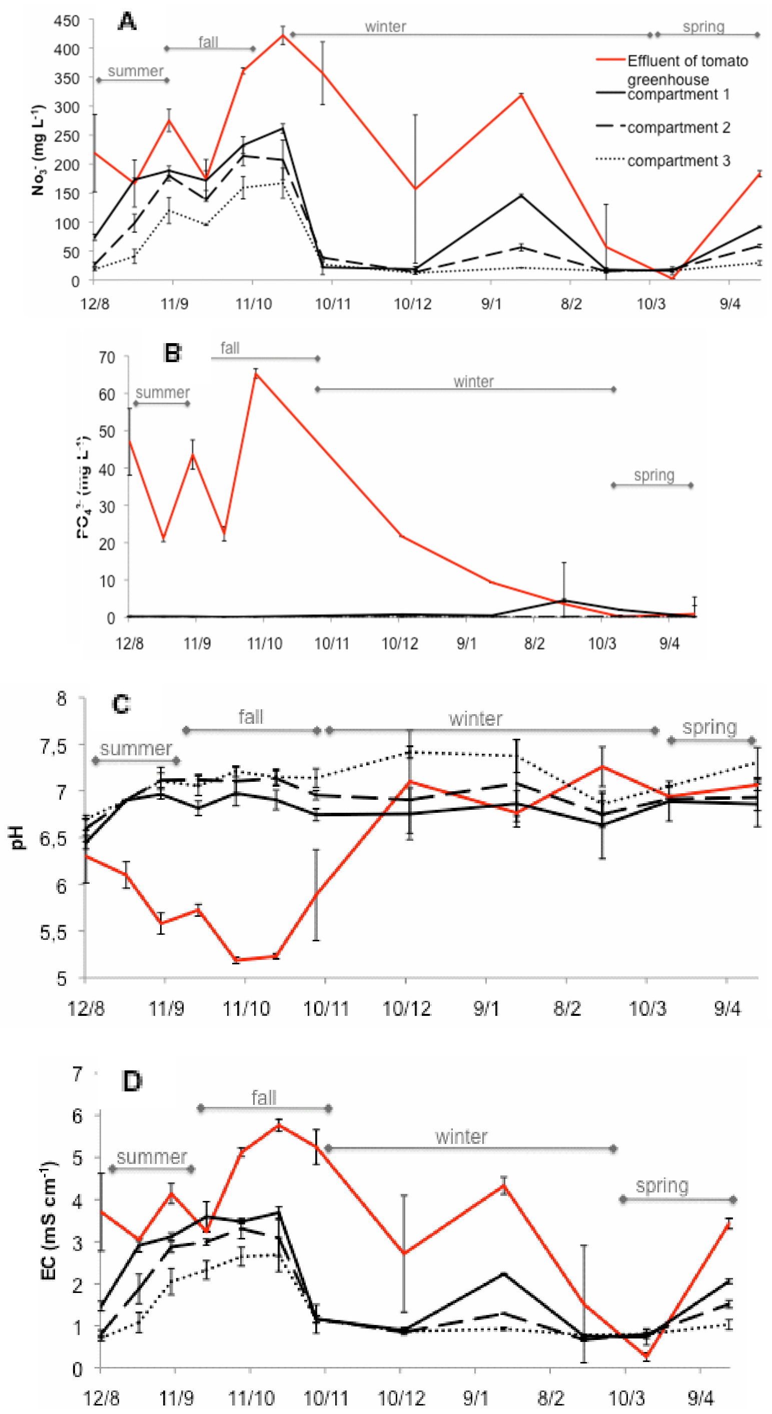


Fig. 2. Time variation of NO_3^- and PO_4^{3-}, pH and EC between tomato greenhouse effluent and treated water from each compartment of the vertical subsurface flow wetlands localized at the commercial site (2008-2009) (n=2).