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Web app for real-time monitoring of the performance of constructed wetlands treating horticultural leachates

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ABSTRACT

Leachates produced in intensive horticulture must be collected, reused and eventually treated in order to prevent environmental pollution of water bodies. Constructed wetlands (CW) try to emulate natural wetlands, where pollutants such as nitrates are removed through the denitrification process. CW are a simple and sustainable technique with a low energy demand that are being used to purify different effluents. No information is currently available on tools used to monitor the performance of such systems in terms of nutrient removal efficiency. Nor is information available on the use of Information and Communication Technologies (ICT) tools to share news on this performance across the Internet. The purposes of the study were: a) to demonstrate the feasibility of using online instruments to measure leachate ions in order to monitor CW performance and to manage it properly and b) to share this real-time data monitoring with the end users through a web App. Under the described experimental conditions, the on-line analyzers are reliable instruments to measure nitrates, nitrite, phosphates and potassium ion. Monitoring of the constructed wetlands through the web is an effective tool that would contribute to show the feasibility of the system to the end users. These two conclusions demonstrated the innovativeness of the whole system to monitor the constructed wetlands through the Internet.

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1. Introduction

Water resources available for agriculture in forthcoming decades will be lower in both quantity and quality (Navarro-Hellín et al., 2015). The efficiency in the use of water and fertilizers in horticultural agro systems is low (Grant et al., 2009). Particularly, losses through leaching could be considerable due to the used fertigation and certain irrigation techniques (Cáceres et al., 2007; Narváez et al., 2012, 2013; Cáceres and Marfà, 2013).

The leachates produced in soilless crops are characterized by high levels of nitrates, phosphorous and potassium and very low levels or absence of organic matter or dissolved organic carbon (Narváez et al., 2011). Therefore, leachates produced in intensive horticulture must be collected, reused and eventually treated in order to prevent environmental pollution of water bodies (O.J., 2000; DOGC, 2009). In order to deal with leachates in pot plant nurseries, a new system, named CLEANLEACH® has been introduced through an Eco-innovation project funded by the European Comission. This new system, in line with the circular economy trends (Stahel, 2016), especially circular agriculture, consists of a technological package divided into two techniques (Marfà et al., 2016): a) Horizontal sand bed that acts as slow sand filter, disposed on the base of the permeable areas of cultivation in containers. This system has been evaluated at pilot scale with satisfactory results, minimal maintenance and low cost of implementation (Marfà et al., 2006) and b) Purification using a horizontal subsurface flow constructed wetland (CW). CW try to emulate natural wetlands and are composed with shallow ponds or channels with wetland vegetation, where decontamination processes occur through interaction between water, substrate, plants and microorganisms.

Both systems are on-site technologies that should be monitored, particularly, CWs. Constructed wetlands are simple and sustainable techniques with a low energy demand that are being used to purify different effluents (Wu et al., 2014). It has been demonstrated that horticultural leachates can be treated using CW in which denitrification process under anaerobic conditions are promoted (Narváez et al., 2011; White, 2013; Park et al., 2015).

Previous studies have been carried out to design and setting up the system adapted to nursery leachate characteristics containing high nitrate concentration (Narváez et al., 2011). In such studies, high denitrification rates have been achieved through the use of an appropriate carbon source dosage. Monitoring of nitrate and

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other chemical species is desired during the nitrification or denitrification processes for treating wastewater. Standardized methods are proven to give reliable and comparable results of wastewater quality parameters, but are mainly based on sample collection and retrospective analysis, which makes their application to real-time monitoring and process control very difficult (Drolc and Vrtovšek, 2010).

In recent years, the incorporation of sensors in the context of agriculture production for water management has received an increasing interest for water management purposes, for example (Gutiérrez et al., 2007; Navarro-Hellín et al., 2015; Fernández-Pacheco et al., 2015; Jiménez-Buendía et al., 2015). However, no information is currently available on tools used to monitor the performance of CWs in terms of nutrient removal efficiency. Nor is information available on the use of Information and Communication Technologies (ICT) tools to share news on this performance across the Internet. In order to offer the technology to the sectors concerned it is necessary to demonstrate the reliability of the system, to have tools to manage it properly, and to disseminate its performance. Therefore, the purposes of the study were: a) to demonstrate the feasibility of using online instruments to measure leachate ions in order to monitor CW performance and to manage it properly and b) to share this real-time data monitoring with the end users through a web App.

2. Material and methods

The implementation and development of the whole system were performed in two main stages. First stage was focused on online monitoring dealing with both, correlation between online measures and standardized analysis and to describe the evolution of online measures. The second stage focused on the definition of the architecture of the system and its implementation to achieve a suitable web App.

2.1. Online measurements

2.1.1. Constructed wetland pilot plant

The experiment was carried out in an intermediate-scale pilot plant, comprising six horizontal subsurface flow CW (HSSCW) made of concrete, constructed in a covered outdoor plot at IRTA in Cabrils (Spain) (41° 25′ N, 2° 23′ E). All beds were covered with a geotextile layer and high-density polyethylene (HDPE) to make the CW impermeable. A slope of 1% was required in the plot to maintain the hydraulic gradient of the beds. The inlet zone consisted of a pipe with 2 L h^{-1} emitters to regulate the flow (0.24 m^3 day^{-1}) per experimental line (Narváez et al., 2011). Two online instruments to monitor the CW were connected to one of the six available beds of the pilot plant at the inflow and outflow pipes (Figs. 1 and 2).

2.1.2. Online instruments

Nitrates, nitrites, potassium and phosphorus have been assessed by means of pieces of equipments that give real time information on the performance of the system. Technical and specifications could be checked at the website of the supplier (http://www.axflow.com) and main characteristics are:

2.1.2.1. Ionometer analyzer (K). The first instrument was a Potassium (K) analyzer to measure this element in the inflow and outflow of the constructed wetland, doing consecutive measures. This instrument is a PowerMon ionometer (Bran + Luebbe, Norderstedt, Germany). The ionometer is a device for the potentiometric measurements of substances dissolved in water. K$^+$ concentration is measured using an ion-selective electrode. The ionometer is permanently connected to the process to be analyzed by means of sampling lines; in this application two lines have been connected: line 1 (inflow) and line 2 (outflow).

Fig. 1. Constructed wetland (CW) module and on-line analyzers connected to the inflow and outflow pipes of the CW.

2.1.2.2. Multiparametric instrument (nitrates, nitrites and phosphates). The second instrument was the PowerMon S multiparameter on-line analyzer (Bran + Luebbe, Norderstedt, Germany) which can measure several parameters in one unit. This piece of equipment was designed to measure the following parameters: Nitrates (NO_3^-), nitrites (NO_2^-) and phosphates (PO_4^{3-}). Determination is based on spectrometric measurement in the UV/VIS range (200–710 nm). The instrument is permanently connected to the process to be analyzed by means of sampling lines (inflow and outflow).

Nitrate and nitrite are measured by the described direct spectrometry measures. However, phosphates do not absorb or absorb only weakly in the UV/VIS range and are measured by means of auxiliary chemical reactions, involving a color reaction. Samples and reagents are mixed by peristaltic pumps in an exactly defined ratio with the help of a mixing device and placed in a vessel to react. The reagents are chosen so that they form a colored compound with the component to be measured; the intensity of the color depends on the concentration of the measured phosphates.

The online instruments were calibrated daily at the beginning of the experiment and each three weeks at the end of the monitored period.

2.1.3. Influent (inflow) and sampling

The influent (inlet or inflow) of simulated nursery runoff containing representative concentrations of fertilizers was prepared using an automatic irrigation system MCU Ferti® (Multi Computer Unit; FEMCO, Damazan, France). The effluent (outlet or outflow) was the liquid that has suffered the treatment through the bed of the constructed wetland. The inflow and outflow pipes located in the wetlands were connected to the feeding lines of the two analyzers mentioned in Section 2.1.2.

To check the performance of the system, samples from inlet and outlet were taken at the same time that display readings of the two devices were written down. Sampling was performed during two months (11/05/2015–16/07/2015).

In order to check the response to changes of the measures made by the pieces of equipment, the set point of the electrical conductivity (EC) to manufacture the nutrient solution was downgraded periodically. The change in the EC set point would change the nutrient concentration. This variability in the inflow concentration would provide variability in the readings of the instruments.

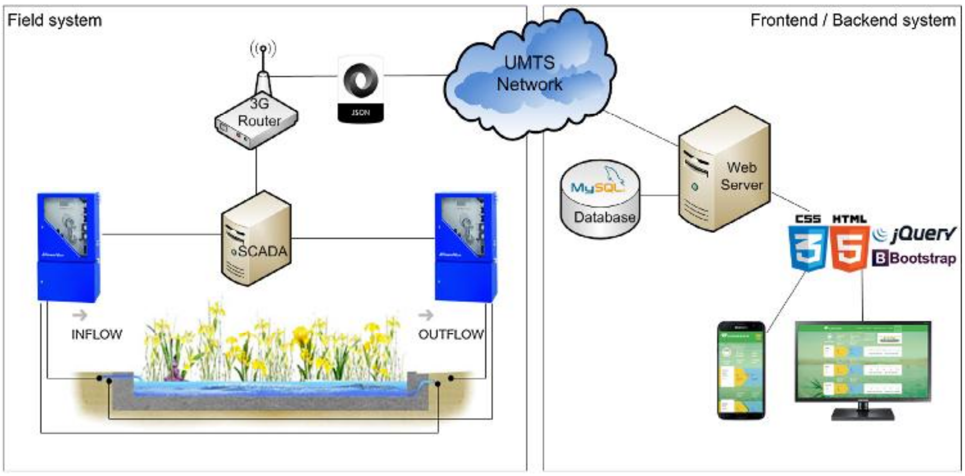


Fig. 2. Architecture of the system.

2.1.4. *Lab methods (standardized analysis)*

Samples were analyzed in the laboratory for the parameters that were measured on line. Nitrate-NO_3^-, Phosphate PO_4^{3-} and Nitrite-NO_2^- concentration were measured by ion chromatography with a Metrohm chromatograph model 761 Compact IC (Metrohm AG, Herisau, Switzerland) and K concentration was analyzed with a Varian inductively coupled plasma ICP-OES model Vista 730ES (Varian Australia Pty. Ltd. Scientific Instruments, Victoria, Australia).

2.1.5. *Statistical analysis*

An analysis of regression was carried out for each parameter between readings recorded with the on-line analyzers and the analysis performed using the standard method at laboratory. The software used to carry out the mentioned statistical analysis was JMP® 8.0.1 2009 (SAS Institute Inc. Cary, NC, USA).

2.2. *Architecture of the system to implement the web App and its development*

Architecture of the system to implement the web App and its development

To remotely acquire data from water plant sensors a small and distributed SCADA system has been developed. This system is composed by a set of applications and its corresponding hardware to allow acquisition, transmission and data process.

The architecture of the whole system has been represented in Fig. 2. The system is divided into two parts, one for the field system and other for the server system.

The field system composed with the described pieces of the equipment (Section 2.1.2), the personal computer (PC) and the 3G router are connected with a STP Cat.6 cable to a 100BASE-TX Ethernet switch (model DES.1005D, D-Link Corporation). The measurement equipment is configured with the function “UDPSEND( );” to send and UDP packet for every measured data to the PC. The program BBDataService.exe (runs as a service) was installed in the PC to automatically receive data sent from the instruments and store it into a text file. For each sensor, it creates automatically a text file with sensor/serial number as filename. For example, 00P101151.txt (Fig. 3a).

Each text file is parsed with the IRTAParser application (developed by Nadir Software Solutions) to send all measurements and its timestamp to the server system over a 3G Internet connection using JSON API to send data over HTTP protocol. The IRTAParser is a console application executed every 30 min to improve real time monitoring.

On the other hand, it should be highlighted that 3G transmission was used instead of other internet access technology. The used device was a router 3G (MTX-ROUTER-HELIOS 3G, Matrix-Flexitron group), with a SIM data card. In any case, the objective of this device was to have a wireless Internet service to transfer the data stored at the personal computer (PC) and, in this way, they would be visualized on the Internet.

The server system is composed by a web server and a database server. The web server has two functions: the first is to publish the API to receive the data from the field system and the other is to publish the web application. The database server is a MySQL (open source database) to store all received measurements, and data needed by the web application. These services are provided by the hosting contracted.The JSON API is developed in PHP and his main function is to receive and store the data from field system into the database.

Regarding the dissemination through the Internet, the solution consists of the development of a responsive web application to be shown in the maximum of possible devices.

The web application frontend is developed with Bootstrap 3, an HTML, CSS and Js framework. The backend is developed in PHP. Several needs were established in order to provide to both, end users and project team, tools to manage the system: main sensors data visualization, main information of the project consortium, a tool to gather data from sensors remotely, figure drawing based on the obtained data, high level of dissemination (languages), private area for administrators to manage the system and to allow the data visualization in mobile devices.

Finally, the web application is published as a common web and also is packaged into an Android application (Web App) to facilitate the access to the mobile users.

The Android application is a native Web App developed with the Android SDK using the Webview class, a simple way to show into a native applications a responsive website.

3. Results and discussion

3.1. *Online monitoring checking*

3.1.1. *Correlation between online measures and reference (or standardized) analysis*

The obtained pairs of data were submitted to analysis of the regression, as it has been described above. An analysis of regression was carried out for each parameter.

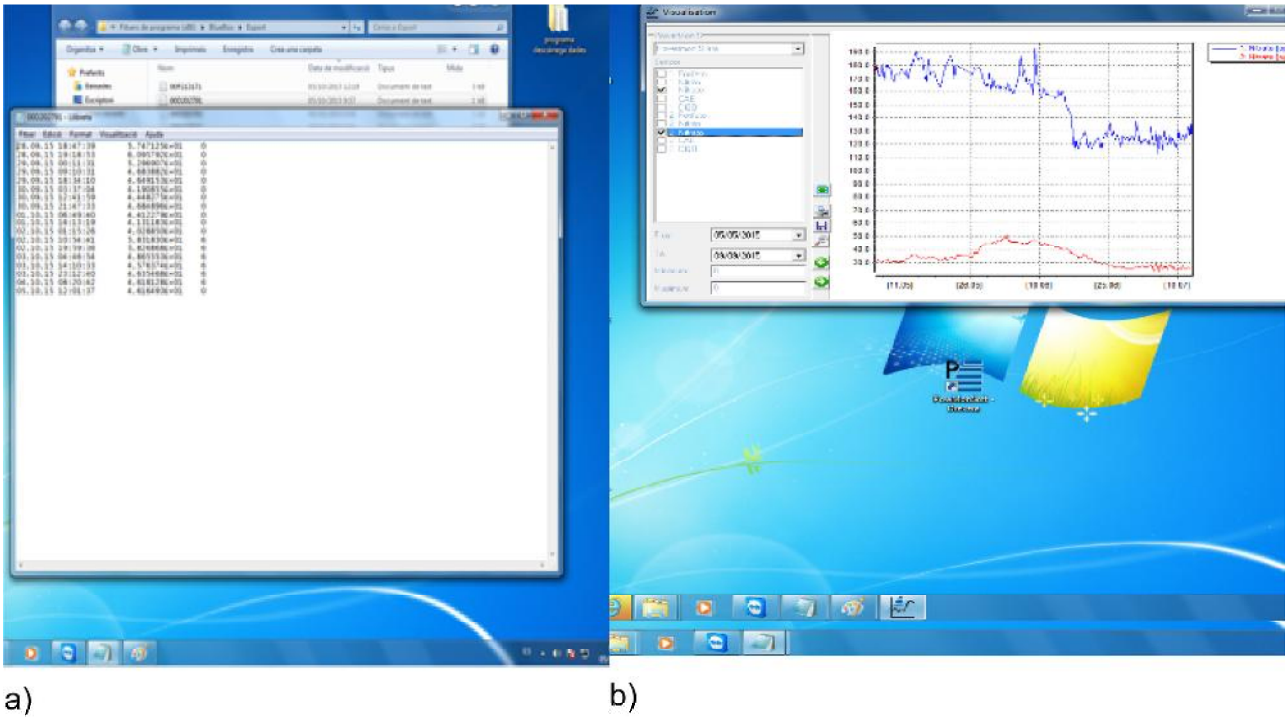


Fig. 3. View of the files being downloaded to the PC (a) and view of the program that allows data monitoring (b).

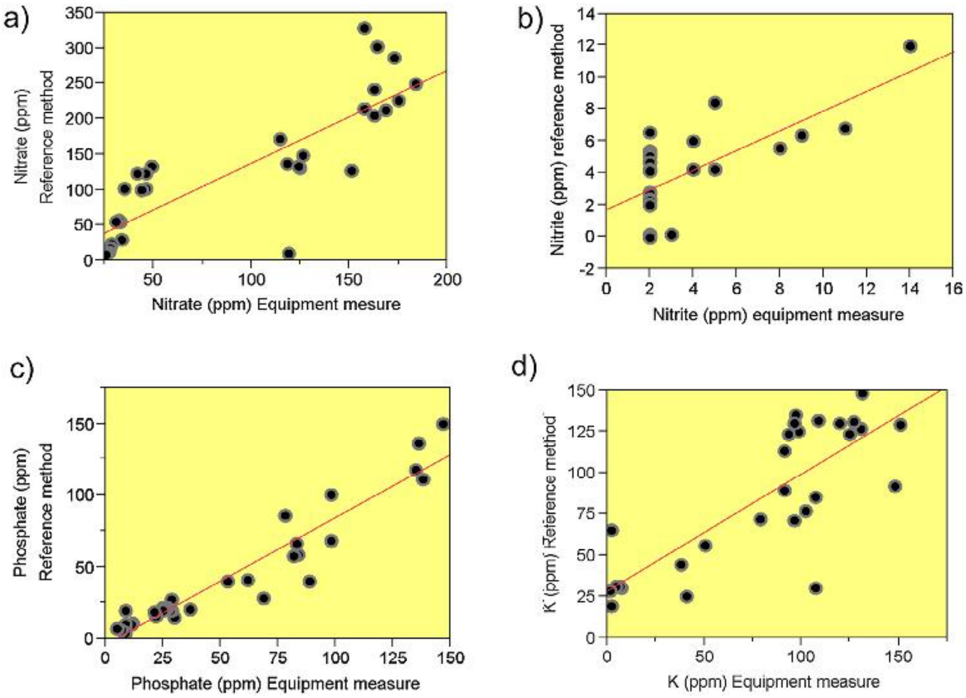
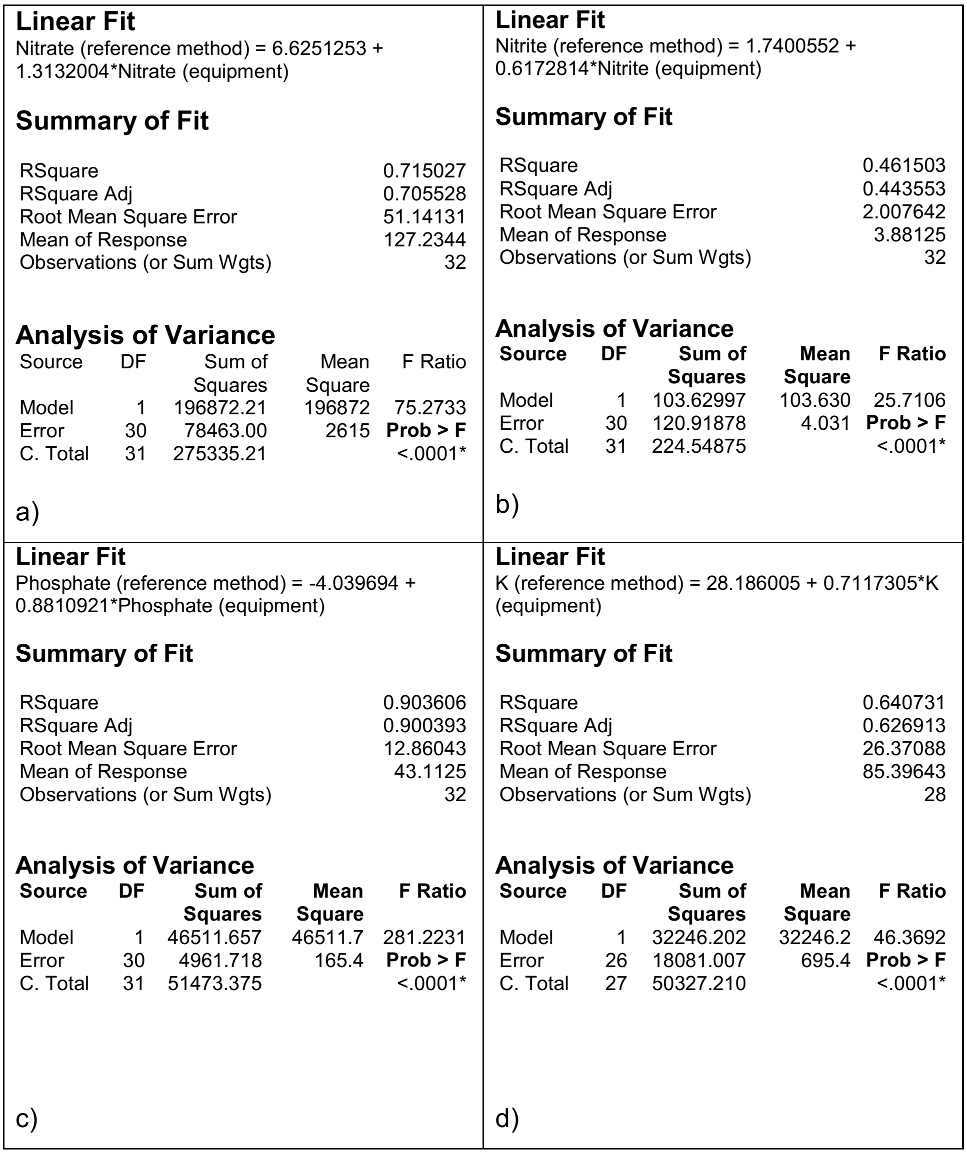


Fig. 4. Relationship between pairs of data regarding nitrates (a), nitrites (b), phosphates (c) and potassium (d) using the new equipment and the reference analysis method.

3.1.1.1. Nitrate. Results show that there is a good relationship between measures performed with the on-line analyzer (Equipment or instrument) and the measures of the same sample analyzed using the reference method (Fig. 4a). The analysis is significant from the statistical point of view and, therefore, a linear equation [Eq. (1)] correlates both parameters (Table 1a).

$$O_3^- [\mathit{Standardized\ \ method}] = 6.6251253 + 1.3132004 \times NO_3^- [\mathit{Analyzer}] \quad (1)$$

Table 1
Output of the analysis of the regression (linear fit, summary of fit and analysis of variance) for each parameter: nitrate (a), nitrite (b), phosphate (c) and potassium (d).



```
Linear Fit
Nitrate (reference method) = 6.6251253 +
1.3132004*Nitrate (equipment)

Summary of Fit

RSquare                              0.715027
RSquare Adj                          0.705528
Root Mean Square Error               51.14131
Mean of Response                     127.2344
Observations (or Sum Wgts)                 32

Analysis of Variance
Source     DF      Sum of      Mean    F Ratio
                  Squares    Square
Model       1   196872.21    196872    75.2733
Error      30    78463.00      2615   Prob > F
C. Total   31   275335.21              <.0001*

a)
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```
Linear Fit
Nitrite (reference method) = 1.7400552 +
0.6172814*Nitrite (equipment)

Summary of Fit

RSquare                              0.461503
RSquare Adj                          0.443553
Root Mean Square Error               2.007642
Mean of Response                      3.88125
Observations (or Sum Wgts)                 32

Analysis of Variance
Source     DF      Sum of      Mean    F Ratio
                  Squares    Square
Model       1   103.62997   103.630    25.7106
Error      30   120.91878     4.031   Prob > F
C. Total   31   224.54875              <.0001*

b)
```

```
Linear Fit
Phosphate (reference method) = -4.039694 +
0.8810921*Phosphate (equipment)

Summary of Fit

RSquare                              0.903606
RSquare Adj                          0.900393
Root Mean Square Error               12.86043
Mean of Response                      43.1125
Observations (or Sum Wgts)                 32

Analysis of Variance
Source     DF     Sum of      Mean    F Ratio
                 Squares    Square
Model       1  46511.657   46511.7   281.2231
Error      30   4961.718     165.4   Prob > F
C. Total   31  51473.375              <.0001*

c)
```

```
Linear Fit
K (reference method) = 28.186005 + 0.7117305*K
(equipment)

Summary of Fit

RSquare                              0.640731
RSquare Adj                          0.626913
Root Mean Square Error               26.37088
Mean of Response                     85.39643
Observations (or Sum Wgts)                 28

Analysis of Variance
Source     DF      Sum of      Mean    F Ratio
                  Squares    Square
Model       1   32246.202   32246.2    46.3692
Error      26   18081.007     695.4   Prob > F
C. Total   27   50327.210              <.0001*

d)
```

3.1.1.2. Nitrites. Nitrites are intermediate species in the denitrification process. When an appropriate carbon dose is added to the influent, in the pipes before entering in the constructed wetland, denitrification process could start at the pipes (Narváez et al., 2011). Results show that there is a good relationship between measures performed with the on-line analyzer (Equipment or instrument) and the measures of the same sample analyzed using the reference method (Fig. 4b). The analysis is significant from the statistical point of view (Table 1b) and, therefore, a linear equation correlates both parameters ([Eq. (2)]; Table 1b). In the present case, it should be mentioned that the measured nitrite readings were low. This fact could be explained because of the complete denitrification that would have been held in the CW (Narváez et al., 2011). Linked to this, readings of several samples using the reference method were <2 ppm (registered as 2 ppm) (Fig. 4b); that means that the readings were below the detection limit. In this regard, if the pairs of data corresponding to these samples had been removed from the statistical analysis, the parameters of the regression analysis would have been improved significantly (e.g. R^2 parameter) (Table 1b).

$$NO_2^- [Standardized\ method] = 1.7400552 + 0.6172814 \times NO_2^- [Analyzer] \tag{2}$$

Other authors have demonstrated the feasibility of using UV spectrometric methods for monitoring nitrates and nitrites in several kinds of wastewater, different from horticultural leachates (Drolc and Vrtovšek, 2010).

3.1.1.3. Phosphates. Results show that there is a good relationship between measures performed with the on-line analyzer (Equipment or instrument) and the measures of the same sample analyzed using the reference method (Fig. 4c). The analysis is significant from the statistical point of view (Table 1c) and, therefore, a linear equation correlates both parameters [Eq. (3)].

$$PO_4^{3-} [Standardized\ method] = -4.039694 + 0.8810921 \times PO_4^{3-} [Analyzer] \tag{3}$$

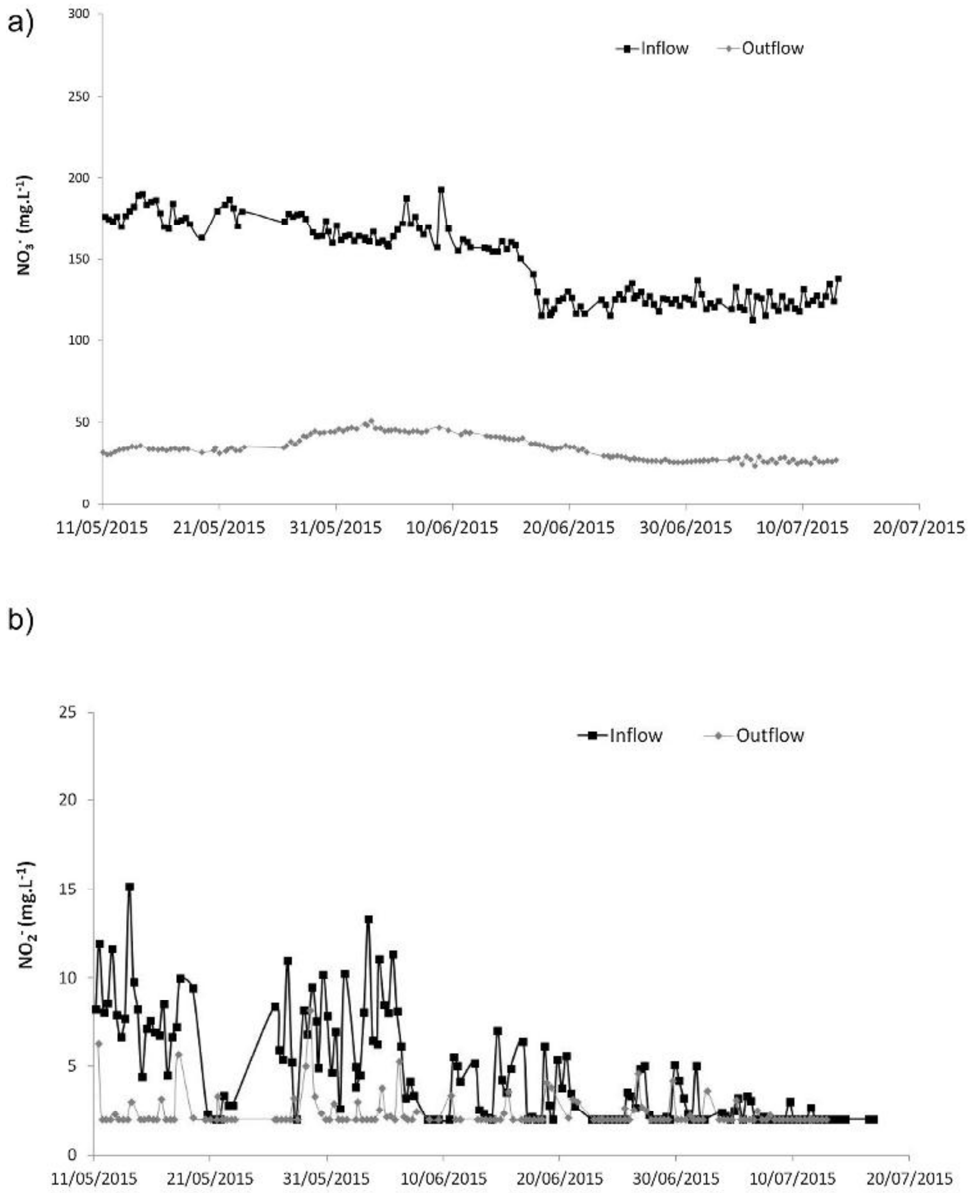

Fig. 5. Nitrate (a) and nitrite (b) concentration at the inflow and outflow of the constructed wetland located in the CW pilot plant.

3.1.1.4. Potassium. Results show that there is a good relationship between measures performed with the on-line analyzer (Equipment or instrument) and the measures of the same sample analyzed using the reference method (Fig. 4d). The analysis is significant from the statistical point of view (Table 1d) and, therefore, a linear equation correlates both parameters ([Eq. (4)]; Table 1d).

$$K^+\,[\mathit{Standardized\ method}] = 28.186005 + 0.7117305 \times K^+\,[\mathit{Analyzer}] \quad (4)$$

3.1.2. Continuous measures in the inflow and outflow using online instruments

As described above, the evolution of the concentration of different ions was monitored at the inflow and the outflow of the constructed wetlands.

3.1.2.1. Nitrates. The evolution of the nitrate content shows that inflow concentration was within the interval 200–100 mg L^{-1}. In contrast, readings registered at the outflow were below 50 mg L^{-1} (Fig. 5a). This difference is due to the denitrification process that is being produced in the CW (Narváez et al., 2011). Therefore, under the studied experimental conditions, the multiparameter analyzer was useful to monitor the performance of the CW at real-time.

3.1.2.2. Nitrites. Regarding nitrite concentration, Fig. 5b shows the evolution of the concentration of this parameter in both liquids (inflow and outflow). First of all, it should be stressed that the inflow concentration was quite low (~15 ppm), as well as the outflow concentration, which was still lower (~5 ppm). Therefore, the weak nitrite concentration in the inflow was reduced considerably after the treatment through the CW. This is the reason why the measurement system is suitable to monitor the whole denitrification process held in the constructed wetland, in which nitrites are also removed through denitrification (Narváez et al., 2011).

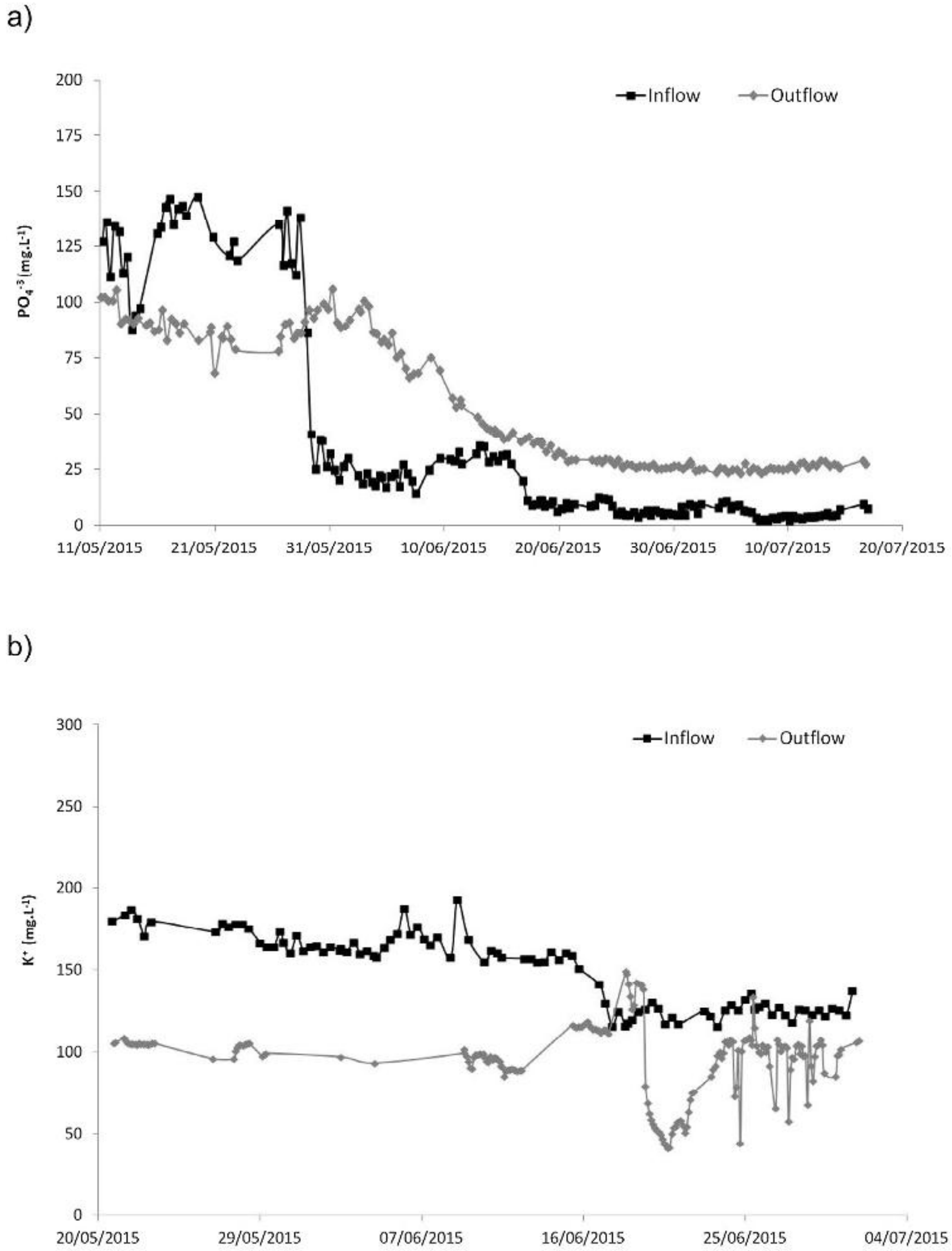

Fig. 6. Phosphate (a) and potassium (b) concentration at the inflow and outflow of the constructed wetland located in the CW pilot plant.

3.1.2.3. Phosphates. Regarding phosphates, results show that -in the first days of the monitoring- the phosphate concentration readings of the effluent (75–100 ppm) were kept below the concentration readings of the influent (∼125 ppm) (Fig. 6a). It means that during such days, the prevalent process in the wetland was the removal, probably by precipitation. However, during the next period, the phosphate readings of the inflow were maintained under the ones registered in the outflow. This pattern could have been explained because of the different pH of the different measured solutions in mentioned periods; however, pH was not determined in the trial.

In both cases, the trend was to downgrade concentration, and this is clearly linked to the EC set point scheduled to get variability in measures.

3.1.2.4. Potassium. Regarding potassium time-course, Fig. 6b shows that inflow readings were around 150 ppm, while readings measured in outflow were lower (∼100 ppm). It should been mentioned that CW does not have an effect on potassium removal; main processes sought in such systems are denitrification or precipitation (for N and P, respectively). Other monitoring measures should be performed in order to gain a deeper insight into the evolution of this parameter in CW.

To sum up, under the described experimental conditions, the online analyzers would represent appropriate instruments to monitor purification processes in CW for treating leachates. However, there is still room in research to check the feasibility of using cheaper sensors that could measure properly key parameters in wastewater treatment such ion selective electrodes (Beltran et al., 2002) or electronic tongues (Gutiérrez et al., 2007). Moreover, online measures of other CW performance parameters (e.g. chemical oxygen demand) should be investigated, particularly using cheap and reliable sensors (Gutiérrez-Capitán et al., 2015).

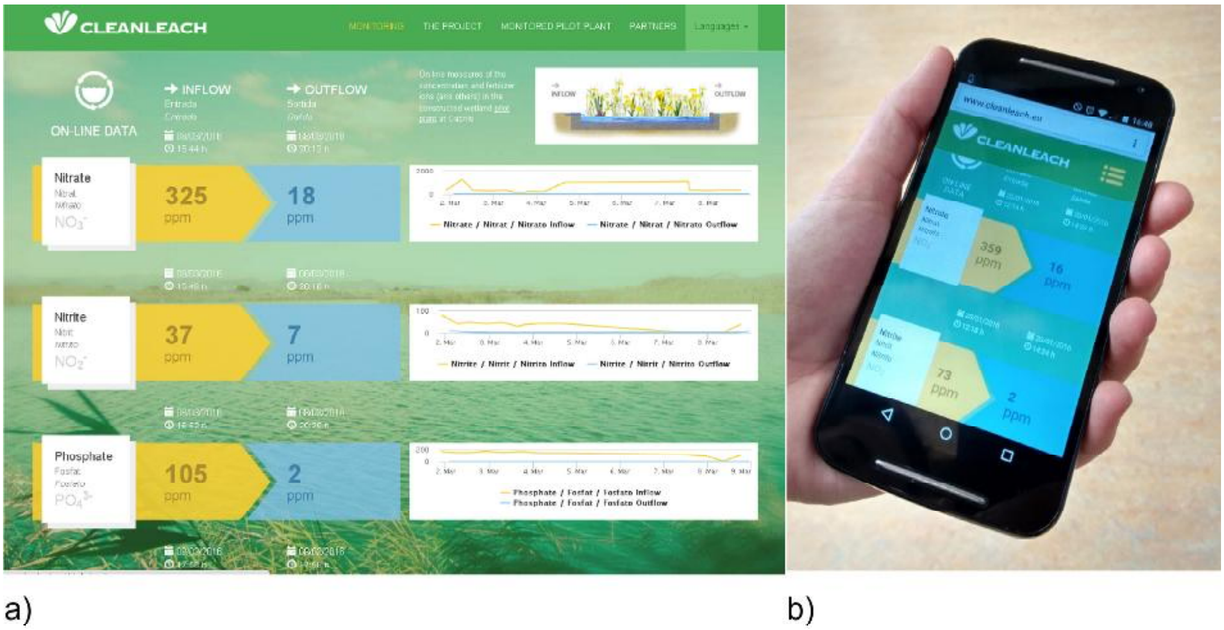

Fig. 7. Web application interface to monitor the constructed wetlands (CW) through the Internet (a) and mobile web app to monitor the CW.

Instead of the promising results achieved, further research is necessary to develop small, less energy consumption but sensitive sensors, which can provide real-time feedback signals for automatic optimization of operation parameters during water treatment processes; particularly, the continuous measure of dissolved organic matter content is needed (Li et al., 2016).

3.2. web App

It has been demonstrated that cheap Internet communication (3G) is enough to ensure the communication of the measuring unit with the server (Navarro-Hellín et al., 2015). The development of a Supervisory, Control and Data Acquisition (SCADA) (Jiménez-Buendía et al., 2015) application was necessary to store and gather data from sensors remotely.

Fig. 7a shows the screen of the web in which nitrate, nitrite and phosphate concentration could be checked at the inflow and outflow of the constructed wetland; a chart showing the last readings is also automatically displayed for each parameter. This was the main page of the web because real data on CW performance could be visualized in real time. Data are updated automatically. Fig. 7b shows a view of the mobile web App in which the same kind of data can be displayed. In addition, the administrator area allows the users to manage data visualization and to download data (tables or chart).

The development of the web App was successful regarding both, web version (available in www.cleanleach.eu/data) and App version, which is available in Google Play Store. It was developed in three languages.

The system proposed uses analyzers and communication technologies, allowing the end user to consult and analyze the information gathered by different sensors from any common device (computer, mobile phone or tablet) (Navarro-Hellín et al., 2015).

The web App does not incorporate any warning system. However, due to the troubles found through the development of the application, new improvements of the system would consider this issue.

4. Conclusions

The main objectives of this paper were, on one hand, to demonstrate the feasibility of using online instruments to measure leachate ions in order to monitor the CW performance and, on the other hand, to share this real-time data monitoring with the end users through a Web app. Main conclusions of this study are:

- According to the regression analysis results, under the described experimental conditions, the on-line analyzers are reliable instruments to measure nitrate, nitrite, phosphate and potassium ion. However, real samples gave too low nitrite content, resulting in worse regression parameters compared to the others.
- Monitoring of the constructed wetlands through the web is an effective tool that would contribute to show the feasibility of the system to the end users and also to manage properly the constructed wetland.
- These two conclusions demonstrated the innovativeness of the whole system to monitor the constructed wetlands through the Internet.

Future research should investigate cheap, small and effective sensors to monitor the performance of wetlands regarding main parameters (nitrates, phosphates and chemical oxygen demand).

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