# REUSE OF TREATED MUNICIPAL WASTEWATER AS A SUSTAINABLE APPROACH TO IRRIGATION AND FERTIRRIGATION IN MEDITERRANEAN COUNTRIES: A CASE STUDY

# RÉUTILISATION DES EAUX USEÉS MUNICIPALES TRAITÉES COMME APPROCHE DURABLE POUR L'IRRIGATION ET LA FERTIRRIGATION DANS LA MÉDITERRANÉE: UNE ÉTUDE DE CAS

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## ABSTRACT

Results of field experiments of wastewater reuse are presented. Two different crops (fennel and lettuce) were grown in succession on sandy loam soil and drip irrigated with three water sources: the effluent of the local full scale municipal wastewater treatment plant (WWTP), the effluent of a pilot scale non-conventional treatment technology, and a conventional source (well water). In order to evaluate the effects of higher ammonia and nitrate concentrations on crop yields and quality, the pilot plant was operated for partial nitrogen removal (mainly nitrification). Results showed that the pilot plant had better removal performance in terms of suspended solids and faecal indicators with respect to the full scale WWTP. As for the agronomic results, crop yields were significantly higher in plots irrigated with treated wastewater.

## RÉSUMÉ

Des résultats d'expérimentations de champ sur la réutilisation des eaux usées sont présentés. Deux cultures différentes (fenouil et laitue) ont été cultivées en suite sur un argileux et sablonneux sol et irriguées goutte à goutte avec trois sources d'eau: l'effluent de la local station d'épuration à pleine échelle pour le traitement des eaux usées municipales, l'effluent d'une technologie de traitement non conventionnel en étude pilote et une source classique (eau de puits). Afin d'évaluer les effets de plus hautes concentrations des ions ammonium et nitrate sur les productions et la qualité des cultures, l'usine pilote a été opéré pour la partielle élimination d'azote (surtout nitrification). Les résultats ont montré que l'usine pilote avait une meilleure performance d'enlèvement en termes de solides suspendus et d'indicateurs fécaux par rapport à la station d'épuration à pleine échelle. Quant aux résultats agronomiques, les productions des cultures ont été significativement plus élevées dans les parcelles irriguées avec les eaux usées traitées.

**Keywords:** Wastewater treatment; reuse; irrigation; agriculture

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# 1. Introduction

Water demands in the Mediterranean area can be barely covered by the conventional resources utilization (Blinda et al. 2007). Due to dry weather conditions and absence of surface water, Apulia (Southern Italy) is one of the European regions most heavily affected by water shortage and its freshwater supply only relies on groundwater. Nevertheless, the regional economy is strongly based on irrigated agriculture. For these reasons, groundwater resources were overexploited during the past decades, so causing a progressive groundwater salinization. Treated municipal wastewater is the most readily available non-conventional water resource to mitigate water stress in the Mediterranean area.

Within the EU funded project Water4Crops different types of treatment schemes are applied at the pilot scale to treat municipal wastewater and polish secondary effluents for reuse in irrigation. In the present study, results from test field experiments carried out at Castellana Grotte (Apulia) are presented.

# 2. Material and Methods

## 2.1 Wastewater treatment plants

The reclaimed wastewater streams used to irrigate the experimental field were the effluent of the local full-scale municipal wastewater treatment plant (WWTP) and the effluents of a pilot plant installed at the WWTP facilities (IMBR).

The full-scale WWTP had a conventional scheme, whose tertiary treatments consisted of coagulation-flocculation, sand filtration and chlorination.

The pilot plant treated the raw municipal wastewater through a biological process, called IFAS-MBR (Integrated Fixed film Activated Sludge Membrane BioReactor (De La Torre et al. 2013)), and a subsequent ultraviolet (UV) radiation, operated only during irrigation (on-demand disinfection). The IFAS-MBR was composed of an aerated IFAS reactor for nitrification and COD (Chemical Oxygen Demand) removal and a membrane bioreactor, where solid/liquid separation was provided through submerged membranes (GE Water) and with a nominal pore size of 0.1 µm. The IFAS technology is based on the presence of plastic carriers in the aerobic bioreactor. These carriers promote biofilm growth, therefore biological processes are carried out synergistically by the suspended biomass and the biofilm. In the present activity, the effluent from the IFAS-MBR plant was accumulated into storage tanks (30 $m^3$) in order to comply with the volumes required for irrigation of the experimental field. The outlet of these tanks was connected to a closed vessel UV disinfection system, that was automatically activated when the irrigation line was switched on. The UV (UV-C) lamps were housed inside a stainless steel cylindrical reactor and placed parallel to the water flow.

## 2.2 Irrigation of crops

In a 2000 $m^2$ experimental field, located immediately outside the main treatment plant, two different crops, lettuce and fennel, were grown in succession. The reclaimed wastewater streams (WWTP, IMBR) were pumped directly from the treatment plants to the irrigation system serving the experimental field. The conventional water (control) was well water. For both crops, drip irrigation was adopted by placing the dripping lines between every other row. Crops were irrigated when the soil water deficit (SWD) in the root zone was equal to 35% of the total available water (TAW). Irrigation was scheduled based on the evapotranspiration criterion, providing water to the crops when the following conditions were met: $\Sigma_1^n(E_{tc} - Re) = 30$ for lettuce and 25 for fennel, where $E_{tc}$ is the evapotranspiration and $R_e$ is the rainfall (mm). The experimental field was cultivated according to the agronomical practices (fertilization, pest and weed control) commonly adopted by the local farmers. In order to evaluate effects of irrigation with a water source containing a high concentration of nitrogen, the IFAS-MBR pilot plant was operated for partial nitrogen removal.

## 2.3 Analyses

Reclaimed water quality was monitored in terms of chemical and microbiological parameters and compared with conventional water. Microbiological indicators Escherichia Coli (E. coli) and Salmonella spp were measured at harvesting time in soil and on the edible parts of crops. Nitrates concentration and water content of the crops and the organic fraction of the soil were also measured. Moreover, for the pilot plant, the pathogen indicators Clostridium perfrigens (C. perfrigens)and Somatic Coliphages were determined. Analyses were performed according to standard methods (APHA 2005, MAF 1992, Scharf 1966).

# 3. Results and discussion

## 3.1 Reclaimed wastewater quality

Average values of the main parameters characterising the effluents of the three treatment plants are reported in Table 1. The effluent of the full scale WWTP complied with the local standards for reuse in agriculture, except for *E .coli*. Considering that the pilot plant was operated only for partial nitrogen removal, results indicate that the pilot plant treatment scheme has the potential for producing water suitable for agricultural reuse (e.g. complying with local laws). *E. coli* in the effluent of the IFAS-MBR was never detected, but its concentration varied between 0 and 142 CFU/100mL in the reservoirs where the effluent of the IFAS-MBR was accumulated, suggesting microbiological contamination or bacteria regrowth in the storage tanks. The final disinfection step, operated by a closed vessel UV system, was effective, since *E. coli* in the UV outlet was below 10 CFU/100mL on average. Also the indicator *C. perfrigens* was never detected in the effluent of the IFAS-MBR. However, its presence was observed in the effluent of the UV disinfection system, even if at very low concentrations, confirming possible contamination of the storage tanks. The membrane ultrafiltration allowed a consistent abatement (about 4 log) of Somatic Coliphages. An additional 2 log removal of Somatic Coliphages was achieved by the UV radiation.

Table 1. Characteristics of the effluents of the treatment plants are compared with the conventional water and with the local limits for reuse. Average values (±standard deviations) of a two-years period are shown.

| Parameter | Control | WWTP | IMBR | Local limits for reuse |
|---|---|---|---|---|
| Electrical Conductivity (µS/cm) | 888±420 | 989±170 | 764±88 | 3000 |
| pH (-) | 7.5±0.3 | 7,7±0.2 | 7.1±0.5 | 6.0-9.5 |
| Chemical Oxygen Demand ($mgO_2/L$) | <15 | 67.1±55.4 | 19.5±5.4 | 100 |
| $NH_4^+$ (mgN/L) | <2 | <2 | 2.6±7.0 | 2 |
| $NO_3^-$ (mgN/L) | 1.5±1.5 | 6.4±5.6 | 29.2±17.1 | 35^(*)^ |
| Total Phosphorus (mg/L) | 0.4±0.7 | 4.2±5.5 | 8.1±4.3 | 10 |
| Total Suspended Solids (mg/L) | <2 | 4.8±1.0 | <2 | 10 |
| Free Chlorine (mg/L) | <0.2 | <0.2 | <0.2 | 0.2 |
| Sodium Absorption Ratio (-) | 0.9±0.8 | 1.1±0.1 | 0.8±0.1 | 10 |
| *E. coli* (CFU /100mL) | 0±0 | 872±1292 | 0±1 | 10^(**)^ |
| *Salmonella spp* | Absent | Absent | Absent | Absent |

(*) Limit related to Total Nitrogen.
(**) Limit that has to be respected by 80% of the samples (maximum value=100 CFU /100mL).

### 3.2 IFAS-MBR pilot plant performances

The pilot plant was started-up in September 2012 at a flow rate of 800 L/h and membranes were operated according to cyclic periods of relax (1,25 min) and suction (9 min). No regular backwashing was performed. Immediately after start-up, several problems related to the presence of the carriers were observed. These caused clogging in several points of the plant and changes in piping and pumping were carried out in the following months. Steady state conditions for the biological reactor were reached only in February 2013.
The IFAS-MBR treatment plant allowed a complete removal (i.e. at least 90%) of COD and TKN. While COD removal was not significantly affected by the hydraulic problems occurred to the plant, the TKN removal strongly decreased after the interruptions required to unclog the piping system, showing the weakness of nitrifying bacteria. Anyway, one week was always sufficient to recover the nitrifying capacity after each stop.
During June and July 2013, with the plant operated at 600-800L/h (corresponding to an organic loading rate of 0.20 gCOD/gVSS/d), the presence of attached biomass on the plastic carriers submerged in the aerobic tank had been noticed. Since October 2013 the plant was operated at a lower flow rate (corresponding to an organic loading rate of about 0.15 gCOD/gVSS/d), and the biofilm attached to the carriers decreased consistently, indicating that the biofilm growth could be significantly limited under very low organic loading rates.
Until June 2014, the IFAS-MBR showed a good denitrifying capacity, with an average removal of $N\text{-}NO_x$ of 82±6%. In June 2014 the anoxic phase was eliminated from the pilot plant and the IFAS-MBR was operated for COD removal and nitrification. However, even after eliminating the anoxic phase from the biological process, a relevant denitrification activity was still observed (on average 43±16% removal of $N\text{-}NO_x$). This was probably related to the presence of anoxic zones in the oxidation tank. Furthermore the plastic carriers, due to the limited oxygen transfer in the biomass accumulated in their inner volume, have probably contributed to this phenomenon.

### 3.3 Effects on crops and soil

As can be seen from Table 2, crop yields were higher in plots irrigated with the pilot plant's effluent, if compared with the other sources of water used in this study. The higher content of nitrates in the pilot plant's effluent not only increased crop yields, but also resulted in an early ripeness. In fact for both crops there was a maturity advance variable from 8 to 30 days between IMBR and Control plots, respectively. The former provided, constantly at each watering, small but still significant amounts of nutrients to a soil, not very fertile, as that of Castellana Grotte.
Differences in terms of nitrate accumulation in the two crops were observed between the plots irrigated with different water sources. However, in all the cases nitrate concentration was clearly below the standard limit for commercialization.

Salmonella spp was absent in all the samples of soil and edible parts at harvesting time. *E. coli* concentration was always less than 10 CFU/10g, except for one sample of edible parts of lettuce.

Table 2. Crop yields (t/ha) obtained during the year 2013 in plots irrigated with the reclaimed wastewater streams and with conventional water.

| Crop | Control | WWTP | IMBR |
|---|---|---|---|
| Lettuce | 34.2 | 38.5 | 53.6 |
| Fennel | 31.6 | 29.8 | 38.7 |

## 4. Conclusions

The wastewater treatment pilot plant composed of an advanced biological reactor (IFAS-MBR) and an UV disinfection system produced effluent water suitable for agricultural reuse (complying with local laws). The quality of produced effluents was higher than that observed for the full scale wastewater treatment plant.

Managing the biological process only for partial nitrogen removal allowed the supplying of a consistent fertilization contribution with the irrigation water. This had positive effects on yield and growth rate of both lettuce and fennel, without affecting the qualitative characteristics of the crops.

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## REFERENCES

APHA, AWWA, WEF, 1995. Standard, Methods for the Examination of Water and Wastewater, 19th ed., American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC.

Blinda, M., Boufaroua, M., Carmi, N., Davy, T., Detoc, S., Froebrich, J., Gabina, D., Iglesias, A., Khalid, A.L., Khalifa, E., Margat, J., Moneo, M., Tagar, Z, 2007. Technical report on water scarcity and drought management in the Mediterranean and the Water Framework Directive, Mediterranean Water Scarcity & Drought Working Group, European Commission. Available from: http://www.emwis.net/topics/WaterScarcity/ [Accessed 2 September 2015].

De La Torre, T., Rodriguez, C., Gomez, M.A., Alonso, E., Malfeito, J.J. (2013) The IFAS-MBR process: a compact combination of biofilm and MBR technology as RO pretreatment Desalination and Water Treatment, 51, 1063-1069.

MAF (Ministero dell’Agricoltura e delle Foreste), 1992. Metodi ufficiali di analisi chimica del suolo. Gazzetta Ufficiale, Serie Generale n.121, Suppl. Ordinario n. 79 (in Italian).

Regional Regulation n. 8, 2012. Rules and measures for the reuse of treated wastewater, Law no. 152/2006, Art. 99, paragraph 2 of Apulia Region and Law N. 27/2008, art. 1 paragraph 1 letter b), Official Bulletin of the Apulia Region, n. 58 of 20/04/2012.

Scharf, J.M., 1966. Recommended methods for the microbiological examination of foods, 2nd ed. New York: APHA.