Environmental Criteria for Alternative Nutrient Removal in Treated Wastewater

J.Muñoz* and L. Sala**

* Empresa Mixta d'Aigües de la Costa Brava S.A. Plaça Josep Pla 4, 3rd floor. E-17001 Girona, Catalonia (E-mail : jmunoz@aiguescb.com)
** Consorci de la Costa Brava. Consorci de la Costa Brava. Plaça Josep Pla 4, 3rd floor. E-17001 Girona, Catalonia (E-mail: lsala@ccbgi.org)

Abstract. Even though wastewater treatment plants have reduced the amount of pollution, in some places discharges are still causing eutrophication. Nutrient removal is usually achieved by upgrading WWTPs by the inclusion of nitrification/denitrification schemes in the case of nitrogen, and of chemical removal facilities in the case of phosphorus. However, perceptions have changed in places where wastewater reclamation and reuse for irrigation has developed. Users of reclaimed water for irrigation benefit from both the water itself and its nutrients, reducing their need for external fertilizers and making important savings. In parallel, recycling nutrients means that these nutrients are not discharged, which means that discharges are reduced while still keeping the same biological reactors. In a given WWTP and when a future upgrade targets nutrient removal, options are expanded if water recycling is considered, especially in the case of the irrigation of high yield crops such as maize. Comparisons of energy consumption for the different alternatives and of balances of CO_2 may reveal new clues on how to tackle nutrient removal in the most effective and environmentally friendly way. This paper aims at providing the rationale for these new criteria, based on a case study of agricultural reuse in the Costa Brava.
Keywords: environmental protection, nutrient removal, water recycling, fertirrigation, sustainability.

INTRODUCTION

The Castell-Platja d'Aro WWTP (35,000 m^3/day and 175,000 p.e) started operation in 1983 and operates according to a conventional activated sludge system with no nutrient removal, followed by a reclamation treatment consisting of filtration and disinfection. Since 1989, reclaimed water has been successfully supplied for agricultural and golf course irrigation, including 25 hectares for fields of maize in Solius (Santa Cristina d'Aro, Costa Brava, Catalonia). Lately, a big interest in the expansion of these irrigation schemes to other farming activities in the area has appeared. Since the early days of golf course irrigation with reclaimed water in the area, nutrient contributions have been accounted for and information has been given to users for efficient agronomic management and fertilizer savings. Reclaimed water from the Castell-Platja d'Aro WWTP is rich in nutrients, mainly nitrogen, which is very suitable for high yield crops such as maize. Average nutrient concentrations in the reclaimed water produced during the irrigation season of 2006 were: total nitrogen, 42 mg N/L; total phosphorus, 3.0 mg P/L; potassium, 20 mg K/L. The first half of 2006 was very hot and dry, and irrigation demand was higher than usual, which caused nutrient contributions to be greater than historical values. These contributions were excessive for golf course turfs, mostly because of nitrogen, but were very welcome for maize, being even higher than the theoretical demand. In 2006, yields from the corn fields irrigated with reclaimed water accounted for 70 tons fresh matter/ha, which is an average level of production in the area; however, they were achieved without application of nitrogenous mineral fertilizers, due to the high irrigation demand already making itself felt from the start of the season. Nutrient contributions to the maize fields accounted for 138% of theoretical nitrogen demand, 52% of that for phosphorus and 71% of that for potassium. These data show that maize cultivators' requirements for water and nutrients match what WWTPs in Mediterranean tourist areas can offer, so the use of reclaimed water for maize irrigation can also be taken into account as a technique for pollution abatement. Where plans for the upgrading of WWTPs to include nitrogen removal are being made, the supplying of reclaimed water for agricultural irrigation, especially if fields of maize or similar crops are available in the area, should be considered. Energy costs related to water treatment (the N/DN step and/or the reclamation process) and water transportation should be compared to the savings permitted by the presence of mineral fertilizers already within the reclaimed water, when assessing what the soundest alternatives are for better environmental protection. A similar approach is proposed by Hatziconstantinou and Andreadakis (2002).

IRRIGATION OF CORN WITH RECLAIMED WATER IN SOLIUS

Economic evaluation

The change of irrigation water in the corn fields of Solius has allowed a comparison of the costs of irrigation and fertilization related to the use of groundwater (until 2004) and to the use of reclaimed water (from 2004 on). As can be seen in Table 1, when water is extracted from wells running on electrical energy, irrigation costs are lower than the water coming from wells operating with gasoil pumps. Fertilization costs are estimated according to the total theoretical fertilizer demand when groundwater is used, whereas for each type of reclaimed water the individual nitrogen, phosphorus and potassium contributions have been taken into account. Data for reclaimed water with a high nutrient content have been gathered from the actual supply to the Solius maize fields, whereas those for water with a low nutrient content have been estimated using data from the Pals WWTP, an extended aeration plant that supplies reclaimed water for golf course irrigation in the central Costa Brava area, as if it had been used as irrigation water in Solius. These data prove that in the Solius area the use of reclaimed water is the option with the lowest overall running costs, even if low-nutrient water is used. On the other hand, the use of wells in which the pumps run on gasoil is the alternative with the highest cost, 2.6 times more expensive than that in which high nutrient-content reclaimed water is used and double the cost of using reclaimed water with a low nutrient content.

Table 1. Comparison of the energy and fertilization costs, in €/ha.year, of corn production with groundwater and reclaimed water in the Solius area (Santa Cristina d'Aro, Costa Brava, Catalonia) during 2006.

Costs	Solius irrigation area, €/ha.year			
	Groundwater		Reclaimed water	
	Wells running on electrical energy	Wells operating with gasoil pumps	High nutrient content (a)	Low nutrient content (b)
Extraction (groundwater) or transportation (reclaimed water) + irrigation	287	632	355	355
Fertilization	409	409	44	168
Total	696	1,041	399	523

(a) Reclaimed water produced in a conventional activated sludge plant with no nutrient removal processess.
(b) Reclaimed water produced in an extended aeration plant with nitrogen removal.

Due to these economic benefits and to the fact that present day reclaimed water supply from the Castell-Platja d'Aro WWTP accounts for only 30% (August 2006) to 50% (June 2006) of total effluent production, interest has been shown by nearby farmers in expanding the irrigation schemes with reclaimed water to other maize fields in the area. The ones further away from the Castell-Platja d'Aro WWTP are located in the municipality of Llagostera, 10 km away and 175 m higher in altitude, and they have also been used for the comparison of the economic costs of the use of reclaimed water versus those derived from the use of groundwater, which include the application of mineral fertilizers (Table 2). Groundwater in the Llagostera area is extracted from depths that range from 80-120 metres, which implies even greater energy consumption than in the case of Solius.

As shown in Table 2, the two options with the lowest cost, even in the case of the most distant maize fields in Llagostera, are those in which reclaimed water is used. The fertilizer savings are able to compensate the higher energy costs even in the case of the wells running on electric energy, which are the option with the lowest energy cost. To be competitive with reclaimed water, groundwater should come from very shallow wells. This is not the case in the Solius-Llagostera area, nor in many of the other agricultural areas in the Mediterranean, so under these circumstances reclaimed water appears as a highly competitive source of irrigation water, even if it has to be transported some distance. Thus, in areas like these, the option of upgrading wastewater treatment plants for nutrient removal should be examined carefully, since higher nutrient concentrations mean that water can be transported greater distances and still produce savings. Reclamation treatments and transportation facilities (pumps and pipelines) should also be taken into account in parallel to new biological reactors when it comes to investments to be made, especially if farmers release valuable amounts of groundwater that can be used for improved urban supply to villages and tourist areas.

Table 2. Comparison of the energy and fertilization costs, in €/ha.year, of maize production with groundwater and reclaimed water in the Llagostera area (Catalonia) during 2006.

Costs	Llagostera irrigation area, €/ha.year			
	Groundwater		Reclaimed water	
	Wells running on electrical energy	Wells operating with gasoil pumps	High nutrient content (a)	Low nutrient content (b)
Extraction (groundwater) or transportation (reclaimed water) + irrigation	359	562	538	538
Fertilization	409	409	44	168
Total	768	971	582	706

(a) Reclaimed water produced in a conventional activated sludge plant with no nutrient removal processes.
(b) Reclaimed water produced in an extended aeration plant with nitrogen removal.

Table 3. Comparison of the CO_2 balances of the production of wheat (dry farming) and maize irrigated with high nutrient reclaimed water on 217 ha of farmland (a) in the Llagostera area (Catalonia).

CO_2, tons/year	Type of crop	
	Wheat (dry farming)	Maize in the Llagostera area irrigated with high nutrient reclaimed water
Activities that produce CO_2 emissions (b)		
Production of fertilizers (c)	+ 38 (d)	+ 14 (f)
Reclamation treatment	-	+ 119 (g)
Transportation of water + irrigation	-	+ 317 (h)
Total emissions	*+ 38*	*+ 450*
Activities that reduce CO_2 emissions		
Crop production	- 2,430 (e)	- 5,664 (i)
Energy savings in WWTP	-	- 34 (j)
Total emission reduction	- 2,430	- 5,698
Overall CO_2 balance	**- 2,392**	**- 5,248**

(a) Maximum surface to be irrigated with reclaimed water from the Castell-Platja d'Aro WWTP. All calculations for both crops have been based on this surface, for a proper comparison.
(b) Average CO_2 emission of energy production in Spain in year 2006: 396 g CO_2/kWh (Ministerio de Industria, Turismo y Comercio, 2007)
(c) Emission in fertilizer production: 1,97 tons of CO_2/ton of nitrogen (Kongshaug, 1998).
(d) Nitrogen requirements of wheat: 90 kg N/ha.year.
(e) Uptake of CO_2 by wheat: 11.2 tons CO_2/ha.year (Johnson *et al*, 2006).
(f) Total nitrogen requirements of corn: 262 kg N/ha.year; nitrogen requirements of maize when high nutrient reclaimed water is used 32 kg N/ha.year.
(g) Based on the reclamation of 1,000,000 m^3/year with an energy consumption of 0.3 kWh/m^3.
(h) Energy cost of transportation between WWTP and maize fields in Llagostera: 0.8 kWh/m^3. Irrigation dose: 4,600 m^3/ha.year.
(i) Uptake of CO_2 by maize: 26.1 tons CO_2/ha.year (Johnson *et al*, 2006).
(j) Energy savings of not transforming the biological process from conventional activated sludge to extended aeration have been estimated at 0.085 kWh/m^3.

Environmental evaluation

Given the fact that energy is consumed in several activities related to agricultural production (fertilizer production, water transportation and irrigation), the proposed expansion of the use of reclaimed water for the irrigation of maize fields in Llagostera has also been evaluated from the environmental point of view in terms of CO_2 balances. Its impact has been compared with that of dry farming in areas which are not under irrigation due to either lack of water or to high costs, but that could be turned into maize fields if reclaimed water were available. As shown in Table 3, CO_2 emissions associated with dry farming are 11.2 times lower (only 38 tones of CO_2/year) than those produced by the production of maize with reclaimed water (450 tones of CO_2/year), since fertilizer demands are lower and no irrigation is needed. However, the uptake of atmospheric CO_2 by maize is 2.2 times greater than that of wheat, which clearly offsets those emissions and renders a much more favourable CO_2 balance, in which the net uptake by maize fields is more that double of that by wheat fields. Data also show that the increase in CO_2 emissions that would cause the upgrade of the biological reactor from a conventional activated sludge type to an extended aeration one are even smaller than those associated with the reclamation treatment itself, and thus negligible in overall terms.

CONCLUSIONS

Based on data gathered from the corn fields grown in the Solius area, the reclaimed water supplied from the Castell-Platja d'Aro WWTP is the most favourable option for irrigation available in the area. Fertilizer savings offset the higher energy costs, even if lower-nutrient reclaimed water is used. The same has been proved true for maize fields located in Llagostera (10 km away and 175 m higher in altitude), where groundwater is abstracted from wells that range between 80 and 120 m in depth. When analysed from the environmental point of view, in terms of CO_2 balances, the conversion of dry farming areas into maize fields in the Llagostera area by using reclaimed water and its nutrients also doubles the atmospheric CO_2 uptake. Thus, in the Mediterranean areas factors such as: a) options for water reuse for agricultural irrigation; b) type of crops; and c) sources of irrigation water, are also to be taken into account at the planning phase of the construction of new wastewater treatment facilities or the upgrading of existing ones, since they can provide a new set of criteria that could be used for better decision making from an overall environmental point of view.

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