Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar

Spanish Journal of Agricultural Research 2010 8(S2), S95-S101
ISSN: 1695-971-X
eISSN: 2171-9292

Twenty-five years using reclaimed water to irrigate a golf course in Gran Canaria

E. Estevez[1], M. C. Cabrera[1], J. R. Fernandez-Vera[2], J. M. Hernandez-Moreno[3], V. Mendoza-Grimon[4] and M. P. Palacios-Diaz[4]*

[1] *Departamento de Física. Universidad de Las Palmas de Gran Canaria. Campus Tafira. 35017 Las Palmas de Gran Canaria. Spain*
[2] *Granja Agrícola Experimental del Cabildo de Gran Canaria. Las Palmas Arucas, km 6,5. 35416 Arucas. Spain*
[3] *Departamento de Edafología y Geología. Facultad de Biología. Universidad de La Laguna. 38204 La Laguna. Spain*
[4] *Departamento de Patología Animal, Producción Animal y Ciencia y Tecnología de los Alimentos. Universidad de Las Palmas de Gran Canaria. 35416 Arucas. Spain*

Abstract

Low focus in water management and short time data availability are the main limiting factors for reclaimed water project analysis. One of the oldest Spanish golf courses with a medium period of available data was selected to study and describe the medium time effects (25 years) on soil and aquifer as a consequence of reclaimed water reuse, and to compare the experimental results with reclaimed water quality criteria under a sustainability point of view. An excess of reclaimed water (83%) is used for this golf course irrigation in spite of the high water price (€ 0.4 m^{-3}). The excess water reduced the risk of substances accumulation in soils, but for several of them the foresaid excess increased the possibility of polluting the aquifer (nitrates). Experimental data confirmed sustainability water quality criteria which predicted phosphorus and boron accumulation in soil. Soil characteristics and water management have to be also considered as critical factors to explain water quality effects in land and environmental conditions.

Additional key words: medium time irrigation; reclaimed water; reuse; soil; sustainability and risk; water quality.

Resumen

Veinticinco años regando con agua depurada un campo de golf en Gran Canaria

Tradicionalmente se ha prestado escasa atención a la importancia del manejo del agua sobre los efectos de la reutilización en el suelo, la especie regada y el medio ambiente. Además no suelen estar disponibles series de datos lo suficientemente largas para poder aplicar los criterios de sostenibilidad. Por ello se ha realizado este estudio en uno de los campos de golf más antiguos de España, Real Club de Golf de Las Palmas, que dispone de series de datos muy completas. Se ha comprobado que, pese al alto precio pagado por el agua (0,4 € m^{-3}), se riega con un exceso muy elevado (83%). Este exceso reduce el riesgo de acumulación de sustancias en el suelo pero potencia su posible llegada al acuífero, como ocurre con los nitratos. Asimismo, se ha comprobado la validez de los criterios de sostenibilidad, que predecían la acumulación de sustancias en el suelo (P y B), y el efecto de las características del suelo y el manejo del agua en la respuesta del medio a la misma, por lo que también deben ser considerados factores críticos de análisis.

Palabras clave adicionales: calidad del agua; reutilización; riego a medio plazo; sostenibilidad y riesgo; suelo.

Introduction

Reclaimed water project success is based on considering not only risk principia but also the sustainability point of view (Jensen *et al.*, 2001). Apart from the papers related to sanitary aspects there are many papers analysing water quality but many of them consider agronomical criteria proposed for conventional resources

* Corresponding author: mpalacios@dpat.ulpgc.es
Received: 20-10-09; Accepted: 30-09-10.

Abbreviations used: COD (chemical oxygen demand), EC (electrical conductivity), ETo (reference crop evapotranspiration), LF (leaching fraction), OM (organic matter), SAR (sodium adsorption ratio), SS (suspended solids).

(*e.g.* Ayers and Westcot, 1985). Reclaimed water usually contains appreciable quantities of nutrients as nitrogen (N) and phosphorus (P) or boron (B) which can affect soils, crops or environment. That is why for reclaimed water projects analysis, agronomical criteria based on short time consideration (risk) has to be complemented by other criteria considering long time effects (sustainability) (ANZECC-ARMCANZ, 2000; USEPA, 2004). At the same time, reclaimed water consequences are based not only on water quality as same as on irrigation design and water management (Assadian *et al.*, 2005; Palacios *et al.*, 2008). Thus, low focus in water management and short time data availability are the main limiting factors for reclaimed water project analysis.

A Spanish project named «CONSOLIDER-TRAGUA», related mainly with reclaimed water quality and management aspects is financed by Spanish Ministry of Science and Innovation. A golf course «Real Club de Golf de Las Palmas», one of the oldest of Spain and with a long period of available data, was selected to study sustainability and risk water quality criteria suitability.

Irrigation with reclaimed water from the Las Palmas de Gran Canaria treatment plant is used since 1976. Effluent quality improvement has been associated with water treatment plant modifications. Since 2002, the effluent quality significantly enhanced due to the installation of a desalination treatment (BOC, 1999; Fernández, Consejo Insular de Aguas personal communication, 2009).

The aims of this paper were: to describe the medium time effects (25 years) on soil and aquifer as a consequence of reclaimed water reuse, considering also the water management applied, and to compare the experimental results with reclaimed water quality criteria under a sustainability point of view.

Material and methods

Bandama golf course is situated in the midlands of Gran Canaria north-eastern coast (Fig. 1), with an annual rainfall of 300 mm. A surface of 14.5 ha is irrigated by spraying since 1983, using 92.8 L min^{-1} at 600 kPa. Sprinklers are 21.5 m apart, as presented in Figure 2. Part of the golf course was established on the natural soil, *in situ* (piroclastic material of 2,000 years old), while the soil for the other fairway was transported from nearby agricultural lands.

The following data are available: rainfall from a rain gauge data (Fig. 3) and reference crop evapotranspiration (ETo, Thornthwaite method; Jensen *et al.*, 1990) since 1961; water consumption measured by a water flow meter since 1981 (Fig. 3), and a medium time series (since 1982) sampled from a reservoir with a few water quality available variables: salinity, pH and suspended solids (SS). Twenty-two samples from the

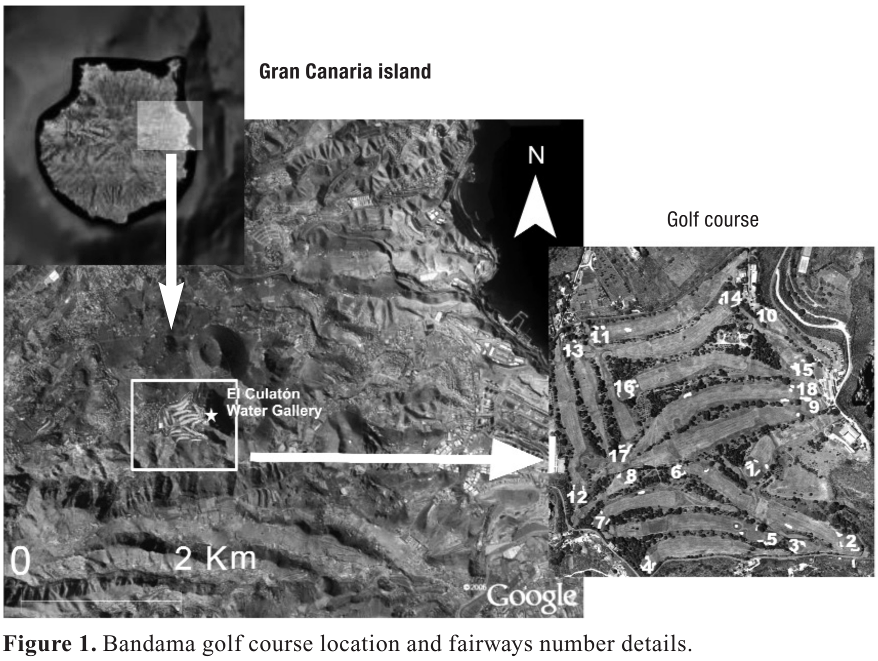

Figure 1. Bandama golf course location and fairways number details.

Figure 2. Sprinkler distribution on fairways 2 (black circles) and 7 (white circles). Detail on the right.

same reservoir before the desalination treatment installation were analyzed to determine the following water quality variables (Fig. 4): sodium adsorption ratio (SAR), electrical conductivity (EC), pH, nitrates (ionic chromatography), chemical oxygen demand (COD, potassium chromate method 6060; ISO, 1989), and SS.

One lysimeter (Drain Gauge, Decagon Devices, Inc.) was installed in November 2008 in fairway 12 to sample the water that percolates through the *in situ* soil, under the root system. Water from the aquifer was sampled in the gallery «El Culatón», just bellow the golf course (Fig. 1). The quality of the reclaimed, lysimeter and aquifer water from 2008 to 2009 is presented in Table 1, as described using 13 variables.

Soil study was started in January 2008 describing soil profiles from the two soil types as determined by their origin: the natural soil, *in situ* (piroclastic material represented by fairway 7) and the transported soil from agricultural lands, represented by fairway 2. Twenty one soil samples from both top profiles (from 0 to 0.15 m) were analysed: 6 from the lane and 5 from the rough (fairway 7), and 5 from the lane and 5 from the rough (fairway 2). A second period of sampling was done in the same places on 2009.

Kikuyu grass (*Pennisetum clandestinum*), a C4 plant well adapted to hot environments and saline and high boron content in soils, is the main species. Water dose increases from winter to summer, with a minimum of 1 mm per week and a maximum of 7 mm per day.

The chemical fertilization was done once a month on the fairways using granulated calcium nitrate. Neither phosphorous nor potassium were applied.

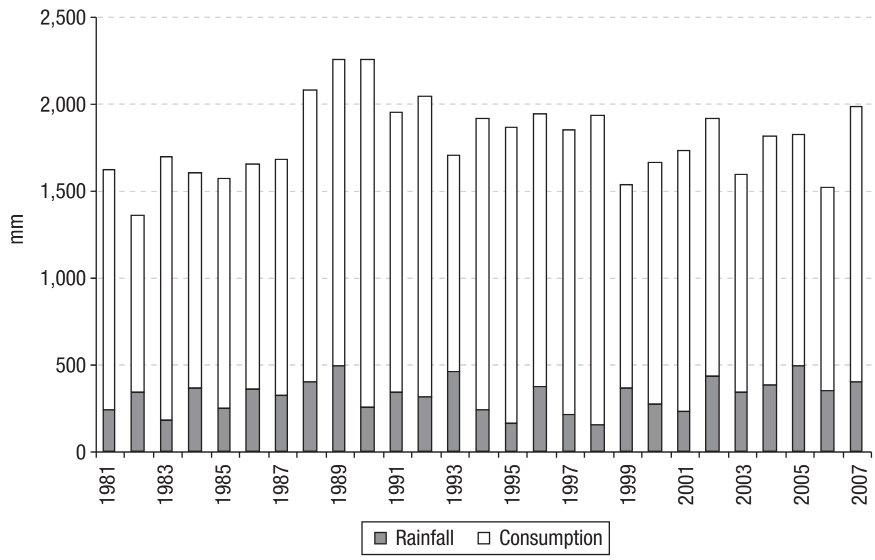

Figure 3. Rainfall (mm) and reclaimed water consumption (mm) data (average per year) since 1981.

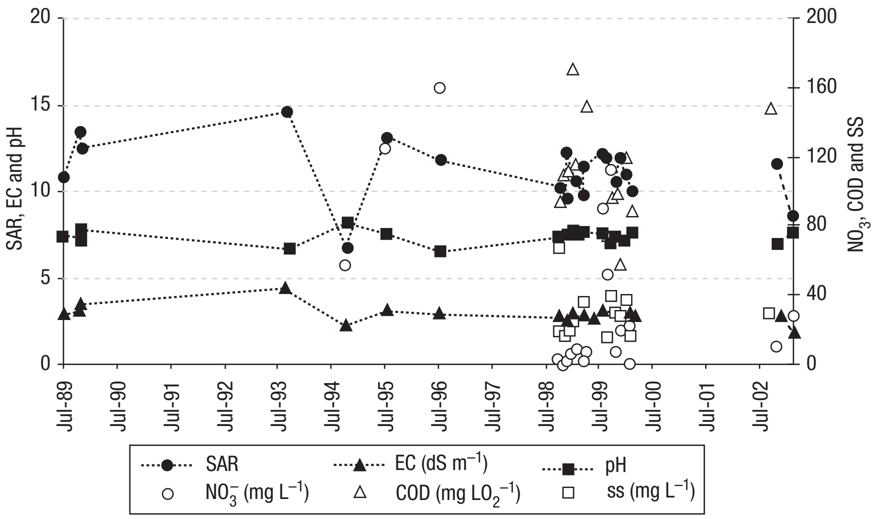

Figure 4. Water quality variables along time (average of 22 samples from a reservoir used only for the golf course irrigation and situated next to it): sodium adsorption ratio (SAR), electrical conductivity (EC), pH, in the left Y axis and nitrates, chemical oxygen demand (COD) and suspended solids (SS) in the right Y axis.

The data were analyzed by t-test with the SPSS software (SPSS Inc., 2008).

Results

Water applied

Using rainfall and reclaimed water consumption data since 1981 (Fig. 3), the water balance comparing water consumption and needs, considering 1 as the water consumption coefficient for the kikuyu grass (*Pennisetum clandestinum*), was calculated to estimate the water excess supplied. Thus, as during the 1990s decade the average amount of water supplied was 1,672 mm yr^{-1} while ETo was 746 mm yr^{-1}, a water excess of 125% can be estimated, even without considering the amount of rainfall. Since 1999, as a consequence of the reduction on the water consumption, the water excess was reduced to about 83%, higher than needed for leaching fraction (LF).

Figure 4 presents results of water quality variables sampled from the reclaimed water reservoir before the

Table 1. Quality of the reclaimed, lysimeter and gallery water, described using 13 variables. EC is expressed in dS m^{-1} and ions in mg L^{-1}

	Irrigation water						Lysimeter water						Gallery El Culatón		
	07 Nov 08	12 Feb 09	19 Feb 09	12 Mar 09	18 Mar 09	Average	13 Nov 08	03 Feb 09	12 Feb 09	19 Feb 09	18 Mar 09	Average	12 Nov 08	28 Jan 09	Average
pH	7.3	7.1	7	8.1	7.3	7.36^{a}	8	8.6	8.6	8.3	8.1	8.32^{b}	7.5	7.9	7.7^{ab}
EC	1.02	0.84	0.74	0.81	1.11	0.91^{a}	1.74	2.31	1.72	2.24	3.12	2.2^{b}	1.67	1.65	1.67^{b}
Na^+	171.5	136.8	118.9	124	170	144^{a}	323.6	474.4	517.9	504	647	493.4^{c}	305	301	303^{b}
K^+	11.2	12	11.6	11	14	12^{a}	31.8	36	39.7	40.4	48	39.2^{c}	7.4	7.6	7.5^{a}
Ca^{2+}	12.3	16.1	15.2	19	17	15.9^{b}	25.9	29.8	25.5	25.2	28	26.9^{c}	8.4	8.6	8.5^{a}
Mg^{2+}	6.8	7.8	6.8	12	8.9	8.5^{a}	9	14.8	15.3	14.7	19	14.6^{b}	9.7	9.8	9.75^{ab}
Cl^-	207	169.1	149.9	141	211	175.6^{a}	297	194	161.7	153.8	387	238.7^{ab}	332.4	329.1	330.7^{b}
HCO_3^-	118.3	109.2	108.6	153	179	—	396.5	—	—	—	—	—	140.3	128.1	—
NO_3^-	29.2	9	4	21	18	16^{a}	1.3	81	75	70	17	48.9^{a}	47	54	50.5^{a}
NH_4^+	0.6	< 0.03	0.4	0.3	13	2.9^{a}	6.04	6.9	4.64	2.89	2	4.5^{a}	< 0.03	< 0.03	0.01^{a}
P	0.7	1.3	1.6	< 0.1	< 0.1	0.7^{a}	0.2	< 0.1	0.3	2.5	0.8	0.76^{a}	0.6	0.4	0.5^{a}
B	1.46	1.094	1.061	1	1	1.09^{a}	7.44	4.93	4.447	4.402	4.22	5.09^{b}	0.5	0.5	0.5^{a}
SAR	7.0	6.3	5.5	8.3	6.8	6.8	—	—	—	—	—	—	—	—	—

—: no available data.

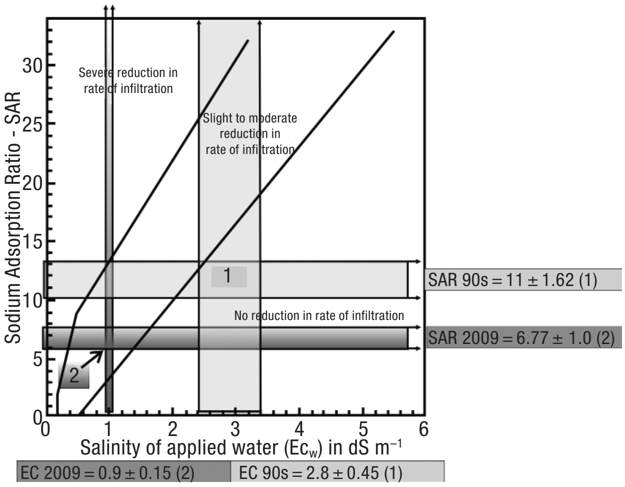

Figure 5. Risk of reduction in rate of infiltration in relation of sodium adsorption ratio (SAR) and electrical conductivity (EC), comparing irrigation water quality before (1) and after (2) the desalination treatment installation. Adapted from Rhoades (1977) and Oster and Schroer (1979).

desalination treatment installation. Occasional high values were removed to obtain the average values: 110 ± 31 mg L^{-1} O_2 (COD) and 28 ± 14 mg L^{-1} (SS). Considering the high values for nitrate and the excess of water used it would be foreseeable to find appreciable amounts of nitrates in the aquifer, as measured in the water gallery (Table 1). Before the desalination treatment installation the moderate-high SAR values were balanced by the high water salinity (Fig. 5-1), avoiding the risk to affect the soil structure. After the desalination treatment, in spite of the reduction in SAR (Table 1), the water quality induces a slight to moderate reduction in rate of infiltration (Fig. 5-2). Except for the phosphorus, all the variables were higher in lysimeter than in irrigation water although the differences in nitrates and ammonia were no significant.

Effects on soil properties

Table 2 shows the average and standard deviation for the main soil variables measured in both top soils: fairway 2 and fairway 7 and respective roughs, during 2008 and 2009. The salinity in 2009 was lower than in 2008, showing the most pronounced decrease in the more saline soil in 2008. There was an abnormally high value in 2008 of the rough of transported soil value. Also, organic matter (OM) percentage was lower in 2009. There was not a clear difference between fairway and rough, but we could distinguish higher values for the transported soil than for *in situ* soil. There was not a significant difference in nitrates, except in the rough of the *in situ* soil, where the values decreased from 2008 to 2009. Although not significant, there was a trend of reduction of phosphorus values over time. Phosphorus concentration was higher in the transported soil from the *in situ* soil and the same increase was observed on the fairway compared to the rough. For boron there was not a clear trend over time, and abnormally high values could be found on the fairway in 2008.

Figure 6 compares actually supplied water values to LF requirements, assuming the crop water pattern for sprinkler irrigation (Ayers and Westcot, 1985). These values are consistent with the top soil EC effectively sampled in 2009 (Table 2), expressed as EC in soil saturated extract and shown also in Figure 6 as a circle.

Table 2. Statistical analysis (average and standard deviation) of main soil variables measured during 2008 and 2009 sampled in both top soils: fairway 2 and fairway 7 and respective roughs. Electrical conductivity (EC) is esteemed in 1:5 and expressed in dS m^{-1}; organic matter (OM) is expressed in % of the total soil; and nitrate (NO_3^-), phosphorus (P) and boron (B) are expressed in mg of nutrient per kg of soil. Different letters express significant differences.

	Date	EC 1:5 (dS m^{-1})		OM (%)		NO_3^- (mg kg^{-1})		P (mg kg^{-1})		B (mg kg^{-1})	
		Average	sd	Average	sd	Average	sd	Average	sd	Average	sd
Fairway 2	Jan 2008	0.19^{ab}	0.04	6.74^{b}	0.68	54.8^{a}	48.32	144.0^{b}	18.28	5.7^{a}	0.96
	March 2009	0.13^{a}	0.04	3.63^{a}	0.68	25.2^{a}	48.32	88.8^{ab}	18.28	5.7^{a}	0.96
Rough 2	Jan 2008	0.31^{b}	0.04	7.98^{b}	0.76	66.5^{a}	54.02	83.2^{ab}	16.69	9.6^{b}	0.88
	March 2009	0.13^{a}	0.04	2.72^{a}	0.76	19.3^{a}	54.02	95.2^{ab}	16.69	5.9^{a}	0.88
Fairway 7	Jan 2008	0.21^{ab}	0.03	5.53^{ab}	0.62	119.8^{a}	44.11	83.2^{ab}	16.69	9.6^{b}	0.88
	March 2009	0.12^{a}	0.03	3.06^{a}	0.62	27.8^{a}	44.11	95.2^{ab}	16.69	5.9^{a}	0.88
Rough 7	Jan 2008	0.15^{a}	0.04	4.10^{ab}	0.68	66.5^{a}	54.02	85.0^{ab}	20.44	5.2^{a}	1.07
	March 2009	0.15^{a}	0.04	3.62^{ab}	0.68	19.3^{a}	54.02	60.5^{a}	20.44	6.1^{ab}	1.07

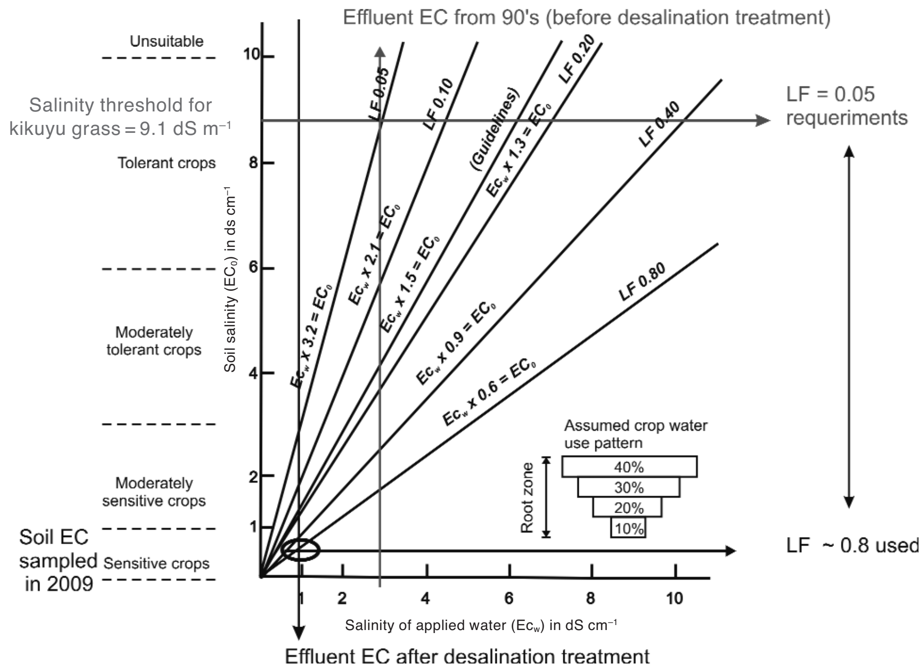

Figure 6. Leaching fraction (LF) required (grey) for kikuyu grass cultivation and LF effectively used (black), as demonstrated by the soil EC sampled in 2009 (circle), assuming the crop water pattern for sprinkler irrigation. Adapted from Ayers and Westcot (1985).

Effects on groundwater

As mentioned, groundwater was sampled in this study from El Culatón water gallery, which supposedly collects the irrigation drainage from the golf-course. Two samples were analyzed (Table 1), allowing to conclude that groundwater chemistry was stable. Comparing groundwater and lysimeter drainage data, an increase on conductivity, chloride and sodium was observed, as well as an important decrease on calcium, potassium and magnesium. Nitrates on groundwater were around 50 mg L^{-1} (below lysimeter drainage values in most samples) and ammonium, as expected, was not found. Boron decreased to 0.5 mg L^{-1}. Nevertheless, the hydrogeology of the area points out the existence of different recharge sources (*e.g.* precipitation, downstream refill of the aquifer, irrigation returns from crops on the area, etc) for this perched aquifer. The chemistry of El Culatón gallery indicates a mixed nature of sources that is under study.

Discussion

Although decreasing in time, the water used for golf course irrigation is still excessive in the Canary Islands (83% more than needed by the plants) in spite of its high price (€ 0.4 m^{-3}). As shown in Figure 6 this waste of water cannot be justified by the requirements on leaching fraction.

In spite of the apparent water quality improvement after the desalination process, if physical soil characteristics are considered the water goes from no risk of reduction of rate of infiltration (before desalination: 1 in Fig. 5) to slight to moderate reduction in rate of infiltration (after desalination: 2 in Fig. 5) as demonstrated by Oster and Schroer (1979).

A high spatial variability was found on top soils of this golf course. Even considering the differences of soils (*in situ* and transported) and the water management applied to fairways and roughs, other authors mentioned the same rank of variability in field conditions studies (Román *et al.*, 2002). Coefficients of variation of 20-25% were calculated for EC and OM, while for nitrates, P and B the values were higher (about 50%). A wider variation was found in the rough (as a consequence of poor water management) and in the transported soil. Values of EC, OM and nitrates measured in 2009 were lower than in 2008, probably as a consequence of the higher rainfall (MARM, 2009), as mentioned by other authors (Caballero *et al.*, 2001; Bustos *et al.*, 2006). High boron contents in soil were related to the usage of non conventional resources from ocean origin for a long time.

The soil and aquifer data obtained in this field study were consistent with the sustainability water criteria. After desalination, water quality improvement allows short term water reuse for N, P and B (USEPA, 2004), but P and B values, consistent with soil accumulation data, are not acceptable for long term irrigation.

An excess of reclaimed water is used for this golf course irrigation in spite of the high water price. The excess water reduced the risk of substances accumulation in soils, but for several of them the foresaid excess increased the possibility of polluting the aquifer. Soil characteristics and water management has to be considered as critical factors to explain water quality effects in land and environmental conditions.

Acknowledgements

The present study is financed by CONSOLIDER-TRAGUA (CSD2006-00044). The authors are grateful for the «Real Club de Golf de Las Palmas» and their staff, especially D. Pelayo Navarro. Authors are also grateful to Laboratorio de la Granja Agrícola Experimental, Cabildo de Gran Canaria for the water and soil chemical analysis.

References

ANZECC-ARMCANZ, 2000. Australian guidelines for water quality monitoring and reporting. In: National Water Quality Management Strategy Paper No 7, Australian and New Zealand. Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

ASSADIAN N.W., DI GIOVANNI G.D., ENCISO J., IGLESIAS J., LINDEMANN W., 2005. The transport of waterborne solutes and bacteriophage in soil subirrigated with wastewater blend. Agr Ecosyst Environ 111, 279-291.

AYERS R.S., WESTCOT D.W., 1985. Water quality for agriculture. Irrig Drain Paper 29, 1st revision, FAO, Rome.

BOC, 1999. Decreto 82/1999 de 6 de mayo por el que se aprueba el Plan Hidrológico de Gran Canaria. Boletín Oficial de Canarias 1999/073, 8 de junio. [In Spanish].

BUSTOS A., CABALLERO R., ROMÁN R., 2006. Net changes of main ions in the soil profile of irrigated field plots in central Spain. Irrig Sci 25, 1-9.

CABALLERO R., BUSTOS A., ROMÁN R., 2001. Soil salinity under traditional and improved irrigation schedules in Central Spain. Soil Sci Soc Am J 65, 1210-1218.

ISO 6060, 1989. Water quality - Determination of the chemical oxygen demand. International Organization of Standardization, Geneva, Switzerland.

JENSEN M.E., BURMAN R.D., ALLEN R.G., 1990. Evapotranspiration and irrigation water requirements. In: Evapotranspiration and irrigation water requirements (Chapter 5). ASCE Manuals and Reports No 70. Am Soc Civil En, NY. pp. 60-74.

JENSEN K., MATSUNO Y., VAN DER HOEK W., CAIRNCROSS S., 2001. Limitations of irrigation water quality guidelines from a multiple use perspective. Irrig Drain Syst 15, 117-128.

MARM, 2009. Sistema de información agroclimática para el regadío (on line). Ministerio de Medio Ambiente y Medio Rural y Marino, Madrid. Available in http://www.mapa.es/siar/Informacion.asp. [In Spanish].

OSTER J.D., SCHROER F.W., 1979. Infiltration as influenced by irrigation water quality. Soil Sci Soc Am J 43, 444-447.

PALACIOS M.P., MENDOZA V., FERNÁNDEZ F., FERNÁNDEZ-VERA J.R., HERNÁNDEZ-MORENO J.M., 2008. Sustainable reclaimed water management by subsurface drip irrigation system: a study case for forage production. Water Pract Technol 3(2), 1659-1666.

RHOADES R.D., 1977. Infiltration as influenced by irrigation water quality. Soil Sci Soc Amer J 43, 444–447.

ROMÁN R., CABALLERO R., BUSTOS A., 2002. Variability of soil solution ions in fallow-land field in Central Spain. Edafología 9, 161-172.

SPSS, 2008. Version 17.0 for Windows, SPSS Inc, Chicago.

USEPA, 2004. Guidelines for wastewater reuse. US Environmental Protection Agency. EPA/625/R-04/108. Washington DC, USA.