Chapter 12
Effect of Treated Wastewater on Plant, Soil and Leachate for Golf Grass Irrigation

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12.1 Introduction

Treated wastewater reuse has been a common alternative for irrigation in many countries which are characterized by arid climate sand water shortage. Application of reclaimed wastewater reuse for irrigation has been expanded due to many reasons such as: its potential in terms nutrients inputs; socio-economic implications; reduction of environmental pollution; and enhancement of the quality of water resources.

In Mediterranean countries, treated wastewater is exponentially used for irrigating ornamental plants in areas suffering from water scarcity. This is perceived as an economic way to decrease pollution of surface waters and provide groundwater recharge for other agricultural uses. A great number of publications have recognized the benefits of this practice. In this perspective, this work was conducted with the aim to investigate the effects of irrigating golf grass with municipal reclaimed water, which contains higher concentration of soluble salts compared to ground water, on leachate and soil (Mouhanni et al. 2008, 2011, 2012; Mouhanni and Bendou 2011).

Similar results were obtained in United States by Gregory et al. (2010) who concluded that the turf grass irrigated by reclaimed wastewater are moderately or highly salt tolerant when fully established. However, continuous irrigation with reclaimed water poses a potential soil Na accumulation problem. Turf grass assimilates a large amount of N and P with minimal potential losses to ground water. In Spain, Salgot

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et al. (2006) studied wastewater reuse and concluded that reclaimed wastewater can be reused for different applications depending on specific water quality categories.

Biological and chemical parameters have to indicate all potential pathogens and chemical intoxications in relation to the origin of sewage. Therefore, it is necessary to find adequate indicators which can be performed by chemical as well as biological quantitative risk assessment. In USA, Zalesny et al. (2008) studied the sodium and chloride accumulation in leaf, woody and root tissue of Populus after irrigation with Landfill leachate and fertilized well water (control). The monitoring started from 2005 to 2006 in Rinelander, Wisconsin. The results showed that the leachate irrigated soils at harvest had the greatest Na^+ and Cl^- levels. The soil Na^+ concentration was nearly 24 times than the control. The leachate soil Cl^- concentration was three times greater than the control. Across all genotypes, Na^+ levels were greatest in the leaves. Similarly, woody sequestered high amounts of Na^+ and Cl^-. As a conclusion, human activities have increased the salts in areas dedicated to plant growth.

In India, Jalali et al. (2008) studied the effects of irrigation with wastewater on soil and groundwater quality in two soil column. The addition of the wastewater resulted in increased exchangeable Na^+ on the exchange complex at the expense of exchangeable Ca^{2+}, Mg^{2+}, and K^+. Hence, the ESP of both soils increased. No adverse effects on soil structure were observed, provided that wastewater is continuously used for irrigation. A change from wastewater to better water quality may well invoke soil structural damage. The use of wastewater for irrigation also increased Mg^{2+} and K^+ losses from the soils.

If wastewater is applied to soil for a long period, leaching concentrations will reach groundwater at high levels (as part of irrigation water evapotranspiration). A rough assessment may thus help to confirm whether or not wastewater use is acceptable.

In our study, we dealt with the case of Agadir (south of Morocco: altitudes between 30 and 31 °N) (Fig. 12.1). The Agadir region is an agricultural area that is characterized by an arid climate, very limited water resources, and poor nutrient soils. The agricultural

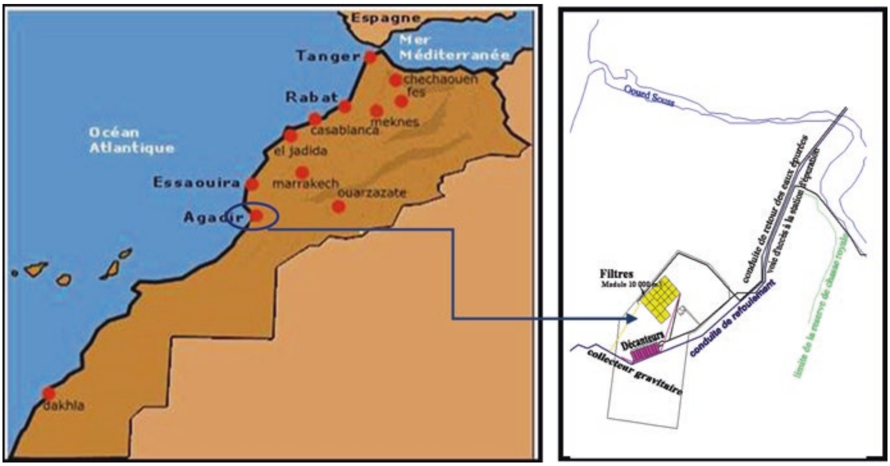

Fig. 12.1 Localization of the M'zar plant of Agadir

sector is the largest water consumer. Thus, the use of treated wastewater in agriculture is a good alternative that will help preserve water resources in the region. Moreover, given the nutritional wealth of the treated wastewater, this solution will permit a recycling of these items and reduce the abusive misuse of fertilizers (Chenini et al. 2002).

The current potential of wastewater treated by the Agadir M'zar plant (Fig. 12.1), which might be used for unrestricted irrigation (category A WHO standards), is 10,000 m^3/day and will reach 50,000 m^3/day in the medium term. A feasibility study on the reuse of the Agadir M'zar plant wastewater was launched by the Water Supply Service of Agadir (RAMSA[1]). In this context, the total surface of green spaces of Agadir city is estimated to be 878×10^4 m^2 with a need of water for irrigation reaching 8106 m^3/year. With a daily flow of 50,000 m^3/day, the treated wastewater of the M'zar plant will completely fill this need. The golf grass alone occupy 30.5% (268×10^4 m^2) of the total area of green space in Agadir (878×10^4 m^2), with a water consumption estimated to be 3216,103 m^3/year (Gregory et al. 2010; Mouhanni et al. 2012).

This study focuses on the reuse of treated wastewater for golf grass irrigation. It provides the planning, protocol and results of the tests that were carried out to evaluate the effects of the reuse of treated wastewater for golf grass irrigation. Particular attention was given to the monitoring of parameters of germination and growth of grass plants irrigated with treated wastewater compared to those irrigated by groundwater. In addition, the analysis of soils in three different depths (20 cm, 40 cm and 60 cm) has been done to demonstrate the interaction between the soil and the two types of water for irrigation.

12.2 Material and Methods

12.2.1 Experimental Site

The in situ tests had been performed on the site of the wastewater treatment plant of M'zar Ait Melloul (Fig. 12.1) where two zones of land have been managed: one for irrigation tests using treated waste water released by the plant; and the other for irrigation tests using the groundwater drawn from a well located in the wastewater treatment plant area.

12.2.2 Tests Scheduling

In order to study the feasibility and evaluate the impact of treated waste water use for irrigation of golf grass, three varieties of golf grass (V1, V2, and V3) had been used on three parcels of land (P1, P2, and P3). For comparison purpose, the same tests are reproduced in the same conditions while using groundwater (drawn from the well). Each parcel had a dimension of 25 m^2 and was subdivided into two

[1] Régie Autonome Multiservices d'Agadir.

parcels of 12,5 m^2 in order to perform a repetition of the conditions of each test. The subdivision of every parcel was assured by the pose of a plastic insulator with a depth of 0,5 m in order to prevent infiltration between the subdivisions. Every parcel contains a layer of 20 cm of soil composed of 75% of the plant earth and 25% of sand.

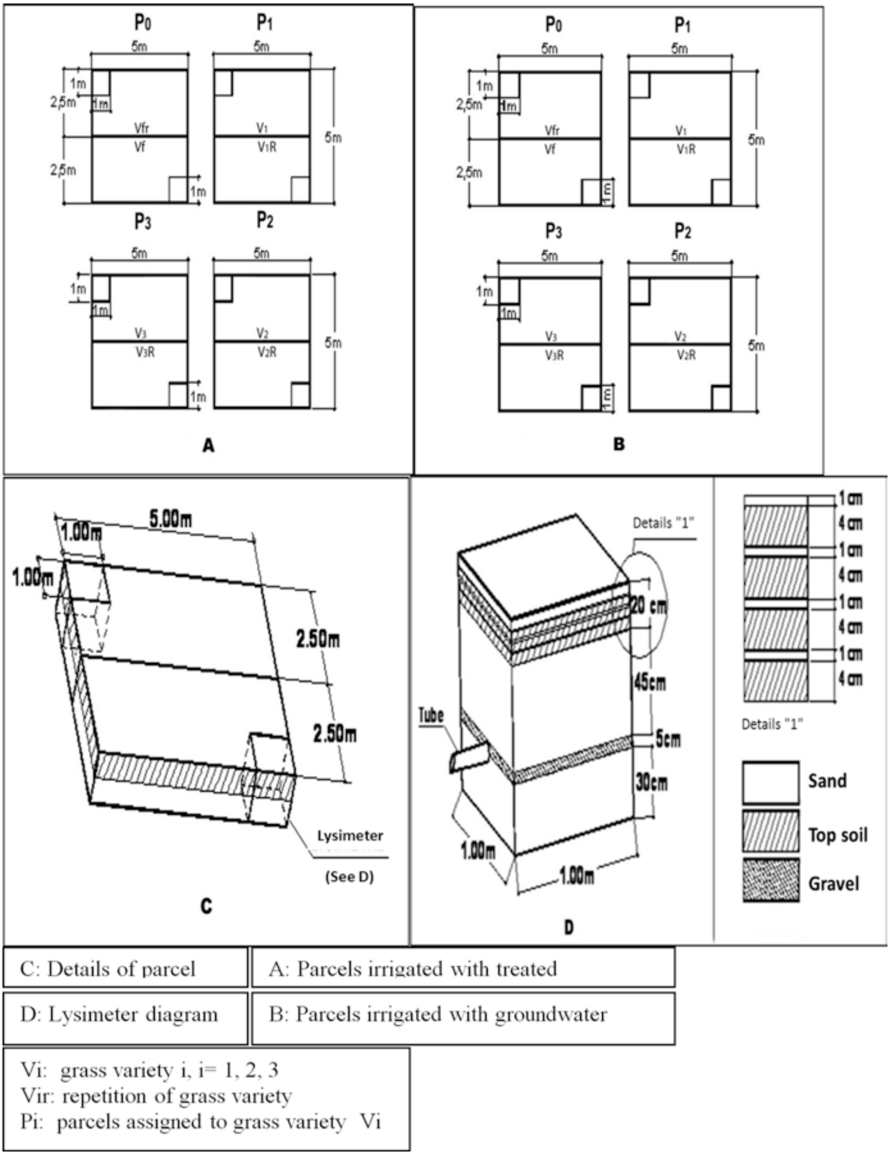

Fig. 12.2 Description of the experimental design and explanatory Diagram giving the disposition of the parcels and lysimeters with the assigned varieties of grass to each parcel

Table 12.1 Physico-chemical parameters of soil and sand

Parameters	Texture	pH	Organic matter (%)	Total nitrogen (%)	Total limestone (%)	EC 1/5 (dS/m)	Soluble salts (g/kg)	P_2O_5 assimilable (ppm)	K_2O exchangeable (ppm)
Topsoil	LSC [a]	8.70	1.85	0.15	5.20	0.12	0.21	14.56	128.70
Sand	S	9.6	0.05	0.01	36.7	0.045	0.16	1	24.9

[a]*LSC* loamy Sandy Clay

A lysimeter was managed in each parcel opposite corners (Fig. 12.2). The lysimeters had a volume of 1 m^3 and reproduced the conditions of soil and the variety of grass sowed in the concerned parcel; they were conceived with a good water tightness permitting the recuperation of leaking water from soil after irrigation. The Fig. 12.2 presents a diagram that shows the disposition of the parcels and lysimeters with the assigned varieties of grass to every parcel, and the repetitions and dimensions of the different characteristics. On this diagram, a fourth parcel noted Po was planned for tests using the composted sludge as organic amendment.

12.2.3 Characteristics of Soils and Irrigation Waters

The soils of the parcels are composed of 75% of plant top soil and 25% of sand. The pedological analyses of the soil constituents are presented in the Table 12.1.

According to the results summarized in Table 12.1, the soil presents an alluvial texture with few of clay and little sand, what proves that its amendment to the sand is going to improve its water and nutriments retention capacity. It is slightly provided in major nutriments and organic matter: the total nitrogen, the assimilated phosphor as well as in exchangeable potash. Besides, the sands are very poor in any fertilizing element. The saltiness of the two types of soil is very low; otherwise the alkalinity of the sands is higher than that of the plant earth. Therefore, soil cannot provoke any prejudicial risk to the cultures as it doesn't provide them with any nutriment which imposes to the grass to take advantage solely from fertilizing elements contained in waters or brought by possible amendments.

Waters used for the irrigation of the experimental parcels are of two types: the groundwater of Souss plain, drawn from the well located in the wastewater plant zone; and the treated wastewater of the plant M'zar Ait Melloul, which uses the infiltration percolation process on bed sands. The main features of waters used for irrigation are indicated below in the Table 12.2.

The assessment of the analyses of the treated wastewater and ground water permits their classification as water for irrigation according to the United States Department of Agriculture (USDA). The USDA classification is based on the values of the electrical conductivity (EC) and the one of the Sodium Adsorption Ratio (SAR) factor (Ayers and Westcot (1988):

- The ground waters are classified as C2S1, they can be used on any type of soil with a minimal risk of sodium accumulation. The saltiness of waters

Table 12.2 Ionic balance of treated wastewater and groundwater used for irrigation

Measured parameters	Groundwater		Treated wastewater	
	mg/L	(×10^{-3}) mole/L	mg/L	(×10^{-3}) mole/L
pH	7.4		7.1	
EC at 25 °C dS/m	0.58		3.15	
SAR	0.84		6.66	
Cl^-	128	3.61	720	20.31
K^+	2.89	0.07	43	1.1
Na^+	30.52	1.32	487	21.21
Ca^{2+}	47.8	1.19	294.8	7.35
Mg^{2+}	32.1	1.32	65.9	2.71
Total Nitrogen	1.5	0.1	44.6	3.18

Table 12.3 The varieties of grass sowed in the different parcels

Parcels	P1	P2	P3
Species	Agrostides	Ray grass	Mixture
Sowed variety (Vi)	Penccross (**V1**)	Ray grass Anglais (**V2**)	Ray grass Anglais 60%
			Red fescue 40% (**V3**)

(CF = 0,520 dS/m) is close to the limit affecting the growth of the grass without applying special treatments for saltiness reduction (limit situated at EC = 0,750 dS/m).

- The treated wastewaters are classified as C4S1, they are very saline (EC at 25 °C is of 3,15 dS/m). However, they can be applied on any type of soil with a SAR value less than 10.

One notes that the treated wastewaters have an important ionic load owing to the contents of the chlorides, sodium and nitrates, able to affect the absorption of other cations like magnesium (Mg^{2+}).

12.2.4 Protocol of Irrigation, Seed And Follow-Up

The parcels irrigated by the treated wastewaters were distant from those irrigated by the groundwater (drawn from the well) to avoid any contamination. Their irrigation was done by the same system which consisted ~~s~~ on an aspersion by a gun having a constant flow rate of 828 l/h, thus ensuring the constancy of the same volume of irrigation water. Every parcel of 25 m^2 is irrigated three times a day and received ~~s~~ a total of 90 l of water per day (Table 12.3).

One of the objectives of this study aims to compare the parameters of grass growth (tillering and evolution of leave length) of the different species of golf grass: the Ray-Grass, the agrostide and the fescue, irrigated with the treated wastewaters

Table 12.4 Means with standard deviation of pH, EC and ionic composition in mmol/l of leachate

	Treated wastewater			Groundwater		
Parameters	V1	V2	V 3	V1	V2	V 3
pH	7,88 ± 0,40	7,99 ± 0,44	7,92 ± 0,38	8,00 ± 0,30	7,92 ± 0,13	7,86 ± 0,25
EC	11,26 ± 4,74	10,01 ± 4,22	9,61 ± 3,17	0,66 ± 0,21	0,82 ± 0,30	0,92 ± 0,23
Na+	99,82 ± 27,43	102,98 ± 28,73	66,72 ± 16,44	3,06 ± 0,59	3,06 ± 0,63	3,16 ± 0,50
Cl-	62,51 ± 31,63	58,46	51,71	3,89	4,39	5,80
		29,67	19,34	1,37	1,01	1,86
Ca++	2,54 ± 0,92	2,41	2,30	0,46	0,48	0,51
		0,86	0,68	0,17	0,14	0,18
Mg++	4,30 ± 1,65	3,83	3,43	0,71	0,85	0,79
		1,36	0,90	0,16	0,27	0,14
K+	0,80 ± 0,31	0,68	0,82	0,12	0,13	0,08
		0,23	0,35	0,04	0,02	0,06
SO4--	1,70 ± 0,79	1,52	1,21	0	0	0
		0,54	0,56	0	0	0
HCO3-	4,21 ± 2,10	4,04	4,47	2,73	3,72	3,66
		1,97	1,53	0,78	1,29	1,95
SAR	17,19 ± 7,82	16,38	16,58	0,99	1,11	1,37
		9,36	5,76	0,45	0,56	0,45

and with the ground water. The Table 12.4 presents the different seeds (V1, V2, and V3) composed of pure or mixed species as well as the parcels assigned to each seed.

The first grass plants germinated after 3 days from the sow. The parameters of grass growth (number of talles (shoots) and length of the leaves) have been monitored during the first 41 days from the apparition of the first plantations on the different parcels (P1, P2, and P3) sowed by the different varieties of grass (V1, V2, and V3) and irrigated by the two qualities of water (groundwater and treated wastewater).

The samplings of soil and leachate are done every 6 days from the first day of germination. This follow-up lasted 60 days resulting in 10 sampling operations. For every sampling operation, 16 samples of leachate and composite samples of soil are collected by auger on the diagonal of each plot and it conserved for analysis.

12.3 Results and Discussion

12.3.1 Influence of the Quality of Irrigation Waters on the Germination of the Seeds

To study the influence of the quality of groundwater and treated wastewater on the germination of the grass seeds, tests of germination concerning the three varieties of grass (V1, V2, and V3) had been performed on the site of the treatment plant. The soil used in the trays of alveolar had the same composition as the one in the parcels.

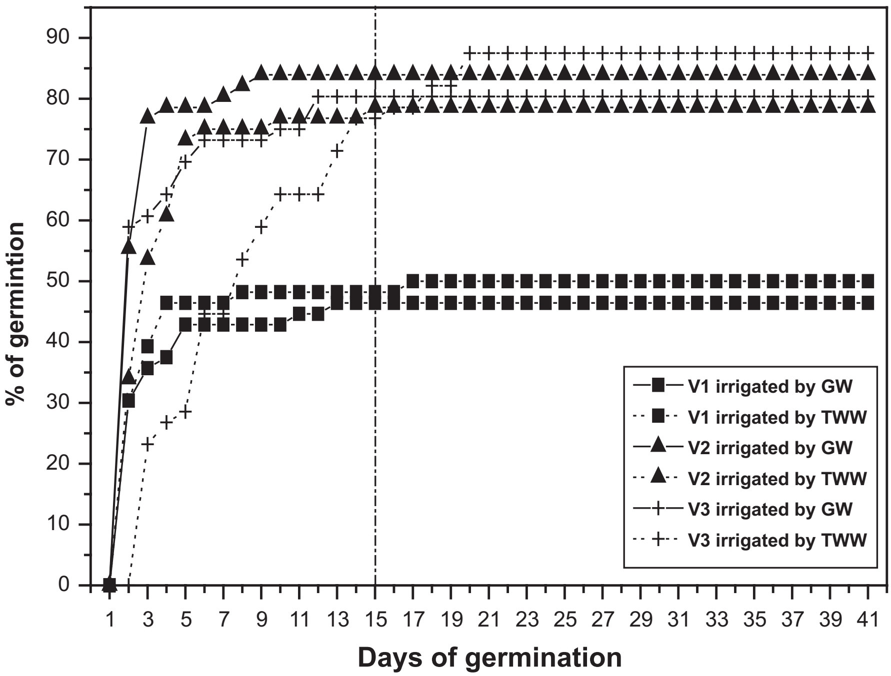

Fig. 12.3 Evolution of the percentage of germination of the different varieties irrigated by the two water qualities: *GW* ground water and *TWW* treated wastewater

For every variety of grass, two trays with 56 alveolars were sowed (a seed by alveolar): one was irrigated by the ground water, and the other by the treated wastewater. The germination of the seeds in the six trays was monitored during 41 days.

The results of these tests are represented in Fig. 12.3 that shows the evolution of the percentage of germination with the time for every variety of grass and for the two types of irrigation water: groundwater and treated wastewater.

The evolution of the percentage of germination in Fig. 12.3 shows that the germination of the varieties V2 and V3 was favored by the irrigation with the groundwater during the first 15 days. The germination of these two varieties accused a time of adaptation to the saltiness of the treated wastewater during this phase. The % of germination of the variety V1 is slightly favored by the treated wastewater. The germination of this variety shows a better tolerance to the saltiness since the first days.

After the 15th day, the percentage of germination remained steady and reached a maximum of 84% for the varieties V2 and V3, whereas the % maximal doesn't exceed 48% for V1. The influence of the water quality on the maximal % of germination reached remained weak for all varieties and fluctuates around ±5%.

12.3.2 *Influence of the Quality of the Water Irrigation on the Parameters of Grass Growth*

The evolution of the number of talles, counted every 2 days, in the different parcels is represented in Fig. 12.4.

The talles are the supplementary shoots produced from a seed mother by stolon or rhizome. The proliferation of talles (tillering) is an important phenomenon that conditions the density of the grass carpet. The increase of the number of talles before the maximal germination rate was reached due to the contribution of germination and to the phenomenon of tillering. According to the evolution of the % of germination discussed above, the maximal germination was reached after 15 days of seedling that corresponds to the 13th day of growth. The increase of the number of talles after the 13th day of growth was exclusively due the phenomenon of tillering.

The irrigation by the groundwater favored the tillering in a first time, but the gap recorded in relation with the irrigation by treated wastewater reduced quickly and annulled itself on the 21st day of growth. According to this tendency, one can expect that the tillering will be favored by the irrigation with treated wastewater after the 21st day.

The length of the leaves provided information on the speed of growth of the aerial part of the plant (grass). A sample of leaf by parcel was collected every 2 days. The length of the leaves of every sample was measured on graph paper. The evolution of this length, for the different varieties irrigated by the two types of water, is represented in Fig. 12.5 for the 21 days of follow-up.

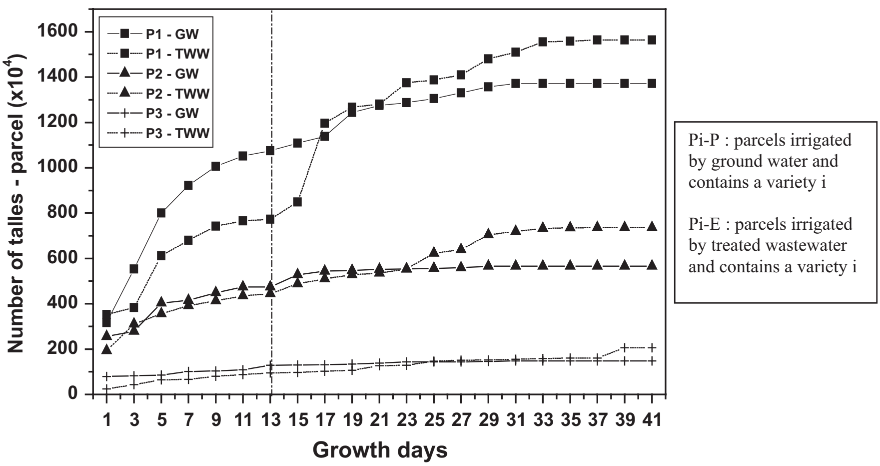

Fig. 12.4 Evolution of the number of talles in the parcels irrigated by the two qualities of water: *GW* groundwater and *TWW* treated wastewater

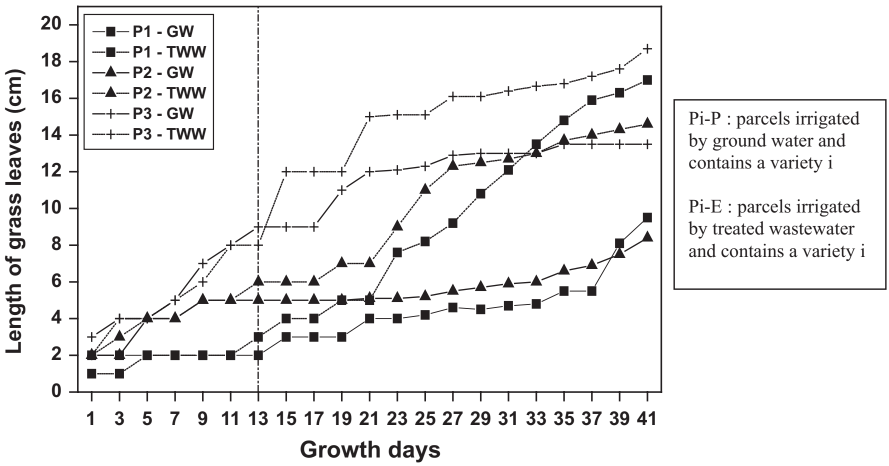

Fig. 12.5 Evolution of leaves length in the parcels irrigated by two water qualities: *GW* groundwater and *TWW* treated wastewater

Before the maximal germination rate is reached, we could not decide about the effect of the irrigation by treated wastewater on the evolution of the leaves length before the 13th day of growth indicated on the Fig. 12.5. However, after the 13th day of growth, it was obvious that the irrigation by the treated wastewaters favored the increase of the leaves length compared to the groundwater irrigation, and it was observed for all varieties.

12.3.3 Leachate Characteristics

As shown in Table 12.4, the ionic content in leachate, in case of irrigation with treated wastewater, is very important. Leachate presents an increase in electric conductivity, Na+, Cl-, and SAR. This increase can be explained by leaching of soluble salts from the soil to the groundwater through irrigation water. The concentration of soluble salt in soil, sand, and the mixture (75% soil and 25% sand) are respectively 0.41, 0.16 and 0.34 g/kg which confirm their leaching (Al-Hamaiedeh and Bino 2010; Francesco and Alarcon 2009).

The high electrical conductivity and SAR in leachate is strongly correlated to the concentration of sodium chloride and reflects a salinization of soil and groundwater in the case of irrigation with treated wastewater. Furthermore, the ionic content in leachate in the case of irrigation with groundwater is very low and it didn't have any negative effect on soil and ground water.

Table 12.5 Ionic Analysis of soils irrigated with reclaimed wastewater

Variety	Soil deep cm	pH	EC dS/m	SS g/l	Na+	Ca++	Mg++	Cl-	K+	SO4–	HCO3-
					mmole/l						
V1	0–20	8.5	1.44	1.02	24.97	8.73	9.95	50.07	0.42	2.32	20.11
	20–40	8.18	1.42	1.00	15.61	5.37	7.82	32.19	0.24	1.32	17.23
	40–60	8	1.05	0.74	14.27	4.28	5.36	30.81	0.22	0.85	15.47
V2	0–20	8.21	1.4	0.99	22.17	5.7	7.11	50.07	0.48	5.74	28.72
	20–40	8.11	1.17	0.83	8.09	4.99	5.69	32.19	0.24	0.72	14.36
	40–60	7.68	0.68	0.43	7.74	2.85	5.01	28.61	0.20	0.42	11.36
V3	0–20	8.37	1.69	1.2	13.03	6.91	7.66	34.66	0.46	0.84	20.11
	20–40	8.17	1.17	0.83	11.56	5.82	6.64	29.21	0.28	0.63	15.47
	40–60	7.88	1.06	0.75	10,21	3,74	4.98	25,04	0.26	0.44	13.08

12.3.4 Ionic Analysis of Soil

The results in Table 12.5 showed a gradual decrease of parameters of salinity (soluble salts, sodium, chloride, potassium, calcium, and magnesium) as a function of depth. This decrease might be explained due to the following reasons: the plants consumed some of these constituent elements (Ca^{2+}, K^{+}, Mg^{++}), while the sodium and chloride provide the phenomenon of ionic exchange with soil aggregates.

The sulfates and bicarbonates prove the formation of precipitates of calcium carbonate and magnesium by increasing concentrations of these elements resulting the leaching in irrigation water (Mouhanni et al. 2008, 2012; Tomas 2008; Vuokko et al. 2010). Therefore, many parameters of salinity are concentrated in the top 20 cm of soil and decrease in the 40 and the 60 cm of soil respectively.

According to the study of Al-Hamaiedeh and Bino (2010), which concerned the effect of treated GW reuse on the properties of soil and irrigated plants at Al-Amer villages, Jordan, the results showed that salinity, sodium adsorption ratio (SAR), and organic content of soil increased as a function of time; therefore leaching of soil with fresh water was highly recommended. The same results had been shown by Lucila et al. (2007) in their study which assessed the soil and groundwater impacts by treated urban wastewater reuse in the irrigation of golf course. They observed that NaO_2 increased of more than 1000 mg kg^{-1} in the top of soil, while Cl^{-} concentration in the aquifer reached up to 1200 mgl^{-1} 10 month after stating irrigation.

12.4 Conclusion

The monitoring of the leachate quality and soil irrigated turf plots by treated wastewater have allowed us to conclude that this kind of irrigation water presents a risk of salinization for the groundwater, and especially in the case of heavy textured soils. Therefore, caution in the management of irrigation intakes to prevent the accumulation of salts in the rhizosphere and increased concentrations of sodium chloride in the water must be taken into consideration. Indeed, the purified water can be valued on coarse textured soils – like sandy or well-drained soils – to ensure leaching and reduce the phenomenon of ion exchange with the soil aggregates. The sulfate ions and bicarbonate of treated wastewater do not bring about concentrations that can present a risk to the water. However, precipitates carbonates of calcium or magnesium may be provided. This will cause the problem of salinization which is a major handicap in the reuse of the treated wastewater for irrigation.

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