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Brackish Water Desalination for Citrus Trees Irrigation: Comparison between Reverse Osmosis and Nanofiltration

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Abstract: *Different waters resources (well, dam, desalinated and blended water) were characterized and their suitability for citrus trees irrigation purposes were evaluated. Results showed that well and dam waters were classified as C_4S_1 and C_5S_1 doubtful and unsuitable for irrigation. However, desalinated and blended waters were classified C_1S_1 and C_2S_1 excellent and good waters qualities. Well and dam waters sodium, chloride, bicarbonate and nitrate concentrations exceeded FAO recommendations for sensitive crops like citrus as well as sodium absorption rate (SAR). The performance study of RO desalination plant with a capacity of 120 m^3/d and a feed water of 3.71 g/L showed that optimum values were 68% for conversion rate, 91% for retention rate and 0.58 KWh/m^3 for consumes energy with a water produced cost of \$0.246/m^3. The nanofiltration was suggested to reduce brine amount and environmental impact. Compared reverse osmosis performance to simulated nanofiltration performance showed that brine amount can be reduced by 12%. The conversion rate can be increased to 80% and the energy consumption can be reduced by 35% with a retention rate of 83% using nanofiltration.*

Keywords*: irrigation water salinity; growth; citrus; nanofiltration; reverse osmosis; brine*

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I. Introduction

Besides the scarcity of water resources, intense agricultural and urban development has caused a high demand for groundwater resources [1]. The economic and social level does not cease to increase as well as the requirement of the quality of the agricultural products in order to win competitive markets requires a large supply of high-quality water. Tunisia use large amounts of water for agricultural sector (82% of available water) [2]. It has 411.4 thousand hectares of irrigated land. Tree crops come first, with an area of 152.6 thousand ha (37% of the total surface), vegetables second (30%), followed by forages (16%), cereals (16%), and other industrial crops (1%) [3]. Citrus which is one of the most relevant crops worldwide with a yearly average production of 90.10^6 Mg in the last decade and, the second largest fruit crop after apples in Mediterranean countries [4], covers actually in Tunisia an area of 27000 ha and 7 million trees. 18630 ha are developed in Cap Bon (Nabeul Government) [5]. Water resource in Tunisia that have a salinity of less than 1.5 g/L are distributed as follows, 72 % of surface water resources, 8% of shallow groundwater and 20% of deep groundwater [**6**]. However, the salinity of irrigation water can have for reaching effects on citrus production. A TDS values exceed 1.2 g/L can severely damage citrus tree growth and fruit production [7]. Zarzo et al.[8] reported that irrigation of citrus trees with desalinated water led to increase in production by 10 to 50% depending on the water quality used prior water desalination. Saline irrigation water decrease the fruit yields about 13% for each 1.0 ms/cm increase in electrical conductivity of the saturated-soil extract (ECe) once soil salinity exceeds a threshold (ECe) of 1.4 ms/cm. Chloride toxicity appears to be the main reason for reduction in its fruit yield [9]. Gradual accumulation of chloride, sodium and boron to toxic levels are equally or even more important effect compared to the osmotic effects [10]. The specific irrigation water quality can be accomplished by introducing desalination [11]. In the world only 2% of total desalinated water production is used for agriculture. The highest proportion of desalinated water use in agriculture occurs in Spain (22%). 13% is used in Kowait, 1.5% in Italy, 1.3% in USA, 0.4% in Bahrain, 0.1 % in Qatar and only 0.5% of the desalination capacity for the Saudi Arabic is used for agriculture purposes [12].Reverse osmosis was reported to be the preferred desalination technology for agriculture uses because of the cost reductions driven by improvements in membranes in recent years [13]. Disposal of the RO retentate stream from desalination plants has a negative environmental impact using the disposal options; evaporation ponds, deep wells, surface water bodies and municipal sewers [11]. Desalination facilities with sea discharge always being the preferred option. When discharge to the ocean or sea is not possible brine water was discharged to the deep well injection like the case of Austria (12% of total brine water) [12]. Few studies exist regarding the injection of brine following desalination, and their environmental impacts

[14, 15, 16, 17, and 18]. Limited efforts have been made to characterize and assess the impacts of the brine discharge on the environment. Taking into account the limited water resources and higher salinity of irrigation water in Tunisia, efforts have been made to improve water quality by farmers. Some small capacities of desalination units are installed and blended water is used for irrigation purposes. The objective of this paper is to evaluate several water resources qualities used in citrus producing farm in North-East Tunisia (well water, dam water, desalinated water and blended water). Toxic components effects and the waters suitability for irrigation purposes were investigated as well as the benefit of using desalination. Then technical economic evaluation of RO desalination plant were carried out in order to help the farmer to minimize specific consumes energy and production water cost. Brine waters generated by RO plant and disposed in deep well injection were characterized and environmental effects were considered. New configuration of desalination system was proposed which consists of replacing reverse osmosis by nanofiltration to minimize brine amount and increase water production flow rate. Simulation results carried out by IMS-Design simulator was used to evaluate consumes energy, conversion rate and quality of desalinated and brine waters using nanofiltration and compared to experimental results using reverse osmosis desalination system.

II. Material And Methods

Case study

This study was carried out in citrus producing farm in North Tunisia (Nabeul Government). At the aim to improve water irrigation quality, farmer have been installed RO plant to desalinate well water and used blended water to irrigate 6 ha of citrus trees. The water production line is described in Fig.1. The well water with salinity near than 4g/L is desalinated by RO plant with the capacity of 120 m^3/d. The pretreatment step contains three cartridge filters, sand filters and injection of fouling inhibitor. The treatment was conducted using two parallel vessel pressures and each vessel pressure contains two housing elements with an active area of 37.16 m^2.

Several water resources water samples were collected from well, permeate of RO, dam, and irrigation tank to evaluate their suitability for citrus trees irrigation and toxic components effects. Brine water generated by RO and from the deep well injection was also sampled to evaluate environmental impact. Samples were carried out three times during March to August, 2017 to take account a variability of water quality according to the season. Each sample was poured into plastic bottles after rinsing several times with the same water. These bottles were tightly closed, labeled and transported from the citrus farms to the laboratory of Natural Water Treatment located in Soliman, Tunisia, for analysis.

Water analysis

The electrical conductivity, pH and temperature were performed by a Proline type conductivity meter and pH-meter in situ. Calcium, magnesium, chloride and bicarbonate were analyzed by the titrimetric method. Sodium and potassium were analyzed by flame photometer. Sulphate and total dissolved salt were analyzed by gravimetric method. Nitrate and COD were analyzed according to NF T 90 012 [19] and APHA [20] standard methods respectively. Finally Ammonium was analyzed by steam distillation using NaOH (30%) followed by back titration of boric acid distillate using sulfuric acid (0.1 M).

Evaluation criteria of irrigation water quality

Sodium concentration plays an important role in evaluating irrigational quality of water. A high concentration of sodium is undesirable as sodium is adsorbed on the exchange sites causing soil aggregates to disperse and reducing its permeability [21]. In water having high concentration of bicarbonate there is tendency for calcium and magnesium to precipitate as carbonates [22]**.** The combination of EC (salinity hazard) and alkalinity hazard SAR calculated by equation1 was used to evaluate the suitability of water for irrigation based in table n° 1 [11].

Table n° 1 : Irrigation water Classes according to the salinity level and SAR [11]

Water class	Conductivity (ms/cm)	TDS (g/L)	Water class	SAR
C_1 Excellent	0 - 0.25	0.175	S_1 low sodium hazard	0 - 10
C_2 Good	0.25-0.75	0.175 - 0.525	S2 medium sodium hazard	10 - 18
C_3 Permissible	0.75 - 2	0.525 - 1.4	S_3 High sodium hazard	18 - 26
C_4 Doubtful	2 - 3	1.4 - 2.1	S_4 Very high sodium hazard not suitable for irrigation	> 26
C_5 Unsuitable	> 3	2.1		

Sodium percent SSP is another important parameter to study the sodium hazard [23]. Also residual sodium carbonate (RSC) is an index used to determine the bicarbonate hazard as well as to distinguish between the different water classes for irrigation purposes. The calculations of parameters RSC, SSP and ESP were achieved using the following equations in milliequivalents per liter (meq/L).

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^{2+}]+[Mg^{2+}]}{2}}}$$ **Equation 1** [24]

$$RSC = ([CO_3^{\ 2-}]) + [HCO_3^{\ -}]) - ([Mg^{2+}] + [Ca^{2+}])$$ **Equation 2** [24]

$$SSP = 100\,(\frac{[Na^+]}{([Ca^{2+}]+[Mg^{2+}]+[K^+]+[Na^+])})$$ **Equation 3** [24]

$$ESP = \frac{100\,(-0{,}0126\ +0{,}01475\ SAR)}{1+(-0{,}0126\ +0{,}01475\ SAR)}$$ **Equation 4** [24]

The conductivities, TDS, toxic elements (sodium, chloride, nitrogen), bicarbonate which caused clogging in irrigation system, SAR, RSC, SSP and ESP of different water resources were compared to FAO guidelines for interpretation of irrigation water quality illustrated in table n° 2 [11,19 and 25].

Table n° 2 : Guidelines for interpretations of irrigation water quality [19, 25]

Potential irrigation problem	Units	Degree of restriction in use		
		None	Slight to moderate	Severe
Salinity				
EC_w	ms/cm	< 0.7	0.7 - 3	> 3
TDS	mg/L	< 450	450 - 2000	> 2000
Specific ion toxicity				
SAR (Surface irrigation)		< 3	3 - 9	> 9
$[Na^+]$ (Sprinkler irrigation)	meq/L	< 3	> 3	
$[Cl^-]$) - Surface irrigation) - Sprinkler irrigation	meq/L	< 4 < 3	4 - 10 > 3	> 10
Boron [B] [11]	mg/L	< 0.7	0.7 - 3	> 3
Ions affects susceptible crops				
$[NO_3\text{-}N]$	mg/L	< 5	5 - 30	> 50
$[HCO_3^-]$ (Sprinkling only)	meq/L	< 1.5	1.5 - 8.5	> 8.5
RSC	meq/L	< 0	0 - 1	> 1
SSP		< 60	60 - 80	> 80
ESP		2 - 10	10 - 40	> 40
pH	6.5 - 8.4			

In order to classify these several waters based on salinity hazard, analyses results were saved in Excel files and used as data input, After that Riverside and Wilcox diagrams were plotted using water software quality hydrochemistry diagrams developed by hydrogeology laboratory in Avignon university version 6.58.

Technical-economic evaluation of RO desalination plant

Performance evaluation of desalination system

Irrigation with desalinated water has the potential to be a more water-efficient and economically viable alternative to brackish water irrigation [26]. RO is particularly appealing because recent advances in membrane technology allow modular construction of desalinating facilities to meet small to large-volume desalination needs [27]. As described below, farmer used a reverse osmosis unit with two parallel vessels and four elements with the area of 37.16 m^2 to desalinate well brackish water. In order to evaluate the performance of this plant, the conversion rate Y and retention rate T_R were calculated for each difference pressure ΔP using the following equations:

$$\Delta P = \frac{P_F + P_R}{2} - P_p$$ **Equation 5** [28]

with P_F: Feed membrane pressure (bar)

P_R: Retentate membrane pressure (bar)

P_P: Permeate pressure (bar)

$$Y = \frac{Q_p}{Q_F}$$ **Equation 6** [28]

Q_p is the permeate water flow rate and Q_F is the feed water flow rate (m^3/h)

$$T_R = 1 - \frac{Cp}{C_F}$$ **Equation 7** [28]

With Cp: permeate water salinity (g/L)
C_F: feed water salinity (g/L)

After analyzing the samples taken from RO plant, the experimental results were used as the data input to IMS-design software developed by Hydranautics Nitto Group Company in order to simulate a process. The experimental data analyzed in 23 March was used as data input for model calibration because the brine water was not recycled to the feed point of plant and only well water was desalinated at this day. Selected membrane was ESP1 based in active area, flow rate and maximum pressure of RO elements installed in the farmer. For each ΔP permeate recovery rate, permeate TDS and brine water TDS were deduced by simulation. Membrane selectivity T_R was calculated using output simulated results. Optimum conversion rate was obtained for a ΔP in which, maximum retention rate and minimum permeate TDS were reached. The Specific Consumption Energy (SEC) defined as the electrical energy needed to produce a cubic meter of permeates. It's assumed equal to the pump word devised by pump efficiency [29] and it was calculated by this equation:

$$SEC = \frac{Q_F * \Delta P}{Q_p \eta_{pump} \eta_{motor}}$$ **Equation 8** [30]

In our case; η_{pump}= 0.8 and η_{motor} is close to 1.

Water cost production

In water desalination cost estimates seem to be very much site specific and the cost per cubic meter ranges from installation to installation. This variability is due to the water cost depends upon many factors, unique in each case, most important of which are the desalination system the feed water salinity, the energy source, the capacity of the desalting plant, and other site related factors [31].

Several assumptions were made for the economic analyses. The project life time was 15 years, the membrane age was 8 years, interest rate was 5% [32], actualization rate was 5%, the system availability was 90%, and the electrical cost was set at 0.58 KWh/m^3. Electricity consumption was calculated for the recovery rate of the RO process of 68%. Indirect charged, replacements of membrane, maintenance and operating costs were also considered in calculations. The table n° 3 [32, 33] lists detailed calculation of Water Production Cost (WPC) which is based on the following equation:

$$WPC = \frac{C_{total}}{f Q_{p,d} 365}$$ **Equation 9**[32]

- C_{total} is the total annual cost defined by the sum of annual fixed charges, operational and maintenance costs.
- f is the plant availability
- $Q_{p,d}$ is the daily permeate flowrate (m^3/d).

Table n°3 : Hypothesis and correlation for water production cost estimation

Annual fixed charges [32]	Annual operational and maintenance costs
C_{fixed} = a.CC CC: capital cost	Membrane replacement 6 % of membrane cost
Amortization factor: $a = \frac{i(1+i)^n}{(1+i)^n - 1}$ i: annual interest rate n: life time of the plant	Chemicals : \$ 0.018 /m^3 [32]
CC= DCC+ICC ICC = 0.1 DCC D: direct ; I: Indirect	Electrical energy fees \$ 0.053/KWh + 2% annual increasing rate [33]
DCC : Civil works, intake and pretreatment, pumps, vessels and membranes cost (Real Data of RO plant)	Operating and spares fees: \$0.033 /m^3 [32] Labor: \$ 0.015 /m^3 [33] Brine disposal cost: \$ 0.015 /m^3 [32]

Brine environmental impact and management

Desalination technology has been associated with potential environmental impacts. At the aim to assess the impact of the brine discharge on the deep well injection disposed brine water were characterized and environmental effects were considered by comparison of ions, COD and nitrogen ammonia to Tunisian Standards 106.002 [34]. Replacement of RO membrane ESP1 with ESNA1-LF-LD nanofiltration with the same active area was proposed to minimize brine amount and increase water production. After that salinity, ions, conversion rate, TDS permeate and TDS brine using nanofiltration was carried out by IMS-Design software. Retention rate, SAR, RSC, SSP and ESP also specific energy consumption were calculated and compared to reverse osmosis experimental results. Nanofiltration produced water quality was compared to FAO requirements for sensitive crops such as citrus.

III. Result and discussions

Physicochemical characteristics of different water resources used in citrus producing farm

As shown in figure n°1 different resources of water were available in the citrus farm for irrigation purposes; well, dam and desalinated water.

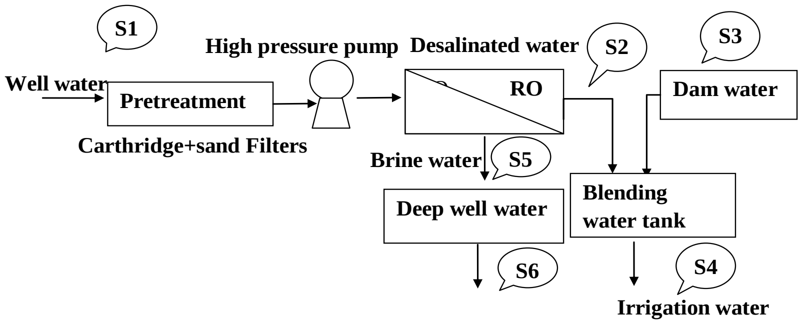

Figure n°1: Water production line of citrus irrigation water

The well water mixed sometimes with recycling brine is the feed water of the desalination plant. The desalinated water is collected in a tank and mixed with the dam water to be finally used for citrus irrigation. The table n°4 summarized the results of experimental analyses and deduced evaluation criteria of different waters qualities.

Table n° 4: different water resources qualities using in citrus producing farm

Water type	Well water		Dam water		Desalinated water		Water Irrigation: mixture of dam and desalinated water
	Min	Max	Min	Max	Min	Max	
T °C	20.1	29.3	28.4	28.8	20.3	29	27.8
pH	6.87	7.1	7.56	8	6.12	6.31	6.95
Conductivity at 25°C (ms/cm)	4.784	5.63	4.12	5.57	0.476	1.182	1.46
TDS (g/L)	3.71	4.21	3.15	4.26	0.37	0.905	1.13
Ca^{2+} (meq/L)	17	26	17.30	25.20	1.90	6.39	7.80
Mg^{2+} (meq/L)	14	15	6.25	9.83	0.79	5.60	4.67
Na^+ (meq/L)	22	23	21.80	26.07	1.65	2.61	6.09
K^+ (meq/L)	3	4	2.35	3.56	0.44	0.77	0.51
Cl^- (meq/L)	30	33	26.00	32.00	3.45	10.00	10.99
SO_4^{2-} (meq/L)	17	18	11.56	17.96	1.04	2.48	5.42
HCO_3^-(meq/L)	8	11	8.03	11.97	0.85	1.64	1.00
$N0_3^-$ (mg/L)	180	206.6	172	174.5	27	45	50
SAR	5.69	5.14	6.35	6.22	1.06	1.42	2.44
RSC	-22	-29	-16	-23	-2	-10	-11
SSP	39.9	34.32	45.7	40.31	34.5	16.9	31.94
ESP	6.66	5.59	7.5	7.34	0.83	0.311	2.28

The waters temperatures fluctuated from 20°C to 29.3°C according to the season. The pH of different water resources (well, dam, desalinated and blended) were in the normal range of FAO guideline (6.5-8.4). Electrical conductivity in this study varied from 4.78-5.63 for well water, from 4.12-5.57 for dam water and from 0.47–1.18 ms/cm for desalinated water. The higher values of desalinated water conductivity were obtained in the case of recycled brine to the feed RO plant. The citrus irrigation water conductivity which is the blended dam and desalinated water was 1.46 ms/cm.

According to the salinity level (tablen°4) and the FAO guideline of irrigation water interpretation (tablen°1) desalinated water was good and excellent for irrigation purposes. Blended water was good. However the dam water which was habitually used in Tunisia was doubtful and unsuitable for irrigation class as well as the well water.

El Yassin [35] reported that the growth of trees on all rootstock was depressed by increasing salinity in the root zone. The fruit yield reduction was associated primarily with a decrease in the number of fruits per tree rather than to differences in weight per fruit.

Brito et al. [36] assessed the growth of citrus under saline water irrigation using five salinity levels (0.8, 1.6, 2.4, 3.2 and 4 ms/cm) of irrigation water applied to 12 genotypes and they conclude that salinity reduces citrus growth and the water potential in soil. They observed also that Troyer Citrange showed linear decreases between 3.3 and 6% in stem diameter with 1 ms/cm increase in EC of water. Aboutalbi and Hasanzadeh [37] considered that citrus tolerance ability EC was 1.1 to 3.2 ms/cm and plant age is very important factor in reaction of crops to salinity.

The citrus growth depends to water salinity but also to the salinity of the soil. Ayers and Wetscot [38] associated the potential growth yield of Citrus to water and soil salinities (table n°5).

Table n°5: Evolution of orange potential yield crop growth according to water and soil conductivity [38]

Crop	Yield potential			
Orange potential yield	100 %	90 %	75 %	50 %
Water conductivity at 25 °C (ms/cm)	1.1	1.6	2.2	3.2
Soil conductivity at 25 °C (ms/cm)	1.7	2.3	3.2	4.8

Grattan et al. [39] described the yield potential of orange based on osmotic effects only as:

$Y_r = 100 - 13.1(ECe - 1.3)$ **Équation 10** [39]

Where ECe is the soil salinity in ms/cm

Specific ion toxicities due to sodium, chloride or boron would reduce the yield potential even more [40].

The FAO recommended for irrigation water 3 and 4 meq/L (table n° 2) as limit sodium and chloride concentrations respectively to avoid damage sensitive crops such as citrus. In our case only desalinated water satisfied these conditions (table n° 4). Ashutosh et al. [9] noted that the presence of NaCl during embryogenesis affects the growth regulators balance. Boman and Stover [41] denounced that with sufficient levels of calcium in the soil solution, it is unlikely that 115 mg/L sodium will produce injury to citrus. In our case study, sodium concentration was higher for both well water (509-530 mg/L) and dam water (501-599 mg/L). Chloride is considered as the most common toxic ion in irrigation water. Since, chloride is not adsorbed by the soil colloids; therefore, it travels easily with soil water, is absorbed by the crop, moves into the transpiration stream, and accumulates in the leaves. If the chloride concentration in the leaves exceeds the tolerance of the crop, injury symptoms develop, such as leaf burn or drying of leaf tissue [42**].** Levy and syverstsen [43] explained that chloride is not mobile in most plants; toxicity will appear on the margins and tips of older leaves first. The first shows up as chlorosis (yellowing) or bleaching in between the veins of the oldest leaves, as chorophyll is lost from the tissue. The maximum chloride concentration in the irrigation water before damage occurs is 152 mg/L. As shown in table n° 4 the chloride concentration of the well water (1050-1172), the dam water (923-1136) and the irrigation water which is the mixture of desalinated and dam water (390 mg/L) was very high and can damage the citrus trees. For desalinated water the chloride concentration is only raised for the case where the feed of the desalination unit is the mixture of well water and brines (355 mg/L). Visual injury to leaves (Chlorisis and necrosis) can became apparent when sodium concentration in the leaves reach 0.1-0.25 % dry wt and yellowing or bleaching in between veins can appear on citrus leaves when chloride concentration in the leaf reach exceed 1% on dry weight base [39].

Evaluation waters resources criteria for citrus trees irrigation purposes showed that the RSC for all waters were negative as well as the SSP (Table 4) were in the common FAO recommendations (table n° 2). As a consequence salts precipitation in the soil were excluded. However the SAR of well and dam waters were high than 3 this is due to higher values of sodium concentrations which can cause a soil sodicity. Based in table n° 1, Riverside (figure n°2) and Wilcox diagrams (figure ° 3) the well and dam waters were classified as C_4S_1 and C_5S_1 doubtful and unsuitable for irrigation however, desalinated and blended waters were classified C_1S_1 and C_2S_1 excellent and good waters qualities.

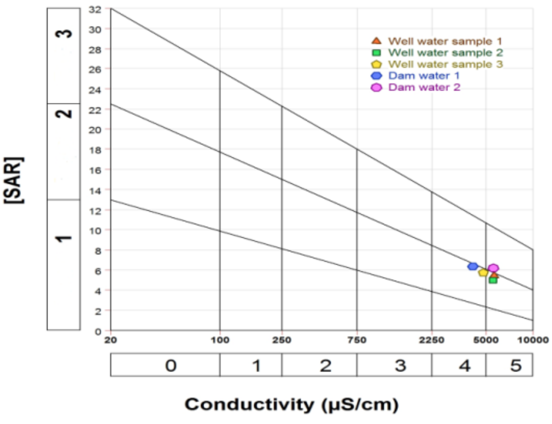

Figure n°2: Riverside diagram

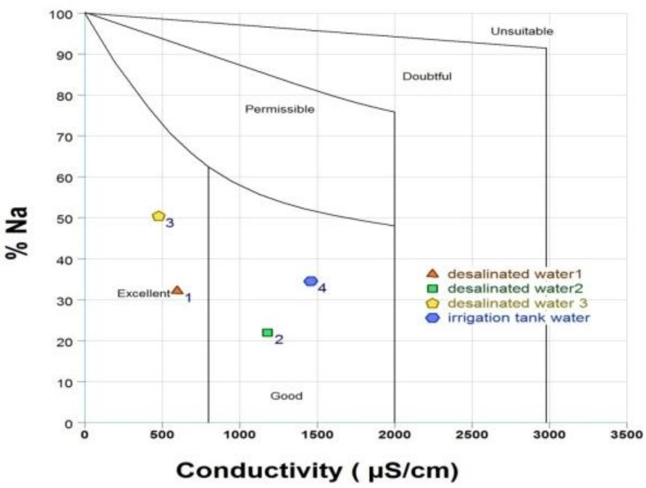

Figure n°.2: Wilcox diagram

Other ions affect susceptible crops like bicarbonate for sprinkling irrigation which can cause clogging of irrigation system and nitrate. The well water and dam water bicarbonate concentration were high than 8.5 mg/L as well as the nitrate concentration were very high than 50 mg/L recommended by FAO (table n°2). These values of nitrate may indicate contamination from excessive use of fertilizers. Nitrogen, phosphorus and potassium are major nutrients for the crop. However, those nutrients can give negative effects such as nutrient imbalances, groundwater contamination, reduces fruit set for crops, delays in maturation and decreases in food nutrients quality [44].

Desalination system performance and produced water cost

The performance evaluation was carried out for brackish water reverse osmosis membranes ESP1 designed to produce water for citrus irrigation purposes. The effect of pressure for the same feed water temperature, salinity and composition on the efficiency of RO system was investigated. Results showed that the conversion rate increased function the pressure but the selectivity of membrane increased then stabilized at a certain value of ΔP (figure n° 4).

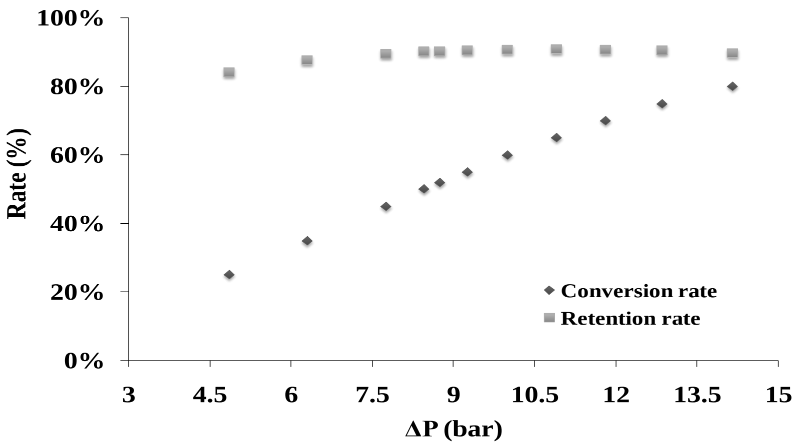

Figure n° 3: Evolution of conversion rate and the selectivity of RO membrane according to difference pressure, TDS_F 3.71g/L, pH_F 6.87, T_F 20.1°C

The less value obtained of permeate TDS was 346 mg/L for the difference pressure of 10.9 bar (figure n° 5).

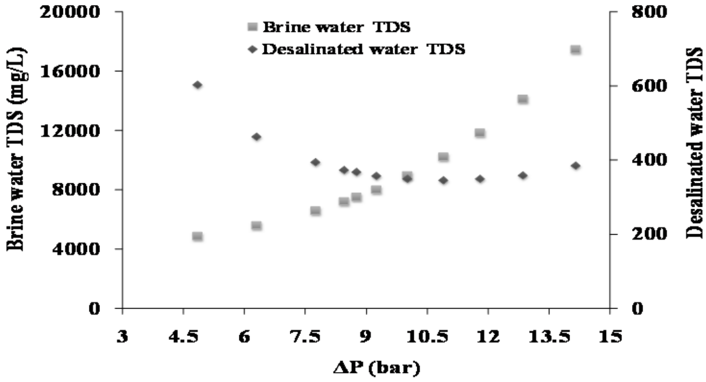

Figure n°4 : Evolution of desalinated and water TDS according to difference pressure, TDS_F3.71g/L, pH_F 6.87, T_F 20.1°C

At this ΔP the optimum values of conversion rate was 68%, the retention rate was 91%, the brine concentrations was 10214 mg/L and the specific energy consumption was 0.58 kWh/m^3.

An economic analysis was carried out to estimate the total water cost in these optimum conditions using hypothesis and equations described in Table 3 and $18484 direct capital cost of the plant which included the cost of two RO pressure vessels and four elements ($ 4484). The total cost to produce 120 m^3/d of water from a feed salinity of 3710 mg/L and a water quality of 346 mg/L was $ 0.246 /m^3. The cost was in good agreement with the desalination cost brackish water for small plant capacities (200 to 1400 m^3/d) in Tunisia which vary from $ 0.240 / m^3 to $ 0.492 /m^3 [33] as well as the high capacities RO desalination plant drinking water located in the south of Tunisia (Kerkenah, Gabes, Zarziz and Djerba) which vary between $ 0.12/m^3 and $ 0.28/m^3 [45].

Ioannis et al. [27] concluded that reverse osmosis desalination costs vary from $ 0.26 to $ 0.54 /m^3 according to the salinity and for a capacities varying from 5000 to 60000 m^3/d. Sarai Atab et al. [46] founded that the total cost to produce 24000 m^3/d of water from a feed salinity of 15000 mg/l and a water quality of less than 400 mg/L was £ 0.11/m^3 with in investment cost of £ 14.4 million for the drinking water, and for irrigation obtained product less than 1600 mg/L was £ 0.9/m^3 with an investment cost of £11.3 million. As a conclusion the variability of the cost depend in various parameters: feed water quality, conversion rate, retention rate and investment cost of plant which is related to plant design, interest rate, and cost of electricity and it should be evaluated for such case study.

Uses desalination water improved crops growth and a trees productivity, and it will be a good alternative for agriculture purposes. However brine generated by RO plant should be managed and minimized.

Characterization of disposal brine, environmental risks evaluation and projected solution

The management of brine from inland brackish desalination plants can be significant problem in case they are placed far from the coast. In our case study brine water was injected in a deep well located far from the feed well water of the desalination unit. The amount of rejected brine was 32% of the feed water and the salts concentration of this brine was 10214 mg/L. chemical analyses of both brine product by RO and disposal in a deep well were carried out and the results were illustrated in table n° 6.

Table n °6: Environmental impact of brine injection in deep well

Concentration (mg/L)	Brine water	Deep well injection brine water	Tunisian Standard 106.02
Ca^{2+}	716	724	500
Mg^{2+}	671	214	200
Na^+	1383	650	300
K^+	392	150	50
SO_4^{2-}	2374	1255	600
Cl^-	2730	1491	600
COD	240	200	90
NH_4^+	15.83	8.05	1

Compared results to the Tunisian water discharge standards showed that all chemicals parameters exceeded limit values of NT 106.02. As a consequence the salinity of groundwater will be increased and the agriculture problems will be accentuated with the addition of environmental impact.

Replacement of reverse osmosis membranes by nanofiltration (NF) membranes was suggested to produce maximum volume of irrigation water and the new desalination system configuration was simulated. The ESNA1- LF-LD membrane was used and the performance of unit was carried out by IMS-Design Software.

The conversion rate of nanofiltration unit was high than reverse osmosis plant for all applied pressure (figure n° 6) and the nanofiltration consumes energy was less than reverse osmosis (figure n° 7).

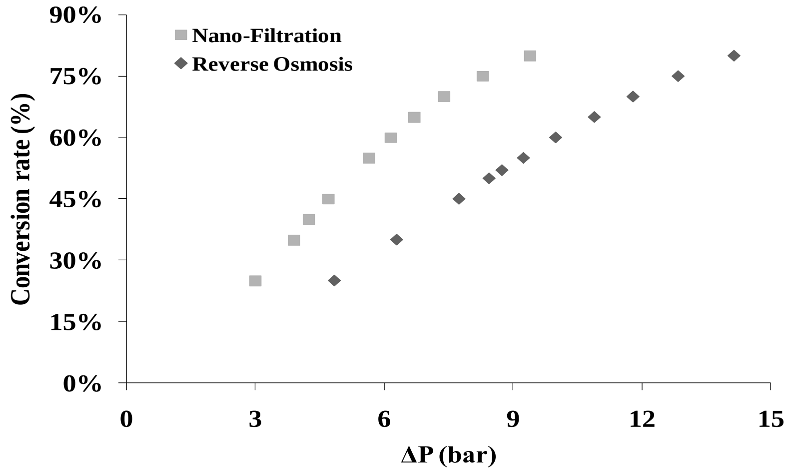

Figure n° 5: Evolution of conversion rate using nanofiltration and reverse osmosis desalination systems, TDS_F 3.71g/L, pH_F 6.87, T_F 20.1°C

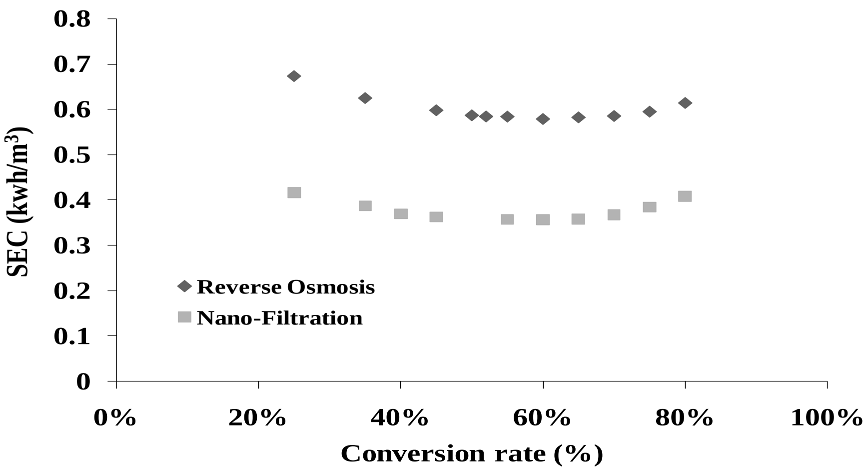

Figure n°6: Comparison between nanofiltration and reverse osmosis specific consumes energy function of conversion rate, TDS_F 3.71g/L, pH_F 6.87, T_F 20.1°C

A conversion rate of 80% was obtained for a difference pressure of 9.4 bar. This process maximized the volume of produced water, consumed less energy and minimized brine amount. Compared results to optimum values obtained for RO desalination plant, the nanofiltration allowed to minimize 12% of brine amount and obtained brine concentration was10800 mg/L near than obtained by RO plant (figure n° 8) and to win 35% of consumes energy (figure n°7).

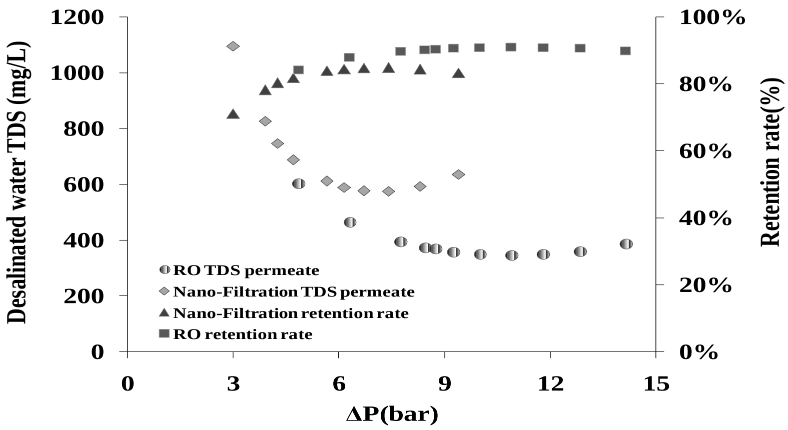

Figure n° 7: Evolution of permeate TDS and retention rate using nanofiltration and reverse osmosis desalination systems, TDS_F 3.71g/L, pH_F 6.87, T_F 20.1°C

Liikanen et al. [47] confirmed that the environmental impact minimization was mostly related to recovery of the process and energy consumption if the nanofiltration installation was used. Ghermandi et al. [48] demonstrated that the investigated solar desalination technology with nanofiltration membranes has the potential to enlarge the portfolio of crops that are currently available to the local farmers, by enabling the cultivation of salt-sensitive cash crops.

Comparing rejection percent in two above-mentioned methods, it could be concluded that, in reverse osmosis process, the rejection ability were rather better than nanofiltration process (fgure n°8). The nanofiltration retention rate at the pressure 9.4 bar was 83% (figure n° 9).

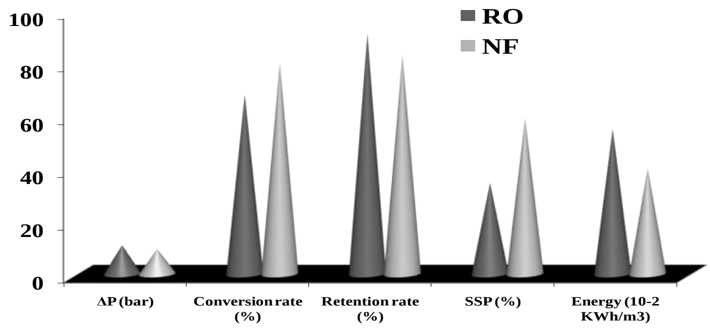

Figure n°8: Comparison between reverse osmosis and nanofiltration performance, TDS_F 3.71g/L, pH_F 6.87, T_F 20.1°C, optimum parameters

Mulyanti and Susanto [49] assumed that the NF ability to remove salinity parameter varies from 75 % to 95 % depending on the membrane in use. The TDS permeate obtained by nanofiltration was 0.635 g/L (figure n°10), worse than reverse osmosis but acceptable for citrus trees irrigation (<1.2 g/L, [7]).

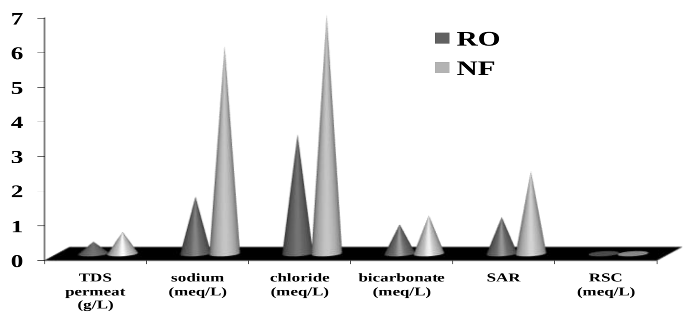

Figure n°9 : Comparison between reverse osmosis and nanofiltration permeate salts concentrations, TDS_F 3.71g/L, pH_F 6.87, T_F 20.1°C, optimum parameters

NF offers several advantages such as low operation pressure, high flux, high retention of multivalent anion salts and an organic molecular above 300,relatively low investment and low operation and maintenance costs. Whereas the rejection of monovalent ions is moderate to low.The rejection by NF of sodium chloride (NaCl) varies from 0 % to 70% [50]. The sodium concentration of NF permeate and chloride was also simulated, as shown in Fig.10 sodium and chloride concentrations was higher (6 meq/L) compared to those obtained by RO, this is due to higher feed water concentrations of these elements. Compared results to FAO guidelines (table n°2) showed that it can be caused a slight to moderate potential irrigation problem. Calculated criteria of water irrigation quality SAR, RSC and SSP (figures n° 9 and 10) using NF were 2.38, -1.02 meq/L and 59 % respectively less than recommended by FAO guidelines (table n°2). Bicarbonate concentration was also less than limit concentration which can cause clogging in irrigation system (<1.5 meq/L) (figure n°10). As a consequence except sodium and chloride toxic elements using the nanofiltration membranes was benefic, not caused soil destruction and the cost of produced water were minimized as well as the amount of the brine and environmental impact (maximum irrigation water, less energy consumes and good quality).

The Tunisian state subsidized the desalination plant which achieves a conversion rate higher than 75%. Therefore farmers can obtain a grant of 50% from the state to sale a nanofiltration desalination plant. Integration NF process with other processes potentially produces higher water quality and improved the retention of monovalent ions [51]. Brine can be used for producing halophyte biomass for forage [52, 53], hydroponic agriculture [54] and fish farming [55].

IV. Conclusion

The evaluation of several water resources qualities used in citrus producing farm in North Tunisia Cap-Bon proved that desalinated water was the most suitable for irrigation purposes. The technical-economic study of RO plant installed in the farm revealed that the amount of produced waters was 68 % of feed water with a specific consumes energy of 0.58 kWh/m3 and a water cost production of $ 0.24/m3.The brine rejection was 32% of feed water with a concentration of 10.2 g/L. Disposal brine waters extracted from the deep well injection was characterized and the salts, nitrogen ammonia and COD concentrations exceeded the 106.002 Tunisian standards. Replacement of RO membranes by nanofiltration membranes were suggested and simulated results showed that the amount of brine water was reduced to 20%, the specific energy consumes was reduced by 35 % and a produced water quality was acceptable for citrus trees irrigation with a precaution to monovalent ions (chloride and sodium). A perspective of this work was using hybrid system (NF-RO) for minimizing a brine amount and using generated brine from desalination unit for producing halophyte culture and fish farming.

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Nomenclature

EC_e	Soil conductivity (ms/cm)
RO	Reverse osmosis
NF	Nanofiltration
SAR	Sodium absorption rate
RSC	Residual sodium carbonate (meq/L)
SSP	Sodium percent (%)
ESP	Exchangeable sodium percentage (%)
FAO	Food agriculture organization
P	Pressure (bar)
T	Temperature (°C)
TDS	Total dissolved salts (g/L)
Y	Conversion rate (%)
F	Feed
TR	Retention rate (%)
Cp	Permeate salinity (g/L)
SEC	Specific energy consumption (kWh/m^3)
η	efficiency
WPC	Water production cost ($\$/m^3$)
Q	Flowrate (m^3/d)
C_{total}	Total annual cost
Ec_w	Water conductivity (ms/cm)
Yr	Yield potential of orange
COD	Carbon oxygen demand (mgO_2/L)
f	Plant availabilty

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