REPORT

SEAWATER INTRUSION AND CROP RESPONSE TO SALINITY IN COASTAL LEBANON

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ABSTRACT

Research conducted between 1999 and 2004 to assess pressure on coastal zone focused on three main objectives: first, the evaluation of seawater intrusion in southern coastal wells, second, the soil salinization in greenhouses irrigated by well waters, and third the management of saline water in two soil textures. Groundwater contamination was assessed by regular sampling of six wells for 30 months. The salinity of water fluctuated around 3 dS m^{-1} *and the Simpson index (*Cl/HCO_3*) indicated levels of moderate to injurious contaminations. The Na/Cl ratios remained < 1, suggesting a seawater intrusion rather than an anthropogenic origin. In all sites, greenhouse growers had to rely on other water sources (e.g. rainwater, domestic) to supply the crop needs. In some cases, the crop had to be interrupted as salinity decreased yields. Improving the management of water and nutrients was studied in a tomato/Jew's-mallow sequence. Three levels of water salinity (1, 2.5 and 5 dS* m^{-1}*) were tested in sandy and clay soils. Under sound management of fertilizers input and a leaching fraction, the salinity had no obvious negative effect on tomato in the clay soil. The Jew's mallow had a role in the removal of residual salts.*

Keywords: soil salinization, groundwater vulnerability, water quality, tomato-jew's mallow succession, soil texture

INTRODUCTION

In Lebanon the share of agriculture represented 59.5% of the total water demand in 2005 (Website 1). In the absence of plans for irrigation networks, some 2000 wells were added to the existing 10 000 wells in the 1992-1995 period (Aquastat, 2008). Excessive pumping from private wells has lead to a rise of salinity in coastal groundwater south of *Beirut* (El Moujabber *et al*., 2006), and in the region of Tripoli, Beirut and Saida (Korfali & Jurdy, 2010). This pressure is encountered in the Lebanese coastal region where 59% of the population is concentrated on 8% of the territory (Atlas du Liban, 2004). There the competition between agriculture and the domestic needs is direct and groundwater as additional water resources become a more pressing issue.

In these areas protected cultures represent one of the remaining agricultural systems. Some practices in these cultures, such as the application of animal manures (35-100 tons ha^{-1}) or the soil application of complex fertilizers, were identified to cause secondary soil salinisation (Atallah *et al*., 2000) independently from the quality of irrigation water. The impact of soil salinity on the crop physiology and yield was studied to some extent. It caused a preferential growth of foliage in an indeterminate variety of tomato (Katerji *et al*., 2009a) and a decrease of leaf area and yield in faba beans (Katerji *et al*., 2009b). Soil texture was an important component interfering with salt impact on crop yield, with loamy soil securing a greater yield than clay soil (Katerji *et al*., 2003).

With more extensive pumping causing seawater intrusion (El Chami *et al.*, 2009), irrigating with brackish waters should be considered as an alternative. This requires a leaching fraction sufficient to remove excess salts from the root zone (Website 2), and a comprehensive analysis to protect the downstream areas and groundwater (Beltran, 1999). In this report, a summary of 5-year-research activities, conducted in the coastal area of Choueifat, Jieh and Rmeileh, an important region of protected strawberry, tomato, cucumber and eggplants, is presented. First, the groundwater quality was followed in six wells within these locations for three years. Second, the soil salinity in six greenhouses irrigated by three of these wells was studied. Third, the effect of three levels of water salinity on a tomato-Jew's mallow (Meloukhieh in arabic) sequence was studied in sandy and clay soils. Jew's mallow was included to remediate salt-affected soils.

QUALITY OF IRRIGATION WATER

Water quality was studied in 6 wells, 3 of them in Choueifat (well 1: 33°40'06''N, 35°30'59''E, 23 m above sea level (asl); well 2: 33°48'17''N, 35°29'43''E, 31 m asl; well 3: 33°48'03''N, 35°29'42'' E, 49 m asl] two in *Jieh* [well 4: 33°41'07''N, 35°25'33''E, 55 m asl; well 5: 33°39'53'' N, 35°25'19''E, 50 m asl) and one in Rmeileh (well 6: 33°36'22''N, 35°23'28''E, 39 m asl). Well water was sampled on a monthly basis, 30 times between July 1999 and April 2002.

Wells in Choueifat had a moderate electrical conductivity -ECw- (Table 1). Only twice, well 1 presented a reading higher than 3 dS m^{-1}. Wells 5 and 6 had slightly greater EC values, while the highest salinity was in well 4 (Table 1) with 73% of values above 3 dS m^{-1}. The sodium adsorption ratio (SAR) presented a similar trend to the electrical conductivities. Critical SAR values (>10) were absent from wells 1 (Figure 1), 2 and 3, not numerous in well 5 (data not shown) nor in well 6 (Figure 1). To the contrary, in well 4 most SAR values were in the critical range (Figure 1), with 20 of them above 10 and two higher than 20.

The electrical conductivity of these well waters (ECw) was checked in July 2012. There was an increase in all cases, compared to July 2001 (as no reading was done in July 2002) despite the significant water recharge associated with the high rainfall between October 2011 and April 2012. The values of ECw more than doubled over this time period, only in Jieh 2 the relative increase was 53% only. In fact, the well owner switched from the greenhouse production requiring winter irrigation, to open field production. The 2012 readings suggest that the quality of the well waters has not improved over time, although this change was not detectable by the growers.

TABLE 1

Mean and Ranges (in Brackets) of the Electrical Conductivity (EC), Chloride, Bicarbonate, Sulfate, Sodium and Calcium plus Magnesium Concentrations Obtained over 30 Months in Six Wells

Region	**Well**	**EC** (dS.m^{-1})	**Concentration (mM)**				
			Cl	**HCO_3**	**SO_4**	**Na**	**(Ca + Mg)**
Choueifat	**1**	1.84 (0.86 - 4.03)	12.46 (2.96-35.7)	3.88 (2.3-5.2)	2.14 (0.13-7.17)	7.69 (2,17-17.69)	10.67 (5.9-23.9)
	2	1.81 (0.70 - 2.98)	12.00 (5.40-22.4)	3.74 (2-5.6)	2.37 (0.15-10.77)	8.12 (5-11.26)	9.87 (5-17.03)
	3	1.82 (0.61 - 2.74)	13.37 (3.80-20.4)	3.55 (1.97-4.8)	1.45 (0.21-5.35)	9.89 (3-14.5)	8.31 (5.4-12.3)
Jieh	**4**	3.77 (1.80 - 5.44)	31.31 (14.8-46.0)	4.33 (2.7-6)	2.20 (0.47-6.15)	27.43 (13.5-38)	9.80 (5.17-13.2)
	5	2.50 (1.16 - 4.47)	19.64 (9.10-23.4)	4.04 (2-5.8)	1.72 (0.09-5.26)	15.18 (7.18-28.0)	9.95 (7.62-17.8)
Rmeileh	**6**	2.16 (0.65 - 4.60)	16.21 (4.70-36.0)	3.98 (2-7.9)	1.27 (0.05-3.38)	13.49 (4-29.5)	7.68 (3.78-12)

The study focused on the chloride contents, one of the clearest indication of seawater intrusion (FAO, 1997). Mean chloride concentrations were above the threshold of 10 mM (Table 1) as 67% of values in wells 1, 2 and 3 were above it.

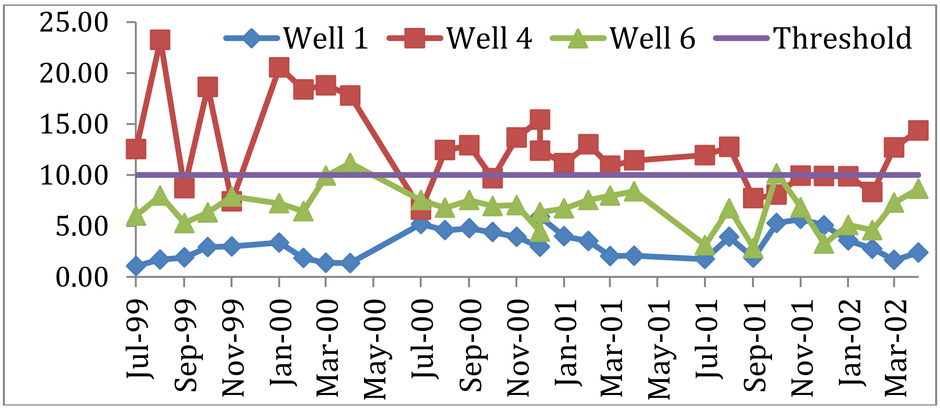

Figure 1. Sodium adsorption ratios for wells 1 (Choueifat), 4 (Jieh) and 6 (*Rmeileh*) between July 1999 and April 2002, the horizontal line represents the threshold level equal to 10.

Rather than the chloride concentrations, others consider the sodium/chloride ratio as a good indicator of the origin of the pollution. A ratio below 1 is a suggestion of seawater intrusion, while a ratio above 1 would indicate a pollution of anthropogenic origin (Jones *et al*., 1999). The relationships sodium/chloride were established separately according to the salinity level: wells 1, 2 and 3 (EC_w<2 dS m^{-1}), then wells 5 and 6 (EC_w 2 to 3 dS m^{-1}) and well 4 (EC_w>3 dS m^{-1}). Linear relationships were found for all levels:

Wells 1, 2 and 3:	[Na] = 0.673 x [Cl]	(r=0.908; n=90)
Wells 5 and 6:	[Na] = 0.800 x [Cl]	(r=0.969; n=60)
Well 4:	[Na] = 0.877 x [Cl]	(r=0.968; n=30)

Correlation coefficients were significant in all three equations. With the rise in salinity the slopes increased but remained below 1 suggesting a seawater intrusion.

SIMPSON RATIOS AND MANAGEMENT OF IRRIGATION WATER

Simpson ratio (Cl/HCO_3+CO_3) gives an evaluation of the level of contamination. Five classes were recognized: good quality (<0.5), slightly contaminated (0.5-1.3), moderately contaminated (1.3-2.8), injuriously contaminated (2.8-6.6) and highly contaminated (6.6-15.5) [cited by El Moujabber *et al*., 2006]. Simpson values followed a similar pattern to that of the salinity. Well 4 was highly contaminated while the other wells were moderately to injuriously contaminated. In well 1, only occasionally, these values exceeded 6.6 (Figure 2). Following the spell of high values (August-December 2001), pumping was interrupted to avoid injury to the sensitive strawberry crop. Well 2 presented the highest values between July 2000 and January 2001. During the winter months, the use of well water was reduced with the switch to open field production. In well 3, a moderate contamination was detected during all seasons. Similarly, in well 5 a moderate contamination prevailed, except for a peak of injurious level during July-August 2000. In this case, the grower diverted the water to domestic use. Well 6 was subject to some seawater invasion, yet the level of contamination remained moderate. Then, the grower mixed the well water with freshwater of drinking quality. In well 4, 60% of values were above the injurious level (Figure 2).

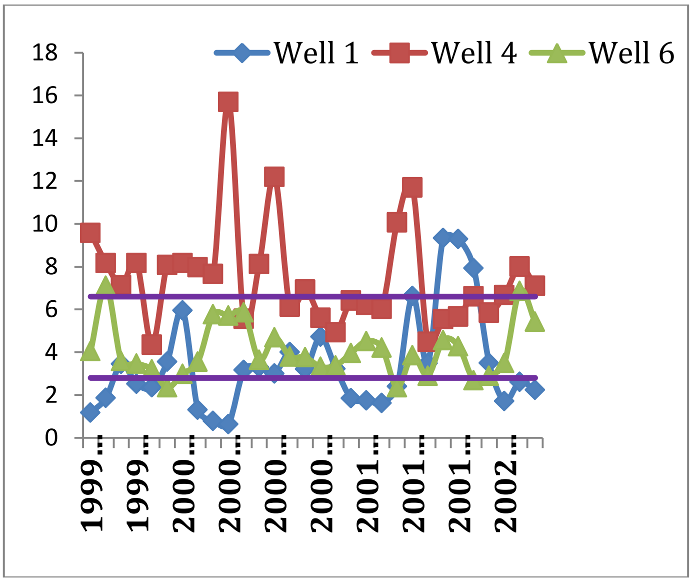

Figure 2. Simpson indices (Cl/HCO_3+CO_3) for wells 1 (Choueifat), 4 (Jie*h*) and 6 (*Rmeileh*) between July 1999 and April 2002, and the thresholds for injurious contamination (Simpson indices between 2.8 and 6.6).

Fluctuations of Simpson values presented a low correlation with the rainfall. Therefore, water pumping was at the origin of these variations. Globally, water quality presented some risk to crops, especially those sensitive to salinity such as strawberries. Five of the wells could not sustain the intensive production, alternative sources of irrigation water had to be found.

SOIL SALINITY IN GREENHOUSES

Soils were sampled from greenhouses I and II irrigated from well 1, greenhouses III and IV from well 4 and greenhouses V and VI from well 6. From each greenhouse, nine soil samples were collected from two depths (0-20 ; 20-40 cm) monthly (September 2000 to April 2001). Soil salinity (ECe) and chloride contents (Cle) were analyzed in the saturated paste extracts (Ryan *et al*., 1996).

Mean values of ECe ranged from slightly saline (3.64 dS m^{-1} in greenhouse I), to moderately saline (6.45 dS m^{-1} in greenhouse II; 7.86 dS m^{-1} in greenhouse V), to highly saline (8.62 dS m^{-1} in greenhouse VI) and to strongly saline (28.3 dS.m^{-1} in greenhouse III; 19.9 dS.m^{-1} in greenhouse IV). Greenhouse I was conveniently planted to strawberry, a crop known for its sensitivity to salinity and particularly to the chloride content. In the strongly saline condition, the size of tomato fruits was reduced (El Moujabber *et al*., 2006).

The origin of soil salinity was investigated at two levels: the irrigation water and soil inputs. Soil salinity was weakly related to the irrigation water: only 23% of it was explained by the fluctuations of ECw (Darwish *et al*., 2005). But the relationship between soil salinity and the soil chloride contents was linear with a significant correlation coefficient (Figure 2). The regression equation had a slope of 6.737, therefore the soil chloride could explain some 67% of the soil salinity. Soil chloride originated essentially from the complex fertilizers containing potassium chloride applied prior to planting in greenhouses (Atallah *et al*., 2000). Indeed, this farmer's practice must be modified to match the agricultural production in protected greenhouses. Using low salinity index fertilizers can help preventing the accumulation of harmful amounts of chloride and salts in the soil.

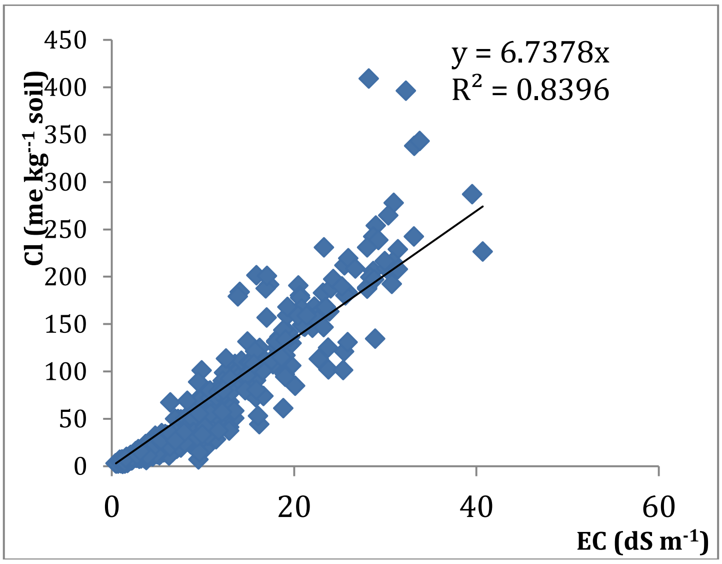

Figure 3. Relationship between the chloride content (Cle) of soil samples and their electrical conductivity (ECe) determined in the saturated paste extracts (n= 532).

SPATIAL DISTRIBUTION OF SALINITY

In crops fertigated through the drip system, it is most likely to have an uneven spatial distribution of salts. To overcome this heterogeneity, nine soil samples were analyzed separately, monthly. To evaluate the possibility of reducing the number of samples, a comparison was done between the mean of nine subsamples and that of five subsamples. Of the nine subsamples collected in three parallel lines, five subsamples were selected in an X shape lengthwise. For all greenhouses and for both depths (0-20 and 20-40 cm), the relationship was linear with a significant correlation coefficient:

$$ECe\ (5) = 1.003 \times ECe\ (9) \qquad (n = 80;\ r = 0.981)$$

By analyzing 5 subsamples separately instead of 9, the soil salinity will be mildly underestimated. Five subsamples provide a suitable representation of the heterogeneity inside the greenhouse, while reducing significantly the workload.

MANAGEMENT OF SALINE WATER IN TWO SOIL TEXTURES

Mildly saline water could be sustainably used, as long as an adequate leaching is included and some remediation measures taken between crops. To address this issue a greenhouse experiment was conducted using pots (120 L) filled with a sandy soil (65% sand, pH: 7.52) or a clay soil (50% clay, pH: 7.7). Three levels of water salinity (S1: 1 dS m^{-1}, S2: 2.5 dS m^{-1} and S3: 5.0 dS m^{-1}) were considered. Salinity of treatments S2 and S3 were obtained by mixing the local well water with seawater. In October, tomato (cv *Tyrade*) was planted at a density of two plants per pot. Jew's mallow (*Corchorus olitorius*) was densely planted before and after tomato. To the amount of irrigation water determined using a Nimah mini-pan (Nimah, 1992) a 10% leaching fraction was added. Nutrients were supplied by fertigation (116-274 days after sowing): N (75 mg L^{-1} as ammonium sulfate), P (25 mg L^{-1} as phosphoric acid) and K (120 mg L^{-1} as potassium sulfate). The fertigation solutions had slightly higher EC than the irrigation waters (Table 2).

Water consumed by the crop, during the differential treatment, was on average 274 mm. As the level of salinity increased, the cumulative consumption of chloride was also higher. When the salinity went up from 1 to 5 dS m^{-1}, the chloride consumption increased by 7.7 fold (clay soil) and 8.7 fold (sandy soil). The larger build-up of salts did not affect the fresh tomato yield in the clay soil, to the contrary of the sandy soil (Table 2). This difference suggests a greater resilience of the clay soil due to its buffering capacity. Within each soil texture, fruits were more affected by the salinity than the vegetative parts. The effect in the sandy soil was around 65% higher than in the clay soil (Darwish *et al*., 2005).

TABLE 2

Quality of Fertigation Solutions, between 116th and 274th Day after Sowing, Water Inputs and Tomato Yield

Treatment (EC_w dS m^{-1})	Fertigation solutions		Water (mm)	Fresh yield (kg pot^{-1})	
	EC (dS m^{-1})	Cl^- (me L^{-1})		Sandy	Clay
S1 (1.0)	1.85	3.28	304	2.57 ab	2.55
S2 (2.5)	3.35	15.6	305	2.80 a	2.74
S3 (5.0)	5.67	35.6	300	1.65**B** b	3.22**A**

Within the same column/row values followed by the same letter/symbol are not significantly different.

During the experiment, soil salinity showed a mild increase in the sandy soil against a 1.8 fold increase between S2 and S3 in the clay soil (Table 3). Still, these salinity values were mostly smaller than those recorded inside the Jieh, Rmeileh and Choueifat greenhouses, despite their lighter textures (sandy clay loam). This could be due to the moderate input of fertilizers and to the regular leaching fraction. Leaching was recommended by the FAO as the most effective procedure for removing salts from the root zone (Website 2). These results confirm the importance of the management when using saline water for irrigation as long as ECw is below ECe values.

To reduce the residual salinity, Jew's mallow was planted during the summer, after tomato. Dry matter production (Figure 3) and nitrogen yields were negatively affected by the level of salinity. For this crop, the soil textures had no visible difference but it was the salinity factor alone that intervened.

TABLE 3

Changes in Soil Salinity Measured in the Saturated Paste (ECe) between the Beginning and the End of the Tomato Crop Irrigated with 3 Levels of Salinity

ECe (dS m^{-1})		Treatment (EC_w - dS m^{-1})	Soil texture
End	Beginning		
1.62	0.99	S1 (1)	Sandy
3.25		S2 (2.5)	
3.27		S3 (5)	
2.22	1.27	S1 (1)	Clay
2.60		S2 (2.5)	
4.70		S3 (5)	

Using Meloukhieh in summer for remediation provides an additional income from cash crop, reduces the build-up of soil-born diseases achieved with the crop diversity while saving some of the water used for the leaching of accumulated salts.

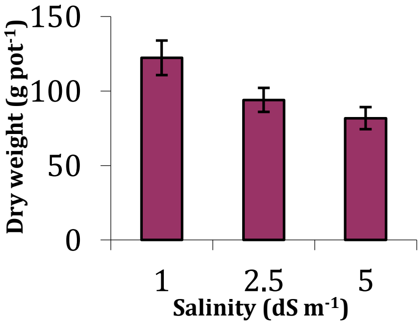

Figure 4. Dry weight of Jew's mallow following tomato in the three salinity treatments. Each bar represents the standard error of the mean.

CONCLUSION

Contamination with seawater was suspected in coastal wells, as salinity fluctuated around 3 dS m^{-1} and the Simpson index (Cl/HCO_3) indicated levels of moderate to injurious contaminations. The low sodium/chloride ratios (<1) suggested a seawater intrusion rather than a pollution of an anthropogenic origin. In all sites, growers had to rely on other water sources to supplement the crop needs. In some cases, the crop had to be interrupted as salinity visually affected the crops and decreased yields.

Inside the greenhouses, soil salinity reached 15 to 20 dS m^{-1}. The salinity of irrigation water could not justify the extent and seasonal fluctuation of soil salinity. Soil chloride explained 68% of soil salinity, suggesting a link with the fertilizers containing potassium chloride. In coastal areas it is necessary to consider the integrated management of irrigation water, the choice of fertilizers, the crop demands and its salt tolerance. With the adequate management of fertigation and the leaching fraction, an irrigation water reaching 5 dS m^{-1} could be used for protected crops. Salinity was better tolerated in the clay soil due to soil buffering capacity and lower rates of consumed Cl. In 2012 ECw increased substantially which can worsen the conditions of agricultural production. Beside measures to reduce seawater intrusion and salinity buildup, a remediation with Jew's mallow could make the use of saline irrigation water more sustainable.

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