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Contribution to the study of the physicochemical evolution of irrigated soils. Case of the irrigated perimeter downstream of the Mellah and Seybouse River is confluence (Guelma province), North-Eastern Algeria

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Abstract

The enrichment of soluble salts process of an irrigated soil causes the build-up of saline soil, which can result an increase in osmotic pressure, toxicity of certain ions to vegetation (Cl^-, Na^{++}) and soil degradation. In Algeria, more than 20% of irrigated soils are impacted by salinization/sodification process. In this regard, this work is aimed at investigating the case of (16) parcels located in the Bouchegouf plain, North-East of Algeria, used for market gardening and irrigated from surface water and groundwater. The findings of surface water and groundwater analyses show conductivity and SAR of the order of: (i) (EC=1.138ds/m and SAR= 4.30) for the Seybouse river, (ii) (EC=1.935dS/m and SAR=9.35) for the Mellah river and (iii) (EC= 1.454 dS/m) and SAR=3.23) for groundwater. A calculation model SMSS2 (simulation model of soil salinization and sodification) used for evaluating and preventing the salinization hazard of irrigated soils with these waters reveals:(i) an increased hazard for Mellah river water, (ii) a lesser hazard for Seybouse river water and (iii) the existence of a mixture of Mellah river water with groundwater.

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Introduction

Globally, the world loses on average 10 hectares of agricultural lands each minute, 3 of which (more than 1.5 million ha per year) because of salinization (Kovda, 1983). Today, soils affected by salinization are estimated at about 400 million (Bot, Nachtergaele and Young, 2000). In Africa, about 40 million ha are affected by salinization, or near 2% of the total surface area. 80% of soil salinization is of natural origin; it is a primary salinization due to salts building up during rock weathering or extreme natural inputs. 20% of saline soils or near 15 million ha on the African continent, have an anthropogenic origin; in this case, we refer to a secondary salinization induced by human activities linked to farming practices, especially to irrigation. This paper is dedicated to the study of the eco-environmental impact of salinization of irrigated soils located downstream of the Mellah and Seybouse rivers confluence. In this regard, the numerical simulation of the salts movement evolution in these soils constitutes the main purpose of this contribution. Thus, with the help of software SMSS2 *developed by the authors M.Lahlou, L. Badraoui, B.Soudi (1998) and Laudelout (1994)*, we made the simulation of transfers and chemical exchanges balances between irrigation water and soil horizons. We then carried out the monitoring evolution of irrigated soils through test profiles during an irrigation campaign. The findings about the real salinity situation are analyzed as compared to those of salinity simulated by the tool SMSS2; this study focuses particularly on the evolution of salinity and the impact of this latter on soils in place.

Materials and methods

Presentation of the study area

The study area with a surface of 232 Km² is part of the Bouchegouf plain, located North-East of Algeria. This plain is drained by the Seybouse river and its main tributary, the Mellah river (Fig.1).

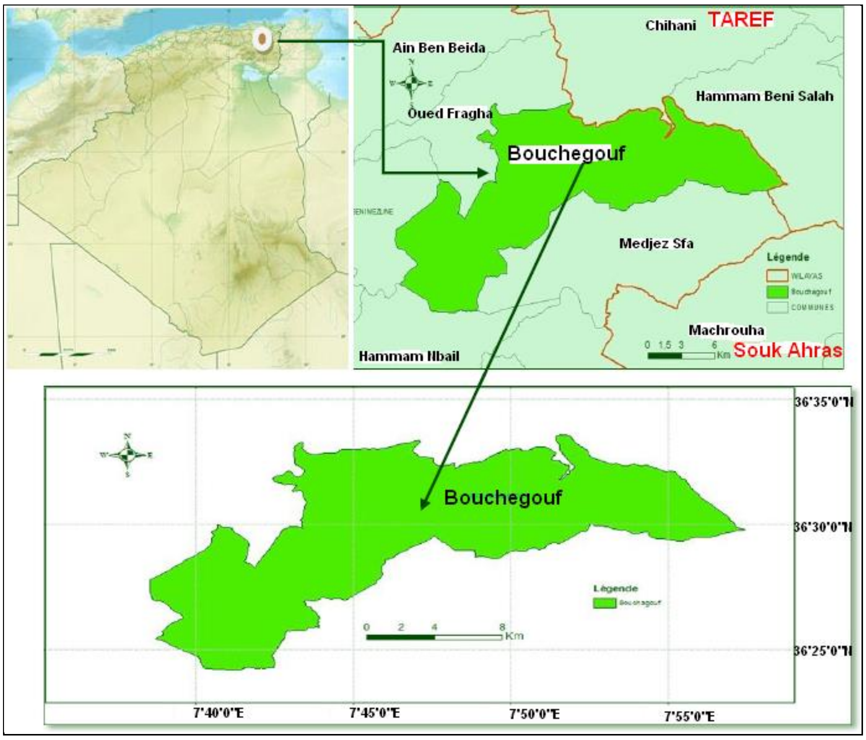

Fig. 1. Geographical location map of the study area.

Geology of the region is represented by three major formations, namely the potentially hydric Quaternary alluvial deposits and the two impermeable or semi-permeable formations constituting the boundaries of the natural reservoirs. These formations are represented by Numidian sandstone and Triassic formations. The alluvial deposits constitute groundwater reservoirs effectively drained by the

Seybouse river and its tributary, the Mellah river (Fig.2). The climate of the area is of Mediterranean type, marked by high evapotranspiration (ETR=416.5mm) that 561.41mm of rainfall cannot compensate. The mean temperature is of the order of 18.5°*C*.The values of agricultural deficit obtained by *C. W. Thornthwaite* method are significant (562.3mm), whereas runoff and interannual recharge are relatively low (64.62mm and 80.28mm/yr, respectively). In such conditions, irrigation is vital, but it is not without risks, if water is saline, soils are enriched with salts and that their agronomic potential is compromised.

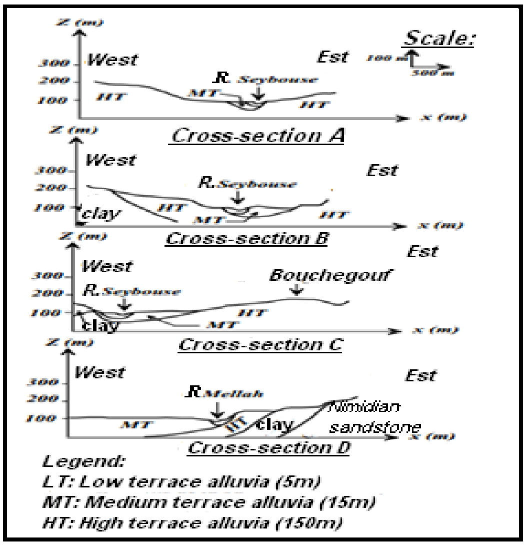

Fig. 2. Geological cross-section of the Bouchegouf plain (in Chaoui. W. 2007).

Definition of the experimental protocol

This protocol is axed on the irrigation tests by different water qualities of surface water and groundwater that we seek to evaluate the impact on the irrigated soils of the Bouchegouf perimeter. The physicochemical analyses of the samples collected from the soil horizons of the Bouchegouf plain are then made before and after tomato harvest for the present case.

Presentation

A sampling campaign during the month of June 2015 allowed taking 09 groundwater samples (6 boreholes, 2 wells and 1 spring) and 08 surface water samples from the Seybouse and Mellah rivers. In order to make it possible to measure the impact of these waters on the perimeter soils, 32 samples were then taken from the irrigated soils (Fig. 3).

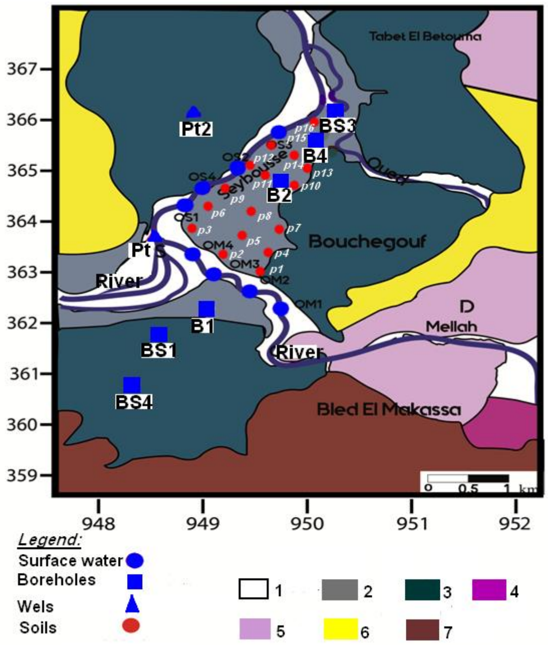

Fig. 3. Water and soil points Location and geological scheme of the Bouchegouf aquifers (after M. J. Flandrin 1930 modified). 1: Low terrace alluvia (5m); 2: Medium terrace alluvia (15m); 3: High terrace alluvia (150m); 4: (red Sandstone clays and conglomerates) clays greybeard and conglomerates red; 5: Numidian Sandstone; 6: Numidian clay; 7: Trias.

Analysis methods of irrigation water

The measurements of the physical parameters were performed in situ by means of a multi-parameters WTW (Multi Line PPH/LF-SET) device. In order to determine the chemical elements and to analyze ETMs, the water samples were put into plastic and glass bottles kept in a cooler at 4°C and then analyzed within the following 72 hours. Flame atomic absorption was used for cations. Anions were dosed by means of spectrophotometer.

Sampling methods and Soil analysis

In order to study the characterization of soil at the vertical scale, 16 samples of 1kg were collected at the different points, two samples were taken from the 0-20cm and 20-40cm horizons.

Before performing the samples analyses, soils were air dried during one night or longer, then sieved (2mm diameter sieve) and conserved in air-tight plastic bags, and then kept in a dry and clean place. The analyses techniques were taken from Jackson (1965). The measurements were concerned about electrical conductivity, pH of saturated paste and dosage of major elements of this paste extract (J.RODIER, 27). The soil MTEs contents were determined using an atomic absorption spectrophotometer.

Results and discussion

The plain irrigation water quality

Electrical conductivity and SAR are the retained parameters to characterizing water quality used for irrigation purposes. According to EC average value equal to 1.454 ds/m, 1.138 ds/m and 1.935 ds/m, for groundwater, Seybouse and Mellah rivers waters, respectively, irrigation water has a high mineralization; it can then give rise to a fairly rapid salinization of soils and limit the productivity of plants sensitive to salts (USSL, 1954). SAR average value equal to 3.23 and 4.30 for groundwater and Seybouse river water does not exhibit any alkaline hazard of soils absorbent complex. In contrast, the SAR average value equal to 9.35 for Mellah river water indicates high alkalinity (Table 1).

Table 1. Chemical characteristics of Bouchegouf plain irrigation water (June 2015).

Parameters	Groundwater	Seybouse river water	Mellah river water
pH	7.63	8.22	8.01
Ca^{++} (meq/l)	8.41	6.25	7.32
Mg^{++} (meq/l)	4.76	4.36	6.11
$Na^{+}+K^{+}$(meq/l)	15.83	10.45	24.45
Cl^{-} (meq/l)	14.38	10.17	24.77
SO_4^{--} (meq/l)	7.75	9.79	6.01
HCO_3^{-} (meq/l)	5.17	3.59	2.96
EC (dS/m)	1.454	1.138	1.935
SAR	3.23	4.30	9.35

Soils quality in the Bouchegouf irrigated perimeters

The chemical analyzis of the control plot allows verifying that the profile is not saline (Table 2), except the two parcels (P8 and P9) which are slightly saline (Table 3). The electrical conductivity values of the solution of the relatively dry irrigated soils at the time of sampling are the highest and fluctuate between 0.235 ds/m and 0.680 ds/m. Soil pH is alkaline between 7.9 and 8.22. The calcium and chloride content is fairly high.

The exchangeable calcium is predominant. The sulfate and sodium content is very low. In the entire profile, sodium does not exceed 0.9 meq/100g (Table 2).

Table 2. Characterization of cultivated soils in the Bouchegouf irrigated perimeters.

Parameters	pH	Ca^{++} (meq/100g)	Mg^{++} (meq/100g)	Na^{+} (meq/100g)	Cl^{-} (meq/100g)	$SO4^{--}$ (meq/100g)	EC (ds/m)	SAR
Max	8.21	36.05	3.55	0.95	284	4.52	0.680	0.21
Min	7.9	32.7	2.4	0.35	88,75	3.08	0.235	0.07
Avg	8.04	35.23	3.02	0.59	181,58	3.84	0.422	0.13

Irrigation water-soil

In order to study the relationship between irrigation water quality and soil irrigated by this latter, we established electrical conductivity curves of irrigation water and soil (Fig. 4). These curves follow the same pattern and indicate a close link. Irrigation water quality (Table 1, 2 and Fig. 4) is noted to have an impact on soil quality reflected by more or less serious deterioration, depending on the nature of this water. In fact, soil of the Bouchegouf perimeter, which is the most deteriorated in terms of salinity, is irrigated with the poorest-quality water. This explains that there is an evident effect of water quality on that of soil at the time of irrigation.

Used method

The data set about the physicochemical characteristics of soil (the coefficients of the Ca-Mg exchange selectivity and divalent-Na, the initial situation of exchangeable bases and the initial situation of the sum of exchangeable cations of the saturated paste extract), about irrigation water quality, about the number of layers forming soil, as well as about the number of pore volumes passing through soil were introduced into a numerical simulation modele nabling to describe water and chemical evolution of soil according to time.

The SMSS2 model (Laudelout *et al.* (1994-1995) is used for three major stages (Fig. 5): (i) the physicochemical balances between the different species present in soil (ii) ion exchange occurring between soil solution and the negatively charged colloids (clays) and (iii) the movements of solutes in soil. The model assumes that the movement of water is in constant regime through saturated soil, that the drainage is perfect and that there is no capillary rise.

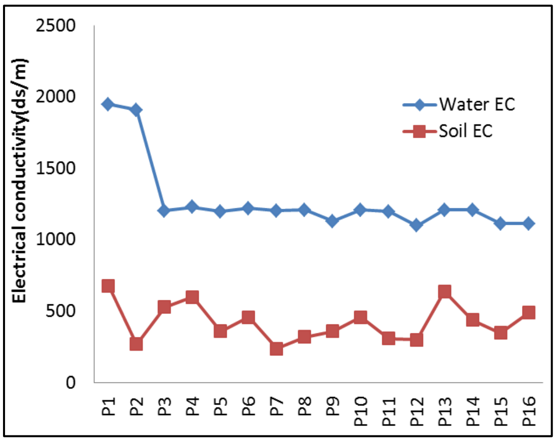

Fig. 4. Water-soil relationship in the Bouchegouf irrigated perimeter.

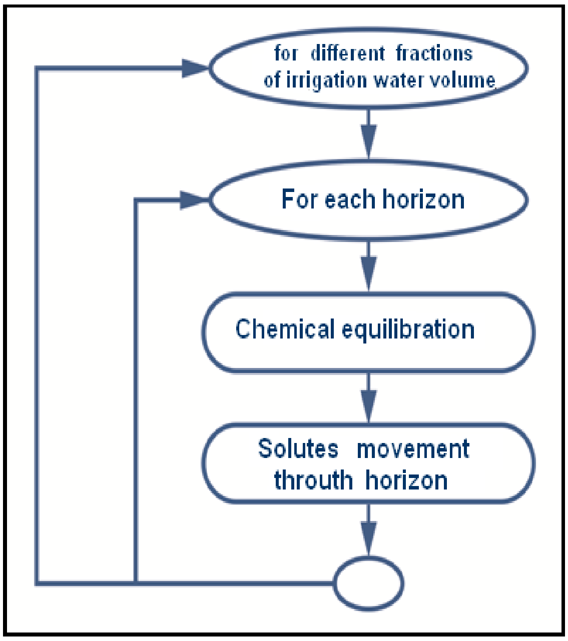

Fig. 5. Simulation flowchart of soils salinization/sodification process, as a result of irrigation by SMSS2 model (in Lahlou.1998) modified.

Simulation results

The model SMSS2 was validated, using the field data from the two control plots located in the Bouchegouf plain irrigated perimeter (Table 3a and 3b); this latter has a perimeter irrigated by surface water (Seybouse and Mellah rivers) more loaded with salts, or using (slightly mineralized) groundwater (Table 1). This example illustrates the use of this model for comparing the impact of irrigation with the two types of water on soil.

Table (3a). Composition of the horizons of soil and its surface in the Bouchegouf irrigated perimeter (June 2015) (non-saline soil).

			Solution (meq/l)						Surface (meq/100g)				
Horizon	NC	pH	Ratio Solution/soil	Ca^{++}	Mg^{++}	Na^{+}	Cl^{-}	SO_4^{--}	Ca^{++}	Mg^{++}	Na^{+}	Gypsum (%)	Calcite (%)
1	1	7.91	2285	6.01	1.02	3.65	10.2	3.82	35.9	3.1	0,4	0	281.3
2	1	7.88	2114	4.03	4.98	5.2	7.8	4.08	36.1	3.3	0,4	0	289.1

Table (3b). Composition of the horizons of soil and its surface in the Bouchegouf irrigated perimeter (June 2015) (slightly saline soil: P8 and P9).

Solution (meq/l)									Surface (meq/100g)				
Horizon	NC	pH	Ratio Solution/soil	Ca^{++}	Mg^{++}	Na^{+}	Cl^{-}	SO_4^{--}	Ca^{++}	Mg^{++}	Na^{+}	Gypsum (%)	Calcite (%)
1	1	8.14	2316	7.2	1.11	3.69	7	3.65	36	2.2	0.4	0	376.2
2	1	8.02	2116	3.79	5.31	5.2	28.4	3.23	36.1	2.6	0.4	0	388.2

The Table 4 and the Fig.s 6, 7 and 8 present the result of these two simulations, respectively. The X-axes represent the quantity of irrigation water used, here expressed in terms of pore volume (PV) (a pore volume is the quantity of water necessary to filling all pores of a given soil). We selected a simulation with 7 pore volumes which are made during an agricultural campaign.

Table 4. Software output table: evolution of the soil parameters after a contribution of 7 pore volumes.

Irrigation of saline soils with groundwater													
				Solution (meq/100g)					Surface (meq/100g)				
Horizon	EC (dS/m)	ESP (dans/m)	SAR (meq/l)	Ca^{++}	Mg^{++}	Na^{+}	Cl^{-}	SO_4^{--}	Ca^{++}	Mg^{++}	Na^{+}	Gypsum (%)	Calcite (%)
1	2.29	1.04	2.81	8.24	4.27	14.21	13.39	7.2	36	2.2	0,4	0	376.2
2	2.22	1.02	2.71	7.71	4.58	13.59	15.75	6.72	36.1	2.6	0,4	0	288.2
Irrigation of non-saline soils with Seybouse river water													
1	1.56	1.02	2.10	5.55	3.91	8.84	10.17	8.99	35.9	3.1	0,4	0	281.3
2	1.66	1.01	2.05	5.93	4.22	9.29	9.85	8.56	36.1	3.3	0,4	0	289.1
Irrigation of non-saline soils with Mellah river water													
1	2.93	1.02	4.26	7.14	5.43	21.67	22.82	5.71	35.9	3.1	0,4	0	281.3
2	2.82	1.01	4.46	6.79	5.62	20.49	21.53	5.60	36.1	3.3	0,4	0	289.1

-We see that irrigation with groundwater tends to increase soil salinity (increase of electrical conductivity: between 0.95 and 2.49 dS/m, after 0.5 pore volume) (Fig.6).

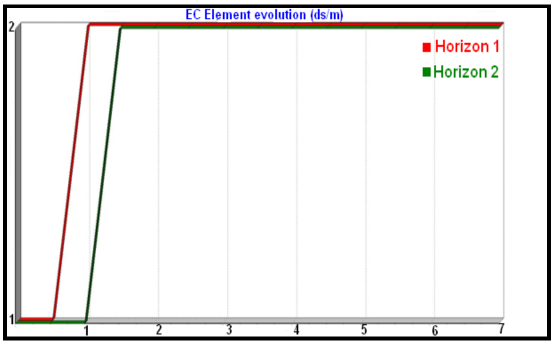

Fig. 6. Irrigation simulation of soil slightly salinized by groundwater: evolution of electrical conductivity after a contribution of 7 pore volumes.

-Irrigation with Seybouse river water increases even more soil salinity (increase of electrical conductivity: EC from 0.83 dS/m up to 1.80 dS/m after 0.5 pore volume) (Fig.7). This salinity becomes higher when irrigating with Mellah river water: EC 0.83 up to 3.25 dm/m after 2.00 pore volume (Fig.8).

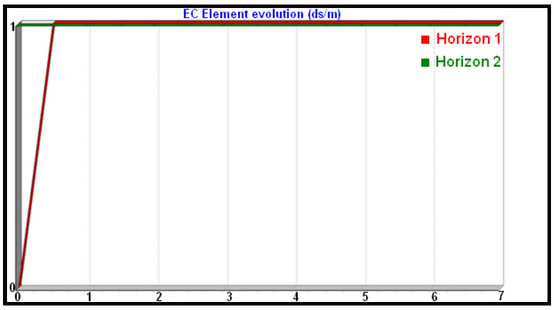

Fig. 7. Irrigation simulation of soil not salinized by Seybouse river water: evolution of electrical conductivity after a contribution of 7 pore volumes.

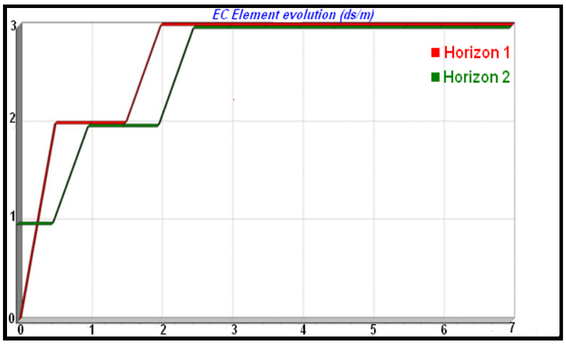

Fig. 8. Irrigation simulation of soil not Stalinized by Mellah river water: evolution of electrical conductivity after a contribution of 7 pore volumes.

Conclusion

The quality evolution of irrigated soils in the Bouchegouf area revealed that the secondary salinisation is a serious problem. The findings obtained from this work suggest that the use of surface water for irrigation gave rise to degradation of soil quality in the irrigated perimeter. This degradation is manifested by the rise in salinity.

As regards irrigation, the poor characteristics of surface water and groundwater cannot directly serve this purpose because electrical conductivity is high. A control and monitoring are necessary to probable quality adjustments. In the case of irrigation with groundwater, salinity of soil solution increases (from 0.95 up to 2.49dS/m). Salinisation occurs when irrigating with Seybouse river water (from 0.83dS/m up to 1.80 dS/m) and becomes higher when irrigating with Mellah river water (from 0.83up to 3.25dm/m).

The study of water-soil interaction explains the impact of irrigation water quality on soil quality. In order to avoid deterioration of water and soil quality, one should adopt an appropriate irrigation using the mixture of surface water with groundwater to avoid the long-term accumulation of salts.

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