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Influence of Groundwater Irrigation on Chemical Properties of Soils in the Vicinity of Wastewater Drainage Canals in Al-Ahsa Oasis, Saudi Arabia

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ABSTRACT

Presently, irrigated agriculture in the Oasis is facing problems of high water infiltration rate, poor drainage, low rainfall and high evaporative conditions resulting in the formation of sabkha lands and above all of that a degradation in irrigation water quality. A field study was carried to determine the influence of groundwater irrigation on chemical properties of soils in the vicinity of main drainage canals. Soil and water samples were collected from 19 irrigated farms and 18 wells. The total salinity of 42% soil samples was less than 4 dS m^{-1} (a category of non-saline soils) and that of 58% soil samples was above 4 dS m^{-1} (a category of medium to highly saline soils). Inter-ions relationship was strong among major cations and anions such as Ca, Mg and Na with HCO_3, Cl and SO_4 radicals. Well waters were classified as C4S1 (very high salinity and low sodium) to C4S4 (very high salinity and very high sodium) waters for irrigation purpose. The order of abundance of cations was Na>Ca>Mg>K while those of anions was Cl>SO_4>HCO_3. The inter-ions relationship of well waters was very poor. In conclusion, irrigating soils with high salinity well waters can develop saline soils and need to adopt certain soil and water management practices such as leaching application, cultivation of salt tolerant crops and improved irrigation systems.

Key words: Groundwater salinity, soil salinity, cations, anions, inter-ions relationship, irrigation water classification

INTRODUCTION

Al-Hassa Oasis embraces the largest irrigated agriculture in the Kingdom of Saudi Arabia. Its geographical location is 25°21'-25°37' latitude North and 49°33'-49°46' longitude East in the Arabian Peninsula. It is situated about 150 km south of Dammam, Eastern Region of Saudi Arabia. Its main water sources are three groundwater aquifers (Neogene, Dammam and Umm-er-Radhuma) for domestic, agriculture, industrial and other uses (Leichtweiss Institute, 1979). The soils of the area are mostly light textured (sandy) with a common feature of hard pan ranging from surface to more than 3 m deep. The irrigated agriculture in the Oasis is facing problems of high water infiltration rate, poor drainage, low rainfall and aridity.

Generally, irrigated agriculture faces problems of increasing soil salinity especially in arid and semi-arid regions of the world with having inadequate irrigation supplies, low annual precipitation, arid climatic conditions and high potential evapotranspiration. Water resources availability and

its acceptable quality for irrigation are important for sustainable irrigated agriculture for optimal productivity (FAO, 2001; Cetin and Kirda, 2003; Kaman *et al*., 2011). Poor irrigation efficiency, high irrigation water salinity and poor soil drainage may develop soil salinity and drainage problems in irrigated agriculture. In some cases, on-farm improper water management practices are conducive to increasing soil salinity and low land productivity (Kaman *et al*., 2011). Oftenly, saline water irrigation increases the soil salinity through out the soil profile than the non-saline water irrigation and the salt build up in soils was uniform (McMartin *et al*., 2001; Al-Ghobari, 2011). Application of high salinity and Sodium Adsorption Ratio (SAR) waters significantly increased the soil salinity and sodicity levels of irrigated soils. The soil profile attained electrical conductivity of saturation paste extract (EC_e) >4.0 dS m^{-1} [with all the levels of electrical conductivity of irrigation water (EC_{iw}) and sodium adsorption ratio of irrigation water (SAR_{iw}] and SAR values >13.3 [with EC_{iw} 6 dS m^{-1} and SAR 20 (mmol $L^{-1})^{1/2}$] which were close to the upper limits of saline-sodic soils (Abid *et al*., 2001). Rapid salinization of groundwater and soils in afforested plots was associated with increased evapotranspiration and groundwater consumption by trees, with maximum salinization occurring on intermediately textured soils (Jobbagy and Jackson, 2004). Management of shallow groundwater is important and should be followed to avoid increasing soil salinity, concentration of other cations/anions and to minimize yield reduction in irrigated agriculture (Shouse *et al*., 2006). Recently, the use of soil water salinity invariant soil water hydraulic parameters in numerical modeling (HYDRUS-1D software package for simulating one-dimensional (1D) movement of water, heat and multiple solutes in variably saturated media) seriously compromised the predictions especially for a variable soil water salinity environment (Singh and Wallender, 2011). Many arid and semiarid regions of the world are experiencing a major environmental issue of saline seepage zone development and the dry land salinity due to the presence of shallow groundwater aquifers with varying salt concentrations (Morgan and Jankowski, 2004). Application of high salinity and SAR waters significantly increased the soil salinity and sodicity levels of irrigated soils. Irrigation water quality is the major factor determining the soil salinity and depends on the irrigation system design, irrigation methods and leaching management (Meiri *et al*., 1999). Some researchers used an innovative device to generate sulphuric acid by burning sulfur to amend high sodic waters and reported that a mixing ratio of 1:4 improved the soil permeability, pH, salinity and sodicity to acceptable levels (Kahlown and Gil, 2004). The changes in soil salinity is directly proportional to that of groundwater salinity and a high increase in soil salinity was recognized. This was mainly related to the mismanagement of groundwater resources, which causes soil degradation in addition to the losses and inefficiency in water usage (Al-Rashed and Al-Senafy, 2004). Irrigation with winery water having high organic matter concentrations (>2000 mg L^{-1} total organic carbon), high potassium and sodium salts (up to 1000 mg L^{-1}) with associated Sodium Adsorption Ratio (SAR) and Potassium Adsorption Ratio (PAR) typically having values >7 indicated that salinity concentrations at shallow depths (30 cm) were controlled by irrigation water composition, while at deeper depths (60 cm), high salinity groundwater (14 dS m^{-1}) was the major influence (Quayle *et al*., 2010). According to the EC and SAR calculations, the most dominant classes of water were C2-S1, C3-S2, C4-S3 and C4-S4 in Eshtehard District, Tehran, Iran. Salinity hazard in 37% of water samples is regarded as medium while in 15 and 48% of water samples is classified as high and very high, respectively. Sodium content in 42% of water samples collected was regarded as low and can be used for irrigation in almost all soils. Thus high salinity, SAR and Na% in most water samples have restricted the water quality for irrigation purposes (Khodapanah *et al*., 2009). The influence of water table salinity, soil

type, depth to the water table and potential evaporation showed that soil salinization occurs more rapidly with increasing water table salinity. The occurrence of salt accumulation at the ground surface was relatively insensitive to water table salinity but the rate of salt accumulation was shown to be strongly dependent on the water table salinity (Werner and Lockington, 2004).

Previously many studies have been conducted on water quality in the regions but there are no comprehensive studies on the effect of groundwater on the irrigated soils under farmer's management practices. Therefore, the main objective of this research was to determine the effect of groundwater on soil chemical properties in the vicinity of two main drainage canals (D-1 and D-2) and its inter-ions-relationship in the soil solution.

MATERIALS AND METHODS

The study was carried in Al-Ahsa Oasis during 2010-2011 season where drainage water (a composite mixture of sewage water, agricultural drainage, industrial waste effluent and overflow from irrigated fields) is being disposed by two main drains i.e., D-1 into Al-Oyun lake and D-2 to Al-Asfar lake in the form of open ponds. The agricultural farms irrigated with well waters were selected along these 2-main drains around 500 m from the main drains.

Collection of soil samples: A total of 20 productive agricultural farms were selected along both the D-1 and D-2 main drains. The soil samples were taken from 0-30 cm depth of soil from each farm with the help of an augur. About one and a half kg of each soil sample was taken in a plastic bag, labeled properly and transferred to the analytical laboratory for analysis. The location map of soil and well water samples is given in Fig. 1.

Collection of well water samples: To determine the effect of well water irrigation, simultaneously 18 well water samples were collected from the same agriculture farms selected for soil samples. It was assured that the wells were operational for at least 2 h or more to take the representative water samples. The samples were collected in sterile plastic bottles, labeled properly, stored in an ice chest and transported to analytical laboratory for chemical analysis.

Analysis of soil samples: Soil samples were air-dried, passed through 2 mm sieve and stored for analysis. Soil saturated paste extract was taken by weighing 300 g of dried soil sample in a plastic cup and soil paste was prepared according to the procedure described in USDA (1954). The soil extract was analyzed for all cations and anions at analytical laboratory of National Center for Water Technology (NCWT), King Abdulaziz City for Science and Technology (KACST) Riyadh, Kingdom of Saudi Arabia.

Analytical procedures: The standard analytical procedures described in the AOAC (2003) and Clesceri *et al.* (1998) were followed for water analysis. The laboratory equipments/instruments used for soil extract and water samples analysis were ICP OPTIMA 2000DV (Perken Elmer) for trace elements, Ion-Chromatography for anions (Cl, SO_4, NO_3, F, PO_4, NO_2, Br and I), Ion-Chromatography for cations (Li Na, NH_4, K Mg, Ca and Ba), Mars-5 Digestion/Extraction Sample Preparation and pH/Conductivity meter/DO Star-5 for field Analysis (EC, DO, Temperature, pH, turbidity). Additionally, adjusted adsorption ratio (adj.SAR), adjusted sodium ratio (adj.R_{Na}) and Exchangeable Sodium Percentage (ESP) were calculated from analytical data of soil and water chemistry according to the procedure described by Ayers and Westcot (1985).

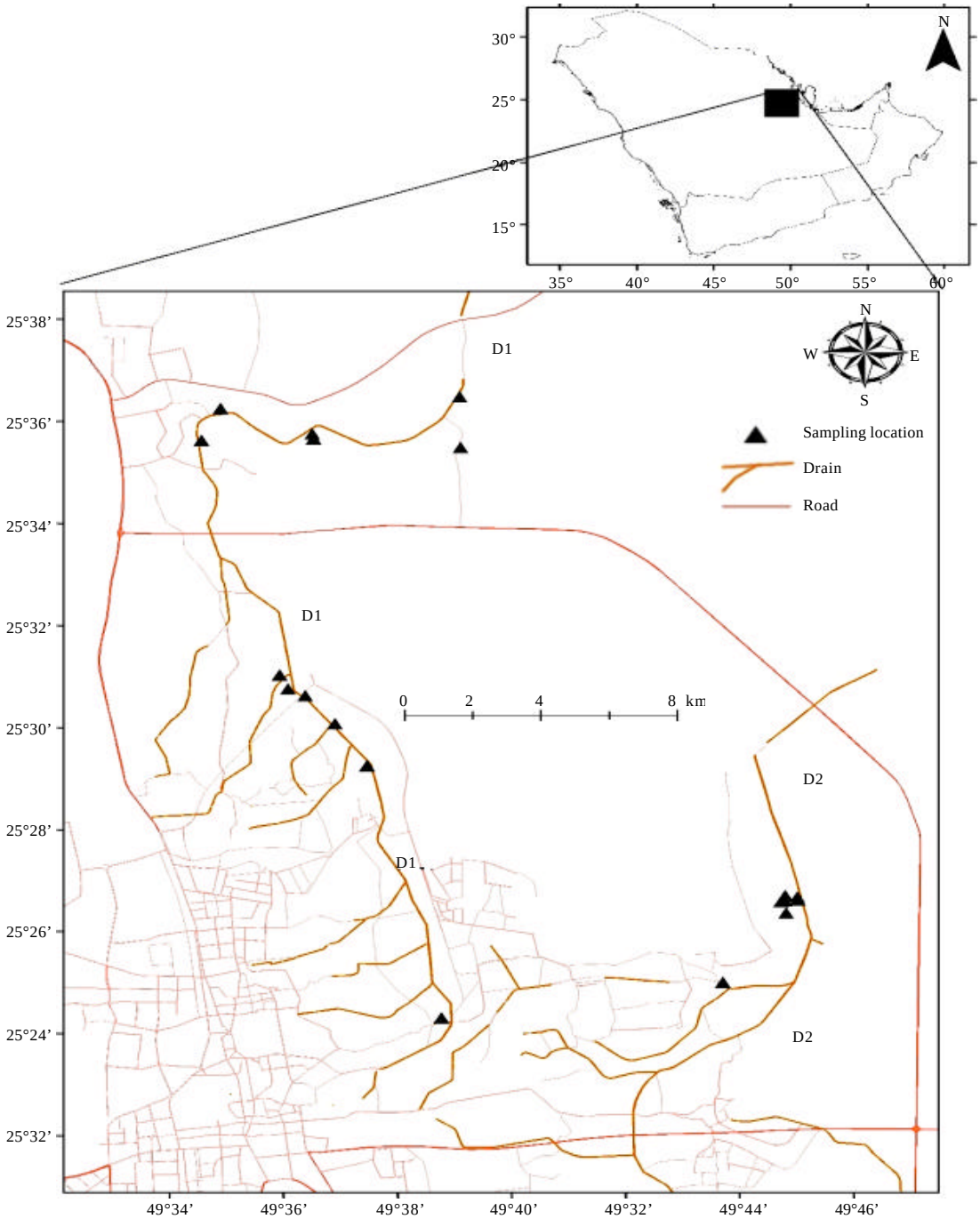

Fig. 1: Location map of soil and well water sampling in Al-Ahsa

Data analysis: Data were analyzed by ANOVA (analysis of variance) and regression techniques for treatment evaluation at 5% level of significance according to SAS (2001).

RESULTS AND DISCUSSION

Soil chemistry: The ranges of different chemical parameters (expressed as meq L^{-1} except pH, EC_e, SAR, adj.R_{Na} and adj.SAR) were 7.4-8.2 (pH), 1.67-33.14 dS m^{-1} (EC_e), 5.94-88.57 (Ca), 4.03-36.94 (Mg), 6.31-197.04 (Na), 0.05-8.77 (K), 3.41-9.64 (HCO_3), 5.75-239.6 (Cl), 5.85-81.37 (SO_4), 0.16-17.47 (NO_3), 0.02-0.23 (F), 34.43-59.47 (Na %), 2.80-24.87 (SAR), 3.29-16.50 (adj.R_{Na}), 6.49-90.36 (adj.SAR) and 2.79-26.16 as Exchangeable Sodium Percentage (ESP) at various locations along D-1 and D-2 main drains in the Oasis (Table 1). The data showed that total salinity of 42% soil samples is less than 4 dS m^{-1} (a category of non-saline soils) and the total salinity of 58% soil samples is above 4 dS m^{-1} (a category of medium to highly saline soils). This suggested that soil with high salinity can be cultivated only by growing medium to high salt tolerant crops and by adopting certain management strategies such as leaching application to lower the soil salinity within acceptable limits for normal crop production and by applying soluble source of Ca to nullify the adverse effects of high Na ions on soil properties according to Ayers and Westcot (1985).

The SAR of soil samples [except one sample (SAR = 24.87)] is within the acceptable limit of 15 according to USDA (1954) for normal crop production without significant yield reduction (Table 1). Because, SAR value of soil solution higher than 15 deteriorates the soil structure by adsorption of Na ion on soil exchange complex by replacing Ca and Mg ions which are useful ions to maintain soil structure. Because high Na ions on soil exchange complex deflocculated soil and seal the macro-pores of soils by the suspended colloidal particles causing considerable reduction in soil permeability.

Trace and heavy metal concentration: The ranges of trace and heavy metal concentration (expressed as parts per billion) were 3.13-5.61 (Fe), 0.86-3.08 (As), 0.0-2.14 (Co), 0.49-3.64 (Ni), 0.0-7.57 (Se), 0.43-0.70 (Cd) and 0.21-1.89 (Zn) in various soil samples at different locations (Table 2). The trace elements and heavy metals such as Mo, Ti, Hg, Be and V were not detected in the soil samples. The concentration of different trace elements and heavy metals is very low indicating that there is no possibility of bioaccumulation of these metals in soils irrigated with well waters under the existing farm management practices. Also, the concentration of the above mentioned metal ions is within the upper permissible limits according to Ayers and Westcot (1985) and WHO (2001) for developing any environmental and health hazards.

Warmate *et al.* (2011) presented concentrations of heavy metals in soil and water receiving used engine oil in Port Harcourt, Nigeria and compared with the given standards for evaluating the environmental hazards. They reported that the concentration of metals in test soil and water samples exceeded permissible limits. A comparison was also made with the established standards for data evaluation (Table 3). The concentration of heavy metals ranged from 20 μg g^{-1} (Ni) to 493 μg g^{-1} (Pb) in soil. However, the concentration of Ni, Cu, Pb and Zn was within acceptable limits according to the established standards of Ayers and Westcot (1985).

Ions inter-relationship: Estimation of inter-ions relationship is important to highlight the role of different cations and anions on soil physical and chemical status.

Table 1: Chemical composition of soils in D-1 and D-2 main drains in Al-Ahsa Oasis

Well No.	Date	Time	pH	EC (dS m^{-1})	HCO_3 (meq L^{-1})	Ca (meq L^{-1})	Mg (meq L^{-1})	Na (meq L^{-1})	K (meq L^{-1})	Cl (meq L^{-1})	SO_4 (meq L^{-1})	NO_3 (meq L^{-1})	F (meq L^{-1})	SAR	Na (%)	Adj.R_{Na}	Adj.SAR	ESP
1	7/11/2009	16:10	7.9	3.99	8.00	11.03	11.44	16.79	0.64	17.80	10.85	3.15	0.04	5.01	42.09	6.24	14.85	5.78
2	7/11/2009	16:25	8.1	2.75	3.80	8.93	4.03	14.44	0.05	15.29	6.56	1.74	0.19	5.67	52.60	7.15	13.79	6.64
3	7/11/2009	16:40	7.7	3.68	5.11	10.58	7.57	18.53	0.15	20.45	9.12	2.03	0.21	6.15	50.31	7.72	16.50	7.25
4	7/11/2009	16:50	7.6	3.44	4.72	11.08	5.18	17.75	0.10	18.39	9.12	1.97	0.20	6.22	52.03	8.17	16.22	7.34
5	7/11/2009	17:10	8.1	4.07	6.95	14.22	8.89	17.49	0.08	16.47	13.37	3.52	0.13	5.14	43.00	6.90	14.99	5.95
6	7/11/2009	17:25	8.2	8.19	8.39	22.55	17.52	41.41	0.38	22.62	48.41	2.39	0.23	9.25	50.58	12.26	29.43	11.02
7	7/11/2009	17:55	7.9	2.99	4.39	9.73	7.90	12.09	0.13	13.99	10.56	0.79	0.09	4.07	40.51	4.95	10.67	4.53
8	7/12/2009	7:30	7.8	1.67	3.41	5.94	4.20	6.31	0.20	5.75	6.31	1.06	0.13	2.80	37.89	3.29	6.49	2.79
9	7/12/2009	8:00	8.2	9.44	8.54	26.65	22.30	44.85	0.54	47.42	35.60	2.53	0.11	9.07	47.54	11.88	29.60	10.80
10	7/12/2009	8:10	7.7	10.05	8.92	29.69	24.76	45.67	0.31	35.66	52.38	3.19	0.13	8.75	45.48	11.51	29.11	10.43
11	7/12/2009	8:15	8.1	15.05	8.85	40.97	30.36	78.34	0.79	47.50	76.20	17.47	0.08	13.12	52.07	16.50	44.71	15.32
12	7/12/2009	12:10	7.6	9.97	7.87	25.40	21.64	52.24	0.41	53.79	29.44	8.37	0.08	10.77	52.40	13.91	34.56	12.76
13	7/12/2009	10:15	7.9	11.40	7.47	30.84	23.36	58.98	0.74	56.50	48.47	1.32	0.08	11.33	51.77	14.73	36.68	13.38
14	7/12/2009	9:45	7.4	8.95	6.42	34.43	11.85	42.89	0.33	53.23	16.14	13.34	0.02	8.92	47.92	13.40	27.83	10.63
15	7/12/2009	9:50	8.2	7.23	6.16	23.70	12.59	33.45	2.53	36.36	26.30	3.37	0.20	7.85	46.28	10.83	23.68	9.36
16	7/12/2009	10:00	8.0	5.30	5.60	13.77	11.60	26.49	1.02	34.75	12.20	0.16	0.10	7.44	50.09	9.31	21.14	8.85
17	7/12/2009	10:30	7.5	2.74	5.11	8.88	8.89	9.44	0.20	13.94	7.77	0.31	0.10	3.17	34.43	3.81	8.54	3.30
18	7/12/2009	10:30	8.1	2.29	5.51	7.88	5.27	9.57	0.20	10.27	5.85	1.19	0.12	3.73	41.74	4.74	9.75	4.07
19	7/12/2009	10:30	7.9	33.14	9.64	88.57	36.94	197.04	8.77	239.61	81.37	0.50	0.21	24.87	59.47	16.20	90.36	26.16
20	7/12/2009	16:30	7.6	12.56	7.85	33.88	31.35	58.90	1.41	76.11	40.20	1.23	0.04	10.31	46.92	12.93	34.36	12.24
Maximum			8.2	33.14	9.64	88.57	36.94	197.04	8.77	239.61	81.37	17.47	0.23	24.87	59.47	16.50	90.36	26.16
Minimum			7.4	1.67	3.41	5.94	4.03	6.31	0.05	5.75	5.85	0.16	0.02	2.80	34.43	3.29	6.49	2.79
Mean			7.9	7.95	6.64	22.94	15.38	40.13	0.95	41.80	27.31	3.48	0.12	8.18	47.26	9.82	25.66	9.43

Table 2: Ionic composition of soils in D-1 and D-2 main drains in Al-Ahsa Oasis

Well No.	Fe (μg L^{-1})	As (μg L^{-1})	Co (μg L^{-1})	Ni (μg L^{-1})	Se (μg L^{-1})	Cd (μg L^{-1})	Zn (μg L^{-1})
1	3.13	1.69	1.95	1.12	1.61	0.55	0.27
2	3.35	0.92	1.51	0.49	7.57	0.53	0.21
3	3.45	1.66	2.14	1.01	0.00	0.62	0.23
4	3.48	1.08	1.77	1.35	5.50	0.69	0.21
5	3.60	1.08	1.97	1.08	0.00	0.57	0.26
6	3.87	1.09	1.69	1.40	0.00	0.52	0.39
7	4.09	1.55	0.72	1.47	0.00	0.52	0.38
8	4.13	0.86	1.60	1.65	0.00	0.70	0.30
9	4.28	0.93	1.42	1.67	0.00	0.49	1.64
10	4.69	3.08	1.38	1.96	0.00	0.56	1.66
11	4.76	1.24	0.93	2.31	0.00	0.64	1.64
12	4.99	0.96	0.61	2.02	0.00	0.44	1.59
13	4.85	1.39	0.37	2.20	0.00	0.54	1.76
14	5.11	1.22	0.72	2.37	0.00	0.65	1.77
15	5.17	1.63	0.55	3.14	0.00	0.58	1.70
16	5.02	2.03	0.00	3.15	0.00	0.45	1.72
17	5.25	1.63	0.00	2.90	1.89	0.57	1.78
18	5.61	1.65	0.25	3.45	0.00	0.61	1.77
19	5.53	1.76	0.20	3.29	0.00	0.43	1.75
20	5.55	1.33	0.00	3.64	0.00	0.56	1.89
Maximum	5.61	3.08	2.14	3.64	7.57	0.70	1.89
Minimum	3.13	0.86	0.00	0.49	0.00	0.43	0.21
Mean	4.50	1.44	0.99	2.08	0.83	0.56	1.15

Table 3: Comparison of concentrations of heavy metals with acceptable limits

Elements	Acceptable limit (μg L^{-1})	Wave length (nm)	FAAS detection limit (mg L^{-1})	Present study (μg L^{-1})
Cu	30-40	324.80	0.077	-
Ni	30-70	232.00	0.140	0.49-3.64
Pb	85-450	217.00	0.190	-
Zn	135-150	213.90	0.018	0.30-1.89

Fuentes *et al*. (2004), FAAS: Flame atomic absorption spectrometry

Ca vs. Cl and SO_4: The regression analysis showed a strong relationship between Ca vs. Cl ($R^2 = 0.767$) and Ca vs. SO_4 ($R^2 = 0.731$) at various locations (Fig. 2). The relationship is stronger of Ca with Cl than the corresponding SO_4 ion. This might be due to the difference in solubility equilibrium being higher for $CaCl_2$ than $CaSO_4$ salt.

Mg vs. Cl and SO_4: The relationship is strong between Mg and SO_4 ion ($R^2 = 0.809$) than Mg and Cl ions ($R^2 = 0.703$) (Fig. 3). This indicated that $MgCl_2$ salt is more stable than Mg SO_4 salt due to the difference in equilibrium solubility which is higher of $MgCl_2$ than Mg SO_4 in aqueous than soil solution. The $MgCl_2$ ionizes more rapidly than other compounds in the soil-water system.

Na vs. Cl and SO_4: Regression analysis showed a strong relationship between Na and Cl ion ($R^2 = 0.758$) as well as between Na and SO_4 ions ($R^2 = 0.827$) (Fig. 4). As, the Na ion is mono-valance and has more affinity for Cl ion than SO_4 (a divalent ion). The difference in the valance might be the possible reason for high concentration of NaCl than Na_2SO_4 salt ion in soil solution.

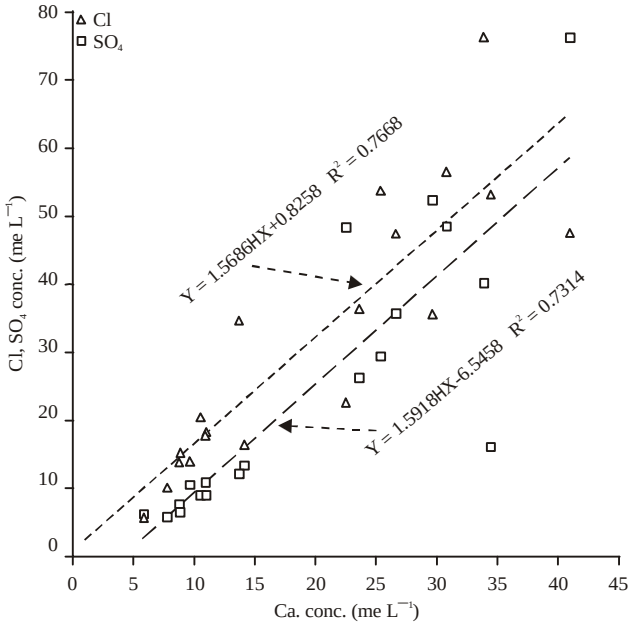

Fig. 2: Relationship between Ca vs. Cl and SO_4 of soil extracts

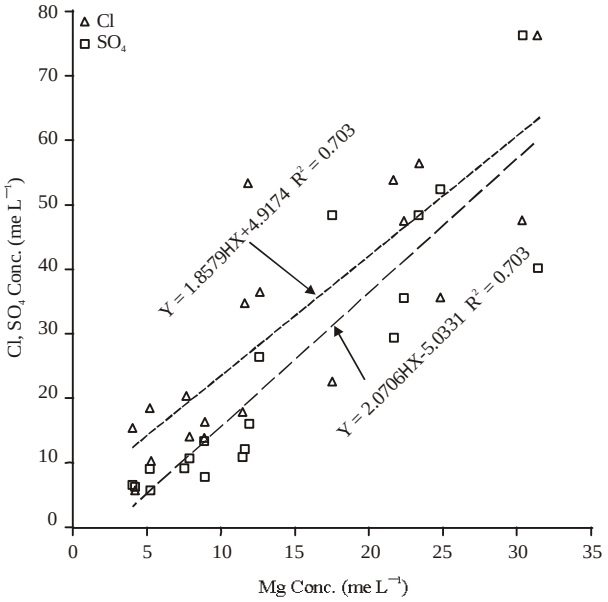

Fig. 3: Relationship between Mg vs. Cl and SO_4 of soil extracts

HCO_3 vs. Ca, Mg and Na: Regression analysis showed a strong relationship between HCO_3 and Na ($R^2 = 0.607$), HCO3 and Mg ($R^2 = 0.714$) and HCO_3 and Ca ($R^2 = 0.582$) (Fig. 5). The little variation in the relationship might be due to variability in solubility constant of different salt ions.

SAR vs. adj.R_{Na} and adj.SAR: A strong relationship was observed between SAR and adj.SAR ($R^2 = 0.988$) as well as between SAR and adj.R_{Na} ($R^2 = 0.983$) of soils (Fig. 6). The slightly higher value of R^2 for the relationship between SAR and adj.R_{Na} is due to the fact that adj.R_{Na} takes into account the precipitation and dissolution reactions of Mg and Ca ions with the CO_2 pressure in the

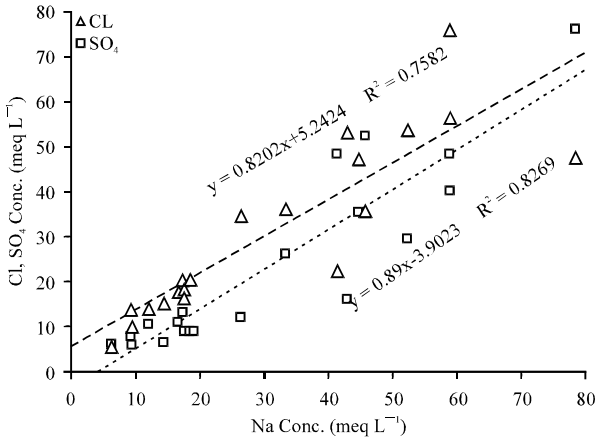

Fig. 4: Relationship between Na vs. Cl and SO_4 of soil extracts

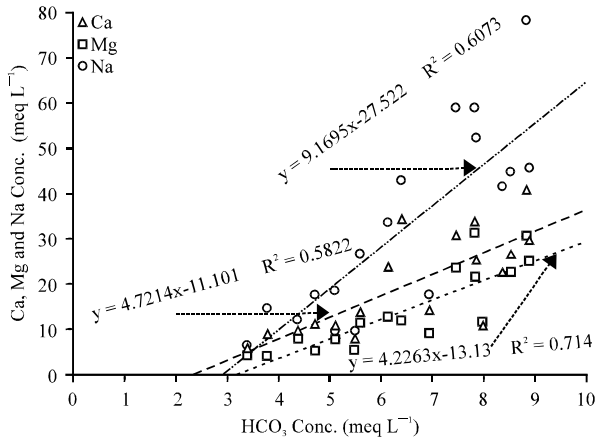

Fig. 5: Relationship between HCO_3 vs. Ca, Mg and Na of soil extracts

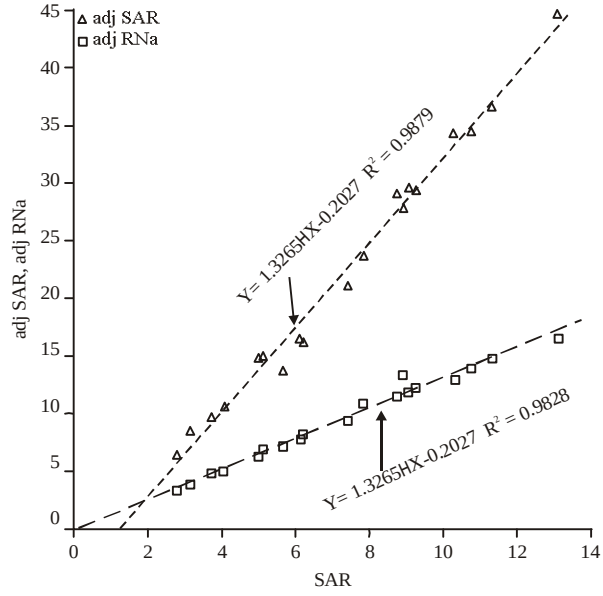

Fig. 6: Relationship between SAR vs. adj.SAR and adj.R_{Na} of soils

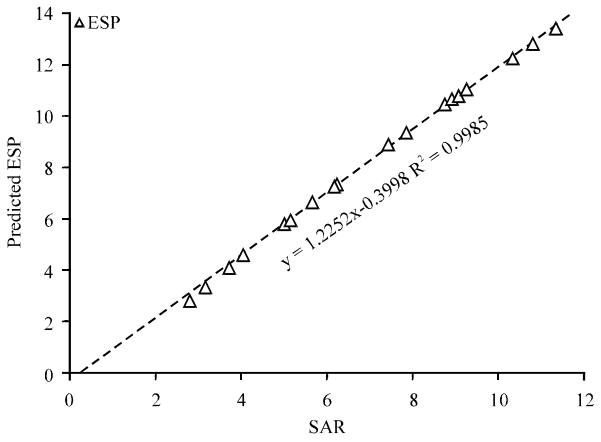

Fig. 7: Relationship between SAR and predicated ESP of soils

soil-water system and determines the final adjusted Ca concentration in the soil solution after irrigation. To calculate adj.R_{Na}, new value of Ca is considered instead of Ca+Mg concentration which precisely predicts the true Na ion status of soils.

SAR vs. predicted ESP of soils: The relationship between SAR and Predicted ESP (exchangeable-sodium-percentage) of soils is very strong after irrigation with these waters with a R^2 value of 0.998 (Fig. 7). The predicted ESP value of the soil samples based on SAR of soil saturation paste extract is within upper acceptable limit of 15, because above this value, the Na contents of the soil complex will increase and deteriorate the soil structure by deflocculation thus hampering the soil permeability.

Well water chemistry: Mean ranges of water quality parameters in agricultural wells were 7.32-8.13 (pH), 2.15-6.92 mg L^{-1} (DO), 2.15-6.92 dS m^{-1} (ECe), 1444-4307 mg L^{-1} (Total dissolved solids, TDS), 2.75-4.85 meq L^{-1} (HCO_3), 4.84-18.79 meq L^{-1} (Ca), 4.36-11.85 meq L^{-1} (Mg), 11.05-40.95 meq L^{-1} (Na), 0.24-1.56 meq L^{-1} (K), 12.81-55.05 meq L^{-1} (Cl), 5.55-26.03 meq L^{-1} (SO_4), 0.45-2.48 meq L^{-1} (NO_3), 0.06-0.10 meq L^{-1} (F), 3.93-10.85 (SAR), 4.54-13.47 (adj.RNa), 9.35-29.79 (adj.SAR) and 4.34-12.84 (predicted exchangeable sodium percentage of soil) (Table 4). Well waters were classified as C4S1 to C4S4 according to USDA (1954) and Ayers and Westcot (1985) water classification scheme for irrigation purpose. The order of abundance of cations was Na>Ca>Mg>K while those of anions was Cl>SO_4>HCO_3 in both the well samples along D-1 and D-2 main drainage canals. The NO_3 concentration ranged from 28-154 mg L^{-1} (0.45-2.48 meq L^{-1}) and F concentration was from 0.54-0.90 mg L^{-1} (0.06-0.10 meq L^{-1}) at different locations. Most of the well waters were Na-Ca-Mg types waters. The NO^3 concentration in 89% of well waters is above the upper permissible limit of 30 mg L^{-1} for irrigation according to Ayers and Westcot (1985). Irrigation with some well waters can develop soil salinity and sodicity problems if the proper management practices such leaching requirements is not followed to maintain root zone salt concentration within acceptable limits for normal plant growth.

Ions inter-relationship between soils (s) and well waters (w): Regression analysis was run to determine the influence of well water irrigation on soil properties by finding the relationship

Table 4: Physicochemical composition of well waters of agriculture farms in Al-Ahsa Oasis

Well ID	Depth (m)	pH	DO (mg L^{-1})	EC (dS m^{-1})	TDS (meq L^{-1})	HCO_3 (meq L^{-1})	Ca (meq L^{-1})	Mg (meq L^{-1})	Na (meq L^{-1})	K (meq L^{-1})	Cl (meq L^{-1})	SO_4 (meq L^{-1})	NO_3 (meq L^{-1})	F (meq L^{-1})	SAR	Adj. R_{Na}	Adj. SAR	ESP	Water class
D2W7	78	7.58	3.62	4.20	2304	3.51	9.08	7.18	21.54	0.81	26.08	8.52	1.04	0.08	7.52	8.77	18.42	8.87	C4S3
D2W10	70	7.69	2.45	2.45	1485	2.80	6.95	5.29	11.85	0.70	15.76	5.55	1.23	0.08	4.80	5.42	10.88	5.49	C4S2
D2W11	70	7.75	3.78	3.78	2318	3.19	8.52	7.08	22.02	0.81	23.76	11.01	0.65	0.08	7.76	8.90	18.71	9.13	C4S3
D2W13	90	7.66	2.25	3.14	1484	3.06	6.79	5.02	11.85	0.73	14.16	6.38	1.48	0.07	4.90	5.58	11.14	5.62	C4S2
D2W12	90	8.13	2.42	2.39	1492	3.33	6.99	5.76	9.92	1.48	12.81	6.75	2.48	0.09	3.93	4.54	9.35	4.34	C4S1
D2W16	150	7.82	2.37	2.37	1444	2.95	6.74	5.31	11.05	0.83	13.95	6.12	1.42	0.08	4.51	5.12	10.33	5.12	C4S2
D2W18	250	7.45	2.15	2.15	1621	2.75	4.84	4.36	16.96	0.49	15.80	7.58	0.63	0.08	7.91	8.67	16.97	9.43	C3S2
D1W1	147	7.62	2.50	2.50	1814	2.80	7.34	6.88	14.69	0.24	15.08	11.80	0.45	0.10	5.80	6.36	13.06	6.77	C4S2
D1W3	120	7.49	5.56	5.56	3579	3.18	16.42	10.28	30.08	1.00	28.19	26.03	0.59	0.07	8.79	10.45	22.18	10.41	C4S3
D1W4	90	7.57	2.82	2.82	1685	2.86	7.06	4.92	15.55	0.70	19.15	5.82	0.63	0.08	6.34	7.19	14.28	7.45	C4S2
D1W5	120	7.64	2.66	2.66	1857	3.61	8.46	5.51	16.66	0.26	17.28	9.53	0.66	0.09	6.35	7.61	15.35	7.45	C4S2
D1W8	150	7.84	3.74	3.74	2299	3.51	8.31	6.58	23.14	0.44	24.43	10.09	0.46	0.07	8.55	9.82	20.32	10.17	C4S3
D1W18	110	7.63	4.22	3.09	2769	4.85	10.68	7.24	27.88	0.44	28.43	12.49	0.73	0.08	9.21	11.55	24.34	10.94	C4S3
D1W20	115	7.45	6.92	6.92	4307	4.70	18.79	11.85	40.95	1.56	55.05	12.66	1.24	0.06	10.85	13.47	29.79	12.84	C4S4
D1W25	85	7.32	2.76	2.76	1948	4.39	8.38	5.35	18.36	0.72	19.38	8.24	0.78	0.09	7.01	8.68	17.56	8.32	C4S2
D1W32	90	7.51	2.64	2.64	1639	3.47	6.74	4.81	15.03	0.63	16.43	6.88	0.74	0.08	6.31	7.23	14.40	7.41	C4S2
D1W46	90	7.72	3.04	3.04	1828	4.17	8.60	5.51	15.57	0.74	17.31	8.47	0.65	0.08	5.86	7.21	14.66	6.88	C4S2
D1W68	300	7.52	2.79	2.79	1708	3.77	9.23	5.14	14.46	0.26	17.91	6.69	0.56	0.07	5.39	6.68	13.31	6.28	S4S2

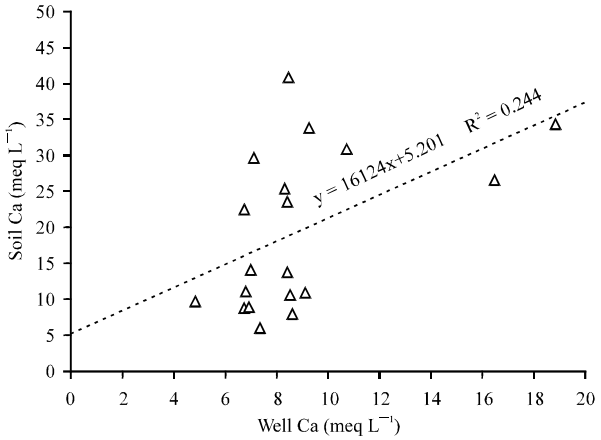

Fig. 8: Relationship between Ca of well waters and soils

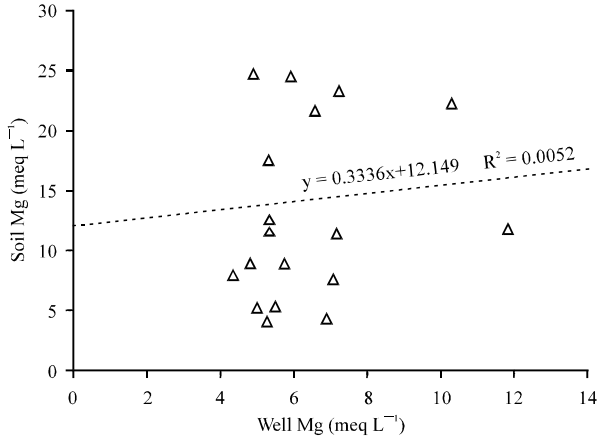

Fig. 9: Relationship between Mg of well waters and soils

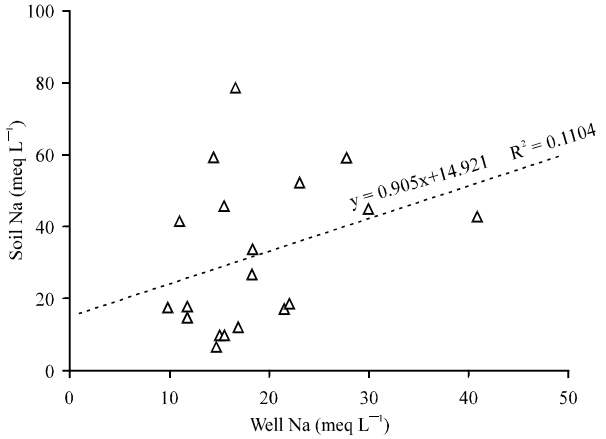

Fig. 10: Relationship between Na of well waters and soils

between various soil and well water cations and anions. The regression analysis of soil chemistry showed that relationship was very poor between Ca_w vs. Ca_s ($R^2 = 0.244$) (Fig. 8), Mg_w vs. Mg_s R^2 value (0.005) (Fig. 9), Na_w vs. Na_s with R^2 value of 0.110 (Fig. 10), Ka_w vs. Ka_s with R^2 value of 0.046 (Fig. 11). The data indicated that the concentration of all major cations did not affect the cationic concentration of soil solution after irrigation. Similar to cations, the inter-ion relationship for various anions was also very poor between Cl_w vs. Cl_s with R^2 value of 0.216 (Fig. 12) and between SO_{4w} vs. SO_{4s} with R^2 value of 0.015 (Fig. 13).

Ec_w vs. Ec_s: The relationship between well water salinity and the soil salinity was not significant because the value of coefficient of determination (R^2) was very low (0.004) (Fig. 14). This means that the irrigation water salinity did not affect the soil salinity after irrigation.

SAR_w vs. SAR_s: The relationship between SAR of well water and SAR of soils is very poor as indicated by the low value of correlation (R^2 = 0.092) (Fig. 15). Similarly the relationship

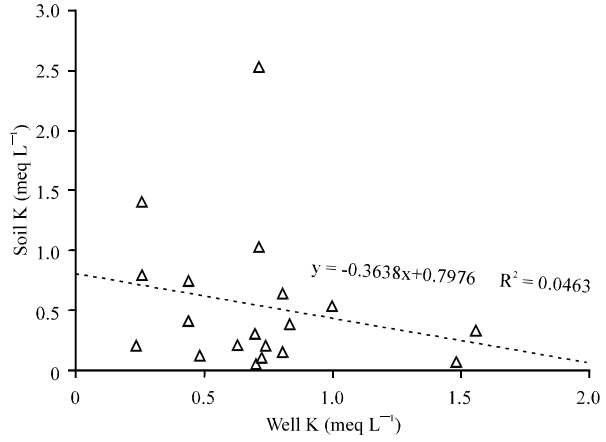

Fig. 11: Relationship between K of well waters and soils

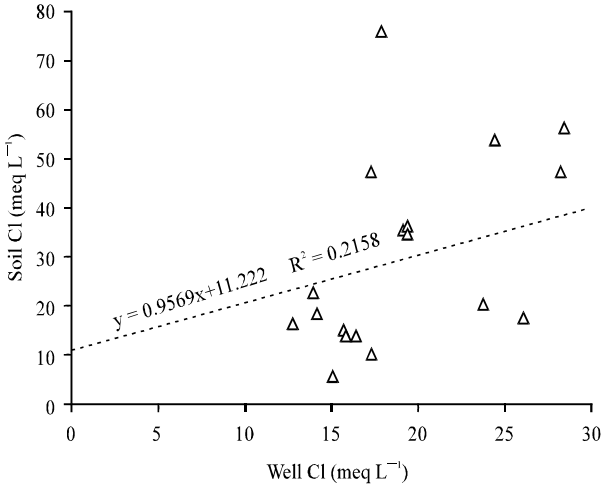

Fig. 12: Relationship between Cl of well waters and soils

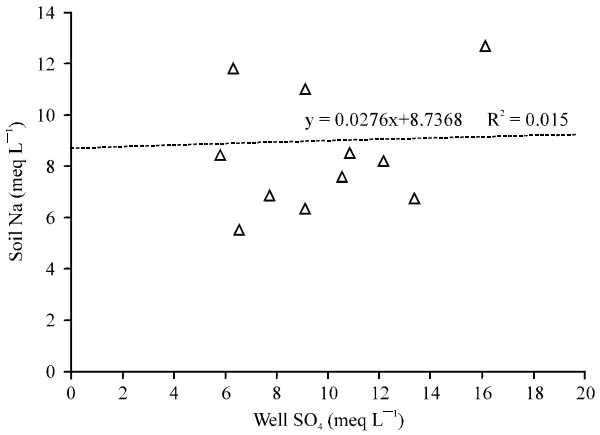

Fig. 13: Relationship between SO_4 of well waters and soils

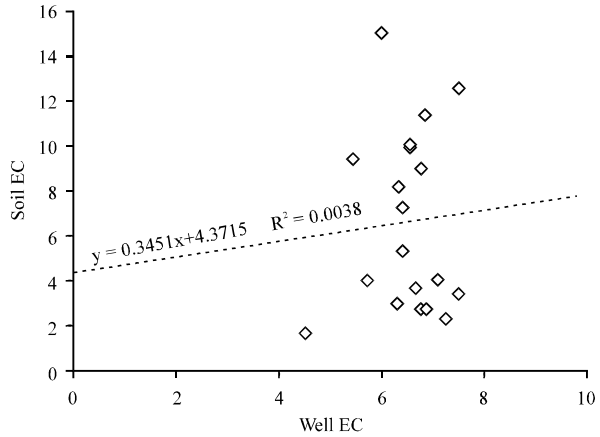

Fig. 14: Relationship between electrical conductivity (EC) of well waters and soils

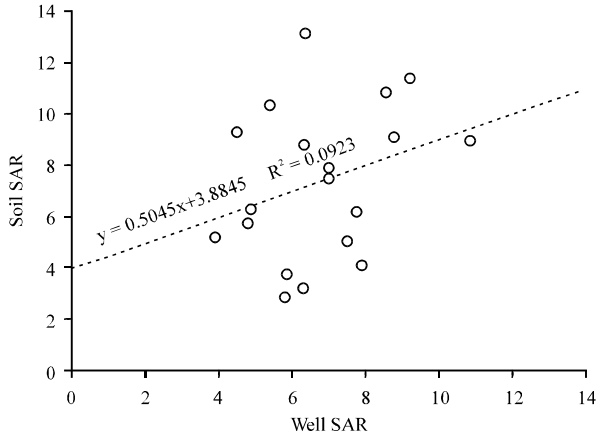

Fig. 15: Relationship between SAR of well waters and soils

between adj.SAR of well waters and adj.SAR of soils was also very poor as presented in Fig. 16 ($R^2 = 0.122$) as well as between adj.R_{Na} of well waters and adj.R_{Na} of soils is very poor (Fig. 17 ($R^2 = 0.169$)).

ESP_w vs. ESP_s: The relationship between predicted ESP of soil from SAR of well waters and predicted ESP of soils from SAR of soil extract was determined to find the adverse effects of Na ion contents of well waters on Na ion status of soils. The regression analysis indicated that the predicted ESP of well waters did not affect the resulting ESP of soils after irrigation with these waters (Fig. 18).

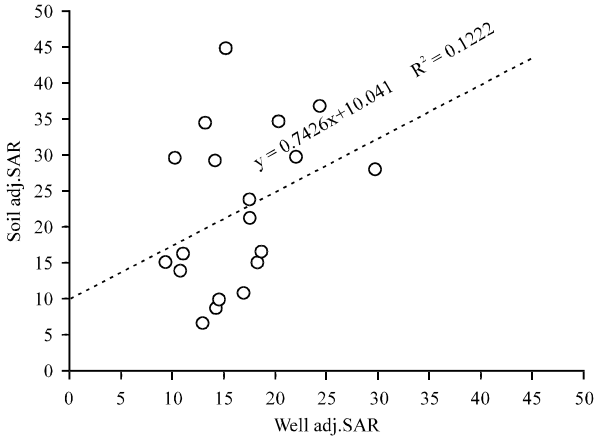

Fig. 16: Relationship between adj.SAR of well waters and soils

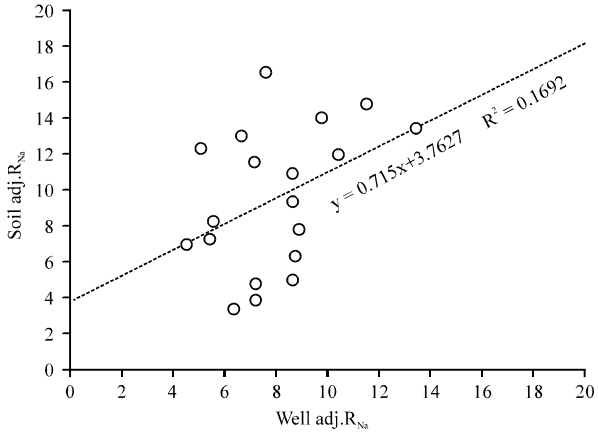

Fig. 17: Relationship between adj.R_{Na} of well waters and soils

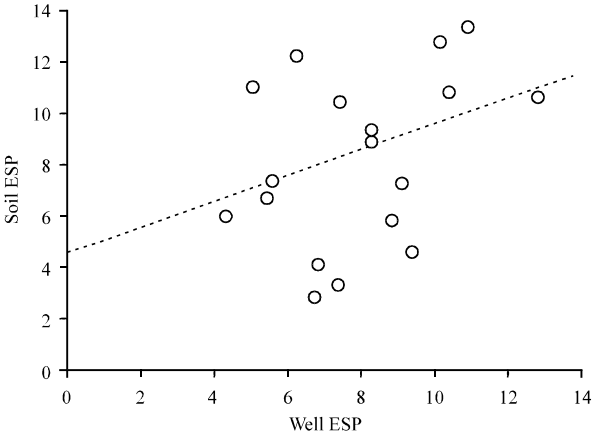

Fig. 18: Relationship between ESP of well waters and soils

Table 5: Criteria for classification of agricultural soils based on soil salinity and sodium adsorption ratio (SAR)

Soil class	pH	EC_e (dS m^{-1})	SAR
Non-saline non-alkali	7.5	<4	<5
Saline	<8.5	>4	<15
Non-saline alkali	>8.5	<4	>15
Saline-alkali	<8.5	>4	>15

EC_e: Electrical conductivity of soil saturated paste extract

Soil salinity classification: Soils of the agricultural farms were classified into different types of saline soils based on the total salinity of saturated soil paste extract (EC_e as dS m^{-1}) and Sodium Adsorption Ratio (SAR) for cultivation of different crops according to soil classification scheme of USDA (1954). The criteria used for this purpose are presented in Table 5.

The soil EC_e ranged between 1.67-15.05 dS m^{-1} at various locations. Out of the total 19 soil samples, soil salinity of 58% samples (11) fell in the category of medium to high salinity soil according to USDA (1954) soil classification criteria. This indicated that the total salinity of well waters increased the soil salinity after irrigation in some farms which could be attributed to well water salinity and the high arid climatic conditions.

CONCLUSION

The soil salinity falls in the category of medium to high salinity soil classifications at different locations in the study area. The inter-ions relationship of soils was highly significant among various cations and anions. On the other hand, the inter-ions-relationship of different cations and anions between well waters and the soil extracts was not significant. The results showed that 58% of soils irrigated with well waters showed increases in soil chemical composition while in 42% cases the soil salinity was not affected under the existing management practices.

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