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Effect of Groundwater Composition on Mineral Composition of Agricultural Plants in the Vicinity of Drainage Canals in Al-Ahsa Oasis, Saudi Arabia

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Abstract: Groundwater salinity varies with time and space which affects the soil and plant mineral composition upon irrigation. In Al-Ahsa Oasis, groundwater is the main source of irrigated agriculture. The main objective of this study was to determine the effect of groundwater composition on the mineral composition of plants from the agricultural farms in the vicinity of main drainage canals. Plants and water samples were collected from 20 agricultural farms located around 500 m distance from the main drainage canals for mineral composition. The concentration of major elements such as Ca, Mg, Na and K ranged between 0.616-3.346, 0.153-1.258, 0.153-1.319 and 0.485-20.019, respectively. The concentration of trace and heavy metal ions was within the permissible limits. The inter ion relationship between well waters and plants was very poor. The mineral concentrations of well waters did not show any appreciable effect on the mineral concentration of plants. Overall, the study findings suggest a long term monitoring for determining the influence of groundwater composition on plant composition under a given set of soil, water and plant growth conditions in Al-Ahsa Oasis.

Key words: Groundwater, water chemistry, plants, mineral composition, date palm, ion-relationship, trace and heavy metal ions

INTRODUCTION

Groundwater salinity affects the ion concentration of both the soil and plants after irrigation depending on its total concentration especially in arid and semi-arid countries of the world having limited fresh water supplies coupled with low rainfall. Al-Ahsa Oasis is one of the potential irrigated agricultural areas in Saudi Arabia where groundwater in the main source of crop irrigation. The mean annual rainfall is around 70.3 mm and the environment is extremely hot and severe (Al-Kuwaiti and Ahmed, 2003; Lin, 1984). Salinity stress increased significantly the leaf sodium (Na^+) and chloride (Cl^-) in different soybean cultivars. However, the salinity stress also reduced the accumulation of K^+, calcium (Ca^{2+}) and magnesium (Mg^{2+}) in the leaves of different soybean cultivars (Essa, 2002). Fernandez-Garcia *et al.* (2004) found in a greenhouse study that the concentration of Na^+ and Cl^- was significantly higher in un-grafted than in grafted 'Fanny' plants due to salinity stress. In another study, long-term irrigation with sewage water improved the organic matter to 1.24-1.78% and fertility status of soils (Yadav *et al.*, 2002). They also observed groundwater contamination and some traces of heavy metals in crops. Besides, when the nitrogen input exceeds the demand of plants, then it increases the nitrates contents of soils (Nosengo, 2003). This causes imbalance of nutrients in soil and increases the nitrate concentration of groundwater supplies (NAAS, 2005) which influences the nitrate concentration of plants (Dapoigny *et al.*, 2000).

Generally, wastewater and recycled water are characterized by a higher salinity than fresh water which demands crop selection suitable for saline plant growth environments. Recently, Escalona *et al.* (2013) observed that wastewater and recycled water contain high salt concentration thus resulting in reduced plant production.

Presently, limited information is available for the effect of groundwater salinity on mineral composition of plants grown in the vicinity of drainage water canals in Al-Ahsa Oasis where the drainage effluent, a compound mixture of different types of waste waters, is flowing in the form of big water streams. Previous studies showed that the drainage water contains high level of salts which might influence the salinity status of irrigated soils and plants (Hussain *et al.*, 2013). Therefore, the main objective of this study was to determine the effect of groundwater composition on the mineral composition of different plants in agricultural farms in the vicinity of main drainage canals in Al-Ahsa Oasis, Saudi Arabia.

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MATERIALS AND METHODS

The study was carried in Al-Ahsa Oasis in the farmers fields along the main drains D-1 and D-2 where most of the agricultural farms use groundwater for crop irrigation. The agricultural farms growing different crops and using the groundwater (well waters) for irrigation were selected within 500 m distance from the main drains.

Collection of well water samples: A total of 20 well water samples were collected from the same farms irrigated with groundwater. Before collecting the water samples, the selected wells were operated for at least 2 h or more for taking the representative water samples. The samples were collected in sterile plastic bottles, labeled properly, stored in an ice chest and transferred to analytical laboratory for chemical analysis.

Collection of plant samples: The plant samples were collected from the agricultural farms that use well water for crop irrigation. The plant samples were collected from date palm, chilli and Fragmitus australis (Reed Plant, growing in many agricultural farms). The plant samples were air-dried, ground to powdery form with a coffee grinder and stored for chemical analysis. The plant samples were analyzed major cations (Ca, Mg, Na, K), major anions (Cl, SO_4, PO_4, NO_3) trace elements (Co, F, Fe, Mn) and heavy metals (As, Cu, Zn, Pb, Hg) according to the procedures given in Chapman and Pratt (1961).

Analytical procedures: Water samples were analyzed by following the standard analytical procedures described in the AOAC (2003). The laboratory equipments/instruments used for water analysis were ICP OPTIMA 2000DV (Perken Elmer) for trace elements, ion-chromatography for anions (Cl, SO_4, NO_3, F, PO_4), ion-chromatography for cations (Na, K, Mg, Ca), Mars-5 Digestion/Extraction Sample Preparation and pH/Conductivity meter/DO Star-5 for field analysis (EC, DO, temperature, pH, turbidity).

Data analysis: The experimental data was analyzed statistically by analysis of variance (ANOVA) and regression techniques according to the procedures given in SAS Institute (2001).

RESULTS AND DISCUSSION

Mineral composition of plants: The ranges for the concentration of macro-element (as %) were 0.616-3.346 (Ca), 0.153-1.258 (Mg), 0.153-1.319 (Na), 0.485-20.019 (K), 0.467-9.713 (Cl), 1.073-19.921 (SO_4) and 0.00-0.180 (NO_3) in plants found in the selected agricultural farms along the main drains (D-1 and D-2) in Al-Ahsa Oasis (Table 1). Major plants include date palm, chilli and Phragmites australis. Out of the total plant samples, 85% were date palm, 5% chili and 10% phragmites australis along both the main (D-1 and D-2)drainage canals.

The ranges for the concentration of trace and heavy metal ions (mg kg^{-1}) were 0.01-23.80 (Mn), 12.80-135.30 (Fe), 0.860-1.500 (Cu), 0.09-1.10 (Ni), 0.05-0.300 (Co), 0.40-13.60 (Zn), 0.00-3.60 (Pb), 0.0-0.49 (As) and 0.0-0.26 (PO_4) in plants found in different agricultural farms along the main (D-1, D-2) drainage canals while the Cd was not detected in any plant sample (Table 2).

Table 1: Major element composition of plants along D-1 and D-2 main drainage canals in Al-Ahsa Oasis

Well ID	Plant type	Ca	Mg	Na	K	Cl	SO_4	NO_3
		(%)						
D1W01	Date palm	1.485	1.258	1.319	20.019	7.860	6.895	0.055
D1W03	Date palm	1.336	0.414	0.086	1.895	0.720	1.680	0.005
D1W04	Date palm	1.959	0.230	0.142	3.566	1.823	2.109	0.012
D1W05	Chilli	2.256	0.201	0.131	1.798	0.610	2.305	0.006
D1W18	Date palm	2.168	0.276	0.209	1.817	1.438	2.277	0.005
D1W20	Date palm	2.560	0.492	0.413	4.511	6.569	19.750	0.001
D1W25	Date palm	1.480	0.276	0.306	6.850	4.565	2.517	0.012
D1W26	Date palm	1.942	0.797	0.279	2.287	0.579	4.179	0.011
D1W32	Date palm	2.575	0.207	0.324	4.141	1.067	2.993	0.004
D1W46	Date palm	2.624	0.224	0.220	1.897	0.860	2.564	0.004
D1W68	Date palm	3.346	0.388	0.129	1.013	6.628	19.921	0.001
D2W07	Date palm	1.655	0.300	0.153	2.194	1.217	1.818	0.006
D2W10	Date palm	2.221	0.294	0.410	0.971	0.933	2.376	0.003
D2W11	Date palm	1.667	0.207	0.384	0.485	0.591	1.630	0.004
D2W12	Date palm	2.053	0.287	0.399	0.981	0.942	2.357	0.003
D2W13	Date palm	2.129	0.153	0.091	1.970	0.768	2.716	0.008
D2W16	Date palm	1.422	0.183	0.082	1.563	0.762	1.073	0.004
D2W18	Date palm	0.616	1.077	0.109	16.591	9.713	4.807	0.041
M.D-2	Phragmites	1.254	0.298	1.246	6.901	3.912	3.242	0.180
M.D-1	Phragmites	1.180	0.294	0.276	4.321	0.467	2.543	0.000

Table 2: Trace elements and heavy metal composition of plants around D-1 and D-2 main drainage canals in Al-Ahsa Oasis

		Cu	Fe	Mn	As	Pb	Co	Ni	Zn	PO_4
Well ID	Plant type	(mg kg^{-1})								
D1W01	Date palm	1.200	46.9	3.90	0.00	0.230	0.07	0.31	9.5	0.000
D1W03	Date palm	0.930	31.0	0.10	0.17	1078	0.15	0.09	2.7	0.000
D1W04	Date palm	0.980	101.3	12.00	0.49	2.300	0.19	0.60	3.7	0.000
D1W05	Chilli	0.970	51.4	1.50	0.65	1065	0.19	0.30	3.2	0.000
D1W18	Date palm	1.300	115.4	8.60	0.30	0.000	0.18	0.92	6.8	0.000
D1W20	Date palm	1.100	76.2	23.80	0.24	0.000	0.23	0.68	3.8	0.010
D1W25	Date palm	1.500	80.2	3.90	0.00	0.000	0.16	0.53	5.6	0.000
D1W26	Date palm	1.100	50.8	7.90	0.00	0.000	0.07	0.46	5.0	0.050
D1W32	Date palm	1.300	135.3	23.30	0.00	0.000	0.30	0.74	4.7	0.029
D1W46	Date palm	1.200	99.6	6.90	0.04	0.340	0.28	0.51	3.6	0.050
D1W68	Date palm	0.970	80.4	7.70	0.00	0.000	0.03	0.52	3.4	0.010
D2W07	Date palm	0.950	60.4	6.20	0.71	0.330	0.07	0.55	1.1	0.037
D2W10	Date palm	0.860	82.8	3.60	0.90	0.300	0.15	0.53	3.7	0.000
D2W11	Date palm	0.920	34.6	1.20	0.28	0.450	0.14	0.28	2.3	0.000
D2W12	Date palm	0.850	34.3	0.85	0.15	0.000	0.11	0.17	2.8	0.000
D2W13	Date palm	1.000	70.8	3.10	0.45	0.390	0.06	0.26	3.5	0.000
D2W16	Date palm	0.900	40.1	1.80	0.10	0.420	0.05	0.25	2.6	0.000
D2W18	Date palm	1.100	13.1	2.50	0.00	0.190	0.15	0.00	13.6	0.255
M.D-2	Phragmites	1.100	12.8	3.30	0.00	0.000	0.08	1.10	0.4	0.000
M.D-1	Phragmites	0.970	16.8	12.20	0.00	3.600	0.14	0.79	2.5	0.000

Table 3: Physio-chemical 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 (mg L^{-1})	HCO_3 (me)	Ca (me)	Mg (me)	Na (me)	K (me)	Cl (me)	SO_4 (me)	NO_3 (me)	F (me)
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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

Well water chemistry: The ranges of various water quality parameters in the agricultural well waters were 7.32-8.13 (pH), 2.15-6.92 mg L^{-1} (DO), 2.15-6.92 dS m^{-1} (EC), 1444-4307 mg L^{-1} (Total dissolved solids, TDS), 2.75-4.85 me L^{-1} (HCO_3), 4.84-18.79 me L^{-1} (Ca), 4.36-11.85 me L^{-1} (Mg), 11.05-40.95 me L^{-1} (Na), 0.26-1.56 me L^{-1} (K), 12.81-55.05 me L^{-1} (Cl), 5.55-26.03 me L^{-1} (SO_4), 0.45-2.48 me L^{-1} (NO_3) and 0.06-0.10 me L^{-1} (F) (Table 3). The groundwater is dominant by Na cation and Cl anion along the main (D-1 and D-2) drainage canals. The concentration of NO_3 and F ranged from 0.45-2.48 and 0.06-0.10 me L^{-1}, respectively in different locations. The groundwater was classified as Na-Ca-Mg type water. Based on the chemical composition of groundwater, there are remote chances of developing soil salinity and sodicity problems upon irrigation.

Ion-inter relationship between well waters and plants

Major cations: Data in Fig. 1 show that the relationship between Na of well waters and plants is very poor as indicated from R^2 value (0.004). This implies that the Na contents of well waters did not affect the Na contents of plants.

Data in Fig. 2 showed a poor relationship between the Ca contents of well waters and plants as indicated from a very poor value of coefficient of determination (R^2 = 0.008). This may be probably due to very low Ca concentration of well water and the plants roots could not take up high contents of Ca as compared to other ions which are mainly related to the total ion concentration of the soil solution in and around the plant root zone.

The regression analysis also showed a poor relationship between K contents of well waters and plants

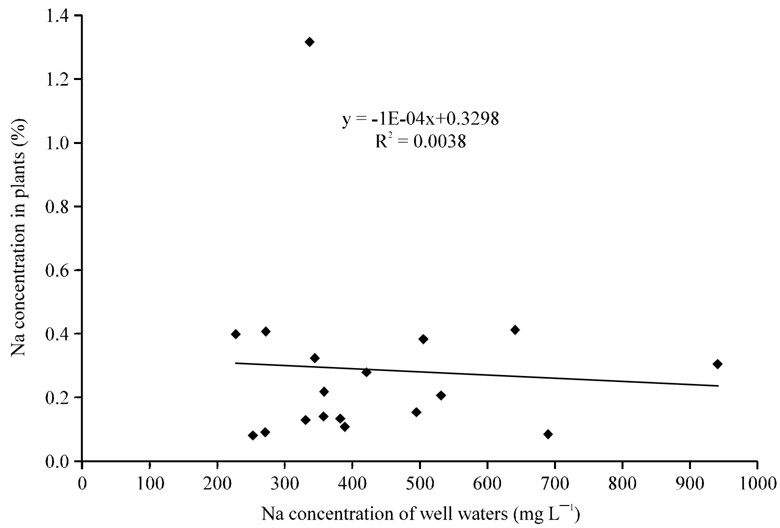

Fig. 1: Relationship between Na of well waters and Na of plants

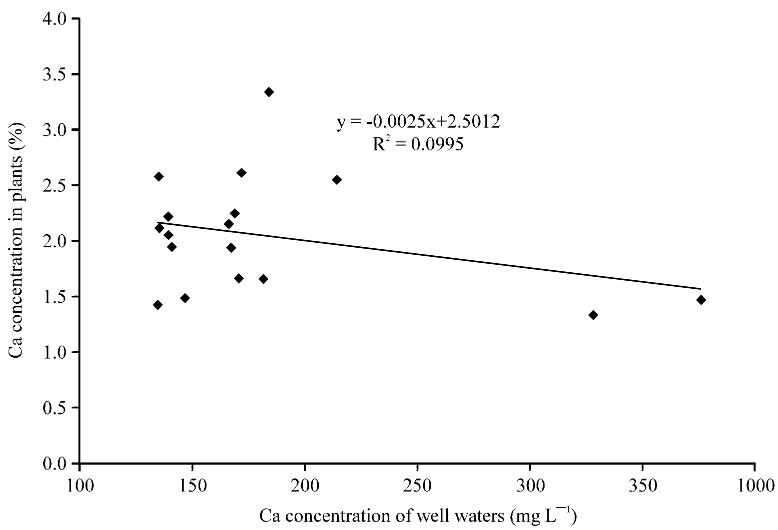

Fig. 2: Relationship between Ca in well waters and Ca of plants

as indicated from the poor value of coefficient of determination (R^2 = 0.007) (Fig. 3). In general, the K requirements of plants is very low, relative to other ions, for normal growth, therefore, it is hard to explain the insignificant effect of K of well waters on the K contents of plants.

Similar to other ions, the relationship between Mg contents of well waters and the plants is very poor as indicated from the low value of coefficient of determination (R^2 = 0.008) (Fig. 4).

Major anions: The relationship between Cl contents of groundwater and plants was very poor as shown from the value of R^2 (0.010) (Fig. 5). Although, the regression analysis showed an increasing trend in Cl contents of plants with increasing Cl contents of groundwater but it was not of great significance. This suggests that the Cl contents of groundwater did not cause any appreciable change in the Cl contents of plants.

The sulfate (SO_4) contents of groundwater did not show any strong relationship with the SO_4 contents of plants as indicated from the poor value of R^2 (0.009) (Fig. 6). Although, the regression line (Fig. 6) showed an increasing trend in SO_4 contents of plants with increasing SO_4 contents of groundwater but was not of significant level. This would mean that SO_4 contents of groundwater did not cause any significant change in the SO_4 contents of plants due to low SO_4 contents of groundwater.

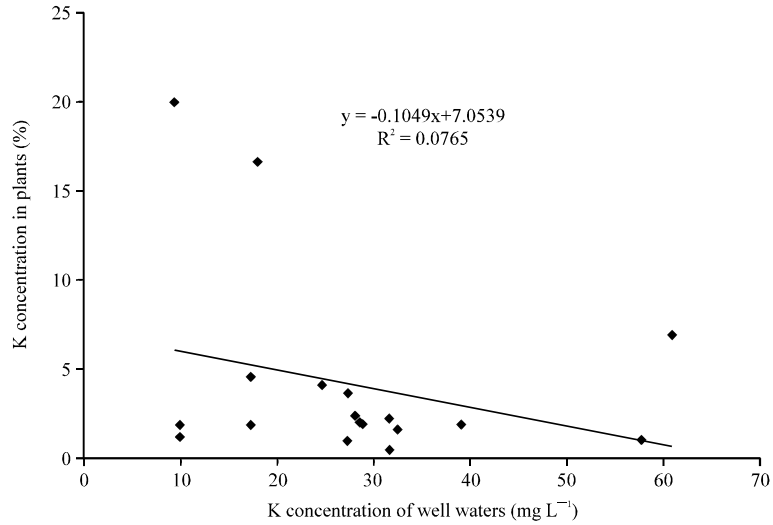

Fig. 3: Relationship between K of well waters and K of plants

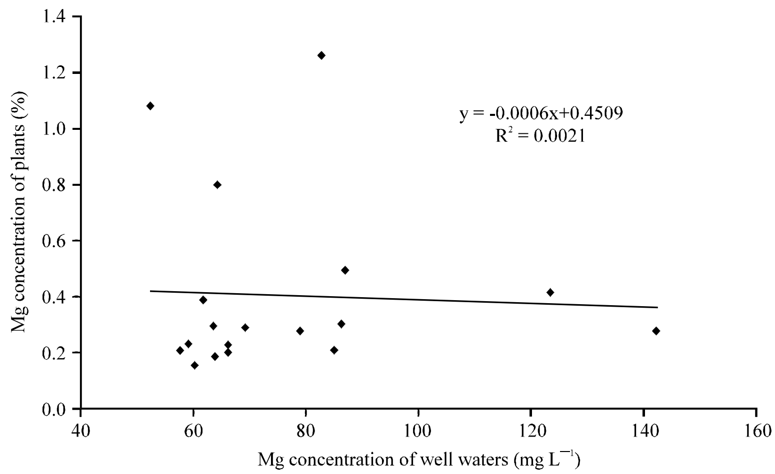

Fig. 4: Relationship between Mg of well waters and Mg of plants

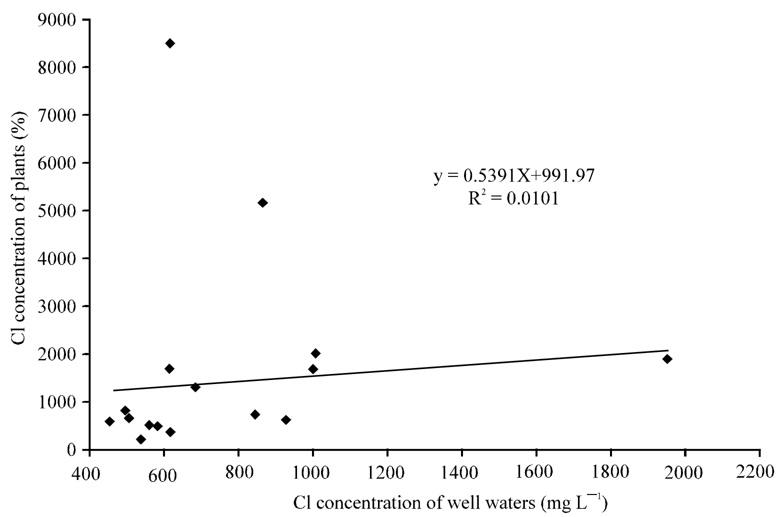

Fig. 5: Relationship between Cl of well waters and Cl of plants

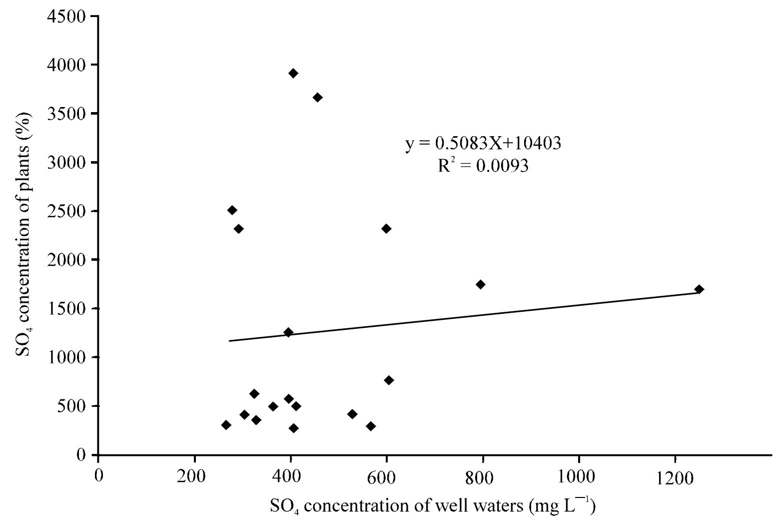

Fig. 6: Relationship between SO_4 of well waters and plants

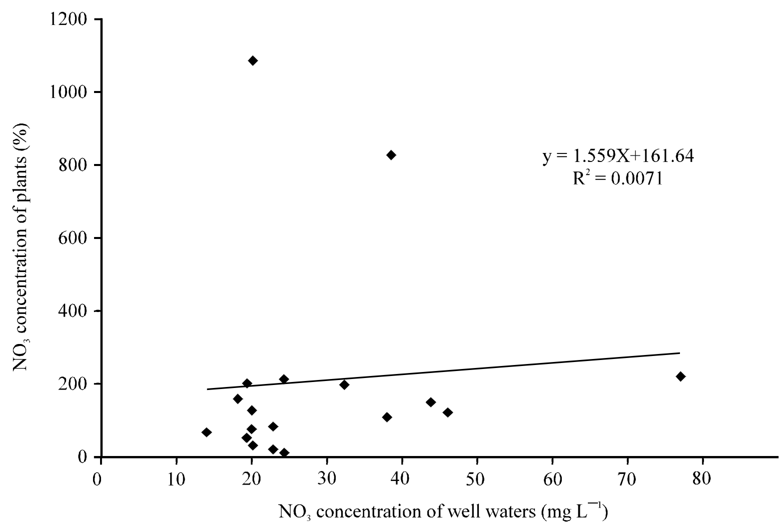

Fig. 7: Relationship between NO_3 of well waters and plants

Similar to other anions, nitrate (NO_3) contents of groundwater did not show any strong relationship with the NO_3 contents of plants as indicated by the poor value of R^2 (0.007) (Fig. 7). Although, the nitrate (NO_3) is considered a useful element for plants growth but under the existing on farm plant growth conditions, it did not show any considerable effect on NO_3 contents of plants.

DISCUSSION

The study results showed that the concentration of mineral elements such as K, Ca, Mg and Na was much higher in the date palm leaves under the farmer's management system. The study findings do not agree with the results of Kassem (2012) who reported much lower concentration of Ca, Mg, Na and K in the date palm leaves under optimal plant growth conditions receiving potassium and sulphur fertilizers. Also, the high concentration of mineral elements in the present study may be due to the high soil salinity under date palm cultivation. The results of the present study showed that groundwater composition did not influence the mineral composition of plants to a greater extent probably due to low concentration of major cations and anions of the groundwater. The results did not agree with many researchers who reported increases in the major elements of plants irrigated with groundwater and effluent of different chemical compositions (Dapoigny *et al*., 2000; Essa, 2002; Fernandez-Garcia *et al*., 2004; Niu *et al*., 2007; Anjana and Iqbal, 2007; Escalona *et al*., 2013).

CONCLUSION

The concentration of major elements such as Ca, Mg, Na and K ranged between 0.616-3.346, 0.153-1.258, 0.153-1.319 and 0.485-20.019, respectively. However, the concentration of trace and heavy metal ions was within the permissible limits. The relationship between ions of well waters and the plants is very poor thus indicating that ion concentrations of well waters did not cause any significant effect on the ion concentration of plants. In conclusion, the study findings suggest a long term monitoring study to determine the influence of groundwater composition on plant composition under a given set of soil, water and plant growth conditions.

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