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Full Length Article

Status of Selenium and Trace Elements in some Arid Soils Cultivated with Forage Plants: A Case Study from Saudi Arabia

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Abstract

The aim of this study was to assess status of selenium (Se) and other trace elements in relation to soil properties in the arid soils of Al-Jouf region, Saudi Arabia. The soils were analyzed for physico-chemical properties and status of available micronutrients. Shoots samples of corn and alfalfa plants analyzed for Se, Mo, Fe, Mn, Zn and Cu. The results showed that the soils were moderately to high alkaline reaction, high in sand content, low in organic matter (OM) and low in cation exchangeable capacity (CEC). Available Fe, Mn, Zn, Cu and Mo of alfalfa soils ranged from 3.07–19.07, 2.08–31.8, 0.70–4.40, 0.09–1.42, undetectable–0.07 mg kg^{-1}, respectively. Meanwhile, in soil samples collected from corn farms, available Fe, Mn, Zn, Cu, and Mo ranged from 1.70–8.35, 0.74–10.5, 0.82–3.12, 0.32–3.91, undetectable–0.04 mg kg^{-1}, respectively. The shoot contents of Se, Mo, Zn and Cu were low and deficient in alfalfa and corn plants. However, it was observed that the shoot contents of Fe and Mn were sufficient. Based on correlation coefficients and multivariate analyses including principal component (PCA) and cluster analyses (CA), soil properties of clay content, CEC and OM altered trace elements availability and consequently can modify the response of forage plant in study area.

Keywords: Trace elements availability; Selenium; Alfalfa; Corn; Multivariate analyses

Introduction

All the plants are relying on the soil for mineral nutrients supply, and then ruminants obtain the majority of their mineral nutrients from plants grown on these soils. It is well known that the concentrations of the elements differ greatly between species, ranging from toxic and inadequate. Generally trace element concentrations of leguminous plants with broadleaf are much higher than their levels in the grass and other forage plants (Belesky *et al.*, 2001; Khan *et al.*, 2006a, b). In spite of that, the elemental concentrations of the forage plants does not depend only on the total content but also depend on the interaction between a number of factors, including soil properties, plant species and maturity, the method of pasture management and climate. Nutrient deficiency in plants and subsequently in animals is associated directly by the characteristics and nutrients status of the soils (McDowell *et al*., 1983).

The soil plays a major role in determining the sustainable productivity in the agricultural ecosystem. The sustainable productivity depends mainly on the ability of the soil to supply plant nutrients needed for growth. Micronutrients [such as iron (Fe), copper (Cu), zinc (Zn) and manganese (Mn)] are necessary for the plants and the lack of these elements has become a major obstacle to sustainable productivity (Kumar and Babel, 2011). Trace elements are also involved in key metabolic events such as respiration, photosynthesis, and fixation and assimilation of some major nutrients (Kabata-Pendias and Pendias, 1991). Among trace elements, the low selenium (Se) content and availability in the soils are of concern (Eich-Greatorex *et al.*, 2007). Se is an essential microelement, necessary for normal functioning of humans and animals (Rayman, 2000). Its deficiency in food and feed causes a number of diseases (Al-Saleh *et al.*, 1999). Low Se content and availability of the soil can show selenium deficiency-related diseases such as white muscle in animals and pancreatic degeneration in poultry (Thompson and Scoot, 1970). Se is one of the most important trace elements for both human and animal health and plays an important role in preventing the disease through its function in the antioxidant enzyme of glutathione peroxidases (Rayman, 2000; Eich-Greatorex *et al.*, 2007). However, high concentrations of Se are toxic for humans, animals and plants. However, Se reactivity, availability and accumulation in plants depends not only on its total content in soil but also on its chemical form and the characteristics of the soils (Jump and Sabey, 1989; Eich-Greatorex *et al.*, 2007).

In Saudi Arabia, due to the lack of rain and the decline of natural pastures, many of the fancier depend on the

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cultivated forage plants such as alfalfa, corn and Sudan grass, which are used as a source of the necessary elements for feeding grazing animals. Efforts have not been made in Saudi Arabia towards determining the levels of micronutrients and Se in the forage plants in terms of their toxicity and deficiency, and their relationship to various chemical characteristics of the soil. Therefore, the objective of this study was to assess the status of micronutrients (Zn, Cu, Fe, Mn, Mo and Se) in soils and in some forage plants (Alfalfa and Corn) and their relationship with physico-chemical soil properties (texture, pH, EC, $CaCO_3$, CEC and organic matter).

Materials and Methods

Study area located in the north-west of the Saudi Arabia between the latitude (37° 41" to the east) and longitude ("28 32° north). There are numerous forage farms in the study area including alfalfa and corn farms.

The soil and plant (alfalfa and corn) samples were collected from 10 farms. The soil samples were collected at 0–30 cm depth. The soil samples were air dried and ground to pass through a 2 mm sieve. The physico-chemical soil properties were measured according to standard methods (Sparks, 1996). The particle size distribution was determined by the pipet method (Gee and Bauder, 1994). Soil pH was measured using a glass electrode in a saturation paste. Electrical conductivity (EC_e) was measured in the extracts of soil saturation paste. Calcium carbonate content was determined using a calcimeter. The soil organic matter was measured according to Nelson and Sommers (1996).

For total content of trace elements, soil samples were digested with HF–H_2SO_4-$HClO_4$ mixture following the method of Hossner (1996). AB-DTPA extracts of soils (Soltanpour and Schwab, 1977). Plant samples were digested using H_2O_2 and H_2SO_4 mixture. The concentrations of Fe, Mn, Zn, Cu and Mo were analyzed using ICP. Se concentrations were analyzed using atomic absorption spectrophotometer with hydride generation (Perkin Elmer 5000).

Statistical Analysis

The values of minimum, maximum, mean and standard deviation (±SD) of the data are calculated. The statistical analysis and the correlations between heavy metals were performed by using Statistica for Windows statistical software (Statsoft, 1995). The multivariate analysis including the PCA and CA was also applied to explain the relationships between different variables.

Results

Physico-chemical Soil Properties

The statistical summary for the values of determined physico-chemical soil properties (pH, EC, CEC, texture, calcium carbonate, organic carbon) are presented in Table 1. Soil pH and sand content was consistently least variable, while silt, clay and chemical properties of CEC, $CaCO_3$ and OM were moderately to highly variable. The texture of soil samples for control site is mainly dominated by sand fraction that amounted to 67–92% in soil samples of alfalfa farms and to 65.79–93.96% in soil samples of corn farms. The textural classes of the investigated soils were sandy, loamy sand and sandy loam. The results on soil chemical properties indicated the soil pH as alkaline. The pH values of the soils of alfalfa and corn ranged from 7.27–7.85 and 7.27–8.19 with mean values of 7.59 and 7.63, respectively (Table 1). The pH values of all representative soils were mostly ranged from slightly to strongly alkaline in reaction. The EC_e recorded for alfalfa and corn soils ranged from 0.65–6.93 dS m^{-1} and 0.57–32.7 dS m^{-1} with mean values of 2.19 and 5.94 dS m^{-1}, respectively. On the basis of EC_e, most of the soil samples are belonging to a category of normal for alfalfa soils with average EC values of 2.19 dS m^{-1} and high with an average of 5.95 dS m^{-1} for corn soils. Lime ($CaCO_3$) content of alfalfa and corn soils ranged from 1.95–9.55 and 1.38–32.3 with mean values of 4.98 and 10.69, respectively. All the soil samples were low in organic matter content (0.07–0.89%) and low CEC values (2.14–12.3 cmol kg^{-1}).

Total Content and Available form of Se and Trace Elements

Micronutrients showed large variation in total and available concentrations in the study sites with high total concentrations of Fe (Table 2 and 3). The total Fe, Mn, Zn, Cu, Mo and Se concentrations in the alfalfa soil samples fell within the range of 8714–25286, 76.9–214, 11.2–42.9, 5.32–10.4, 0.92–5.48 and ND–0.19 mg kg^{-1} with mean values of 14909, 166, 26.4, 7.87, 2.09 and 0.03 mg kg^{-1}, respectively (Table 2). The total Fe, Mn, Zn, Cu, Mo and Se concentrations in the corn soil samples fell within the range of 5058–12689, 61.5–297, 13.4–29.8, 4.29–22.5, 1.22–2.43 and ND–0.16 mg kg^{-1} with mean values of 9183, 147, 22.3, 8.28, 1.93 and 0.05 mg kg^{-1}, respectively. The concentrations of total Fe, Mn, Zn, Cu and Mo are in the common range in soil according to Lindsay (1979). However, the mean concentrations of total Fe, Mn, Zn and Cu are lower than their corresponding values of the common range in soil.

Available Fe, Mn, Zn, Cu, and Mo of alfalfa soils ranged from 3.07–19.07, 2.08–31.8, 0.70–4.40, 0.09–1.42, ND–0.07 mg kg^{-1} with a mean of 10.1, 10.0, 2.03, 0.66 and 0.03 mg kg^{-1}, respectively (Table 3). Meanwhile, in soil samples collected from corn farms, available Fe, Mn, Zn, Cu, and Mo ranged from 1.70–8.35, 0.74–10.5, 0.82–3.12, 0.32–3.91, ND–0.04 mg kg^{-1} with a mean of 4.19, 3.98, 1.58, 1.57, and 0.01 mg kg^{-1}, respectively.

The results of the total Se and its available content in soils are shown in Table 2 and 3. The total Se content varied from undetectable to 0.19 mg kg^{-1} with an average of 0.03 mg kg^{-1} in soil samples of alfalfa farms, whereas in

Table 1: Summary statistics for physical and chemical soil properties

Summary statistics	Sand%	Clay%	Silt%	pH	EC_e dS m^{-1}	$CaCO_3$%	CEC cmol kg^{-1}	OM %
Alfalfa farms								
Min	67	2	0.0	7.27	0.65	1.85	2.51	0.22
Max	92	21	16	7.85	6.93	9.55	7.18	0.89
Av	77.95	13.07	8.97	7.59	2.19	4.98	4.51	0.51
SD	6.73	5.27	4.33	0.20	1.35	2.27	1.40	0.22
CV	8.6	40.3	48.2	2.62	61.6	45.5	31	42.2
SKW	-0.01	-0.31	-0.04	-0.13	2.38	0.23	0.40	0.52
Kurt	-0.40	-0.57	-0.36	-1.46	7.94	-0.83	-0.91	-1.22
Corn farms								
Min	65.79	1.51	0.50	7.27	0.57	1.38	2.17	0.07
Max	93.96	15.09	31.69	8.19	32.73	32.25	12.29	0.79
Av	81.31	7.24	11.44	7.63	5.94	10.69	6.10	0.38
SD	9.14	4.41	7.41	0.25	8.20	9.02	2.59	0.25
CV	11.2	60.9	64.8	3.22	98.92	84.36	42.52	66.03
SKW	-0.02	0.29	0.85	0.36	2.37	1.66	0.33	0.36
Kurt	-1.35	-1.26	1.49	-0.22	5.62	1.74	0.03	-1.40

Table 2: Summary statistics for total content of trace elements in the investigated soils

Summary statistics	Fe	Mn	Zn	Cu	Mo	Se
				mg kg^{-1}		
Alfalfa farms						
Min	8714	76.9	11.4	5.32	0.92	ND
Max	25286	244	42.8	10.4	5.48	0.19
Av	14909	166	26.4	7.87	2.09	0.03
SD	4021	41.35	8.20	1.31	0.96	0.05
CV	27.0	24.9	31.0	16.7	46.1	181
SKW	0.72	0.18	0.05	-0.02	2.27	2.01
Kurt	1.01	0.14	-0.32	-0.75	7.88	3.69
Corn farms						
Min	5058	61.5	13.4	4.29	1.22	ND
Max	12689	297	29.8	22.5	2.43	0.16
Av	9183	147	22.30	8.28	1.93	0.05
SD	2066	49.21	4.48	3.65	0.34	0.06
CV	22.5	33.5	20.1	44.1	17.8	105
SKW	-0.22	1.20	0.07	3.36	-0.72	0.71
Kurt	-0.66	3.77	-0.54	13.34	-0.52	-0.91
Common range according to Lindsay (1979)						
Min	7000	20	10	2	0.02	0.1
Max	55000	3000	300	100	5	2
Av.	38000	600	50	30	2	0.3

soil samples of corn farms its content varied from undetectable to 0.16 mg kg^{-1} with an average value of 0.05 mg kg^{-1}. The available content of Se in alfalfa farms was undetectable in all soil samples, whereas its content was detected only in 20% samples of corn farms with an average value of 0.002 mg kg^{-1}.

Se and Trace Element Contents in Plant

The concentrations of total Fe, Mn, Zn and Cu in shoots of alfalfa plants ranged from 341–885, 26.4–47.1, 9.09–41.8 and undetectable to 4.19 mg kg^{-1} with mean values of 618, 32.7, 22.1 and 0.98 mg kg^{-1}, respectively (Table 4). Meanwhile, their concentrations in shoots of corn plants ranged from 86–335, 33–53, 5.15–24.7, and not-detectable to 13 mg kg^{-1} with mean values of 160, 42.9, 12.6 and 2.31 mg kg^{-1}, respectively. Of both plants, alfalfa had higher contents of Fe, Zn and Mo than does corn. Meanwhile, corn had higher contents of Mn, Cu and Se than those of alfalfa.

The results of the Mo and Se content in shoot plants are also shown in Table 4. The shoot Mo content varied from not-detectable to 1.20 mg kg^{-1} with an average of 0.17 mg kg^{-1} in alfalfa plants, whereas its shoot content were not-detectable in 100% plant samples of corn. Similarly, shoot content of Se was very low and not-detectable in all alfalfa plant samples, whereas its content of corn shoots ranged from not-detected to 0.008 mg kg^{-1} with an average value of 0.001 mg kg^{-1} in shoots of corn plants.

Multivariate Statistical Analysis and Correlation Study

The correlation study showed that significant positive correlations among various trace elements and properties of soil samples in study area (Table 5 and 6). According to Pearson's coefficient, soil available Fe and Cu as well as total Fe are significantly correlated with clay content in the soil samples of alfalfa farms (r = 0.55 and 0.45, respectively).

Table 3: Summary statistics for AB-DTPA extractable trace elements of the investigated soils

Summary statistics	Fe	Mn	Zn	Cu	Mo	Se
				mg kg^{-1}		
Alfalfa farms						
Min	3.07	2.08	0.70	0.09	0.00	ND
Max	19.08	31.85	4.40	1.42	0.07	ND
Av	10.10	10.03	2.03	0.66	0.03	ND
SD	4.75	8.13	0.97	0.33	0.02	-
CV	47.0	81.0	47.9	49.9	60.0	-
SKW	0.44	1.49	0.93	0.39	0.30	-
Kurt	-0.65	1.69	0.80	-0.01	-0.63	-
Corn farms						
Min	1.70	0.74	0.82	0.32	ND	ND
Max	8.35	10.5	3.12	3.91	0.04	0.02
Av	4.19	3.98	1.58	1.57	0.01	0.002
SD	1.80	3.37	0.64	1.03	0.01	0.01
CV	42.9	84.8	40.3	65.6	119	241
SKW	0.51	0.79	0.90	1.04	1.43	2.84
Kurt	-0.11	-1.00	0.23	0.73	2.11	8.55
Index values according to Soltanpour (1985)						
Low	<3	<0.6	<0.9	<0.3		
Medium	3-5	0.6-1	0.9-1.5	0.3-0.5		
High	>5	>1	>1.5	>0.5		

Table 4: Summary statistics for total content of trace elements in the alfalfa and corn plants

Summary statistics	Fe	Mn	Zn	Cu	Mo	Se
				mg kg^{-1}		
Alfalfa plants						
Min	341	26.4	9.09	ND	ND	ND
Max	885	47.1	41.8	4.19	1.20	ND
Av	618	32.7	22.1	0.98	0.17	ND
SD	158	7.51	9.96	1.34	0.39	-
SKW	-0.16	1.45	0.64	1.79	2.46	-
Kurt	0.11	0.77	0.15	3.24	5.96	-
Corn plants						
Min	86.0	33.0	5.15	ND	ND	ND
Max	335	53.0	24.7	13.0	ND	0.008
Av	160	42.9	12.6	2.31	ND	0.001
SD	69.1	6.41	6.98	3.96	-	0.003
SKW	1.99	-0.14	0.71	2.66	-	2.769
Kurt	5.18	-0.58	-0.82	7.50	-	7.837
Index values according to Kabata-Pendias and Pendias (1991)						
Deficient	NA	10-30	10-20	2-5	0.1-0.3	NA
Sufficient	NA	30-300	27-150	5-30	0.2-5	0.01-2
Toxic	NA	400-1000	100-400	20-100	10-50	5-30
ND: not detectable; NA: not available						

Additionally, soil total and available Fe and Mn as well as total Zn and available Mo showed significant positive correlation with the clay content in the soil samples of corn farms.

The Pearson's coefficient of the current study showed significant positive correlation between available Mn and the OM content of alfalfa soil samples (r = 0.71). Moreover, total and available Fe and Mn as well as available Mo of corn soil samples showed significant positive correlation with OM content. By contrast, total content of Mo and Se and soil available Cu showed significant negative correlation with the OM content in corn soil samples (r = -0.48, -0.75 and -0.51, respectively).

It was also observed that total content of Fe and Mn in alfalfa soil samples and total Cu and Se in corn soil samples showed significant positive correlation with $CaCO_3$. However, $CaCO_3$ content has no effect on AB-DTPA-extractable trace elements.

The results of PCA showed that 7 factors in soil samples of alfalfa farms and 5 factors in soil samples of corn farms are extracted, which account for 84.03% and 84.26% of the total variance, respectively (Table 7). Factor 1 is dominated by sand, CEC and $CaCO_3$ in the soil samples of alfalfa farms or clay content, OM, CEC, total content of Fe, Mn and Zn and available Fe and Mn in the soil samples of corn farms, which amounted to 25.7% and 44% of the total variance, respectively. Factor 2 dominated by total content of Fe, Mn, Zn and Cu in soil samples of alfalfa farms or by clay content and EC in soil samples of corn farms accounts for 16.1 and 14.05% of the total variance, respectively.

Table 5: Pearson correlation coefficients between soil properties and trace element in alfalfa farms

			Soil properties								Total content of trace elements					DTPA-extractable trace elements				
		Sand	Clay	Silt	pH	EC	CEC	$CaCO^3$	OM	Fe	Mn	Zn	Cu	Mo	Se	Fe	Mn	Zn	Cu	Mo
Soil properties	Sand	1.00																		
	Clay	-0.77*	1.00																	
	Silt	-0.62*	-0.03	1.00																
	pH	0.17	-0.50*	0.35	1.00															
	EC	-0.35	0.14	0.37	0.03	1.00														
	CEC	-0.93*	0.77*	0.51*	-0.32	0.35	1.00													
	$CaCO_3$	-0.74*	0.68*	0.33	-0.14	0.33	0.69*	1.00												
	OM	-0.19	0.25	-0.01	-0.26	-0.17	0.21	-0.02	1.00											
Total content of trace elements	Fe	-0.30	0.45*	-0.08	-0.27	0.14	0.40	0.46*	0.02	1.00										
	Mn	-0.30	0.16	0.27	0.08	0.33	0.26	0.51*	0.14	0.63*	1.00									
	Zn	-0.39	0.17	0.40	0.13	0.16	0.30	0.07	-0.09	-0.55*	-0.51*	1.00								
	Cu	-0.11	-0.02	0.20	0.06	0.22	0.05	0.41	-0.09	0.65*	0.83*	-0.54*	1.00							
	Mo	0.51*	-0.55*	-0.13	0.48*	-0.17	-0.42	-0.31	-0.03	0.05	0.22	-0.50*	0.23	1.00						
	Se	0.29	-0.13	-0.30	-0.19	-0.09	-0.15	-0.14	-0.09	-0.06	-0.26	-0.28	-0.01	0.18	1.00					
AB-DTPA-extractable trace	Fe	-0.25	0.52*	-0.25	-0.23	-0.03	0.13	0.28	0.32	0.22	0.15	-0.12	-0.04	-0.33	-0.25	1.00				
	Mn	-0.17	0.43	-0.26	-0.20	-0.13	0.11	0.04	0.71*	0.10	0.08	-0.16	-0.20	-0.04	-0.10	0.66*	1.00			
	Zn	0.11	-0.04	-0.13	0.21	-0.19	-0.18	0.14	-0.37	-0.28	-0.35	0.41	-0.19	-0.03	-0.05	-0.30	-0.26	1.00		
	Cu	-0.44	0.45*	0.14	-0.19	0.02	0.44	0.36	0.31	0.17	0.03	0.22	0.07	-0.30	0.30	0.15	0.20	0.18	1.00	
	Mo	-0.11	0.23	-0.11	0.03	0.13	0.18	0.01	0.14	0.09	0.03	0.10	-0.04	-0.02	0.19	0.18	0.19	-0.24	0.09	1.00

Table 6: Pearson correlation coefficients between soil properties and trace element in corn farms

			Soil properties								Total content of trace elements					DTPA-extractable trace elements				
		Sand	Clay	Silt	pH	EC	CEC	CaCO3	OM	Fe	Mn	Zn	Cu	Mo	Se	Fe	Mn	Zn	Cu	Mo
Soil properties	Sand	1.00																		
	Clay	-0.61*	1.00																	
	Silt	-0.87*	0.14*	1.00																
	pH	-0.62	0.56*	0.43	1.00															
	EC	-0.49*	-0.09*	0.69	-0.01*	1.00														
	CEC	-0.87*	0.71*	0.65*	0.66*	0.31	1.00													
	$CaCO_3$	0.25*	-0.45*	-0.03	-0.16*	-0.06	-0.20*	1.00												
	OM	-0.54*	0.85*	0.14	0.71*	-0.12	0.67*	-0.41	1.00											
Total content of trace elements	Fe	-0.72	0.66	0.50	0.67	0.29	0.72	-0.29*	0.63	1.00										
	Mn	-0.64	0.73	0.35	0.66	-0.04	0.87	-0.09	0.67*	0.63	1.00									
	Zn	-0.58*	0.45*	0.43	0.58*	0.03	0.61*	0.13*	0.43*	0.71	0.72*	1.00								
	Cu	0.11*	-0.28*	0.03	-0.25*	-0.04	-0.08*	0.74	-0.25*	-0.18	0.03	0.39	1.00							
	Mo	0.10*	-0.34*	0.09	-0.20*	0.19	-0.29*	0.39	-0.48*	0.15	-0.24*	0.21	0.28	1.00						
	Se	0.66	-0.72	-0.39	-0.72	-0.30	-0.72	0.44	-0.75	-0.86	-0.67	-0.48	0.37	0.08	1.00					
AB-DTPA-extractable trace elements	Fe	-0.61	0.63	0.38	0.47*	0.32	0.63	-0.42	0.52*	0.80	0.42	0.41	-0.30	-0.04	-0.67	1.00				
	Mn	-0.54	0.87*	0.14	0.47	0.02	0.64*	-0.30	0.87*	0.58	0.57	0.35	-0.16	-0.43	-0.61	0.62	1.00			
	Zn	0.13	-0.26	0.01	-0.20	-0.06	0.01	0.12	-0.16	-0.29	0.01	-0.18	0.03	-0.22	0.32	-0.08	-0.09	1.00		
	Cu	0.15	-0.36	0.04	-0.53	0.21	-0.30	-0.22	-0.51	-0.07	-0.38	-0.20	-0.13	0.38	0.23	0.10	-0.39	0.18	1.00	
	Mo	-0.36	0.47	0.18	0.27	0.20	0.49	0.04	0.47	0.27	0.42	0.10	-0.09	-0.18	-0.33	0.31	0.58	0.35	-0.45	1.00

Factor 3 is dominated by OM and available Mn in soil samples of alfalfa farms or by $CaCO_3$ and total Cu accounting for 14.7 and 11.9% of the total variances, respectively. However, Factor 4 is dominated only by soil pH in the soil samples of alfalfa farms or only by available Zn in the soil samples of corn farms accounting for about 9% of the total variance. Factor 5 is dominated only by total Se in the soil samples of alfalfa farms or only by available Cu in the soil samples of corn farms accounting for about 7.1 and 5.5% of the total variance, respectively. Factors 6 and 7 are dominated only by available Zn and Mo in the soil samples of alfalfa farms accounting for 6.3 and 5.5% of the total variance, respectively.

Based on the cluster analysis (CA), the investigated trace elements and soil properties are grouped into different clusters (Fig. 1). It was observed that there is a cluster containing available Fe and Mn and OM in soil samples of alfalfa or available Mn-OM-Clay in soil samples of corn farms. Additionally, that there is a cluster containing total Fe-total Zn-CEC–pH, which associated with total Fe-available Fe and available Mn-OM-Clay in soil samples of corn farms.

Discussion

The results on soil properties indicated the soil pH as alkaline and EC_e values in most of the soil samples are belonging to a category of normal for alfalfa soils with average EC values of 2.19 dS m^{-1} and high with an average of 5.95 dS m^{-1} for corn soils. Such high EC values of corn soils are of concern in terms of soil productivity and plant growth. The soils of the study area were moderately to high in calcareous content. These soils have low CEC values (2.14–12.3 cmol kg^{-1}) and this might be due to their coarse texture, low organic matter and presence of high amount of $CaCO_3$.

Table 7: Principal component analysis (PCA) for various parameters in alfalfa and corn farms

Property	Alfalfa farms							Corn farms				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Sand	-0.94*	-0.06	-0.11	0.02	-0.11	0.05	-0.02	-0.64	-0.69	-0.05	0.00	0.12
Clay	0.69*	0.10	0.29	-0.49	0.08	0.18	0.23	0.86*	-0.07	0.28	0.02	-0.25
Silt	0.63	-0.03	-0.18	0.58	0.08	-0.29	-0.24	0.27	0.91*	-0.10	0.00	0.01
pH	-0.18	-0.01	-0.12	0.85*	0.20	0.20	0.15	0.67	0.24	0.03	-0.24	-0.43
EC	0.43	0.13	-0.39	0.09	0.13	-0.36	0.29	-0.04	0.88*	0.09	0.04	0.18
CEC	0.90*	0.08	0.07	-0.12	-0.06	-0.14	0.06	0.77*	0.47	0.01	0.18	-0.24
CaCO3	0.73*	0.42	-0.04	-0.10	0.10	0.30	0.06	-0.28	-0.01	-0.87*	0.08	-0.11
OM	0.14	-0.02	0.86*	0.02	-0.12	-0.28	-0.10	0.80*	-0.06	0.26	0.02	-0.45
Total Fe	0.23	0.79*	0.03	-0.30	-0.01	-0.01	0.09	0.88*	0.32	0.05	-0.20	0.17
Total Mn	0.24	0.85*	0.08	0.20	0.18	-0.17	0.01	0.82*	0.11	-0.17	0.12	-0.27
Total Zn	0.48	-0.75*	-0.15	0.19	0.13	0.18	0.05	0.75*	0.15	-0.52	-0.19	0.05
Total Cu	0.11	0.88*	-0.17	0.14	-0.05	-0.04	-0.07	-0.09	-0.04	-0.89*	0.04	0.00
Total Mo	-0.56	0.37	0.06	0.53	-0.17	0.01	0.02	-0.07	0.12	-0.46	-0.33	0.62
Total Se	-0.21	0.00	-0.11	-0.16	-0.86*	-0.02	0.19	-0.79	-0.30	-0.29	0.21	0.10
Av. Fe	0.12	0.12	0.55	-0.38	0.43	0.07	0.32	0.75*	0.26	0.29	0.08	0.28
Av. Mn	0.03	0.01	0.87*	-0.16	0.13	-0.02	0.20	0.77*	-0.03	0.23	0.22	-0.31
Av. Zn	0.01	-0.25	-0.25	0.11	-0.03	0.86*	-0.15	-0.16	0.00	-0.06	0.89*	0.10
Av. Cu	0.55	0.01	0.32	-0.03	-0.55	0.31	0.00	-0.22	0.07	0.20	0.07	0.90*
Av. Mo	0.09	-0.04	0.11	0.05	-0.16	-0.14	0.89*	0.39	0.18	0.00	0.62	-0.34
Eigenval	4.88	3.06	2.78	1.65	1.34	1.21	1.04	8.36	2.67	2.27	1.67	1.04
% total	25.68	16.11	14.65	8.71	7.06	6.35	5.46	44.01	14.05	11.94	8.79	5.47
Cumul.	25.68	41.80	56.45	65.16	72.22	78.57	84.03	44.01	58.06	70.00	78.79	84.26

The values of soil available Fe, Mn, Zn and Cu are within the reported values by AI-Jaloud *et al.* (2013) in arid calcareous soils. Based on the critical limits for soil available Fe suggested by Havlin and Soltanpour (1981), 10% soil samples in alfalfa farms were found marginal and 90 percent samples were sufficient in available Fe. However, in corn soil samples, 5% soil samples were found low, 40% samples were marginal and 55% samples were sufficient in soil available Fe. The available content of Mn in alfalfa farms was sufficient in all soil samples, whereas it was sufficient only in 65% samples of corn farms. The soil available content of Zn in alfalfa farms was sufficient in 70% soil samples, whereas it was sufficient only in 45% samples of corn farms. The available content of Cu in alfalfa farms was sufficient in 55% soil samples, whereas it was sufficient in 80% samples of corn farms.

The total Se with the mean values of 0.03 and 0.05 mg kg^{-1} were lower compared to the average, which was reported to be 0.29 mg kg^{-1} (Tan, 1989) and the Se mean concentration in earth crust (0.12 mg kg^{-1}, Chen and Wang, 2004). The minimum, maximum and mean concentrations of total Se are lower than their corresponding values of the common range in soil according to Lindsay (1979). Mayland *et al.* (1989) had placed the critical values of total Se as 0.5 mg kg^{-1} in terms of soil fertility problem. It should be pointed out that the content of total Se in soil samples of the current study is very low and inadequate, suggesting that fertility problem can take place. Similar to our findings, Al-Saleh *et al.* (1999) found that Se content in some Saudi dairy farms was low. Our results suggest that Se supplementation of the forage soils in Saudi Arabia should be recommended.

On the basis of standard values reported by Kabata-Pendias and Pendias (1991), the shoot Zn and Cu concentrations were low in alfalfa and corn plants. However, it was observed that the shoot Fe and Mn concentrations were sufficient in 100% plant samples of corn and alfalfa.

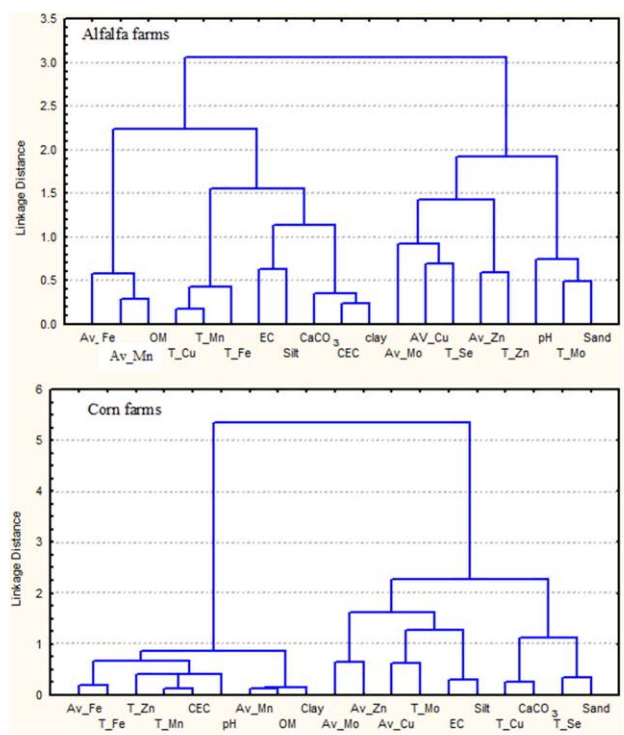

Fig. 1: Dendrogram of clusters from alfalfa and corn soil samples (T: total trace element; Av: available fraction of trace element; OM: organic matter content)

Overall, shoot Fe and Mn concentrations in plant samples of study area were found adequate, but shoot Zn, Cu, Mo and Se concentrations were low and deficient in alfalfa and corn plants. Under the arid environments, the deficiency of trace elements in crops can be mainly explained by low soil organic matter content and fixation of soil trace elements (Moreno *et al.*, 2013). This is the situation in most Saudi Arabia soils, which are mainly alkaline and particularly calcareous. These conditions might provide chemical constraints for agricultural production associated with the alkaline soil environment and the dry land climate, which include macronutrient and micronutrient deficiencies and some toxicity related to high sodicity and salinity.

Though a higher Se availability to plants can generally be expected in mineral soils having high pH (Eich-Greatorex *et al.*, 2007), the current study showed that shoot Se concentrations was very low and deficient. This can be explained by the low soil content of total Se rather than chemical constraints of the study soils having high sand content. Similarly, the total content and availability of Se in many soils around the world is so low that Se contents in the crops are low and deficient. It has been previously reported that lowest Se contents are recorded in sandstones and limestones among main rock types (Kabata-Pendias and Pendias, 1991). Therefore, soils formed on such substrates typically have low Se concentrations.

According to Pearson's coefficient, soil available Fe and Cu as well as total Fe are significantly correlated with clay content in the soil samples of alfalfa farms ($r = 0.55$ and 0.45, respectively). Additionally, soil total and available Fe and Mn as well as total Zn and available Mo showed significant positive correlation with the clay content in the soil samples of corn farms. Soil texture can be considered as the most important factor influencing the content and availability of trace elements. Sharma *et al.* (2004) found that total content of Fe, Cu, Zn and Mn increased with an increase in clay and silt. Several other researchers reported also that the total trace elements increased with increasing silt and clay content (Katyal and Vlek, 1985; Katyal and Sharma, 1991; Sharma *et al.*, 1992). Kishk *et al.* (1980) reported that there was very close correlation between soil texture and both total and DTPA-extractable Fe. Shuman (1985) found that the Zn content associated with the clay fraction was much higher than that associated with the sand fraction.

The Pearson's coefficient of the current study showed significant positive correlation between available Mn and the OM content of alfalfa soil samples. Moreover, total and available Fe and Mn as well as available Mo of corn soil samples showed significant positive correlation with OM content. By contrast, total content of Mo and Se and soil available Cu showed significant negative correlation with the OM content in corn soil samples. Organic matter has an important factor controlling soil trace elements solubility (McBride *et al.*, 1997). Both solid and dissolved OM contains functional groups responsible for forming complexes with trace elements (Kaschl *et al.*, 2001). Insoluble, high molecular weight organic molecules have a high tendency to trace elements. On the contrary, low molecular weight molecules with high solubility are responsible for increasing trace elements solubility. The dissolved organic matter represent the most mobile form of OM in the soil and is released by various processes from the solid phase: simple dissolution, adsorption and desorption processes, exchange protonation and dissolution reactions, biological decomposition of OM, and metabolites released by microorganisms, soil fauna and plants (Kaschl *et al.*, 2001). Complexation of trace elements by soluble organic ligands influences the solubilization and sorption/desorption of trace elements. The extent of complexation between a trace element and soluble organic matter depends on the competition between the metal-binding surface sites and the soluble organic ligand for the element (McLean and Bledsoe, 1992). Elgala and Amberger (1982) reported that the DTPA-extractable Fe increased as a result of incorporation of organic matter into the soil. Similarly, Sharma *et al*. (2004) found that DTPA-extractable trace elements increased with an increase in organic carbon content.

It was also observed that total content of Fe and Mn in alfalfa soil samples and total Cu and Se in corn soil samples showed significant positive correlation with $CaCO_3$. However, $CaCO_3$ content has no effect on AB-DTPA-extractable trace elements. Similar results were reported by AI-Jaloud *et al.* (2013) on calcareous soils in Saudi Arabia, who found a lack of correlation between $CaCO_3$ and DTPA-extractable trace elements. Total content Fe, Mn and Zn and available Fe, Mn and Mo in corn soil samples showed significant positive correlation with CEC. Kumar and Babel (2011) observed that the availability of micronutrients indicating positive and significantly correlated with silt, clay, organic carbon and CEC of soils. Although several researchers reported that pH can play master factor in controlling trace elements availability, our correlation study did not confirm this fact. This can be explained by the small variability of soil pH in the investigated farms.

On the basis of principal component analysis, there is high loading of total content and availability of some trace elements (such as Fe, Mn and Zn) and some soil properties of clay content, CEC and OM, especially in corn farms. Based on the cluster analysis (CA), it was observed that there is a cluster containing available Fe and Mn and OM in soil samples of alfalfa or available Mn-OM-Clay in soil samples of corn farms. Moreover, the correlation coefficients between them are also found to be significant. This finding may reveal that the availability of trace element of Fe and/or Mn are controlled by clay and organic matter content in such arid soils. It was also found that there is a cluster containing total Fe-total Zn-CEC–pH, which associated with total Fe-available Fe and available Mn-OM-Clay in soil samples of corn farms. The high obtained loading of trace elements (Fe, Mn, Zn and Cu) and their significant positive correlations with clay, organic matter and CEC suggests that these soil parameters might play a major role in soil trace element distribution and availability. In PCA, it was found that factor 1 is dominated by sand, clay, CEC and $CaCO_3$ and factor 2 dominated by total content of Fe, Mn, Zn and Cu in soil samples of alfalfa farms. Similarly, the HCA indicates that total Fe, Mn and Cu were also found together in the same cluster which is associated with other clusters containing CEC-EC-Clay-Silt-$CaCO_3$ or available Fe-available Mn-OM. This could further confirm the importance of soil properties on soil trace element distribution and subsequently, its availability to plants.

Conclusion

The soils of alfalfa and corn farms were moderately to high alkaline reaction, high in sand content, low in organic matter (OM) and low in cation exchangeable capacity (CEC). The shoot contents of Se, Mo, Zn and Cu were low and deficient in alfalfa and corn plants. However, it was observed that the shoot contents of Fe and Mn were sufficient. Among these trace elements, soil and shoot contents of Se was the lowest, leading to fertility problem. The low trace elements concentrations might be due to high sand content and low organic matter content. Based on principal components, there is high loading of total content and availability of some trace elements (such as Fe, Mn and Zn) and some soil properties of clay content, CEC and OM. This suggest that these soil properties may play a major role on status of trace elements availability and consequently can modify the response of forage plants under arid conditions. Our results suggest that proper fertilization of trace elements to forage in Saudi Arabia should be taken into consideration.

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