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Bioreclamation of a Saline Sodic Soil in a Semi Arid Region/Jordan

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Abstract: Field study was conducted in Jordan Valley-Jordan to investigate the effects of growing three types of salt accumulator halophyte species, *Tamarix aphylla L., Atriplex numularia L., Atreplix hallimus L.,* on chemical properties of saline sodic soil. Different halophyte plant species showed different decline in soil salinity of all plots at the end of the experiment as the salinity decreased from an average electrical conductivity (soil paste) of 84 to 5.46, 5.04 and 6.3 mS /cm at the top layer (0-30 cm depth) and from 49.6 to 5.46, 13.45 and 7.14 mS/cm for the lower soil (30-60 cm depth) for *Atreplix hallimus L., Atriplex numularia L and Tamarix aphylla L.,* respectively. Higher reduction in salinity was found in the upper zone which was attributed to high root density.

Key words: Jordan · Soil Salinity · Halophytes · Bioreclamation

INTRODUCTION

Saline soils are those which have an electrical conductivity of the saturation soil extract of more than 4 mS cm^{-1} at 25°C [1]. Although some countries such as USA had lowered the boundary between saline and non-saline soils to 2 mS cm^{-1}, in this investigation saline soil is considered when a solution extracted from saturated soil is greater than 4.0 mS cm^{-1}.

Saline-sodic soils can significantly reduce the productivity of affected land which is one of the major problems facing development of agricultural sector in Jordan due to it's adversely affect on the growth of most crop plants. Worldwide, salt affected soils cover about $1x10^9$ ha of which 62% are saline sodic [2], from which more than 180,000 ha of the arable land are located in Jordan [3].

Anions of salts in soils are primarily chlorides (Cl^-), sulfates ($SO_4^=$)carbonate (HCO_3) and sometimes nitrate (NO_3^-) and the cations sodium (Na^+), calcium (Ca^{++}), magnesium (Mg^{++}) and sometimes potassium (K^+). Ready soluble salts of these ions occur in highly variable concentrations and proportions and therefore these ions are the focal point in this investigation.

Cleaning up a site contaminated with salts usually requires extensive washing which usually consume large amount of water. In a country like Jordan where the water resources are very scarce this method is not recommended. However, other biological methods can be used such as planting the soil with salt tolerant plants where salts are taken up by these plants and removed from the soil. For farmers, bioremediation is very useful as it requires low initial investments, improves the soil quality and the produced crops can be used as an animal feed lots.

Growing halophyte plants under saline conditions had been reported. Boyko, [4] was the first to suggest that halophytic plants could be used to desalinate soil and water. Singh *et al*. [5] reported that plants of economic value can be used for reclamation of saline and sodic soils. Using *Portulaca oleraceal L* as a salt removal crop was reported by Kilic *et al*. [6] where they showed that considerable amounts of salt from soil were removed after planting this plant species. Bioremediation of saline soils in Jordan was studied by Al-Abed *et al*. [7] at a laboratory scale using aerobic bacteria where they found that bacteria were very efficient in reducing the EC values in the first week of application.

The aim of this study is to investigate salt removal from the soil by using salt tolerant plants in Jordan Valley that could be grown, harvested and then used as a feed lot for animals.

Study Area: Experimental plots were constructed in Ghor Al-Safi area at southern part of Jordan valley about 10 km away from the southern edge of the Dead Sea (Figure 1). The area is nearly flat with just a very slight slope to the West.

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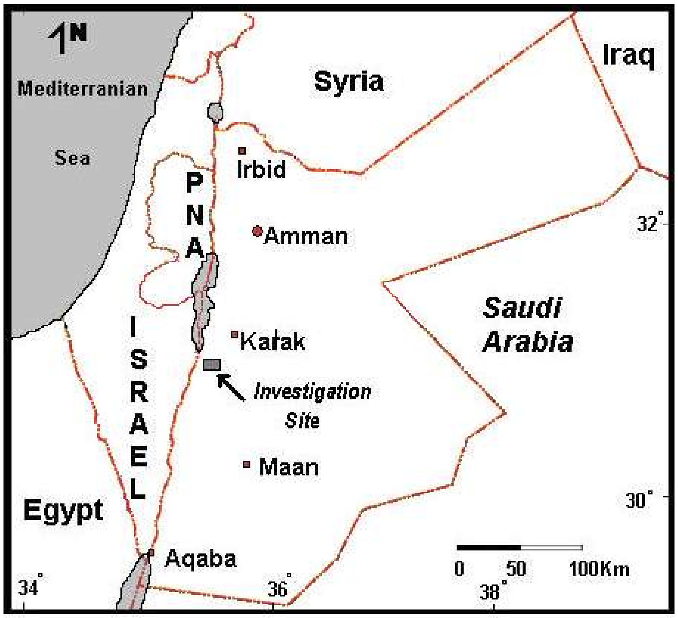

Fig. 1: Location Map

The investigated site is considered arid with rainfall less than 80 mm/year occurring mainly in 2 or 3 main rain events during the winter season. The area is exposed to frequent strong hot winds which cause erosion of the poor structured soil. Severe droughts were observed during recent years as the average rainfall was below its annual average for the last ten years.

The area suffers from high salinity as there is a general absence of natural vegetation cover. The present vegetation of the surrounding area includes only scattered wild halophyte plants. The dominant soil texture is fine silty with poor soil structure, which affects soil productivity. Soil salinity is too high, which prevents cultivation of many agricultural crops (98.1 mS cm^{-1}) using brackish irrigation water with salinity of about 4 mS cm^{-1} extracted mainly from artesian wells in the area. According to the Jordan Valley Authority, this land has been categorized as an extremely salty area.

MATERIALS AND METHODS

Nine blocks (7x8 m^2 each) were prepared by ploughing and was properly leveled for plantation for three fast growing halophytes (*Tamarix aphylla L., Atriplex hallimus L. and Atriplex numularia L*) on salt-affected soils for reclamation study and irrigated with fresh water (Na^+ 60.1; K^+ 6; Ca^{++} 56.0; Mg^{++} 27.0; HCO_3^- 146.0; Cl-113.0; $SO_4^=$95.2; NO_3-0.4 ppm) in a very limited amount at 80% of soils field capacity to eliminate the leaching affect from soil in addition to plots planted with the same plant species in non saline soil irrigated with the same type of water and considered blanks. Each treatment had three replicates. For*, Atriplex hallimus L., Atriplex numularia L. and Tamarix aphylla L.* the density of plantation was four plants per each square meter.

Soil samples were collected randomly from two depths (0-30 and 30-60 cm) and plant samples were harvested at the end of the experiment which lasted for two years. For fresh plant samples were measured by standard method [8] for Na, Ca, Mg and Cl. Three replicate of soil samples were collected before the start of the experiment representing initial conditions and at the end of the experiment representing final conditions. The soil samples were dried then crushed gently using wooden wallet and sieved through 2 mm sieve. The dry soil and plant samples were analyzed after extraction with concentrated HNO_3 and heating to 80°C. The digest was filtered through Whatmann filter paper no. 42. The filtrate was diluted to the desired volume with double-distilled water. The total concentrations of major cations (Na^+, K^+, Ca^{+2} and Mg^{+2}) were analyzed using atomic absorption spectrophotometer model Analyst 300 (Perkin Elmer, Germany). Cl-and SO_4^{-2} were analyzed by ion chromatography on Dionex 100 equipped with AG4A-SC guard column, AS4SC separating column and SSR1 anion self-regenerating suppressor and conductivity meter. The sample was injected through 25 µl sample loop and eluent at 2.0 ml/min using Na_2CO_3 in mille-Q water. Data were collected by 4400 integrator from Dionex. The soluble ions were determined by preparing soil past. EC in plants were measured by mixing crushed dry plants with distilled water in 1:7 plants to distilled water ratio. Exchangeable cations were determined after Thomas [9], by using Ammonium Acetate Method. Organic matter was determined by dichromate oxidation method [10]. Titration method was used for determination of $CaCO_3$ content after Rayment and Higginson, [11]. Soil textures were determined at 20 cm depth interval for the upper 80 cm depth using wet hydrometeric method [12].

At the end of the experiment, dry biomass was determined for each plot.

RESULTS AND DISCUSSION

Soil samples collected from the upper one meter soil profile at 20 cm interval showed a homogeneous texture with around 45 sand, 40 silt and around 15 % clay with high organic content for soils under prevailing climatic conditions ranging from 1.9 to 3.1% with an average value of 2.6% in the upper soil profile and from 0.2 to 2.8% with an average value of 1.8% in the lowest soil profile making it permeable for water movement which is associated with soluble ions.

The physiochemical properties of the experimental field for two depths upper soil (0-30 cm) and lower soil (30-60 cm) where most of the root zones occurred before the starting of the experiment representing initial conditions is presented in Table 1. The results showed that both depths were affected with higher salt content as the electrical conductivity at the top layer ranged from 60 to 120 mS/cm with a mean value of 84 mS/cm and from 38 to 64 mS/cm with a mean value of 49.6 mS/cm for the lowest soil. The highest salinity at the top layers was due to evaporation from the surface of the soil enhanced with upward movement of capillary water under high tension at the surface [13]. The highest salt concentrations are mainly due to evaporation process as the average concentrations of evaporites / gypsum (4.8 and 3.7%), soluble sodium (332 and 278 meq/l) and for soluble chloride (767, 408 meq/l) for upper and lower layer respectively (table 1).

The pH values were below 8.5 with EC of soil paste above 4mS/cm which gives reason to characterize the investigation area of one with saline-sodic soils. However, the slight differences in pH values could be attributed to the change in the soil-to-water ratio [14].

Generally, SAR is an important parameter to understand the equilibrium between soluble salts and exchangeable cations. In present study, SAR declined from 22.8 for the upper soils to 3.30, 3.52 and 3.45 and from 25.1 for the lowest soil to 3.44, 5.6 and 4.22 for plots cultivated with *Atriplex hallimus L, Atriplex numularia L. and Tamarix aphylla L. respectively.*

Table 1: Chemical properties of the soil before starting the plantation experiment

	Depth					
	0-30 cm			30-60 cm		
Parameter	Min	Max	Mean	Min	Max	Mean
EC mS/cm	60	120	84	38	64	49.6
pH	7.13	7.5	7.25	7.1	7.7	7.5
Cl (meq/L)	516	1123	767	329	540	408
SO_4 (meq/L)	55	75	67.7	52	114	89
HCO_3 (meq/L)	1.8	2.4	2.0	1.6	2.4	1.8
Na (meq/L)	240	460	332	184	520	278
K (meq/L)	15	32	21.7	11.1	32	16.4
Ca (meq/L)	104	252	166.5	37	99	69.1
Mg (meq/L)	202	284	252.6	122	200	176
$CaCO_3$ %	20.0	40.0	34.7	37.0	40.8	38.7
CEC meq/100g	12.5	15.5	13.4	13.5	19.0	16.3
EXCH. Na meq/100g	4.0	5.5	4.6	2.8	6.0	5.6
EXCH. K meq/100g	3	3.8	3.5	2.2	2.8	2.5
EXCH. Ca+Mg meq/100g	5.5	6.2	5.6	8.5	10.7	9.2
E.S.P	21.4	28.7	24.5	23.3	38	26.9
SAR	19.4	28.1	22.8	20.6	42.5	25.1
Org. matter (%)	1.9	3.1	2.6	0.2	2.8	1.8
Gypsum Conc. (%)	2.8	7.4	4.8	2.1	5.8	3.7
Sat. (%)	59.0	67.5	64.4	67.0	82.0	75.0

Table2: Exchangeable cations concentration of the soil at the end of the plantation experiment

Plant Species	Ion / Depth	Na (meq/100g) 0-30	Na (meq/100g) 30-60	K (meq/100g) 0-30	K (meq/100g) 30-60	Ca and Mg (meq/100g) 0-30	Ca and Mg (meq/100g) 30-60
Atriplex hallimus L.	Min	0.61	0.63	0.99	0.8	11.19	13.52
	Max	1.48	1.62	1.43	1.16	11.67	14.87
	Mean	0.90	0.90	1.10	0.90	11.40	14.10
Atriplex numularia L.	Min	0.6	1.03	0.82	0.84	11.9	13.79
	Max	0.98	1.35	1.26	1.48	12.26	14.38
	Mean	0.70	1.20	1.00	1.10	12.10	14.00
Tamarix aphylla L.	Min	0.67	0.72	0.78	0.96	11.66	14.43
	Max	1.14	0.88	1.14	1.24	12.28	14.51
	Mean	0.80	0.80	0.90	1.10	12.10	14.50

Table 3: Chemical properties of soil paste extract at the end of the plantation experiment

Plant Species	Ions / Depth	Na meq/L 0-30	Na meq/L 30-60	Mg meq/L 0-30	Mg meq/L 30-60	Ca meq/L 0-30	Ca meq/L 30-60	SAR 0-30	SAR 30-60	ESP 0-30	ESP 30-60	EC (mS/cm) 0-30	EC (mS/cm) 30-60	pH 0-30	pH 30-60
Atriplex hallimus L	Min	8.82	8.820	9.24	7.98	15.97	15.55	2.48	2.57	2.34	2.47	4.09	4.04	7.43	7.87
	Max	18.49	19.330	12.18	15.55	22.69	32.35	4.43	3.95	5.01	4.37	6.64	7.61	8.19	8.49
	Mean	12.61	14.290	10.50	11.34	18.91	23.11	3.30	3.44	3.48	3.67	5.46	5.46	7.90	7.97
Atriplex numularia L.	Min	10.50	34.030	10.50	33.61	14.29	48.74	2.23	5.30	1.99	6.15	4.44	10.08	7.93	8.12
	Max	15.97	43.700	11.34	46.64	19.75	74.37	4.05	6.60	4.50	6.94	5.47	17.23	8.11	7.82
	Mean	13.03	38.660	10.92	37.82	16.39	58.40	3.52	5.60	3.78	6.54	5.04	13.45	8.00	7.81
Tamarix aphylla L.	Min	14.71	15.130	7.98	10.50	19.75	23.95	3.02	3.20	4.33	3.34	5.24	5.28	7.66	7.77
	Max	15.97	21.850	16.81	20.59	34.03	29.83	4.29	3.67	4.82	3.99	7.03	8.16	7.82	8.77
	Mean	15.55	19.330	12.18	15.55	28.57	26.47	3.45	4.22	3.69	4.73	6.30	7.14	7.70	8.03

ESP showed a decline in its value with desalination of soil using halophytes as it was reduced from an average value of 24.5 to 3.48, 3.78 and 3.69% for the upper soil profile and from 26.9 to 3.67, 6.54 and 4.73% for plots planted with Atriplex hallimus L, Atriplex numularia L. and Tamarix aphylla L.,respectively (Tables 1 and 3). Similar tendency regarding decrease of ESP using halophytes had been reported for other halophytes [15].

The chemical properties of soil paste extract at the end of the experiment (Tables 2 and 3) showed that salt concentration was generally higher in the lowest soil layers at the end of the experiment. This can be attributed extraction through halophytes where higher root density exists in the upper part of the soil in addition to that some salts were leached from the top layer to subsurface layers through irrigation with very small amount of water (only *few liter/m^2/week) which took place at the early stage of the experiment.*

After two years of halophyte plantation, it was observed that EC was reduced from 84 and 49.6 mS/cm at upper and lower soil layers to 5.46 mS/cm in *Atriplex halimus* L. cultivated saline soil at both layers and correspondingly the EC increase from 20.0 to 43.3 in plants. For other plant species, the salinity of the plots showed also a sharp decrease in all of its ions as the salinity was dropped to an average value of 5.04 and 6.3 in the upper 30 cm of the soil and to 13.45 and 7.14 mS/cm in the lowest layer (30-60 cm) for *Atriplex numularia L. and Tamarix aphylla L.,* plant species associated with an increase of plant salinity compared to not saline soil from 18.0 to 29.5 and from 26.7 to 16.3 mS/cm for the above mentioned species,respectively. The highest concentrations of Na and Cl in tissues, particularly in the final stages is probably because of continues contact with salt in the root zone. These results are consistent with Kilic *et al*. [6] who studied *Portulaca oleraceal L* growth under saline conditions.

The sharp decrease in salinity was reflected in the highest concentration of all cations in the plant species at the end of the experiment as shown in Table 4 especially for Na ion concentration as it reached an average concentration in the plants of 2305.2 to 3137.7 after

Table 4: Ionic concentration (meq/kg) in plant leaves from different species of plants used in the investigation site at different periods

	Ionic Species	Na			Ca			Mg			Cl		
Plant Species	Date	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Atriplex hallimus L.	Blank	2040.1	2530.5	2305.2	71.5	156.2	102.6	554.0	670.6	655.0	70.3	102.40	85.0
	One Year	2810.0	3456.1	3137.7	144.9	218.7	181.5	669.2	988.7	678.7	108.1	159.30	132.4
	Two Years	2690.0	2978.6	2818.0	93.5	208.7	163.4	653.7	798.1	663.9	96.7	123.10	108.7
Atriplex numularia L.	Blank	937.6	1469.5.	1207.3	85.0	180.5	134.6	530.1	640.8	627.0	88.3	120.80	100.0
	One Year	1285.4	2517.1	1664.1	135.4	235.0	172.4	619.5	687.6	652.4	120.5	128.14	123.8
	Two Years	1173.9	1886.8	1587.1	113.2	205.2	167.0	586.6	670.0	622.7	115.6	131.00	121.3
Tamarix aphylla L.	Blank	605.2	784.3	687.6	186.1	230.1	201.2	520.8	625.3	631.0	83.1	115.90	102.1
	One Year	1274.0	1426.2	1339.8	275.1	294.2	280.2	647.5	695.3	653.3	113.2	130.50	120.2
	Two Years	721.1	891.5	814.5	230.0	271.0	252.5	641.6	653.3	645.8	108.1	125.20	114.6

one year and to 2818.0 meq/kg dry weight after two years for *Atriplex hallimus* and from 1207.3 to 1664.1 meq/kg dry weight after one year and 1587.1 meq/kg dry weight after two years for *Atriplex numularia L* and from 687.6 to 1339.8 after one year and 814.5 after two years meq/kg dry weight *for Tamarix aphylla L.*. The chloride concentrations in the planted leaves increased in a similar trend as it ranged from 85.0 to 132.4 after one year and to 108.7 meq/kg dry weight after two years for *Atriplex hallimus* and from 100.2 to 123.8 meq/kg dry weight after one year and 121.3 meq/kg dry weight after two years for *Atriplex numularia L* and from 102.1 to 120.2 after one year and 114.6 after two years meq/kg dry weight *for Tamarix aphylla L.*

Dry weight of the plant at the end of the experiment was 192.3, 50.44 and 95.9 Kg/m^2. Therefore, it can be estimated that one kilogram of dry weight samples can accumulate 68.9, 34.6 and 22.8 gram of NaCl for Atriplex hallimus, Atriplex numularia L. and Tamarix aphylla L, respectively. Therefore planting saline soils with these plant species can remove 3.45, 3.32 and 4.38 kg of NaCl from each square meters.

Conclusion and Recommendations: The results showed that the four halophyte plant species (*Atriplex numularia L., Atriplex hallimus L.* and *Tamarix aphylla L.*) are efficient in removing salts from sodic-saline soil and storing it in its tissue. The electrical conductivity of investigated soil was reduced with corresponding increase in the plant tissue samples. Similar results were observed in SAR. Among the four planted halophytes, Tamarix is the best plant species used to rehabilitate the sodic-saline soil.

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