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CHANGING THE SABKHA SCENARIO FROM DESERTED LAND TO AN EMERGING AGRICULTURE FARM LAND – A CASE STUDY IN QATAR

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ABSTRACT

Studies are continued on production of useful biomass production system on highly saline Sabkha lands (EC>100 dS/m) underlain by super brine ground water (EC>110 dS/m) present at 0.80 meter depth at Nuclear Research Station for Bio-saline Agriculture, Dukhan Sabkha Qatar, (165500 North, 409500 East). The soil is light textured and completely exhausted of essential macro/ micro nutrients except sodium chloride and calcium. Using a combination of agronomy, hydrology and soil physics approaches, highly salt-tolerant plants were grown including *Acacia ampliceps*, Salt Bush (*Atriplex lentiformus), Eucalyptus camaldulensis, Prosopis Juliflora,* Pomegranate (*Punica granatum L.*), Kallar grass (*Leptochloa fusca*), Para grass (*Brachiaria mutica*) , *Kochia indica*, and *Sesbania acculeata*.

Limited surface irrigation with treated sewage water was applied through drip/ bubbler irrigation system for plant establishment phase. Salt tolerant material was planted in April-May, 2009 peak dry summer season (peak open air temperature 54.9o C, minimum RH=15%, maximum Class-A Pan Evaporation = 22.1 mm/day) while harvesting for biomass sampling was completed on July 13, 2009. The plants survived under all exposed stresses of very high soil salinity, high air temperature and very dry and fast winds. The plants showed wide genetic diversity in biomass production potential, fodder value and ionic retention potential. Pomegranate appeared to contain very effective differential selective membrane system from a mass of high flux of salts present in saline soil and treated sewage water. Hence, its gene pool may be of specific interest of researchers for inducing tolerance against specific biotic and abiotic stresses. The study is still continued as part of collaborated IAEA Technical Cooperation Project (Number QAT 5002) for assessing long term survival of plants and soil rehabilitation.

Key words: Hyper saline land, sewage irrigation water, Sabkha, Halophytes

INTRODUCTION

Soil salinity has adversely affected the agricultural productivity on around one billion hectares of arable land world over (Taiz and Zeiger, 1991, FAO, 2002). Sabkha (s) are among most saline degraded lands with salinity levels higher than sea water salinity and may also have underlain highly brackish water. Under such situation, these lands are ignored for raising agricultural activity. Under salinity stress, the plant health hazards are associated with:

(1) Low osmotic potential of soil solution (water stress).
(2) Nutrition imbalance.
(3) Specific ion effect (salt stress)
(4) A combination of these factors.

All these cause adverse apheliotropic effects on plant growth and development at physiological, biochemical and molecular level. Abiotic stresses such as; salinity, elevated pH and drought reduces growth of plants and agricultural productivity more than other factors (Karakas *et al*., 1997, Beeftink & Rozema, 1995). Higher salinity levels cause significant reduction in growth parameters like leaf area, leaf length, root and shoot dry weight (Hamda and Al-Hakimi, 2001; Ashrafuzzaman *et al*., 2002), Nitrate reductase (NR) activity is main limiting step in nitrogen assimilation in plants (Srivastava, 1990; Lea, 1997). Under saline stress NR is inactivated and nitrogen metabolism is hampered in plants (Khan *et al*., 1990; Botella *et al*., 1993). Munns (2002) and Ashraffazzaman *et al*. (2002) reported that impairment of the photosynthate/ chlorophyll activity greatly accounted for growth restrictions of non-halophytes under salinity stress. Depressive effects of salinity are thought to arise from stomatal and/or non-stomatal limitations i.e., stomatal closure and/or damage to Calvin cycle enzymes (Meloni *et al*., 2003). Under osmotic stress, an important consideration is given to accumulate the osmotically active compounds called osmolytes in order to lower the osmotic potential. These are referred to as compatible metabolites because they do not apparently interfere with the normal cellular metabolism. Molecules like glycerol, sucrose and proteins, etc. were discovered by empirical methods to protect macro-biological molecules against the damaging effect of salinity (Sairam and Tyagi, 2004).

Only 1% of the water on earth surface is potable and available for domestic, industrial and agricultural uses. Since agriculture is the lowest priority, use of brackish ground water or treated domestic/ industrial treated effluents is increasingly gaining importance to make up the irrigation deficiency necessary to meet with the ever increasing food demand. In addition to many other nutrient salts, it also contains high concentrations of N and P that could be used as free fertilizer alternatives during plant vegetative growth. Wan *et al*., (2007) reported that irrigation with the treated sewage had no significant adverse affect on the loess soil and no health hazard resulted from contact with the treated water irrigation for 14 months; rather a slight increase in the organic content of the soil was observed. Even with sodic treated water (EC= 0.7 - 1.4 dS m-1, pH=8.8 – 9.7) irrigation, no adverse effects on soil health were reported in presence of gypsum that also reduced nitrate-N accumulation in the soil profile (Hulugalle *et al*., 2004).

Bio-Saline Agriculture Technology (BSAT) is one of the optimum options for useful biomass production on degraded salt-affected lands usually irrigated with poor quality water. Salt-tolerant plant species are screened for different soil, water and environment stress tolerance and successfully grown to produce useful biomass production (Maas, 1986, Maas, and Grattan, 1999, O'Larry, 1997, NIAB, 1982, Al-Turki *et al*., 2004). This biomass may be used as feed, food, cloth, domestic furniture, building structures, pulp, paper, energy briquettes, fuel source, wood charcoal, agro-chemicals, bio-fertilizers, forensic medicines, activated charcoal, agro-chemicals, bio-fertilizers, energy chemicals, solvents and for various other agro-chemical purposes (Wahed, 2007). Usually ground water, treated domestic/ industrial effluent, drainage water or a combination thereof are used as low cost irrigation sources for this purpose.

MATERIALS AND METHODS

Dukhan Sabkha site is located at 73 km by road at Zikreet Qatar Petrolelum Residential camp in Dukhan area (Coordinates 165500 North, 409500 East). A view of the field area at site is shown in Fig. 1 indicating only very sparse semi-dried herbs of *Suda fruitocosa* plants and swollen soil due to crystalline salts deposition on surface. The water table was at 0.80 cm from surface.

Fig. 1. View of the Dukhan Sabkha field site.

A saline land tract of 350 x 350 m. sq was selected to start the model Bio-Saline Agriculture at the field scale and was subsequently allocated for the purpose by Qatar State Authorities. The field plots size was fixed as 50 x 50 m2 with paths of 6 meter. A total of 36 plots were to be arranged in square type layout. Two field plot were selected for demonstration scale plantation of herbs/grasses and shrubs/ trees, respectively. Composite soil samples were collected for 0-125 cm profile depth and analyzed for chemical and physical components at Central Agricultural Laboratory, Doha, Qatar. Salient results are shown in Fig. 2.

As obvious from Fig. 2, the soil salinity ranged 116.3–83.7 dS/m that was very high compared to maximum permissible limit for control soil (4.0 dS m-1) at both sites throughout the profiles. The Sodium Adsorption Ratio (SAR) ranged 77–110 units that was very high compared to maximum permissible limit of (<13) for soil. Sodium was the dominant monovalent cation with toxic values ranging 899-1435 meq L-1 in the soil profile; almost double to that found in sea water. The chloride was the dominant anion with toxic values ranging 1021–1681 meq L-1. The micronutrients including Cu, Fe and Mn and Zn were present in the concentration range of 0.22-0.34, 0.09-1.05, 0.5-1.0, 0-0.2 ppm, respectively. No phosphorous was available in soluble form. Organic matter was 0-0.24 % and Nitrogen was available in 0.01-0.05 % range. Hence, nutrient supplementation to plants growing in this soil was necessary to avoid deficiency.

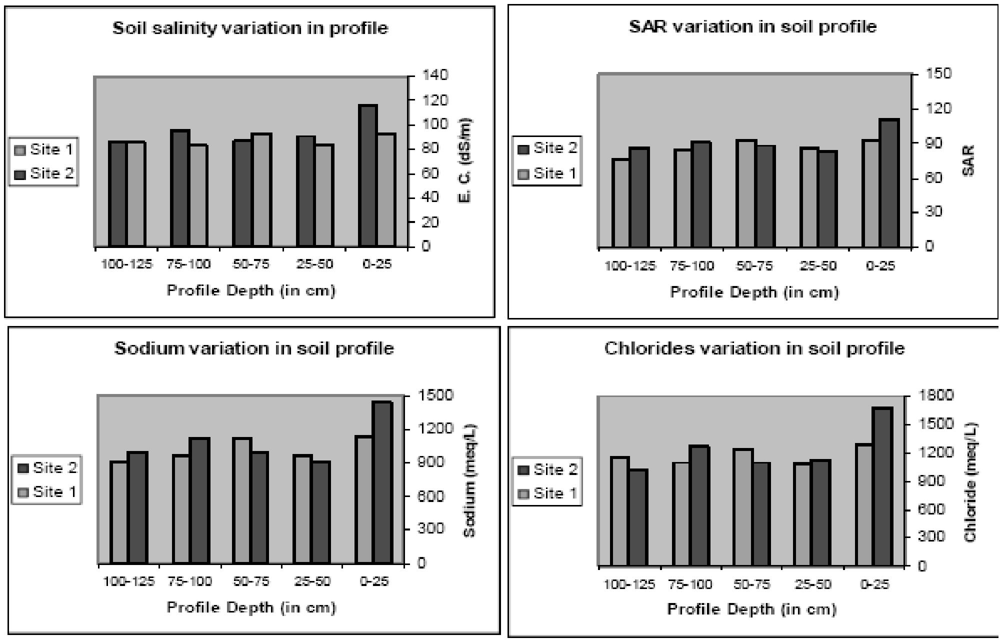

Fig. 2. Soil Chemical Analysis.

Table 1. Stratification of profile material (depth wise) at the field site.

Horizon No.	Dominant material	Depth from surface (meter)	Remarks
1	Coarse sand	0.-1.6	Unsaturated zone
1-a	Coarse sand	1.6 -7.4	Saturated zone
2	Hard Lime Stone (HLS)	7.4 – 7.8	Impervious rock
3	Shale mixed with HLS	7.8 – 9.8	Saturated zone
4	Red Shale	9.8 – 12.8	-do-
5	Clay	12.8 – 19.8	-do-
6	Mixed Clay + Gypsum stone + sand	19.8-20.8	-do-
6-A	Void / gap / fault	20.8 – 21.8	Pressurized water source
7	Gypsum stone + Sand + small gravel of lime stone	21.8 – 27.8	-do-
8	Lime stone + platy clay	27.8 – 29.8	-do
9	Gypsum + lime stone + iron mottling + Clay traces	29.8 – 30.8	-do-
10	Course Gypsum & Lime stones + iron mottling + Clay traces	30.8 – 31.8	-do-

The saturation percentage of the two sites throughout the profile ranged 20.11–30.66% with higher values at top soil profile descending gradually downwards. The pH ranged 7.7- 8.1. There was much variation among two sites with respect to gypsum and $CaCO_3$ constituents. At first location $CaCO_3$ content was higher (14.98– 18.20 %) but gypsum was low (1.62– 5.09 meq 100gm-1 of soil). At 2nd site reverse order was observed i.e., relatively low $CaCO_3$ (12.5–16.67%) but high gypsum content (21.67–57.05 meq 100gm-1 of soil) was observed. Physical analysis showed that soil was generally light textured with mostly coarse sand ranging 83–89 %. The field capacity ranged 2.53–14.17% showing very limited soil moisture storage potential.

For study of soil profile depth and underground aquifers characteristics, three tubes well bore holes were dug and water salinity was studied. The profile samples were subjected to texture analysis and the results are given in the following table.

The water salinity ranged 77.9–101 dS m-1 and pH 6.6–7.4 for the three Tube-wells with slight irregular variation pattern down the profiles up to maximum of 40 meter depth. This super brine water was unfit for supporting the agricultural activity but could be used if diluted to safe limits with treated municipal or industrial effluents – surplus and cheap resources for irrigation.

Table 2. Water salinity and pH of Tube well site No. 3.

Sr. No.	Aquifer Depths	Water Salinity (dS m-1)	Water pH	Fitness for agriculture use
1	7 m	106.1	6.9	Unfit
2	10 m	121.4	7.5	Unfit
3	20 m	98.2	7.6	Unfit
4	30 m	93.5	7.4	Unfit
5	40 m	100.6	7.3	Unfit

Table 3a. Chemical analysis of treated effluent irrigation water (Macro-nutrients).

pH	EC	TDS	Anion (meq L^{-1})				Cation (meq L^{-1})			
	dS/m	ppm	CO_3+HCO_3	Cl	SO	N (ppm)	Ca	Mg	Na	K
7.43	0.86	516	3.12	2.95	0.0	21	2.53	0.36	2.40	0.60

Table 3. Trace elements (ppb) in tertiary treated sewage.

Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Cd	Pb	Hg
3	4	25	761	4	4	14	27	4	4	2	ND

ND= No detection

Table 4. Weather data for the period Jun-Sept, 09 collected at the station.

Parameter		June, 09	July, 09	Aug, 09	Sept, 09
Open Air T ◦C	Max	54.9 – 42	51.9 – 46.6	15.8 – 24.4	22.9 – 27.0
	Min	51.4 – 43.2	50.7 – 45.8	22.6 – 28.7	17.7 – 22.9
RH %	Max	91 – 60	89 – 51	91 – 59	97 – 90
	Min	13 - 16	14 - 17	12 - 15	12 - 14
Class-A Pan Evap (mm)		502	559	381.4	260.4
Water Table (cm)		81	82	ND	82

The water table depth was 0.80 meter near the experimental field plots. For establishing the nursery plants, treated sewage water was partly provided to the plants source through drip (for grasses and herbs) and bubbler (for shrubs and trees) irrigation systems as shown in Table 3a & b. The herbs/ grasses were planted in one meter apart lines at .60 cm inter plant distance. The shrubs/ trees were planted on four meter apart dikes (40 x 60 cm sq) at four meter inter plant distance. Para grass and Kallar grass covered the areas in between the lines during the passage of time. Nursery for *Prosopus*, *Acacia amplicpes*, Atriplex, Kallar grass and Kochia were raised in Agriculture Farm No.117 (Shimal) and transferred in the field plots in April-May, 2009. Nursery plants of Eucalyptus and Pomegranate were collected from DAWR Agricultural Farm and planted in last decade of May, 2009. Para grass root stubbles/cuts were directly planted at site and *Sesbania* was grown by direct seed sowing. The field soil was completely exhausted of organic matter and essential macro/micro nutrients except sodium and calcium, hence the potting medium prepared for raising nursery included essential micro-nutrients, Peat Moss, Hydrosol and sand for primary root system establishment. Weather data during the study period is shown in Table 4.

RESULTS AND DISCUSSIONS

1. Biomass Production Potential

The biomass production potential of the salt-tolerant plants, grown successfully at Sabkha land for a period of 17-20 weeks is presented in Table 5. Among grasses and herbs, Para grass produced maximum fresh biomass (8.51 g/plant-day) followed by *Kochia indica* (7.67 g/plant-day) while maximum dry biomass was produced by Kallar grass (2.61 g/plant-day) followed by *Kochia indica* (2.33 g/plant-day). Kallar grass remained minimum fresh biomass producer (5.98 g/plant-day) but maximum dry biomass producer (2.61/plant-day).

In shrubs/trees species, maximum fresh biomass was produced *by Acacia ampliceps* (13.03 g/plant-day) followed by *Prosopus juliflora* (7.67 g/plant-day). Maximum dry biomass was produced by *Prosopis Juliflora* (3.34 g/plant-day) comparable to *Acacia ampliceps* (3.34 g/plant-day). Pomegranate indicated the minimum fresh and dry biomass.

Table 5. Biomass production potential (g/day) of salt-tolerant plants.

S.No.	**Plant species**	**Fresh biomass**	**Dry biomass**
1	*Acacia ampliceps*	13.03	3.34
2	*Atriplex lentiformis*	3.87	1.50
3	*Prosopus juliflora*	7.67	3.35
4	Pomegranate	1.12	0.50
5	*Kochia indica*	7.28	2.33
6	Kallar grass	5.98	2.61
7	Para grass	8.51	2.07
8	*Sesbania acculeata*	6.08	1.62
9	*Eucalyptus camaldensis*	4.05	1.42

2. Fodder quality Assessment

Fodder quality analysis of the selected salt-tolerant plants grown under Sabkha conditions is given in Table 6 and discussed separately for each component as under:

2.1 Protein synthesis

In shrubs/ trees group, maximum Protein synthesis was observed in *Prosopus juliflora* (17.22 %) followed by Pomegranate (10.08 %) whereas minimum was recorded in *Atriplex lentiformis* (7.18 %). In grasses and herbs group maximum protein was synthesized in *Sesbania acculeata* (20.5 %), a nitrogen fixer, followed by Para grass (8.81 %). It was noticed as minimum in Kallar grass (3.45 %) under prevailing Sabkha conditions.

2.2 Crude fiber

Maximum crude fiber was produced in *Ac. Ampliceps* (18.74 %) and *Prosopus juliflora* (18.27 %) and minimum in *Atriplex lentiformus* (6.91 %) in shrub/tree group. Kallar grass produced maximum crude fiber (23.43 %) followed by Para grass (22.38 %) and minimum by *Sesbania acculeata* (9.71 %) in grasses/herbs group.

2.3 Organic Carbon

Eucalyptus camaldulensis fixed maximum organic carbon (37.57%) followed by Pomegranate (36.20%) while *Atriplex lentioformis* remained lowest (22.57%) in shrubs/trees group. *Sesbania acculeata*, Para grass and Kallar grass fixed comparable organic carbon in the range of 33.43–33.04% and *Kochia indica* remained lowest (25.47 %) in grasses/herbs group.

2.4 Nitrogen

In shrubs/trees group, maximum N was assimilated by *Prosopus juliflora* (2.75%) followed by *Eucalyptus camaldulensis* (1.66%) and minimum with *Atriplex lentiformis* (1.25 %). Being a nitrogen fixer, maximum nitrogen was assimilated by *Sesbania acculeata* (3.28%) followed by Para grass (1.32%) and minimum in Kallar grass (0.63%).

2.5 Phosphorus

Pomegranate also derived maximum P from soil followed by *Eucalyptus camalldulensis* while *Acacia ampliceps* and *Atriplex lentiformis* derived minimum in shrubs/trees group. In herbs/grasses group, *Sesbania acculeata* and Para grass accumulated maximum P while *Kochia indica* and Kallar grass minimum in their biomass.

2.6 Ash Content

As expected, maximum ash content (minerals) was observed in *Atriplex lentiformis* and and minimum in Pomegranate in shrub/trees group. In grasses/herbs group *Kochia indica* produced maximum while *Sesbania acculeata produced minimum ash content.*

Table 6. Fodder quality assessment of salt-tolerant plants grown on Sabkha.

S.No.	Plant species	Ash %	P %	N %	Protein %	Crude Fibre %	Organic Carbon %
1	*Acacia ampliceps*	20.09	0.11	1.43	8.89	18.74	29.94
2	*Atriplex lentiformis*	23.80	0.12	1.25	7.18	6.91	22.57
3	*Prosopus juliflora*	11.44	0.15	2.75	17.22	18.27	31.04
4	Pomegranate	9.09	0.23	1.61	10.08	8.86	36.20
5	*Kochia indica*	24.45	0.08	0.84	5.75	10.48	25.47
6	Kallar grass	14.03	0.08	0.63	3.45	23.43	33.04
7	Para grass	11.00	0.19	1.32	8.81	22.38	33.38
8	*Sesbania acculeata*	10.37	0.19	3.28	20.50	9.71	33.43
9	*Eucalyptus camaldensis*	13.06	0.18	1.66	10.38	11.60	37.57

3. Ion retention potential

The plants showed genetic diversity towards ionic retention potential. The analysis results are given in Table 7. No contamination of Cu was observed in any sample hence excluded from the Table. *Atriplex Lentriformus*, being halophyte, retained more Na, K, Mg, K and Hg but minimum Mn salts than others. *Kochia indica*, also being halophytes, retained more Na, K, Mg, Fe and Pb but less Mo and Ni salts than others. *Acacia ampliceps* retained maximum Ca, Fe, Mo and Hg and minimum K, Cr and Pb. Kallar grass retained more Mn, Cr, Co, Ni and minimum Ca, Fe and Zn nutrients. More accumulation of Ca and Fe but least of; Na, Mg, Mo, Hg and Pb was recorded in *Sesbania acculeata* than others. Para grass retained more Cr and Ni but less Ca, Fe, Co than other metals. *Eucalyptus camaldulensis* retained more Mn, Zn and Pb but less Co and Hg in leaf biomass. Pomegranate proved to be least affected by high flux of salinity as it retained little salts in its leaf biomass particularly Na, Mg, Mn, Mo, Zn, Cr, Co, Ni and Pb. Thus its biomass would be almost safe being very little contaminated by toxic metals present in the saline soil or irrigation water.

Table 7. Selective Ion retention potential of salt-tolerant plant.

Ions % or ppm	*A. ampliceps*	*A. lentiformis*	*P. juliflora*	Pomegranate	*K. indica*	Kallar grass	Para grass	*S. acculeata*	*E. camaldensis*
K	0.72	2.45	0.98	1.17	2.41	1.20	2.33	1.41	1.41
Na	0.19	4.70	0.42	0.15	4.12	0.60	0.73	0.07	1.19
Ca	5.66	2.92	2.77	2.31	2.46	0.43	0.47	3.49	2.52
Ma	0.36	1.64	0.59	0.30	1.37	0.35	0.46	0.29	0.47
Fe	1385	932	934	616	584	180	90	1008	691
Mn	62.8	55.29	113.90	38.62	176.4	216.6	68.25	149.9	232.5
Mo	2.72	0.85	2.06	0.02	0.12	0.45	0.34	0	0.27
Zn	10.85	17.86	20.43	12.74	15.7	12.76	22.60	15.97	21.04
Cr	1.79	6.12	3.47	2.28	6.82	14.86	6.85	2.32	3.25
Co	0.54	0.42	0.39	0.30	0.37	0.56	0.35	0.44	0.35
Ni	4.73	4.03	3.14	2.65	3.13	7.78	6.88	3.99	3.24
Pb	0.36	0.72	0.62	0.44	0.95	0.64	0.59	0.50	0.78
Hg	0.05	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01

4. Inter-plant ion retention genetic diversity

Acacia ampliceps, Prosopus juliflora and pomegranate followed the cation retention ability in the order of Ca > K> Mg> Na whereas *Eucalyptus camaldulensis* retained cations in the order of Ca>K> Na> Mg. The Kallar grass and Para grass retained maximum K followed by Na, Ca and Mg respectively. The Halophytes *Atriplex lentiformis* and *Kochia indica* retained maximum Na (as expected) followed by Ca, K and Mg respectively as given in Table 8.

The changed scenario of Sabkha from a barren ocean desert to a productive agriculture farm after less than six months period through Bio-saline Agriculture activity is shown in Figure 3.

Table 8. Inter-plant ions retention trend of salt-tolerant plant.

Metals	Maximum retaining species	Minimum retaining species
K	*Atriplex. lentiformus* and *Kochia indica*	*A. ampliceps* and *Kochia indica*
Na	*A.. lentiformus* and *K. indica*	*Sesbania acculeata* and Pomegranate
Ca	*Acacia ampliceps* and *Sesbania acculeata*	Kallar grass and Para grass
Ma	*Atriplex. lentiformus* and *K. indica*	*Sesbania acculeata* and Pomegranate
Fe	*A. ampliceps* and *S. acculeata*	Kallar grass and Para grass
Mn	*Eucalyptus camaldulensis* and Kallar grass	Pomegranate and *A.. lentiformus*
Mo	*A. ampliceps* and *Prosopus juliflora*	*Sesbania acculeata* and Pomegranate
Zn	Para grass and *E. camaldulensis*	Pomegranate and Kallar grass
Cr	Kallar grass and Para grass	*A. ampliceps* and Pomegranate
Co	Kallar grass and *A. ampliceps*	Pomegranate and Para grass / *E. camaldulensis*
Ni	Kallar grass and Para grass	Pomegranate and *Kochia indica/ P. juliflora*
Pb	*K. indica* and *E. camaldulensis*	*A. ampliceps* and Pomegranate
Hg	*A. ampliceps* and *A.. lentiformus/ P. juliflora*	*E. camaldulensis* and *Sesbania acculeata*

Fig. 3. On-site comparison of pre and post Biosaline agriculture activities

SUMMARY

Combining all this information, the suitability of the salt-tolerant plants grown in very high salt flux under Sabkha conditions provides basic information on:

1. The biomass production potential of salt-tolerant plants grown under extreme salinity and intense weather conditions.
2. Fodder quality assessment may help in nutritive status assessment of the plants fodder value and any deficiency to be made up.

3. Ionic retention potential provides information of the fertilizer inputs required to make up the deficiency in exhausted soil due to excessive uptake of certain essential nutrients during specific salt-tolerant plant growth.
4. Pomegranate appeared to contain very effective differential selective membrane system from a mess of high flux of salts present in saline soil and treated sewage irrigation water. Hence its gene pool may be of specific interest for inducing tolerance against specific biotic and abiotic stresses.

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