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Salinity Characteristics of Soils Supporting Halophyte Vegetation in Saline Desert Ecosystems in Western India

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Abstract: Saline soil limits plant growth by affecting osmotic balance in soil-plant systems. Vast areas of saline deserts exist in arid areas of India where crop production is not feasible. One of the ways to effectively utilise such landscape is to use plant species adapted to such hostile environments. Field survey was carried out in two major saline desert ecosystem of western India, namely Great Rann of Kachchh (GRK) and Little Rann of Kachchh (LRK), during 2013 and 2014. The study indicated that these unique ecosystems were deficient in soil organic carbon with content less than 0.77%. Extremes of salinity are common in the study area recording salinity as high as 102.3 dS m^{-1} in GRK and 85.38 dS m^{-1} in LRK. The major halophytic plants were *Aeluropus lagopoides, Sporobolus marginatus, Suaeda nudiflora* and *Cressa cretica*. *Aeluropus* was able to grow in soils having salinity upto 27.7 dS m^{-1}, whereas *Sporobolus* could grow in ecological niches with salinity as high as 83.1 dS m^{-1}. The halophytic non grasses like *Suaeda* and *Cressa* were widely distributed in both the saline desert ecosystems. The presence of salts increased the plant population of *Suaeda* and *Cressa* up to certain salinity levels. Beyond salinity value of 9.9 dS m^{-1}, the plant density of *Suaeda* decreased, whereas in *Cressa*, the salinity value beyond which reduction in population decreased was 27.2 dS m^{-1}. These plants which are able to survive at extremely salinity environments, could be explored for greening saline deserts and could be used as local fodder resource to support livestock population.

Key words: *Aeluropus lagopoides*, *Cressa cretica,* salinity, soluble ions, *Sporobolus marginatus*, *Suaeda nudiflora.*

Salinisation is one of the most serious degradation affecting crop growth and productivity especially in arid and semi-arid areas, where rainfall is insufficient to leach excess salts and sodium ions out of rhizosphere (Odeh and Onus, 2008). It is the process leading to excess concentration of dissolved salts in soil due to natural processes or anthropogenic actions (Ghassemi *et al*., 1995). Worldwide, salt affected soils occupy about 952 million hectares (7% of earth's land surface) under various degrees of deterioration (FAO, 1974; Flowers *et al*., 1977). About 20% of the cultivated lands and 33% of irrigated lands are reported to be affected by salinity (Shrivastava and Kumar, 2015) rendering these lands economically unproductive. In India, salt affected lands occupy 6.73 million hectare (Mandal *et al*., 2010). A unique vast stretch of saline desert occurring in West Central India known by name Rann of Kachchh, is regarded as the largest salt desert in the world (Pandit *et al*., 2014). It is spread in two stretches; one part in 7505.22 sq. km known as Great Rann of Kachchh (GRK) and the other in 4,953 sq. km known as Little Rann of Kachchh (LRK). During monsoonal period from June to September, the area becomes marshy land by inundated water from runoff resulting from rainfall and water driven by forces of winds and tides from Arabian Sea. Unlike other deserts where soil texture is dominated by sand, the soils of the desert is dominated by clay (Gupta and Ansari, 2014), which make infiltration and percolation of water through the soil very poor. During rest of the months the land turns into a hyper saline desert.

Soil salinization restricts the plant growth mainly due to low osmotic potential of soil solution which adversely affects the water and nutrient uptake by plants, and toxic effect of specific ions (Patel *et al*., 2010). Natural salinization occurs due to weathering of minerals or parent materials rich in salts or from deposits of fossil salts (Abrol *et al*.,

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1986) especially in areas with high water table and in areas with evaporation rate higher than rainfall (Amezketa, 2006). Low rainfall and high evaporation rate in arid and semi-arid climates lead to accumulation of salts at the soil surface causing salinity hazards (El-Saidi, 1997). Irrigated agriculture is the source of secondary salinization of soil and water resources in arid regions, where solubilized salts are brought to soil surface by evaporation (Judkins and Myint, 2012). The use of saline ground water and poor quality water speed up the process (Panta *et al.*, 2014).

The management of salinity requires thorough knowledge of its occurrence and variability within the landscape. In extremely saline soils where profitable production of agricultural crops is impossible, the land is left fallow which aggravate soil degradation processes. The yield of agricultural crops is drastically reduced in saline soils since most of the agricultural crops are salt sensitive (Munns and Tester, 2008). Restoring the productivity of saline lands is important looking to the limited land resources to feed increasing population of human and livestock. Halophytes are plants which are able to grow under saline conditions and they are adapted to saline environments by various tolerance mechanisms. Halophytes vary in their tolerance to salt concentration. They are important vegetation in salt laden arid and semi-arid areas and survive in areas with salinity levels even more than sea water (Gulzar and Khan, 1994). Different species occupy ecological niches specific to each class based on relative tolerance to salinity, moisture and nutrient requirements. Halophytes serve as potential food, fodder and biofuel resource apart from medicinal importance of some species (Khan *et al.*, 2000; Xianzhao *et al.*, 2013). Some of the halophyte plants serve as palatable fodder resource (Gihad and El Shaer, 1992; Hassan and Shaer, 2010). By domesticating halophytes, they can be utilized for reclamation and rehabilitation of barren and abandoned salt affected soils, at the same time providing valuable fodder resources for livestock. Le Houérou and Henry (2000) reported that rehabilitation of saline lands require characterization of natural habitats in terms of plants requirements. Identification of halophytes and characteristics of their habitats is important to achieve this. Understanding the distribution of halophyte species in natural saline environments is crucial in sustaining the complex ecosystems in which they exist (Chinnusamy *et al.*, 2005). With this background the present study was carried out to understand the soil characteristics of major halophyte growing saline deserts in western India. The study also aims to determine ecological adaptability of halophyte species to soils of varied salinity.

Materials and Methods

Location of the study area and survey

The study was conducted in saline desert areas of Kachchh (also known as Kutch) in the western India. The field surveys were carried out in two vast stretch of saline deserts, Great Rann and Little Rann (23°7′ to 23°40′ N latitude and 70°38′ to 71°44′ E longitude). The region is characterized by typical arid climate with erratic and irregular rainfall. The average annual rainfall is 389 mm received in 12 rainy days. The annual minimum temperature ranges from 1 to 8°C and maximum temperature ranges from 39 to 45°C. Field surveys were carried out in these two regions at 10 km intervals during post rainy season of 2013 and 2014, respectively (Fig. 1). Eleven sites were selected at Great Rann area and 10 sites

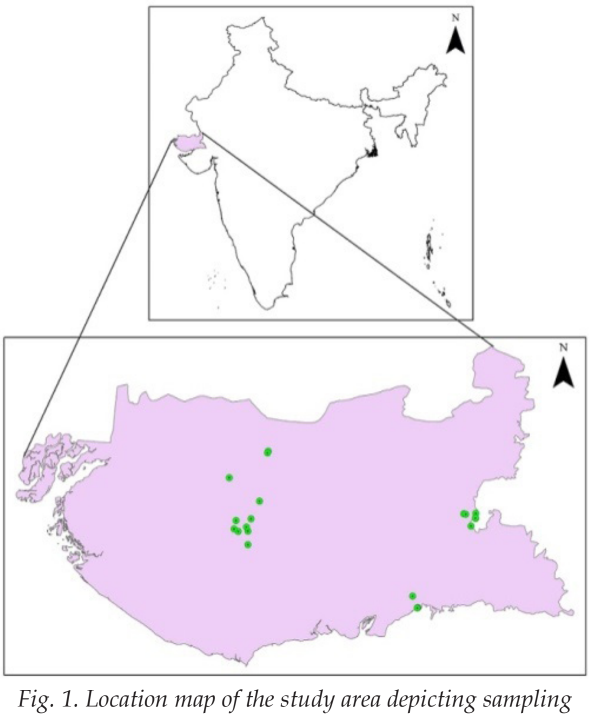

Fig. 1. Location map of the study area depicting sampling locations.

in Little Rann area. At each site, soil samples were collected from three different depths 0-15 cm, 15-30 cm and 30-45 cm. Soil samples were air dried and passed through 2 mm sieve in the laboratory and stored for salinity characterisation of soil. The plant population of halophytes were studied at each site for their density by quadrat method using a 5 x 4 quadrat and the density was expressed per square metre basis. These saline desert support large number of halophytic plants species. Four prominent halophytes namely *Aeluropus lagopoides* (L.) Thwaites, *Sporobolus marginatus* A. Rich, *Suaeda nudiflora* Moq. and *Cressa cretica* L. were selected for the study.

Soil analysis

Soil samples were analysed for pH and electrical conductivity (EC) (in 1:2 soil water suspensions). Soil organic carbon (SOC) was determined using Walkley and Black (1934) method. Water soluble ions were determined in extracts of soil: water ratio of 1:5. Among different soil-water ratios in use to estimate electrical conductivity and soluble ion concentrations such as 1:1, 1:2, 1:5, 1:10 and extract from saturation paste, 1:5 ratio is most popular (Liu *et al*., 2006). The extraction in saturation paste although time consuming, was advocated mainly due to the fact that it simulate the field conditions. Many authors attempted to study the relationships between EC and ionic contents extracted in soil solution and in saturated paste. Khorsandi and Yazdi (2011) reported regression equations that relate EC_e as five times $EC_{1:5}$, Na^+, K^+, Ca^{2+}, and Mg^{2+} were determined using atomic absorption spectrophotometer (AA500, PG Instruments, UK). Cl^- content was determined following conventional titration method using 0.1 N silver nitrate and 10% potassium chromate and SO_4^{2-} was measured spectrophotometrically (Page *et al.*, 1982).

Statistical analysis

Statistical analysis was carried out using Genstat (14th Edition, VSN International Ltd., Hemel Hempstead, UK). A two way analysis of variance was applied to the soil data using site and soil depth as factors separately for two saline desert ecosystems. For different halophyte species, ANOVA was carried out individually. Mean values were compared at P<0.05 level. Linear regressions were carried out to find out the relationships among different parameters.

Results and Discussion

Soil properties

The ranges in soil properties covering all three depths and results of statistical analysis are given in Table 1. In Great Rann, the soil pH varied from near neutral to alkaline range, across different soil layers (7.17 to 9.83) and organic carbon content was very low (0.01 to 0.37%) with significant difference among site and depths (P<0.01) (Table 1). In Little Rann areas, pH and organic carbon values were 6.91 to 8.94 and 0.05 to 0.77% respectively. The organic carbon content in soil is largely related to biological, climatic and other soil forming factors. The equilibrium content in soil depends on the balance between C inputs into the soil by addition of organic materials through litter

Table 1. Ranges in soil properties (0 to 45 cm depth) in Great Rann and Little Rann areas in Kachchh, India

Parameters	Ranges in soil properties		F statistic	
	Great Rann	Little Rann	Great Rann (Site x depth)	Little Rann (Site x depth)
pH	7.2-9.8	6.9-8.9	1.92*	NS
Electrical conductivity (dS m^{-1})	0.1-102.3	0.1-85.4	24.47**	6.19***
Organic carbon (%)	0.01-0.37	0.05-0.77	5.26*	NS
Na^+ (ppm)	15.6-59122	65.9-58850	14.1**	2.13**
K^+ (ppm)	8.6-97.8	15.3-1795	4.89**	NS
Ca^{2+} (ppm)	18.8-9023.5	50.1-1130	27.96**	16.98**
Mg^{2+} (ppm)	4.6-2339	10.6-1130	6.47**	NS
Cl^- (ppm)	104.8-41974	543.0-58269	11.47**	1.93*
SO_4^{2-} (ppm)	73.4-2814	40.2-4130	12.72**	NS

NS: non-significant; ***P<0.001, ** P<0.01, * P<0.05.

fall, root decomposition and microbial by-products, and C losses through decomposition and mineralisation (Schlesinger and Andrews, 2000; Wang *et al.*, 2014). At surface 0 to 40 cm depth, the land use is the most important factor controlling SOC concentration (Albaladejo *et al.*, 2013). In a deserted environment constrained heavily by soil salinity, the contribution from land use is limited. Also the climatic constraints in the region in terms of extremes of temperature and deficiency of moisture further decrease the carbon content (Rey *et al.*, 2005). Soil organic carbon is an important parameter deciding the soil quality and targeted efforts are needed for its sequestration in soil. Vegetation restoration in such soils could significantly enhance the addition of organic materials, soil aggregation (Tang *et al.*, 2010) and increased microbial activity (Wang *et al.*, 2015). In general, pH showed an increasing trend and organic carbon a decreasing trend down the profile. High organic carbon content and low pH values in Little Rann soils can be ascribed to micro climatic variation. The LRK region receives higher annual rainfall (542 mm) compared to GRK (334 mm), which might have helped flushing of salts, thus promoting more plant growth adding biomass and carbon to the soil. Moreover, in a highly saline environment the growth and survival of microorganisms responsible for decomposition of organic materials are also adversely affected (Wichern *et al.*, 2006). The soluble salt measured in terms of electrical conductivity varied significantly and ranged from 0.11 to 102.3 dS m^{-1} in GRK and 0.10 to 85.38 dS m^{-1} in LRK ($P<0.001$). Such high soil EC makes the area a hyper saline desert rendering growth of plants difficult. EC of up to 119.8 dS m^{-1} in the nearby areas and up to 166.7 dS m^{-1} in saline depressions of this landscape was reported by Singh and Kar (2001). Merh and Chamyal (1997) reported that major part of saline desert of the region was a marine gulf that emerged out of sea during the last 2500 years. Tectonic and seismic activities and siltation by rivers, together with the effects of climatic change caused gradual recession of sea. The inherent salinity characteristics of the region can mainly be ascribed to seasonal flush of saline water from the Gulf of Kachchh aided by storm tides and wind. Due to geological characteristics, the inundated water failed to percolate down the profile. The prevailing arid climatic conditions characterized by low rainfall and high temperature aids in evaporative loss of inundated water leaving behind the salts.

The saline desert exhibit high variability in ionic composition. The water soluble cations content followed the order, Na>Ca>Mg>K in GRK and Na>K>Mg>Ca in LRK and showed significant variation with site and depth (Table 1, 2 and 3). All the cations were higher in the GRK compared to LRK. Among different soil layers in GRK, sodium content ranged from 15.6 to 59122 ppm and LRK from 65.9 to 58850 ppm with significant site x depth interactions ($P<0.01$). Potassium content in GRK and LRK ranged from 8.6 to 97.8 ppm and 15.3 to 1795 ppm respectively. Calcium and magnesium

Table 2. Salinity characteristics (EC, Na and Cl in Great Rann area of Kachchh, India)

Site No.	Latitude (N)	Longitude (E)	EC (dS m^{-1}) 1:2			Na (ppm)			Cl (ppm)		
			0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
1	23°25′58.1′′	69°39′42.4′′	0.15	0.14	0.14	63.1	43.3	33.3	236.7	207.1	209.1
2	23°30′22.6′′	69°35′43.2′′	2.69	3.44	9.11	299.5	411.8	4213.1	1741.3	2586.8	2360.3
3	23°35′5.6′′	69°40′10.3′′	27.74	17.47	20.73	13072.3	8181.3	15181.6	16891.7	25453.7	25993.3
4	23°41′25.9′′	69°42′50.2′′	0.57	0.69	1.24	80.5	25.6	25.0	408.3	423.8	648.3
5	23°58′58.5′′	69°44′44.2′′	1.10	1.56	3.17	129.8	239.2	455.1	1979.2	4421.7	7703.3
6	23°58′25.7′′	69°44′33.0′′	83.06	84.91	68.33	34138.9	34114.0	32111.3	31280.0	38283.3	30166.7
7	23°30′41.8′′	69°39′21.9′′	6.79	5.68	7.54	1755.6	1559.6	958.7	12125.0	6500.0	5016.7
8	23°32′3.1′′	69°38′41.7′′	4.32	4.05	4.47	925.6	1042.7	647.0	9025.0	4808.3	6358.3
9	23°34′6.2′′	69°34′32.5′′	11.25	11.99	11.08	5269.4	5366.3	5669.0	24616.7	20850.0	23950.0
10	23°31′8.1′′	69°34′6.6′′	21.92	17.56	18.68	7475.8	14066.6	9869.8	38025.0	17966.7	30175.0
11	23°48′47.6′′	69°30′48.5′′	12.05	12.06	12.22	6176.5	5965.3	5864.0	8716.7	13758.3	11833.3

Statistical significance of data are provided in Table 1.

Table 3. Salinity characteristics (EC, Na and Cl in Little Rann area of Kachchh, India)

Site No.	Latitude (N)	Longitude (E)	EC (dS m^{-1}) 1:2			Na (ppm)			Cl (ppm)		
			0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
1	23°08′10.7″	70°45′04.0″	11.1	8.9	7.4	17809.0	18954.8	18098.4	16034.7	17035.0	7478.7
2	23°08′09.1″	70°44′57.4″	27.2	16.8	17.7	31527.8	38744.8	40147.3	46329.2	47010.2	40767.5
3	23°08′04.1″	70°44′51.8″	7.9	10.1	11.2	11999.7	13789.9	12887.9	17999.3	18123.3	15821.5
4	23°12′03.7″	70°42′54.3″	23.2	32.4	42.4	43599.3	48448.2	42034.2	48479.0	39050.0	43960.0
5	23°41′51.8′′	71°00′01.6′′	23.2	32.4	42.4	43599.3	48448.2	42034.2	48479.0	39050.0	43960.0
6	23°41′45.8′′	71°00′47.6′′	2.2	2.7	3.3	237.7	321.9	463.9	2366.7	2130.0	3195.0
7	23°42′17.7′′	71°04′36.8′′	0.1	0.1	0.15	89.1	76.0	95.0	930.0	885.0	775.0
8	23°40′34.5′′	71°04′38.0′′	9.9	9.1	9.15	13091.9	13302.4	9697.2	12070.0	12425.0	13857.0
9	23°40′36.0′′	71°04′33.0′′	11.9	12.0	11.4	9499.8	10473.6	11670.9	10135.0	14673.3	15146.7
10	23°37′48.2′′	71°03′07.7′′	8.8	6.5	5.5	7027.3	6539.1	7170.6	9585.0	7100.0	6922.5

Statistical significance of data are provided in Table 1.

also showed significant variation with respect to site and depth in GRK (18.8 to 9023.5 ppm and 4.6 to 2339 ppm, respectively). In LRK the calcium content varied from 50.1 to 2807 ppm and magnesium content from 10.6 to 1130 ppm.

Among the studied anions, chloride was dominant over sulphate. The anions content were higher in LRK compared to GRK. The chloride content ranged from 104.8 to 41974 ppm in GRK and 543 to 58269 ppm in LRK. The sulphate content ranged from 73.4 to 2814 ppm in GRK and 40.2 to 4130 in LRK. Similar to the hyper saline desert in East Africa (Great Salt Lake and Lake Assal), sodium and chloride were the important ions in solution (Ollivier *et al.*, 1994). In majority of sites sodium accumulation was observed in lower layer (30-45 cm). Singh and Kar (2001) observed maximum accumulation of salts in the C horizon of Banni mud flat soils of arid western India. The concentration of all soluble ions were positively and significantly correlated (P<0.01) with electrical conductivity values indicating all the salts collectively contributed to salinity.

Distribution of halophyte vegetation in saline ecosystem

Under extremes of salinity in these deserts, only halophyte plants were able to survive. The distribution of major halophytes of these saline deserts in India is presented in this paper. The major halophyte grasses were *Aeluropus lagopoides, Sporobolus marginatus* and non-grass halophytes were *Cressa cretica* and *Suaeda nudiflora*. The plant density of these halophytes with respect to increase in soil salinity (EC) at surface 0-15 cm layer is presented in Fig. 2 to 5.

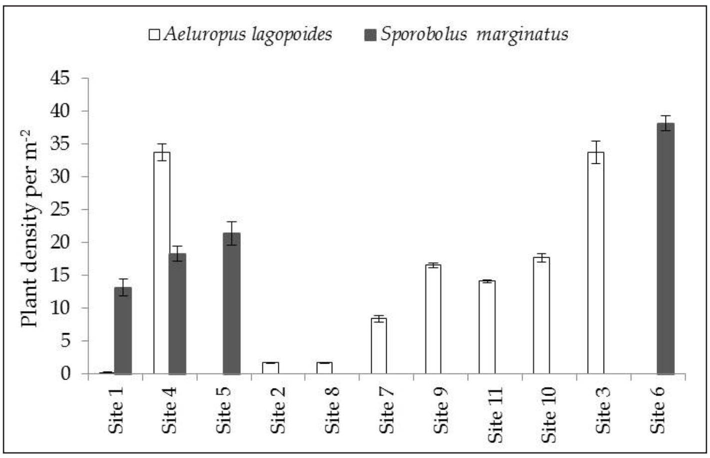

Fig. 2. The density of Aeluropus lagopoides and Sporobolus marginatus at GRK (Sites are arranged in the increasing order of salinity).

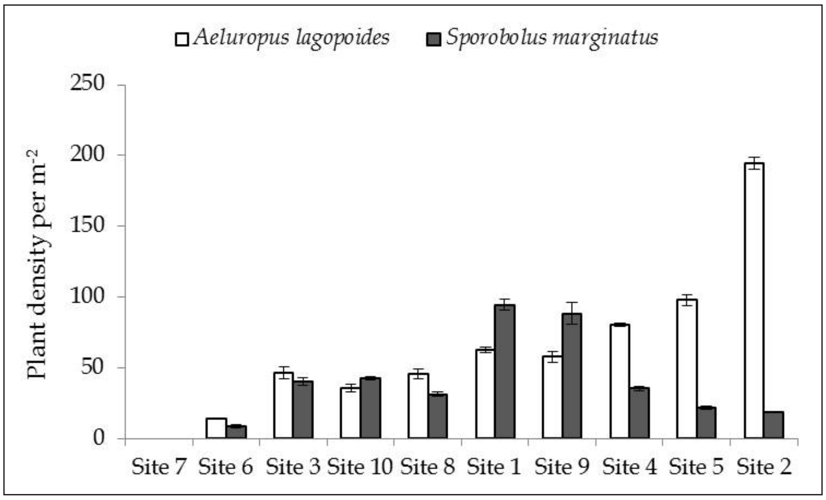

Fig. 3. The density of Aeluropus lagopoides and Sporobolus marginatus at LRK (Sites are arranged in the increasing order of salinity).

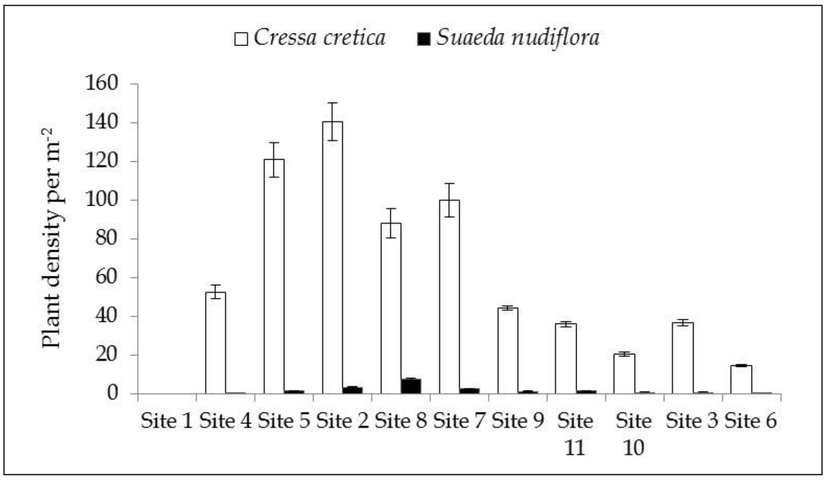

Fig. 4. The density of S. nudiflora and C. cretica at GRK (Sites are arranged in the increasing order of salinity).

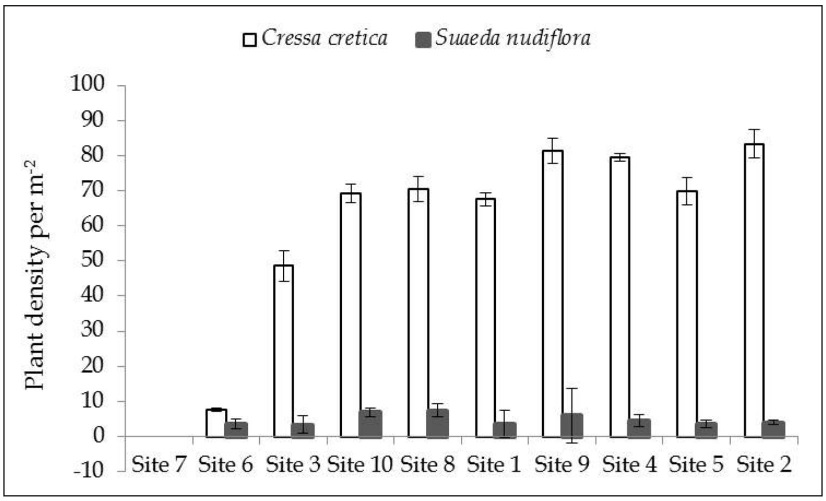

Fig. 5. The density of S. nudiflora and C. cretica at LRK (Sites are arranged in the increasing order of salinity).

The density of *Aeluropus lagopoides* in GRK ranged from 0 to 36.8 plants m^{-2} and in LRK from 0 to 201.5 plants m^{-2}. The study reflected more adaptability and salinity tolerance of this grass, occurring at sites with salinity even as high as 27.7 dS m^{-1}. As the salinity increased the density of plants also increased in GRK. In LRK also the grass showed increasing plant density with increase in salinity and maximum plant density of 194.7 plants m^{-2} was observed at salinity level of 27.2 dS m^{-1}. Similar levels of salinity tolerance was observed for *S. marginatus*, and was observed in soils having salinity levels upto 83.1 dS m^{-1} in GRK, whereas in LRK it was observed at sites with salinity as high as 27.2 dS m^{-1} at surface 0 to 15 cm layer. In salt loving halophytic plants, the presence of salts stimulate the growth of plants. Naz *et al*. (2010) observed optimal population and growth of *A. lagopoides* at highest salt levels of 300 mM NaCl, in a pot study conducted on halophytic grass collected from Cholistan Desert, Pakistan. They also observed optimal growth of *Sporobolus ioclados* at moderate to high salinity.

The non-grass halophyte plants, *Suaeda nudiflora* and *Cressa cretica* were widely distributed in the study area. These were absent from the non-saline sites in both GRK and LRK. However, these plants were present in all other sites of higher salinity. In GRK the plant density of *Suaeda* increased with increase in soil salinity up to 4.3 dS m^{-1} and thereafter decreased with increase in salinity. In LRK, the plant density was highest at soil salinity of 9.9 dS m^{-1}. Beyond this salinity, the plant density decreased. *Cressa cretica* showed wide adaptability to salinity in LRK with highest plant density at soil salinity of 27.2 dS m^{-1}. In GRK maximum density of *C. cretica* was recorded in site with EC value of 2.7 dS m^{-1}. These two non-grass halophytes showed less tolerance to salinity in the study areas compared to grass halophytes. Increasing salinity beyond certain levels in soil reduced the population of these two halophyte plants. Halophyte plants survive in saline environment by various mechanisms which include osmotic adjustment and compartmentation especially in salt accumulating halophytes. It prevents from the toxicity due to excess salts by partitioning toxic ions away from cytosolic compartment (Ravindran *et al.*, 2007). Such halophytes resort to controlled accumulation and sequestration of inorganic ions (Khan *et al.*, 2000). Vegetation in deserted landscapes in the drylands can add carbon to soil and biomass thus helping to mitigate climate change (Keller and Goldstein, 1998). One of the ways to restore productivity and to arrest degradation in saline desert is re-seeding and re-vegetation of such lands using halophytes. These plants are reported to remove salts from soil to a significant extent. For example *Suaeda salsa* reported to produce dry matter of 20 t ha^{-1} with the ability to remove 3 to 4 tons NaCl per hectare. Proper planning and management of saline land re-vegetation programmes offer the possibility to convert such lands into productive landscapes and contribute to local livelihoods by enhancing fodder availability.

Conclusions

The present study revealed extreme salinity characteristics and soluble salt concentrations in saline desert ecosystems of arid Western India. Only halophytic plants with adaptation characteristics are able to thrive in these environments. The study revealed that halophytic grasses such as *Aeluropus lagopoides* and *Sporobolus marginatus* able to survive at soil salinities ranging from 0.15 to 27.7 and 0.15 to 83.1 dS m^{-1} respectively. There was wide adaptability and distribution of non-grass halophytes such as *Suaeda nudiflora* and *Cressa cretica*. However their density was adversely affected at higher salinity levels. The study indicated that halophytes adapted to hyper saline environments can be effectively utilised for greening the vast stretches of saline deserts that potentially can meet the fodder requirement of the livestock in the region, apart from arresting further degradation of natural resources.

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