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# Pattern of salt accumulation and its impact on salinity tolerance in two halophyte grasses in extreme saline desert in India

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Halophytes growing in natural saline desert environment survive high levels of salinity adopting suitable mechanisms. Scientific information on such survival mechanisms can be useful in devising management options for extreme saline soils. A field survey on two major halophytes [*Aeluropus lagopoides* (Linn.) Trin. Ex Thw. and *Sporobolus marginatus* Hochst. ex A. Rich.] was carried out in the saline desert of Northwest India, Great Rann of Kachchh, to study the pattern of ion accumulation under natural conditions and to assess survival mechanisms of these halophytes. Studied areas in Great Rann had electrical conductivity (EC) values ranging 0.15-83.1 $dSm^{-1}$. Occurrence of *Sporobolus* was observed at sites having salinity as high as 83.06 $dSm^{-1}$ and *Aeluropus* up to 22.7 $dSm^{-1}$. Greater accumulation of $Na^+$ and $Cl^-$ ions were observed in the roots of these halophytes indicating its restricted uptake by them. There was selective absorption of $K^+$, $Ca^{2+}$ and $SO_4^{2+}$ in the leaves of *Aeluropus* and $K^+$, $Ca^{2+}$, $Mg^{2+}$ and $SO_4^{2-}$ in *Sporobolus*. With increase in soil salinity, the uptake of $Na^+$, $K^+$ and $SO_4^{2-}$ were reduced in *Aeluropus* whereas the uptake of $Na^+$, $K^+$ and $Cl^-$ was increased in *Sporobolus*. Possible mechanisms of salt tolerance of these halophytes are also discussed.

**Keywords:** Abiotic stress, *Aeluropus lagopoides*, Great Rann of Kachchh, Na/K ratio, Saline soil, Selective transport, *Sporobolus marginatus*

Abiotic stresses such as temperature extremes and salinity adversely affect the growth and productivity of crop plants[1]. Salinity influences water uptake by lowering osmotic potential of soil water and through ion imbalance or ion toxicities[1-3]. Globally, salanization affects crop productivity in more than 800 million hectares of land[4]. Climatic features, topographic settings and soil properties together with the use and management causes variability in salinity levels in natural saline habitats both temporally and spatially[5]. Rann of Kachchh in Northwest India is a unique saline marshy desert. It is described as "a desolate area of unrelieved, sun-baked saline clay desert, shimmering with the images of a perpetual mirage"[6] and is regarded as the largest salt desert in the world[7]. In the Indian part it stretches in 7505.22 sq. km known as Great Rann and 4,953 sq. km known as Little Rann. The area's uniqueness is that it becomes marshy land by inundated water from runoff during monsoonal rainfall and water driven by forces of winds and tides from Arabian Sea, mainly during June to September[8]. In contrast to other deserts where soil texture dominated by sand, the soils of this landscape is dominated by clay[9], which make infiltration and percolation of water through soil very poor. During rest of the months the land turn into a hyper saline desert[10,11] and serve as an important ecological habitat for rare and endangered animals and plant species[6]. The region, once a part of Arabian Sea, reached the current status of a mud flat due to factors such as geological uplift, silting and earth quakes[7]. As the inundated water evaporates, plants rejuvenate from the dormant plant parts or from native seed bank and contribute to fodder resources to support livestock based livelihood of the region. Owing to the extreme salinity characteristics associated with the soil, salt tolerant halophytes forms predominant vegetation in the region[12]. This ecosystem supports many flowering plants, shrubs, climbers, herbs, trees and grasses and

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supply fuel, food, fodder and timber for local people and livestock[13]. Ever increasing livestock population and increasing demand for fuel wood in deserts exert pressure on natural vegetation[14] and migration of families with livestock is a common practice in this desert[15,16].

Many halophyte grasses and non-grasses having potential to be used as fodder, grows in the region that exhibit inherent potential to survive salt concentration higher than the sea water[17,18]. They survive saline environments by developing mechanisms to overcome water deficit in the root zone arising from low water potential, ion toxicity and nutrient imbalances[14,19]. Effect of salinity on ion characteristics of halophytes in this unique ecosystem is not well understood. Information on survival and occurrence of halophytes play an important role in formulating reclamation strategies[20] such as its use in reclamation of saline lands[21]. Two major halophyte grasses of the region namely*, Aeluropus lagopoides* (Linn.) Trin. Ex Thw. and *Sporobolus marginatus* Hochst. ex A. Rich. were selected for the present investigation. The effect of natural variability in soil salt concentration on ion accumulation in these halophyte plants was studied.

## Materials and Methods

**Site selection and sample collection**

The study was conducted in one of the world's largest saline marshy area, the Great Rann of Kachchh in the Northwest India[22]. The region is characterised by scanty, erratic and irregular rainfall (coefficient of variation 73%) with 397 mm rainfall (average for 1998 to 2013). The monsoon starts generally in the first week of July and recedes in middle of September. Drought and high salinity levels are characteristics of the region[23]. The annual minimum temperature ranges from 1 to 8ºC (December) and the maximum temperature ranges from 39-45ºC (May-June). The native vegetation of the area consists of grasses, thorny scrubs/shrubs and only a few trees such as *Prosopis juliflora*. Field survey was carried out from the main land to the northern part at 10 km interval for the first four sites and for rest of the sites within the Ranns was based on occurrence of halophyte plants and soil salinity analysis using field level conductivity metre, in the post rainy season of 2013. A total of 11 sites were selected for the study (Fig. 1). At each site, soil samples were collected from three different depths *viz*., 0-15, 15-30 and 30-45 cm in three replicates. Soil samples were air dried and passed through 2 mm sieve in the laboratory for undertaking various analyses. The plant population of selected halophytes were studied at each site for their density by quadrat method using a 5×4 $m^2$ quadrat and the density was expressed in square metre. Plant samples of selected halophytes were collected from each sites and separated into roots, shoots and leaves in the laboratory. The plant parts were thoroughly washed with distilled water and dried at 70ºC in a hot air oven.

**Soil properties**

Soluble salt content in soil was measured after extraction with distilled water at the soil:water ratio of 1:5. Concentration of $Na^+$, $K^+$ and $Mg^{2+}$ were determined using atomic absorption spectro-photometer (AA500, PG Instruments, UK). The calcium ion ($Ca^{2+}$) was measured by EDTA complexometry; $Cl^-$ content was determined using 0.1N silver nitrate and 10% potassium chromate; and $SO_4^{2-}$ was measured spectrophotometrically. Soil pH and electrical conductivity (EC) was measured at 1:2 soil-water ratio using pH and conductivity electrodes, respectively. Soil organic carbon (OC) status of soil was measured by potassium dichromate method[24].

**Determination of soluble ions in plants**

For estimation of soluble ions, the plant parts were dried at 70ºC, ground and sieved to pass through a 0.5 mm sieve. The ions were extracted by digestion with concentrated $HNO_3$ on a sand bath. As done for soil above, concentrations of $Na^+$, $K^+$ and $Mg^{2+}$ in the extract was determined using atomic absorption spectrophotometer (AA500, PG Instruments, UK); $Ca^{2+}$ estimated with EDTA complexometry; and $Cl^-$ by titration with silver nitrate using potassium chromate as indicator. Sulphate content was estimated using turbidometric method using $BaCl_2$.

***Selective absorption and selective transport***

Selective absorption (SA) is a term introduced by Flowers and Yeo[25] to describe how well the plant

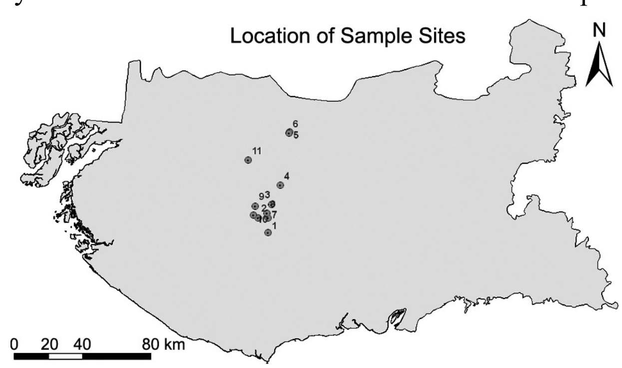


Fig. 1 — Location of sampling sites in Great Rann, Kachchh, India

root systems exclude $Na^+$ and take up $K^+$, and is determined as in equation 1.

$$SA = \frac{(Available \frac{Na+}{K+} \; in\; root\; zone\; soil)}{(\frac{Na+}{K+} \; in\; whole\; plant)} \quad \ldots (1)$$

Selective transport (ST) is another index showing capacity of roots to transport $K^+$ to stems in preference to $Na^+$ as provided in equation 2[26].

$$ST = \frac{\left[\frac{Na+}{K+} \; in\; roots\right]}{\left[\frac{Na+}{K+} \; in\; stem\right]} \quad \ldots (2)$$

**Statistical analysis**

A two way analysis of variance was applied to the soil data using site and soil depth as factors. Due to variation in the occurrence of different plants studied, ANOVA was carried out individually on each halophyte with site and plant parts as factors. Mean values were compared at $P$ <0.05 level. Linear regressions were carried out to find out the relationships. All the statistical analysis was carriedout using Genstat (14th Edition, VSN International Ltd, Hemel Hempstead, UK).

## Results

**Soil characteristics of the study area**

The soil properties at surface 0-15 cm layer varied significantly at different sites studied (Table 1). At surface 0-15 cm layer, soil pH varied from 7.7 at site 8 to 9.1 at site 4. Soil pH showed a general decrease down the soil profile. The electrical conductivity varied from 0.15 at site 1 to 83.1 $dSm^{-1}$ at site 6 in the top 0 to 15 cm layer. Generally, electrical conductivity was higher in the surface layers of studied sites. The soils recorded very low organic carbon status and it ranged from 0.02 to 0.26% in the upper 0-15 cm layer. Organic carbon content decreased with depth. Water soluble ions such as $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, $Cl^-$ and $SO_4^{2-}$ varied significantly with different sites and depth (Table 2). Water soluble $Na^+$ content ranged from 3.1 to 138.9 ppm at surface 0-15 cm and $K^+$ from 14.06 to 84.91 ppm. Water soluble ions and salinity (EC) were positively correlated with significant correlation coefficient of 0.61, 0.67, 0.89, 0.43 and 0.40 for $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, $Cl^-$ and $SO_4^{2-}$, respectively.

**Distribution of selected halophytes in the study area**

The density per square metre of *Aeluropus* and *Sporobolus* of the study area is presented in Fig. 2. *Aeluropus* exhibited a wide adaptability occurring in 9 of the 11 sites studied, whereas *Sporobolus* was only recorded at 4 sites.

**Accumulation of soluble ions in various plant parts of halophytes and its implications**

Sodium content in various plant parts of *Aeluropus* and *Sporobolus* varied significantly with respect to

Table 1 — Details of sampling locations and soil properties (pH, EC and OC) at different depths

| Site No. | Latitude (N) | Longitude (E) | pH (1:2) | | | EC ($dSm^{-1}$) 1:2 | | | OC (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 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 | $23^0$ 25’ 58.1’’ | 69 39’ 42.4” | 7.88 ±0.04 | 8.00 ±0.06 | 8.14 ±0.02 | 0.15 ±0.02 | 0.14 ±0.01 | 0.14 ±0.01 | 0.19 ±.01 | 0.16 ±0.02 | 0.12 ±0.01 |
| 2 | $23^0$ 30’ 22.6” | $69^0$ 35’ 43.2” | 8.06 ±0.09 | 8.17 ±0.07 | 8.19 ±0.03 | 2.69 ±0.34 | 3.44 ±0.26 | 9.11 ±0.48 | 0.24 ±0.01 | 0.28 ±0.001 | 0.23 ±0.02 |
| 3 | $23^0$ 35’ 5.6” | $69^0$ 40’ 10.3” | 8.32 ±0.06 | 8.20 ±0.03 | 8.11 ±0.02 | 27.74 ±0.71 | 17.47 ±1.55 | 20.73 ±2.83 | 0.12 ±0.02 | 0.13 ±0.006 | 0.18 ±0.01 |
| 4 | $23^0$ 41’ 25.9” | $69^0$ 42’ 50.2” | 9.07 ±0.37 | 9.33 ±0.43 | 9.18 ±0.40 | 0.57 ±0.04 | 0.69 ±0.07 | 1.24 ±0.059 | 0.02 ±0.01 | 0.03 ±0.002 | 0.01 ±0.01 |
| 5 | $23^0$ 58’ 58.5” | $69^0$ 44’ 44.2” | 8.24 ±0.03 | 8.29 ±0.07 | 8.21 ±0.02 | 1.10 ±0.18 | 1.56 ±0.12 | 3.17 ±0.07 | 0.15 ±0.02 | 0.10 ±0.001 | 0.10 ±0.01 |
| 6 | $23^0$ 58’ 25.7” | $69^0$ 44’ 33.0” | 8.14 ±0.01 | 8.20 ±0.04 | 8.25 ±0.03 | 83.06 ±2.76 | 84.91 ±1.06 | 68.33 ±7.2 | 0.26 ±0.03 | 0.20 ±0.017 | 0.24 ±0.01 |
| 7 | $23^0$ 30’ 41.8” | 69 39’ 21.9” | 7.85 ±0.11 | 8.12 ±0.04 | 8.27 ±0.07 | 6.79 ±0.33 | 5.68 ±0.31 | 7.54 ±0.33 | 0.17 ±0.02 | 0.15 ±0.009 | 0.15 ±0.01 |
| 8 | $23^0$ 32’ 3.1” | $69^0$ 38’ 41.7” | 7.66 ±0.09 | 7.61 ±0.12 | 7.75 ±0.04 | 4.32 ±0.04 | 4.05 ±0.07 | 4.47 ±0.25 | 0.16 ±0.01 | 0.13 ±0.01 | 0.13 ±0.01 |
| 9 | $23^0$ 34’ 6.2” | 69 34’ 32.5” | 8.00 ±0.05 | 8.07 ±0.04 | 8.14 ±0.02 | 11.25 ±0.6 | 11.99 ±0.33 | 11.08 ±0.19 | 0.08 ±0.01 | 0.05 ±0.009 | 0.08 ±0.01 |
| 10 | $23^0$ 31’ 8.1” | $69^0$ 34’ 6.6” | 7.79 ±0.04 | 7.96 ±0.05 | 7.99 ±0.10 | 21.92 ±1.5 | 17.56 ±0.72 | 18.68 ±0.59 | 0.10 ±0.02 | 0.11 ±0.014 | 0.05 ±0.01 |
| 11 | $23^0$ 48’ 47.6” | $69^0$ 30’ 48.5” | 8.47 ±0.25 | 8.55 ±0.03 | 8.47 ±0.07 | 12.05 ±0.90 | 12.06 ±0.24 | 12.22 ±0.98 | 0.22 ±0.01 | 0.07 ±0.01 | 0.07 ±0.01 |

[Values are mean±standard error. EC, electrical conductivity; OC, organic carbon] site and plant parts (Tables 3 and 4, $P$ <0.001) In *Aeluropus,* among the plant parts, sodium content was higher in roots and it ranged 236.2-687.8 ppm with the highest content being recorded at site 1. The lowest accumulation of sodium was observed in the leaves in all the selected sites. In leaves, highest content of Na was observed when soil salinity was lowest and the content decreased with increase in salinity ($R^2$ = 0.25, $P$ <0.05). The same trend was observed for stem and roots. In *Sporobolus*, the highest sodium accumulation was observed in roots (469.2-742.1 ppm) followed by leaves (376.2-390.3 ppm) and least in stem (296.2-323.0 ppm). In roots, sodium content was highest at site with highest salinity with similar trends in stem and roots ($R^2$ = 0.84, $P$ <0.001 for roots; $R^2$ = 0.37, $P$ <0.05 for stem). Potassium content varied significantly with site and plant parts. In *Aeluropus*, the highest $K^+$ content was recorded in the leaves in majority of sites except site 1 and 2 with contents ranging from 931 to 2066 ppm. Irrespective of sites, the K content was lowest in roots. Similar to $Na^+$, the $K^+$ content in various plant parts had an inverse relation with soil salinity ($R^2$ = 0.15, $P$ <0.05 for stem; $R^2$ = 0.16, $P$ <0.05 for leaves). In *Sporobolus*, among different plant parts, the $K^+$ content was highest in leaves, followed by stem and least in the roots. The $K^+$ content in roots and stem of *Sporobolus* was highest at sites having highest salinity ($R^2$ = 0.64, $P$ <0.01 for roots; $R^2$ = 0.36, $P$ <0.05 for stem), but for leaves the maximum $K^+$ content was observed in soils of low salinity ($R^2$ = 0.4, $P$ <0.05). Calcium content varied with the site and plant parts with significant interaction ($P$ <0.001) in *Aeluropus*, however, the interaction effect was not significant in *Sporobolus* ($P$ >0.05). Similar to $K^+$, the calcium content was highest in leaves of both *Aeluropus*

Table 2 — F statistics of soil properties at different locations and soil depths

| Parameter | Site | Depth | Site × depth |
|---|---|---|---|
| pH | 35.3** | 12.53* | 1.92* |
| Electrical conductivity | 623.1** | 38.84** | 24.47** |
| Organic carbon | 59.52** | 13.8** | 5.26* |
| Water soluble $Na^+$ | 391.33** | 7.77** | 14.1** |
| Water soluble $K^+$ | 442.3** | 0.54$^{ns}$ | 4.89** |
| Water soluble $Ca^{2+}$ | 534.9** | 174.06** | 27.96** |
| Water soluble $Mg^{2+}$ | 248.45** | 27.8** | 6.47** |
| Water soluble $Cl^-$ | 360.49** | 6.86** | 11.47** |
| Water soluble $SO_4^{2-}$ | 221.0** | 12.14** | 12.72** |

[ns, non-significant. ** $P$ <0.01, *$P$ <0.05]

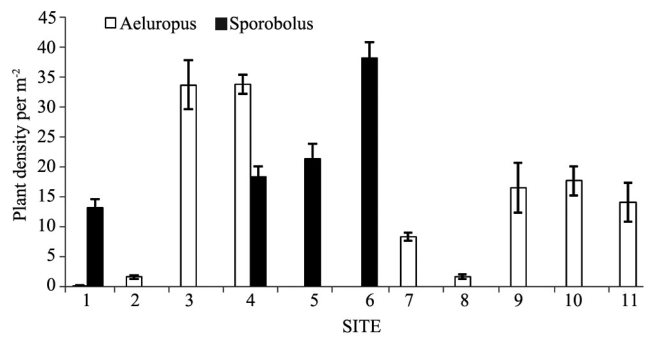


Fig. 2 — Plant density per sq.m of *Aeluropus* and *Sporobolus* at different sites, obtained by quadrat method

Table 3 — Ion content in different plant parts in *Aeluropus lagopides* from different locations in Great Rann of Kachchh

| Site | $Na^+$ (ppm) | | | $K^+$ (ppm) | | | $Ca^{2+}$ (ppm) | | | $Mg^{2+}$ (ppm) | | | $Cl^-$ (ppm) | | | $SO_4^{2-}$ (ppm) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R | S | L | R | S | L | R | S | L | R | S | L | R | S | L | R | S | L |
| 1 | 687.8$^{a}$ | 576.8$^{a}$ | 547.5$^{a}$ | 1066$^{a}$ | 2128$^{a}$ | 2066$^{a}$ | 144$^{a}$ | 125$^{abc}$ | 167$^{e}$ | 829.4$^{a}$ | 260.2$^{ab}$ | 302.6$^{a}$ | 11005$^{ab}$ | 7988$^{abc}$ | 4885$^{bc}$ | 11855$^{ab}$ | 14453$^{a}$ | 32484$^{a}$ |
| 2 | 492.7$^{b}$ | 365.2$^{b}$ | 308.5$^{b}$ | 805$^{a}$ | 1033$^{b}$ | 1008$^{b}$ | 142$^{a}$ | 102$^{bc}$ | 184$^{bc}$ | 496.9$^{b}$ | 357.5$^{ab}$ | 273.5$^{a}$ | 10295$^{ab}$ | 6568$^{c}$ | 5325$^{b}$ | 21478$^{a}$ | 22499$^{a}$ | 29931$^{ab}$ |
| 3 | 480.0$^{bc}$ | 353.2$^{b}$ | 211.7$^{e}$ | 885$^{a}$ | 917.1$^{b}$ | 931.2$^{b}$ | 130$^{a}$ | 86$^{c}$ | 265$^{abc}$ | 574.9$^{b}$ | 386.2$^{a}$ | 370.4$^{a}$ | 8165$^{b}$ | 7100$^{bc}$ | 4083$^{bc}$ | 6996$^{bc}$ | 8952$^{a}$ | 16981$^{bc}$ |
| 4 | 483.9$^{b}$ | 319.4$^{bc}$ | 248.5$^{c}$ | 939.4$^{a}$ | 1041$^{b}$ | 1048$^{b}$ | 214$^{a}$ | 148$^{abc}$ | 182$^{bc}$ | 474.6$^{b}$ | 219.4$^{b}$ | 339.1$^{a}$ | 9052$^{b}$ | 5858$^{c}$ | 4858$^{be}$ | 11155$^{abc}$ | 17784$^{a}$ | 13745$^{c}$ |
| 7 | 236.2$^{e}$ | 169.8$^{e}$ | 133.5$^{e}$ | 938.1$^{a}$ | 1002$^{b}$ | 1103$^{b}$ | 222$^{a}$ | 122$^{bc}$ | 261$^{abc}$ | 487.4$^{b}$ | 296.2$^{ab}$ | 285.0$^{a}$ | 11360$^{ab}$ | 7455$^{abc}$ | 1065$^{d}$ | 918$^{e}$ | 1188$^{a}$ | 5227$^{c}$ |
| 8 | 357.5$^{d}$ | 228.5$^{d}$ | 209.8$^{cd}$ | 1006$^{a}$ | 1088$^{b}$ | 1115$^{b}$ | 224$^{a}$ | 145$^{abc}$ | 351$^{abc}$ | 366.1$^{b}$ | 329.2$^{ab}$ | 318.1$^{a}$ | 8520$^{b}$ | 5710$^{c}$ | 3575$^{bc}$ | 1967$^{bc}$ | 2549$^{a}$ | 4730$^{e}$ |
| 9 | 299.8$^{de}$ | 268.5$^{cd}$ | 131.6$^{e}$ | 854.6$^{a}$ | 986$^{b}$ | 1051$^{b}$ | 129$^{a}$ | 282$^{a}$ | 465$^{ab}$ | 375.9$^{b}$ | 358.8$^{ab}$ | 257.2$^{a}$ | 14910$^{a}$ | 10235$^{c}$ | 7710$^{a}$ | 3991$^{bc}$ | 2446$^{a}$ | 5227$^{c}$ |
| 10 | 268.0$^{de}$ | 156.6$^{e}$ | 130.3$^{e}$ | 925.4$^{a}$ | 1046$^{b}$ | 1071$^{b}$ | 286$^{a}$ | 248$^{ab}$ | 464$^{ab}$ | 351.9$^{b}$ | 292.8$^{ab}$ | 308.2$^{a}$ | 9390$^{b}$ | 6905$^{bc}$ | 2710$^{cd}$ | 2732$^{bc}$ | 3618$^{a}$ | 3742$^{e}$ |
| 11 | 363.5$^{cd}$ | 291.2$^{c}$ | 170.7$^{de}$ | 734.3$^{a}$ | 911$^{b}$ | 1027$^{b}$ | 164$^{a}$ | 82$^{c}$ | 524$^{a}$ | 469.0$^{b}$ | 388.5$^{a}$ | 369.4$^{a}$ | 12070$^{ab}$ | 9710$^{ab}$ | 4065$^{be}$ | 4423$^{bc}$ | 22673$^{a}$ | 15153$^{c}$ |

[*Turkeys Homef significant difference (HSD) test ($P$ = 0.05). Names with same letter are not significantly different. R, Roots; S, Stem; and L, Leaves]

Table 4 — Ion content in different plant parts in *Sporobolus marginatus* from different locations in Great Rann of Kachchh

| Site | $Na^+$ (ppm) | | | $K^+$ (ppm) | | | $Ca^{2+}$ (ppm) | | | $Mg^{2+}$ (ppm) | | | $Cl^-$ (ppm) | | | $SO_4^{2-}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R | S | L | R | S | L | R | S | L | R | S | L | R | S | L | R | S | L |
| 1 | 469.2$^{c}$ | 305.4$^{a}$ | 389.9$^{a}$ | 615$^{d}$ | 1031$^{a}$ | 1192$^{bc}$ | 94.5$^{a}$ | 141.2$^{b}$ | 184.1$^{a}$ | 624.3$^{a}$ | 907.6$^{a}$ | 750.0$^{a}$ | 10560$^{b}$ | 6420$^{b}$ | 3180$^{b}$ | 20140$^{a}$ | 26318$^{a}$ | 24692$^{b}$ |
| 4 | 575.3$^{b}$ | 296.2$^{a}$ | 376.2$^{a}$ | 824$^{b}$ | 999$^{a}$ | 1622$^{a}$ | 148.5$^{a}$ | 185.0$^{ab}$ | 223.8$^{a}$ | 273.0$^{b}$ | 294.9$^{c}$ | 421.0$^{c}$ | 11269$^{b}$ | 5237$^{b}$ | 3460$^{b}$ | 10822$^{b}$ | 17286$^{b}$ | 18809$^{c}$ |
| 5 | 478.9$^{c}$ | 300.7$^{a}$ | 381.2$^{a}$ | 672$^{c}$ | 998$^{a}$ | 1335$^{b}$ | 141.6$^{a}$ | 224.4$^{a}$ | 313.8$^{a}$ | 364.8$^{b}$ | 392.2$^{b}$ | 471.1$^{b}$ | 10235$^{b}$ | 5217$^{b}$ | 2640$^{c}$ | 10856$^{b}$ | 11274$^{a}$ | 11480$^{d}$ |
| 6 | 742.1$^{a}$ | 323.0$^{a}$ | 390.3$^{a}$ | 946$^{a}$ | 1124$^{a}$ | 1069$^{c}$ | 162.8$^{a}$ | 123.1$^{b}$ | 180.1$^{a}$ | 303.0$^{b}$ | 360.1$^{b}$ | 502$^{b}$ | 15290$^{a}$ | 8940$^{a}$ | 6720$^{a}$ | 14284$^{b}$ | 15167$^{bc}$ | 28310$^{a}$ |

[*Turkeys Homef significant difference (HSD) test ($P$ = 0.05). Names with same letter are not significantly different. R, Roots; S, Stem; and L, Leaves]

(167-524 ppm) and *Sporobolus* (180-314 ppm), but lowest in *Aeluropus* stem (82-282 ppm) and *Sporobolus* roots (94.5-162.8 ppm). Magnesium content in both *Aeluropus* and *Sporobolus* varied significantly with site and plant parts ($P$ <0.001). In *Aeluropus*, roots contained more $Mg^{2+}$ in all the sites, followed by stem in majority of sites. Generally, leaves recorded lowest $Mg^{2+}$ content. Site 1 recorded highest $Mg^{2+}$ content in roots (829 ppm), site 11 recorded highest $Mg^{2+}$ (389 ppm) in stem and site 3 recorded the highest Mg (370 ppm) in leaves. In *Sporobolus*, the leaves recorded highest $Mg^{2+}$, followed by stem and least in roots except for site 1. $Ca^{2+}$ and $Mg^{2+}$ content did not follow a particular pattern with respect to soil salinity in *Aeluropus*. However in *Sporobolus*, the plant growing in soils of lower salinity tend to contain more $Mg^{2+}$, with no particular pattern in $Ca^{2+}$.

Chloride content significantly varied with sites and plant parts ($P$ <0.001). However, the interaction was not significant. Roots recorded highest chloride accumulation in all the sites with the highest being 12070 ppm at site 11 and lowest in site 3 (8165 ppm) in *Aeluropus*. The same pattern was observed in *Sporobolus* with site 6 recording the highest (15290 ppm) and site 5, the lowest (10235 ppm). Leaves of both *Aeluropus* and *Sporobolus* accumulated lowest chloride content at all the sites. Effect of salinity on $Cl^-$ content in *Aeluropus* varied without a particular trend. *Sporobolus* tend to contain higher $Cl^-$ content in soils of high salinity ($R^2$ = 0.55, $P$ <0.01 for roots and $R^2$ = 0.66, $P$ <0.001 for stem and $R^2$ = 0.94, $P$ <0.001 for leaves,). Highest sulphate accumulation was noticed in leaves of *Aeluropus* and *Sporobolus* with significant site and plant parts interaction ($P$ <0.05). In majority of sites roots recorded the lowest sulphate contents. In general $SO_4^{2-}$ content in *Aeluropus* and *Sporobolus* decreased with increase in soil salinity.

The Na/K ratio varied significantly with sites and different plant parts. Roots recorded the highest Na/K ratio in both *Aeluropus* and *Sporobolus*. The lowest ratio was noticed in leaves except for site 6 in *Sporobolus*. Among different sites of varying salinity, Na/K ratio was higher in soils of low salinity for roots and leaves of *Aeluropus* as indicated Table 5. In contrast, for *Sporobolus* Na/K ratio was positively correlated with the salinity for roots and leaves (Table 6).

The selective absorption values ranged from 0.39 in site 1 to 7.64 in site 11 in *Aeluropus*, whereas in *Sporobolus*, it ranged from 0.33 in site 1 to 4.2 in site 4 (Fig. 3A). When the two grasses were compared in site 1 and 4 where it occurs commonly, it was noticed that *Aeluropus* had higher selective absorption values. Selective transport values were higher for *Sporobolus* (Fig. 3B). Significant positive correlation was recorded

Table 5 — Cross correlation between electrical conductivity (EC) and chemical characteristics in *Aeluropus lagopoides*

| Traits | EC | Na/K (Roots) | Na/K (Stem) | Na/K (Leaves) | SA | ST |
|---|---|---|---|---|---|---|
| EC | 1.00 | −0.24$^{ns}$ | 0.00$^{ns}$ | −0.38* | 0.49* | 0.41* |
| Na/K (Roots) | | 1.00 | 0.60** | 0.59** | −0.68** | −0.64** |
| Na/K (Stem) | | | 1.00 | 0.48** | −0.50** | −0.55** |
| Na/K (Leaves) | | | | 1.00 | −0.77** | −0.86** |
| SA | | | | | 1.00 | 0.91** |
| ST | | | | | | 1.00 |

Table 6 — Cross correlation between electrical conductivity (EC) and chemical characteristics in *Sporobolus marginatus*

| Traits | EC | Na/K (Roots) | Na/K (Stem) | Na/K (Leaves) | SA | ST |
|---|---|---|---|---|---|---|
| EC | 1.00 | 0.57$^{ns}$ | −0.30$^{ns}$ | 0.69* | 0.23$^{ns}$ | 0.52$^{ns}$ |
| Na/K (Roots) | | 1.00 | 0.54$^{ns}$ | 0.61* | 0.30$^{ns}$ | 0.88** |
| Na/K (Stem) | | | 1.00 | −0.29$^{ns}$ | −0.17$^{ns}$ | −0.87** |
| Na/K (Leaves) | | | | 1.00 | −0.35$^{ns}$ | 0.55$^{ns}$ |
| SA | | | | | 1.00 | −0.09$^{ns}$ |
| ST | | | | | | 1.00 |

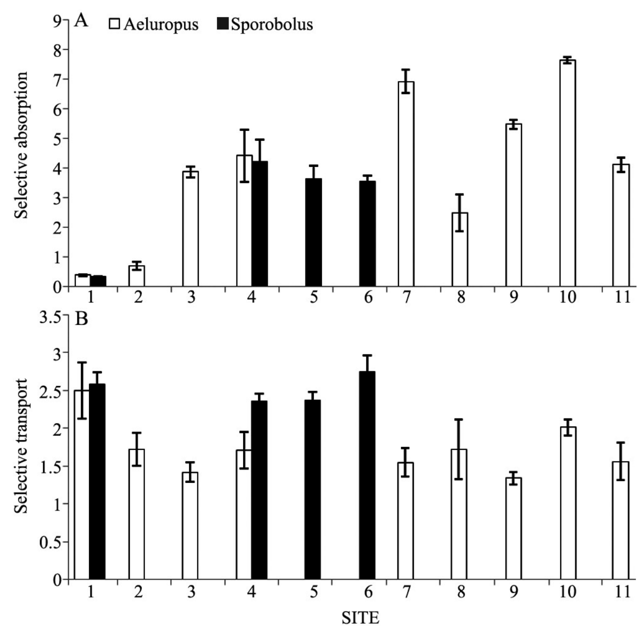


Fig. 3 — Selective absorption by *Aeluropus* (A) and *Sporobolus* (B) at different sites

with salinity and both SA and ST in *Aeluropus* (Table 5). Same trend was recorded for *Sporobolus*, however the effect was not significant (Table 6).

## Discussion

The increased salinity of Great Rann soils has been reported by Thomas *et al.*[27] and Gupta and Ansari[9]. *Sporobolus* found to survive at salinity values as high as 83.06 $dSm^{-1}$ at upper 0-15 cm layer. In the present study, the highest salinity of soil in which the halophyte, *Aeluropus* found was 27.74 $dSm^{-1}$. *A. lagopoides* reported to survive salinity up to 500 mM NaCl salinity[28] and *A. littoralis* was reported up to 800 mM NaCl salinity[29] under controlled experiments. *Sporobolus* also reported to germinate at saline conditions up to 500 mM[30]. *Aeluropus lagopoides* and *Sporobolus marginatus* are few among the major halophytes adapted to the extremely saline environment in the Great Rann of Kachchh.

Under higher concentration of soluble ions in the soil, plants develop different mechanism to prevent adverse impact on growth and development[2,31,32]. Greater accumulation of $Na^+$ in the roots followed by stems of both *Aeluropus* and *Sporobolus* indicate that the transmission of these ions to leaves is prevented to reduce the adverse impact. This may be a survival mechanism of these halophytes to adapt in a highly saline environment as reported by Gulzar and Khan[33]. Selective accumulation of $Cl^-$ and $Mg^{2+}$ in roots of *A. lagopoides* was also reported by Gulzar *et al.*[28]. There was increased accumulation of ions such as $K^+$, $Ca^{2+}$ and $SO_4^{2-}$ in the leaves in both *Aeluropus* and *Sporobolus*. The increased uptake of these ions by both halophytes might serve as a mechanism to adjust osmotic pressure of plant with outside soil environment[34]. Wang *et al.*[35] indicated ion ratios such as Na/K could be used for identifying physiological response of halophytes. Plants adopt different mechanisms to maintain a favourable Na/K ratio which may vary with the plant and environment[36]. In some halophytic plants, this may be vacuolization of excess sodium and chloride ions[37] and in other cases, modified photosynthetic pathways[38]. The higher Na/K in *Aeluropus* and *Sporobolus* roots also indicate that Na is accumulated in roots as an adaptive mechanism to avoid toxic effects to aerial parts.

In *Aeluropus*, ions such as $Na^+$, $K^+$ and $SO_4^{2-}$ exhibited inverse relationship with soil salinity. At sites of higher salinity lower contents of these ions were recorded in plant parts. The Na/K ratio also increased at low salinity in various parts of *Aeluropus*. This indicates the plants show preference for $K^+$ instead of Na under higher salinity or by secretion of Na through leaves[30,39] and the mechanism of salt tolerance in *Aeluropus* may be exclusion or excretion. Higher selective absorption values indicate the ability of root system to exclude $Na^+$ and absorb $K^+$[34]. Higher SA values recorded for *Aeluropus* compared to *Sporobolus* indicate that former is a better excluder of salts. In *Sporobolus* with increase in salinity of soils at different sites, the ion contents of $Na^+$, $K^+$ and $Cl^-$ were also increased. The data suggest that ion accumulation also play an important role in adaptation mechanism in *Sporobolus*. Similar to this, Gulzar *et al.*[28] also reported that *Sporobolus arabicus* survive up to EC of 30 $dSm^{-1}$ and its survival was attributed to greater accumulation of $Na^+$ in plant tissues.

## Conclusion

The halophyte grasses such as *Aeluropus* and *Sporobolus* found to flourish in extreme saline Great Rann of Kachchh, Gujarat, India with salinity as high as 83.06 $dSm^{-1}$. The detrimental effect of increased soluble salt content of $Na^+$ and $Cl^-$ in soil is prevented by reduced uptake of these ions, increased uptake of ions such as $K^+$, $Ca^{2+}$, $Mg^{2+}$ and $SO_4^{2-}$ or exclusion through leaves. Ion accumulation is also seen as adaptation mechanism in *Sporobolus*. The study indicates that vast saline desert areas could be adequately used for saline tolerant grasses to increase fodder production and efficient utilisation of these otherwise barren areas.

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